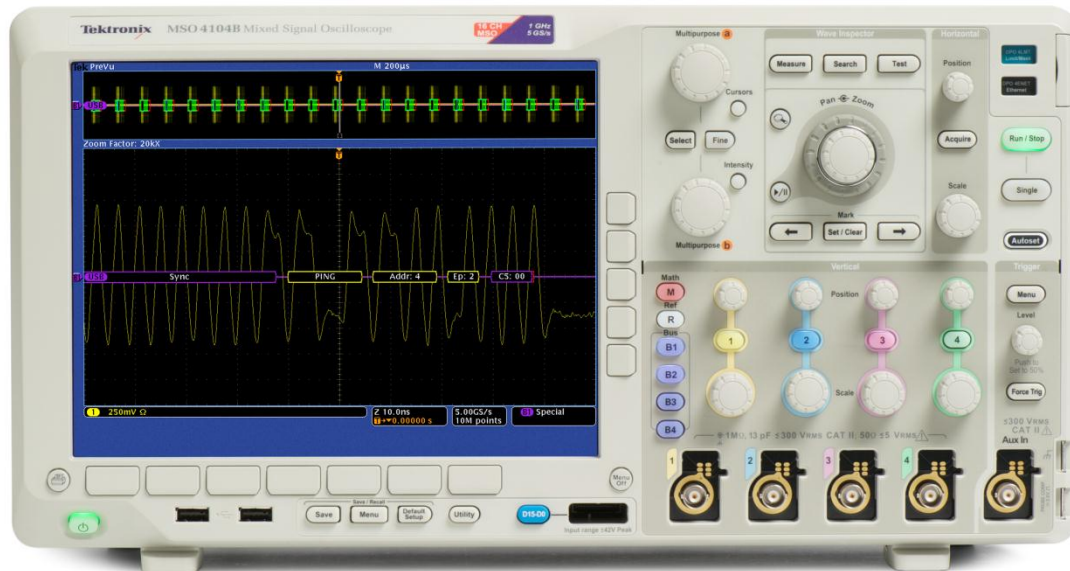


# MSO4000B/DPO4000B Series

## Lab Exercise Book



A collection of lab exercises to help you hone your skills at using the MSO4000B/DPO4000B Series Digital Phosphor Oscilloscopes. These exercises also apply to the MDO4000 Series Mixed Domain Oscilloscopes, which have a superset of the MSO4000B feature set.

NOTE: Always use the latest instrument firmware for demonstrations. Go to [www.tek.com/software](http://www.tek.com/software) and search for “MSO4000B” or “DPO4000B”. Follow the installation instructions on the web page. Note that the MSO/DPO4000B firmware is not interchangeable with the MSO/DPO4000 firmware.

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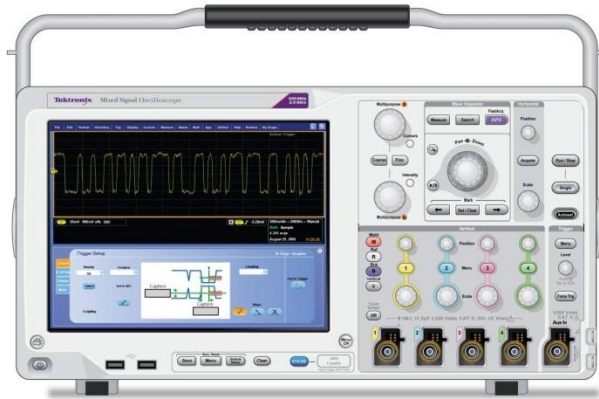
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# MSO4000B/DPO4000B Series

## User Interface and Feature Improvements



### Equipment List

One MSO/DPO4000B Series oscilloscope with the latest firmware version installed

One TPP0500 or TPP1000 passive probe

DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or

DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)

[Note: screen shots in this document were made with 020-2924-XX demo board]

## MSO/DPO4000B Feature Improvements

This short lab provides a high-level tour through the new product features that are not addressed elsewhere in this lab notebook. With the introduction of the MSO/DPO4000B series, customers now have access to the following capabilities:

- New LED-backlight display.
- Two USB high-speed host ports on front panel.
- Rear-panel 100 mm VESA mount.
- TekVPI support for TPP0500 / TPP1000 passive probes.
- Additional power probes have been added to the probe deskew list.
- Record length has been increased from 10 M points per channel to 20 M points per channel.
- Increased maximum clock rates for SPI and FlexRay serial signals.
- "DPO Off" or Persist Time Off mode has been added.
- CSV waveform file import has been added.
- Timeout trigger and AC edge trigger coupling have been added.
- External reference clock input has been added, and AUX OUT signals can now be selected.
- Test button now enables power analysis and limit and mask testing.
- Math and references added as differential USB and Ethernet bus sources.
- Mounting network drives or Network Attached Storage (NAS) for file save/recall.
- Socket server interface

## MSO/DPO4000B User Interface Improvements

This lab also highlights some of the many changes that have been made in the user interface, to implement the new features as well as improve the usability of the products based on customer and sales force feedback. The usability improvements include:

- Improved digital threshold preset selection mechanism.
- A solid graticule has been added.
- Ethernet setup improved. (This will be covered in the LXI Class C lab below.)
- Vertical Impedance has been renamed to Vertical Termination for consistency with other products in the portfolio.
- Vertical Ground Coupling has been removed to eliminate customer confusion around display of tiny offsets.

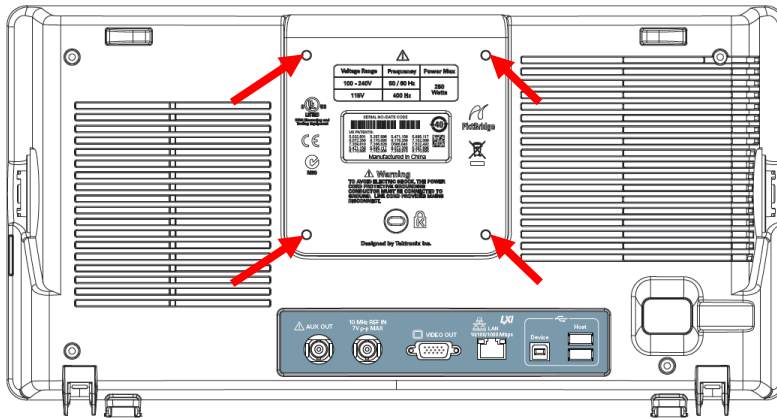
## Objectives

- Obtain a basic awareness of the new features and how they are used.
- Obtain a basic awareness of the new user interface elements.

## Externally-visible Feature Differences

### Key Take Away Points

- The MSO/DPO4000B Series now has a bright LED-backlit display.
- Notice that there are now two USB host ports on the front panel for easier access. (You will also notice that the Compact Flash from the MSO/DPO4000 “non-B” oscilloscopes is no longer there.) There are two additional characteristics you will find very useful:
  - These ports are now USB High-Speed ports. You will notice that new firmware versions can be installed in about half the time, even though the file size is considerably larger than for the MSO/DPO4000 “non-B” oscilloscopes.
  - Also, you will notice that the connectors have been inverted, so you can easily see the activity light on the USB flash drives as you save files to them.
- The rear panel of the instrument has been designed to allow the oscilloscope to be mounted via an industry-standard 100 mm VESA mount:



- The TekVPI connector on the front of the MSO/DPO4000B Series has been modified to accept the mechanical key of the TPP0500 / TPP1000 passive probes:



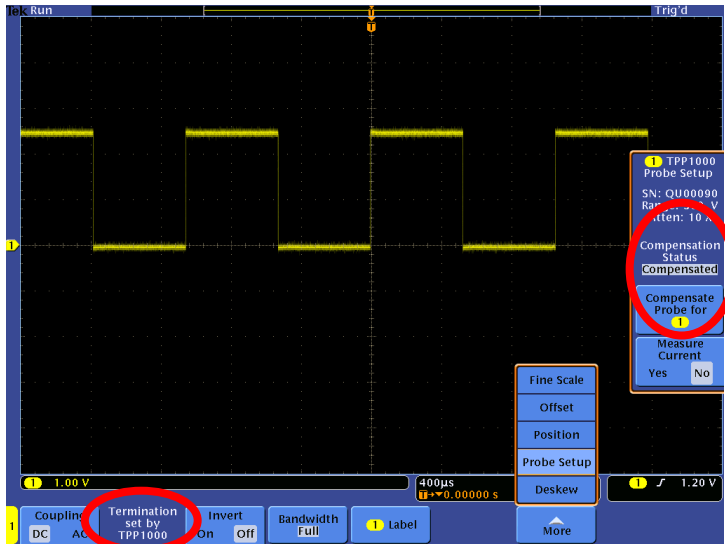
### MSO/DPO4000B Series Procedure:

- Notice the quality of the new display.
- The backlight can be adjusted by pressing the front panel **Utility** button, pressing the **Utility Page** bottom bezel button, selecting **Display**, and pressing the **Backlight Intensity** bottom bezel button.
- If you have a USB flash drive, install it in one of the front panel USB host ports. Notice that the host ports on the MSO/DPO4000Bs are oriented upside-down from the host port on the front of the “non-B” MSO/DPO4000s.
- Notice the VESA mounting holes on the rear panel.
- Notice the AUX OUT and EXT REF IN connectors on the rear panel. (More on these connectors later in this lab.)
- Notice the LXI label next to the Ethernet connector on the rear panel. (More on the LXI Class C compliant interface in a later lab.)
- Notice the notch on the right side of the TekVPI connectors on the front panel.

## TekVPI support for TPP0500 / TPP1000 passive probes

### Key Take Away Points

- Most passive probes use manual adjustment of a variable capacitor to compensate the step response of the probe.
- AC compensation of the TPP1000 and TPP0500 probes is done electronically, through the Probe Setup menu:



- Notice the bottom bezel readout indicating that the probe **Termination** has been automatically set by the probe.

### MSO/DPO4000B Series Procedure:

- ❑ Connect the TPP0500 or TPP1000 probe to channel 1.
- ❑ Connect the probe tip to the PROBE COMP signal on the lower right corner of the oscilloscope.
- ❑ Connect the probe ground to the ground connection just above the PROBE COMP signal.
- ❑ Press the front panel **Default Setup** and **Autoset** buttons to automatically set up the oscilloscope to get a stable display.
- ❑ Press the front panel **1** button to display the Vertical menu.
- ❑ Repeatedly press the **More** bottom bezel button until **Probe Setup** is selected.
- ❑ Press the **Compensate Probe for 1** side bezel button and press the **OK Compensate Probe** side bezel button.
- ❑ While the compensation routine is done, notice the **Compensation Status** side bezel readout indicates **Compensated**.

## Additional Power Probes in Probe Deskew Menu

### Key Take Away Points

- To support accurate timing and power measurements, additional probes have been added to the list of supported probes that can be manually selected.
- In addition, the new TPP1000 and TPP0500 probes are automatically recognized and the nominal deskew values are automatically inserted.

### MSO/DPO4000B Series Procedure:

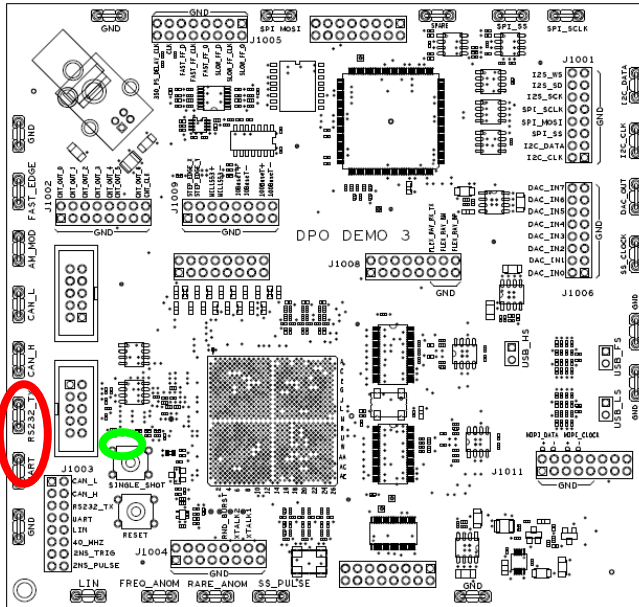
- ❑ With the channel 1 Vertical menu displayed, press the **More** bottom bezel button until **Deskew** is selected.
- ❑ Remove the probe from channel 1.
- ❑ Press the Probe Model side bezel button.
- ❑ Using the Multipurpose **a** control, scroll through the available probes, including the P5205 and P5210 (which both require the use of the TPA-BNC adapter).



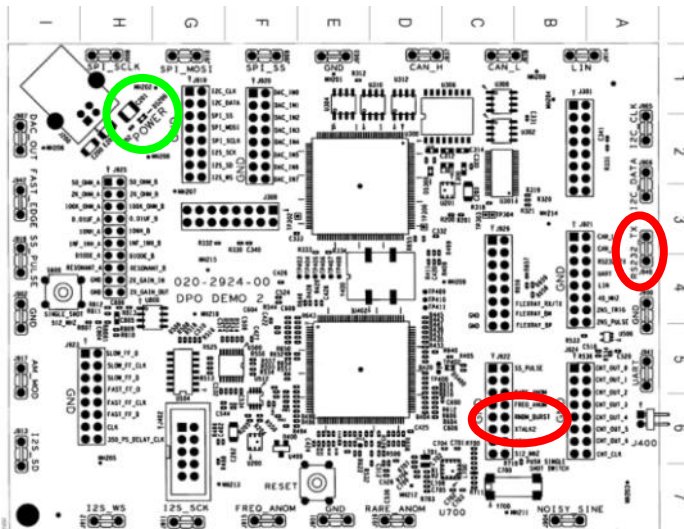
## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has various signals which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has various signals which we can use for this lab:



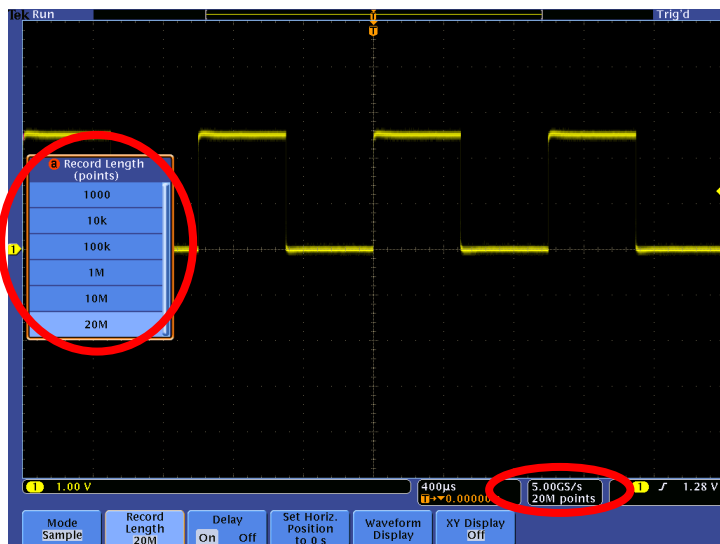
### DPO Demo Board Procedure:

- Power up the demo board.
- Verify the green **POWER** LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.

## 20M Standard Record Length

### Key Take Away Points

- The standard record length for the MSO/DPO4000B oscilloscopes has been increased to 20 M points per channel. To accommodate the additional record length selection, the record length choices have been moved from a side menu to a list. You use the Multipurpose **a** control to select the value. The display should look about like this:



### MSO/DPO4000B Series Procedure:

- Connect the TPP0500 or TPP1000 probe to channel 1.
- Connect the probe tip to the PROBE COMP signal on the lower right corner of the oscilloscope.
- Connect the probe ground to the ground connection just above the PROBE COMP signal.
- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Press the front panel **Autoset** button to automatically set up the oscilloscope to get a stable display.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Turn the Multipurpose **a** control fully counter-clockwise to select the maximum record length.

## Increased Maximum Serial Speeds for SPI and FlexRay

### Key Take Away Points

- With the new trigger FPGA in the MSO/DPO4000B, the maximum clock rate / bit rate for SPI serial signals has been increased to 50 Mb/s when using the analog channels.
- The maximum bit rate for FlexRay signals has been increased to 100 Mb/s when using the analog channels.

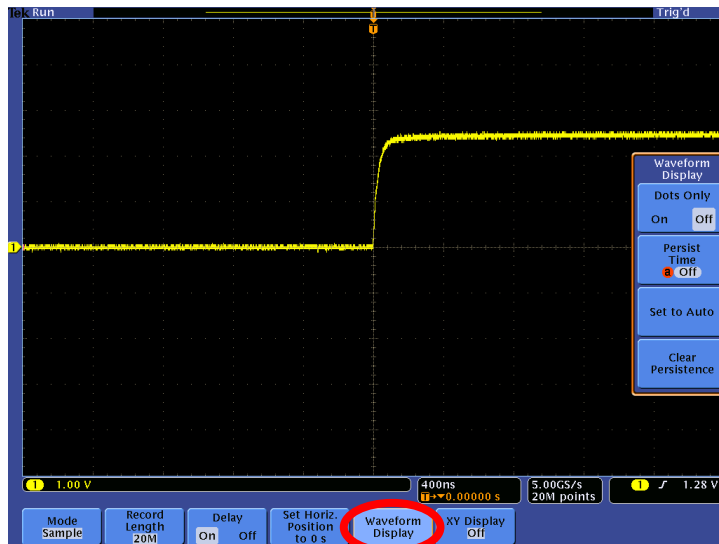
### MSO/DPO4000B Series Procedure:

- (Because the clock rate for SPI is automatically set based on the clock signal, there is no demo for this new spec for SPI.)
- Press the purple front panel **B1** button and the **Bus B1** bottom bezel button.
- Using the Multipurpose **a** control, select **FlexRay**.
- Press the **Bit Rate** bottom bezel button.
- Select Custom with the Multipurpose **a** control and turn the Multipurpose **b** control fully clockwise to select the maximum bit rate.

## “DPO Off” or Zero Persistence

### Key Take Away Points

- For intermittent-signal applications, one of the most common field requests has been for a “DPO Off” mode to display only a single acquired waveform when the Stop button is pressed.
- The default display persistence typically leaves an image of multiple waveforms when the Stop button is pressed. It is possible to get the desired result by using Single Sequence mode, but the user has to manually re-start the acquisition each time. It is also possible to slightly move any of the position or acquisition controls, but again this is a manual operation.
- The new display mode provides the desired display automatically. The display looks about like this:



### MSO/DPO4000B Series Procedure:

- ❑ Press the **Waveform Display** bottom bezel button.
- ❑ Notice the intensity grading on the display.
- ❑ Turn the Multipurpose **a** control one click clockwise to select Persist Time **Off**.
- ❑ Notice how the intensity grading has disappeared.
- ❑ Press the **Run/Stop** button.

## CSV Waveform File Import Added

### Key Take Away Points

- Previous versions of the product allowed you to save (or export) waveform data in either ISF or CSV format, but only allowed you to recall (or import) ISF file data into the reference memories.
- The MSO/DPO4000B adds the ability to recall CSV data files of waveform data into the oscilloscope’s reference memories.

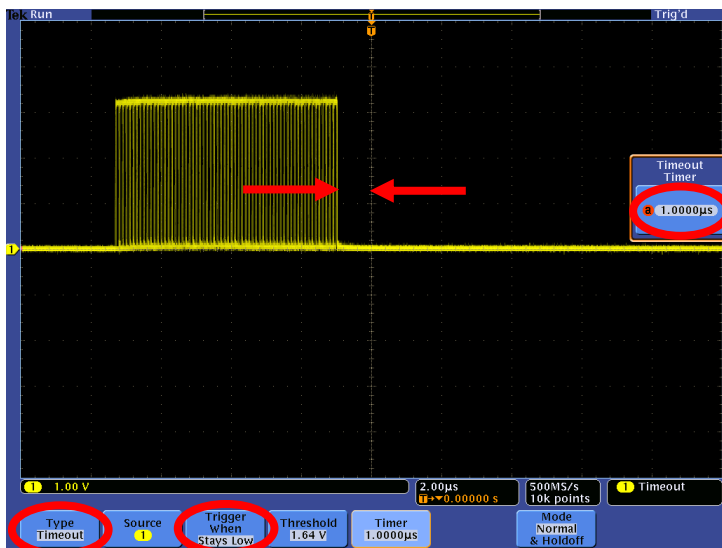
### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Save/Recall Menu** button.
- ❑ Press the **Save Waveform** bottom bezel button and use the Multipurpose **b** control to select the default file location.
- ❑ Press the **Recall Waveform** bottom bezel button and use the Multipurpose **a** control, select the CSV waveform file and press the **Recall to R1** side bezel button.

## Timeout Trigger and AC Edge Trigger Coupling

### Key Take Away Points

- For applications, such as verifying a continuous clock signal, the timeout trigger can be a very useful digital debug tool. You simply specify the length of signal inactivity that qualifies as an error and the trigger will capture the error.
- The display looks about like this:



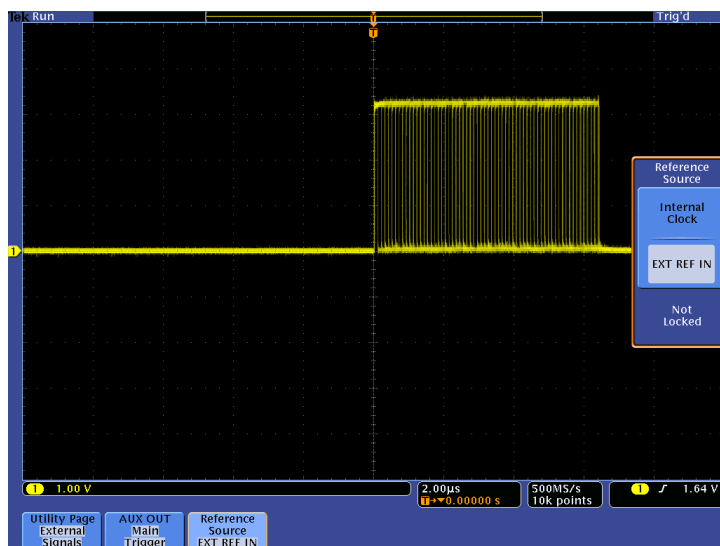
### MSO/DPO4000B Series Procedure:

- Connect the probe ground to a **GND** test point on the demo board.
- Connect the probe tip to the **RNDM\_BURST** signal on the demo board.
- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Press the front panel **Autoset** button to automatically set up the oscilloscope to get a stable display.
- Set the Horizontal **Scale** to **2 µs/div**.
- Press the front panel Trigger **Menu** button.
- Press the **Mode** bottom bezel button and the **Normal** side bezel button.
- Press the **Type** bottom bezel button.
- Using the Multipurpose **a** control, select **Timeout**.
- Press the **Trigger When** bottom bezel button and the **Stays Low** side bezel button.
- Press the **Timer** bottom bezel button.
- Using the Multipurpose **a** control, set the **Timeout Timer** to about **1 µs**.
- Press the **Type** bottom bezel button.
- Using the Multipurpose **a** control, select **Edge**.
- Press the **Coupling** bottom bezel button.
- Notice that **AC Coupling** has been added to the side menu.

## External Reference Clock and Aux Out Selections

### Key Take Away Points

- Normally, the internal crystal oscillator is used as the timebase clock for the oscilloscope. However, if you want higher horizontal timing stability (such as provided by a Cesium or Rubidium frequency standard) or you want to lock multiple oscilloscopes to the same frequency standard, you can input a 10 MHz frequency reference:

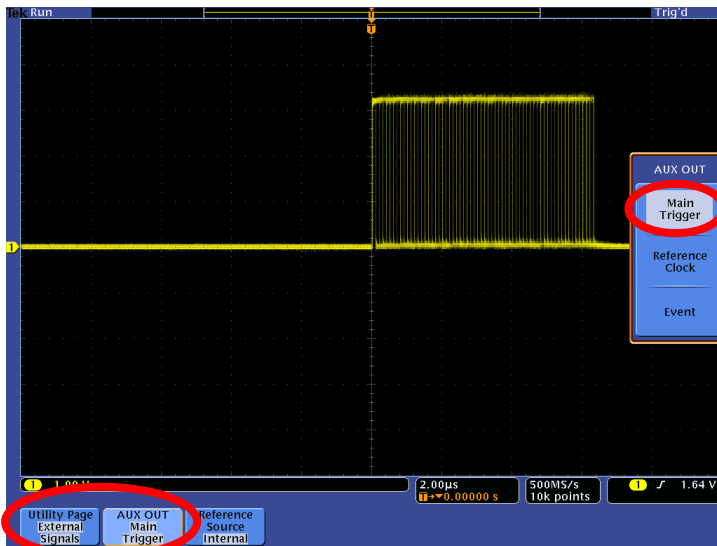


### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Utility** button.
- ❑ Press the **Utility Page** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **External Signals**.
- ❑ Press the **Reference Source** bottom bezel button.
- ❑ Press the **EXT REF IN** side bezel button. The status appears below the button.
- ❑ If you do not have a valid frequency reference connected to the **EXT REF IN** rear-panel connector, you will see the **Not Locked** status message in the side menu.

### Key Take Away Points

- The Aux Out connector can now output three different signals:
  - By default, the Aux Out connector outputs a signal each time the oscilloscope triggers. This is useful for triggering other devices and for measuring the waveform capture rate.
  - With the addition of the external reference clock input, some users want to also output this reference signal to other equipment.
  - With the addition of limit and mask testing, some users want to output a signal each time there is a violation.
- The Aux Out selection looks like this:



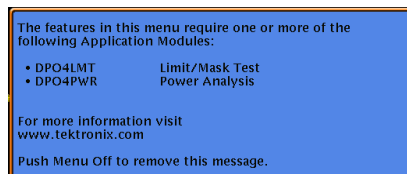
### MSO/DPO4000B Series Procedure:

- ❑ Press the **AUX OUT** bottom bezel button.
- ❑ Press the **Reference Clock** side bezel button to output the reference clock signal.
- ❑ Press the **Event** side bezel button to output a pulse whenever a limit test or mask test violation occurs.

### Test Button Supports Limit and Mask Testing

#### Key Take Away Points

- Previous versions of MSO/DPO4000 firmware supported only the DPO4PWR power application via the front panel Test button. The DPO4LMT Limit and Mask Testing application is also supported there.
- If neither of the application modules is installed, you will see a message like this:



### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Test** button.
- ❑ If there is a DPO4PWR application module installed, the lower left bezel button will indicate **Application Power Analysis**.
- ❑ If there is only a DPO4LMT application module installed, the lower left bezel button will indicate **Application Limit/Mask Test**.
- ❑ If both application modules are installed, you can press the lower left bezel button and use the Multipurpose **a** control to select between the applications.

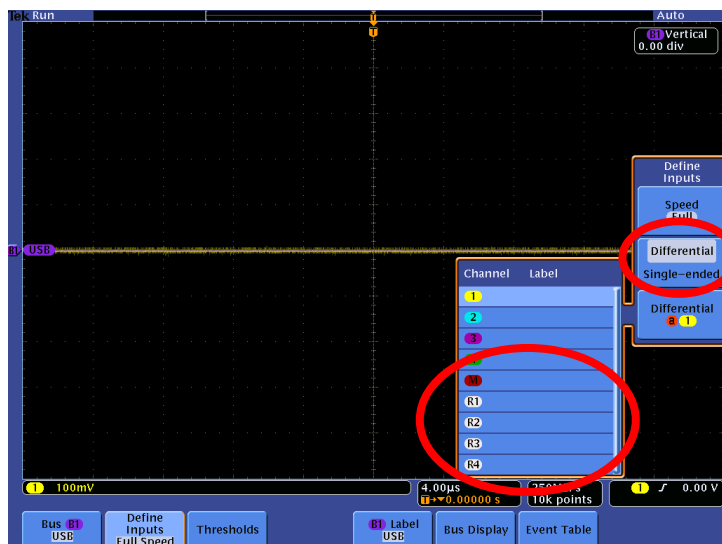
## Math and Reference Sources for Differential Bus Decoding

### Key Take Away Points

- To support customer requests for decoding differential USB and Ethernet buses, where the differential signal has been acquired with a pair of passive probes, math and references have been added as sources for differential bus decoding.
- The Single-ended bus source selection menu looks like this:



- The Differential Input bus source selection menu now looks like this:



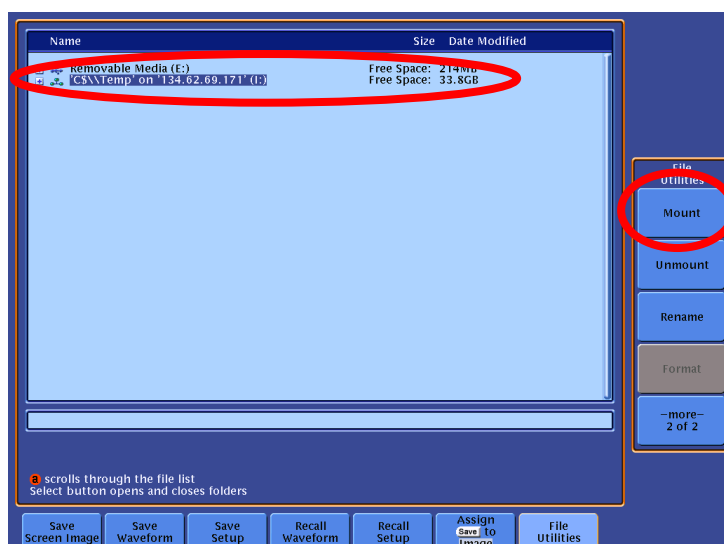
### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Default Setup** button.
- ❑ Press the purple front panel **B1** button.
- ❑ Press the **Bus B1** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **USB** Bus Type.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ In the side menu, select **Single-ended**.
- ❑ Repeatedly press the **D+** side bezel button until the list of sources is displayed.
- ❑ In the side menu, select **Differential**.
- ❑ Repeatedly press the **Differential** side bezel button until the list of sources is displayed.

## Mounting File Systems

### Key Take Away Points

- In response to customer requests to be able to mount network drives or Network Attached Storage (NAS) for file save/recall, the file system has been modified to allow mounting and unmounting drives. This allows the user to mount a network drive and save screen shots and waveform files directly, or recall reference waveforms and instrument setup files.



### MSO/DPO4000B Series Procedure:

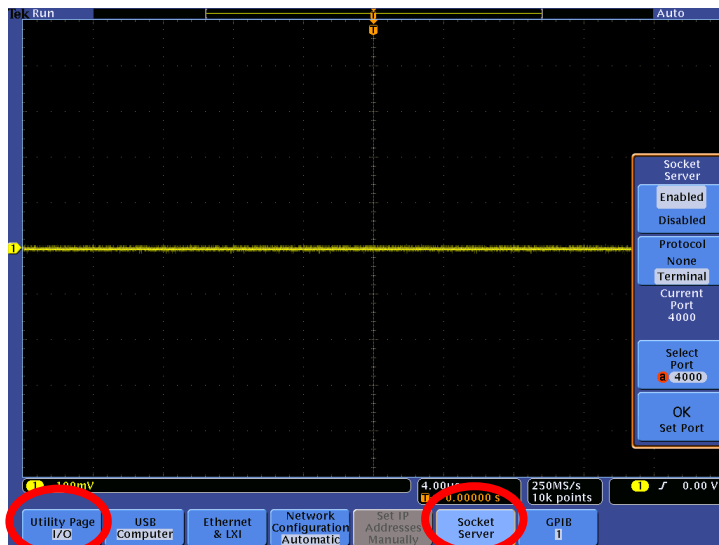
- ❑ Press the front panel **Menu** button.
- ❑ Press the **File Utilities** bottom bezel button.
- ❑ Press the **-more- 1 of 2** side bezel button.
- ❑ Press the **Mount** side bezel button.
- ❑ Using the Multipurpose **b** control, select the desired **Drive Letter:**, such as **I:**.
- ❑ Press the down arrow side bezel button.
- ❑ Using a keyboard or the on-screen interface, enter the **Server Name or IP Address:** for the file server or PC.
- ❑ Press the down arrow side bezel button.
- ❑ Using a keyboard or the on-screen interface, enter the shared file **Path:** on the server. For example, by default, a PC's "C:" hard disk share name is "C\$".
- ❑ Press the down arrow side bezel button.
- ❑ Using a keyboard or the on-screen interface, enter the **User Name:**, if necessary.
- ❑ Press the down arrow side bezel button.
- ❑ Using a keyboard or the on-screen interface, enter the **User Password:**, if necessary.



## Socket Server Interface

### Key Take Away Points

- The MSO/DPO4000B supports socket-based inter-process communication across an Internet Protocol-based computer network. The socket address is the combination of the oscilloscope's IP address (or DNS name), and a port number (which is mapped to the application program process). By default, the socket server is enabled, but it can be disabled for security reasons.
- There are two modes of operation. With Protocol set to "None", "raw socket mode" is enabled, as is needed for a VISA socket connection. With Protocol set to "Terminal", telnet socket communication is enabled.
- The socket server is set up with the following menu:



- VISA, the industry standard for instrument communication, connections via TCPIP (Ethernet) can be established using either VXI-11 or socket resources.
- As you have probably seen in the OpenChoice Instrument Manager, VXI-11 resource expressions look like this:
  - TCPIP0::<instrument\_name>::INST0::INSTR
  - TCPIP0::<IP\_address>::INST0::INSTR
- Socket resource expressions look like this:
  - TCPIP0::<instrument\_name>::<port>::SOCKET
  - TCPIP0::<IP\_address>::<port>::SOCKET
  - Note: <port> is the socket server port (default value for our instruments is 4000).
- For socket VISA connections, the socket server protocol should be set to "None" (raw socket).

### MSO/DPO4000B Series Procedure:

- Press the front panel **Utility** button.
- Press the **Utility Page** bottom bezel button.
- Using the Multipurpose **a** control, select **I/O**.
- Press the **Socket Server** bottom bezel button.

- Press the **Protocol** side bezel button until **None** is selected.

## Key Take Away Points

- A telnet connection requires the Protocol to be set to "Terminal". This is an example of what a telnet connection to an instrument looks like:

```
% telnet MSO4054-PQ30003 4000
Trying 134.62.74.160...
Connected to MSO4054-PQ30003.cse.tek.com (134.62.74.160).
Escape character is '^]'.
Tektronix MSO4054 Instrument Control Terminal Session
Control commands:
  !t <timeout> : set the response timeout in
milliseconds.
  !d : send device clear to the instrument.
  !r : read response from instrument.
  !h : print this usage info.
Responses to queries which contain a ? are read
automatically.

Timeout is 10000 milliseconds
>
```

- The socket server can be set up through the user interface, or with the following programmable interface commands:

```
:SOCKETServer:ENable?
:SOCKETServer:ENable <Boolean>

:SOCKETServer:PROTOCOL?
:SOCKETServer:PROTOCOL <Enum>
      where <Enum> is either TERMinal or NONE

:SOCKETServer:PORT?
:SOCKETServer:PORT <NR1>
```

## MSO/DPO4000B Series Procedure:

- ❑ Press the **Protocol** side bezel button until **Terminal** is selected.
- ❑ Using the Multipurpose **a** control, you can change the port number.
- ❑ Press the **OK Set Port** side bezel button. This button assigns the new port address for all subsequent socket connection sessions (but does not interrupt the current session).

## Improved Bus Threshold Preset User Interface

### Key Take Away Points

- One of the critical settings for proper acquisition of digital signals is the setting of the digital threshold value. To simplify the user interface for many applications, the interface provides a list of preset threshold values (such as 1.4V for TTL logic). However, the “non-B” products required the user to press the Apply Preset side bezel button before the selected preset value was applied. This was a user trap for some users.
- The threshold controls have been improved so the preset threshold value is applied immediately and simplifies the setup.



- Now, when the user manually changes the threshold values, the User values are updated:



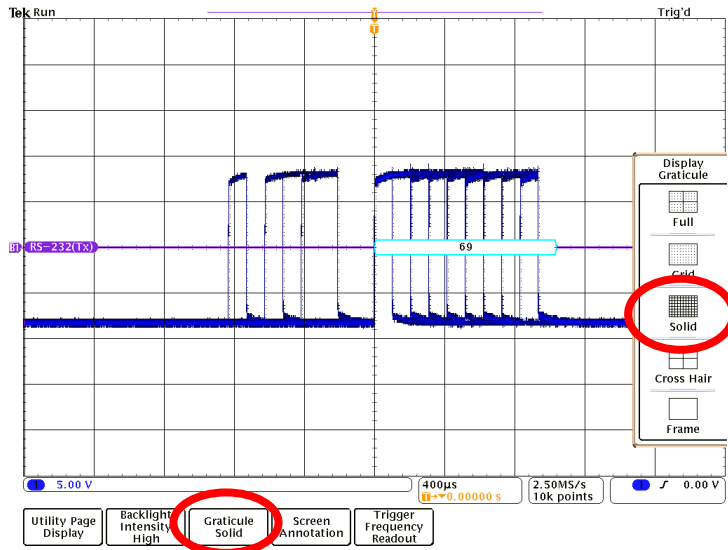
### MSO/DPO4000B Series Procedure:

- ❑ Connect the probe tip to the **I2C\_CLK** signal on the demo board.
- ❑ Press the front panel **2** button to turn on channel 2. (You can connect a probe to channel 2 and connect it to I2C\_DATA if you want to.)
- ❑ Press the front panel **Autoset** button.
- ❑ Press the purple front panel **B1** button.
- ❑ Press the **Bus B1** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **I2C Bus Type**.
- ❑ Press the **Thresholds** bottom bezel button.
- ❑ Press the **Choose Preset** side bezel button. Notice that the current threshold value is shown as the User value.
- ❑ Using the Multipurpose **a** control, select **TTL**. Notice that the User value and the channel 1 and 2 threshold values are immediately changed.
- ❑ Using the Multipurpose **a** and **b** controls, set the thresholds to different values. Notice that the User preset is automatically selected and that the new threshold values are updated.

## Solid Graticule

### Key Take Away Points

- When the resolution of the projector or the printer is not matched to the original image, the default dotted graticule lines can disappear. A solid graticule has been added to provide better displays with projectors and with ink saver mode printouts:



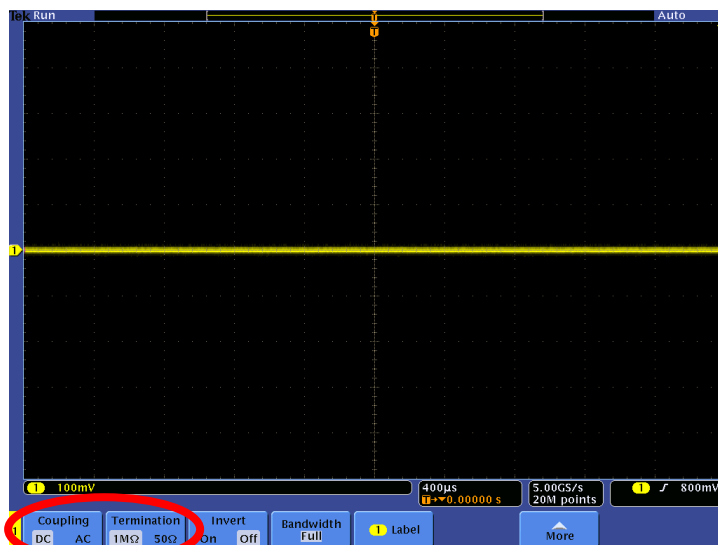
### MSO/DPO4000B Series Procedure:

- Press the front panel **Utility** button.
- Press the **Utility Page** bottom bezel button.
- Using the Multipurpose **a** control, select **Display**.
- Press the **Graticule** bottom bezel button.
- Press the **Solid** side bezel button.

## Vertical Menu User Interface Improvements

### Key Take Away Points

- Ground coupling was confusing customers because it wrongly displayed a DC offset and provided no real value so it has been removed. Also, changing "Impedance" to "Termination" makes the control consistent with other products in the portfolio. The new vertical menu should look about like this:

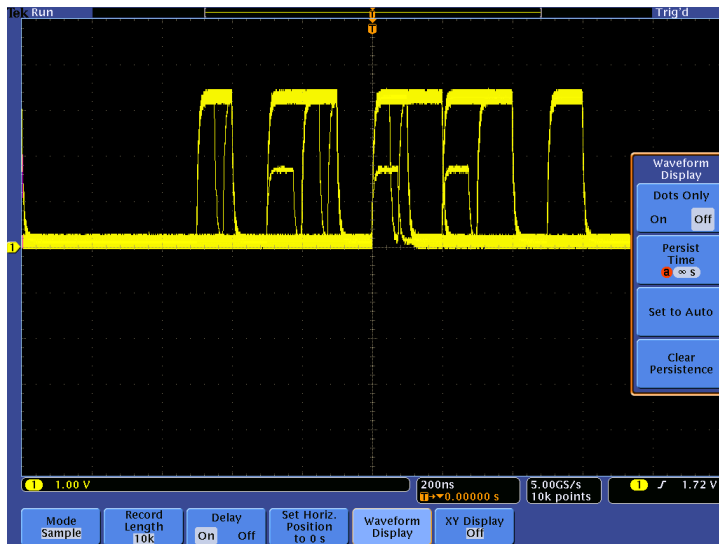


### MSO/DPO4000B Series Procedure:

- Remove the probe from channel 1.
- Press the channel **1** button to display the vertical menu.
- Notice that the **Coupling** bottom bezel control contains only **DC** and **AC**. You choose between these selections by simply pressing the bottom bezel button.
- Notice that the next bottom bezel button is now labeled **Termination** instead of Impedance.
- The Termination depends upon the probe attached. Many TekVPI probes forces it to 50Ω. The P6139A forces it to 1MΩ. The TPP0500 and TPP1000 probes gray out the choices and indicate that they are specifying the termination.

# MSO4000B/DPO4000B Series

## Discover, Capture, and Search Lab



### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
  - One TPP0500 or TPP1000 passive probe
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]

## Discover, Capture, and Search

As digital designs become more complex, engineers need tools to help find and diagnose problems quickly. Oscilloscopes are used in the design and debug process to discover problems quickly, capture events of interest, search for and gain insight into those events of interest, and then analyze the circuit behavior and solve the problem. This lab focuses on the first three of the four distinct steps of Discover, Capture, Search, and Analyze.

### Discover

To solve a problem, you must first be able to find and visualize the problem. The first step to visualizing signals is accurately getting those signals into the instrument. To do this, you need to use the right probes to maintain high signal fidelity and minimize any loading effects on the circuit.

Then you need a lively display of the signals so you can visualize how the signals are changing over time. Because an oscilloscope displays “snapshots” of the signals, you need an oscilloscope with a fast waveform capture rate. The result is the ability to see glitches or other infrequently occurring transients within seconds, revealing the true nature of faults.

Seeing the problem is only half of the solution. You also need to understand how frequently the signal anomaly is occurring relative to the normal signals. This is where a DPO (Digital Phosphor Oscilloscope) with an intensity-graded display of waveforms shows a “history” of a signal’s activity by intensifying areas of the signal that occur more frequently. This provides a visual display of just how often anomalies are occurring relative to other signals.

### Capture

Once you have an event of interest, you want to capture that event in memory and better understand the underlying causes of the event. Oscilloscopes use specialized triggers to narrow your focus to the events of interest by capturing specific digital events such as runts, glitches, pulse widths, setup and hold violations, and serial and parallel patterns.

You will often want to view signals before and after the trigger event so you can understand the context around the event of interest or to capture many events of interest for further analysis. Or you may want to acquire only a few events of interest but retain enough sample point resolution to be able to zoom in on fine signal details. In either case, you will often want to use long record lengths to capture long time periods with high timing resolution. Record length, one of the key specifications of an oscilloscope, is the number of samples it can digitize and store in a single acquisition. The longer the record length, the longer the time window you can capture with high resolution (high sample rate).

In complex designs, you may need to capture several analog, serial, and parallel digital signals to understand the circuit conditions that are causing the trigger event. Mixed Signal Oscilloscopes (MSOs) are ideally suited to these applications. MSOs have unique capabilities for capturing digital signals, including Threshold controls which allow you to specify what voltage represents a digital ‘1’ and which represents a digital ‘0’. Some MSOs can automatically detect multiple transitions on digital edges.

### Search

Finding one specific event in a long waveform record can be challenging. The MSO/DPO4000B oscilloscope shows 1000 points of waveform data at one time on its display. A 20 million point record length represents 20,000 screens worth of data! Waveform navigation and search tools, such as Wave Inspector® on the MSO/DPO Series, simplify finding an event of interest. Wave Inspector offers dedicated front panel controls for panning and zooming of records for manual navigation and inspection of long data records. You can add your own marks to any location you want to reference later for further investigation. In addition, the automated search will search through millions of acquired data points looking for your specified event, including analog, digital, and serial bus data. Along the way it will automatically mark every occurrence of the event of interest so you can quickly move between matching events.

### Analyze

Once you have discovered, captured, and located events of interest, you need to analyze the signals. Subsequent labs will demonstrate a variety of analysis techniques, including cursor measurements, automated measurements, waveform histograms, limit testing, and waveform math for analyzing signals.

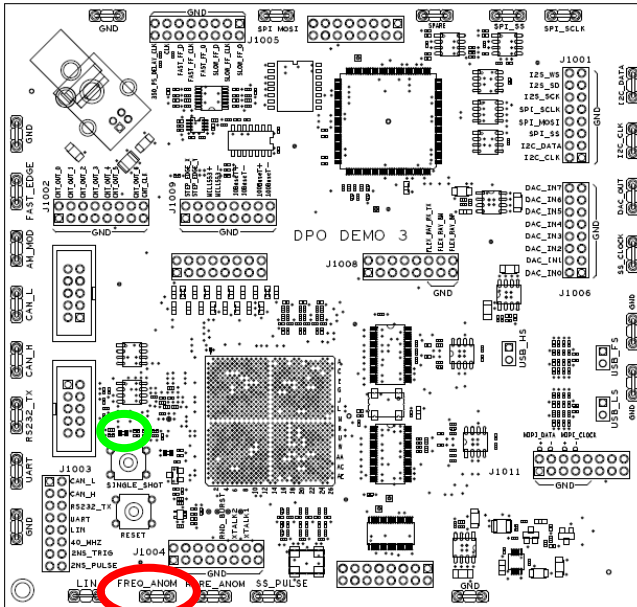
## Objectives

- Obtain a basic understanding of the discovery and capture process.
- Learn how to quickly discover anomalies on digital signals.
- Learn how to easily capture those anomalies once you discover them.

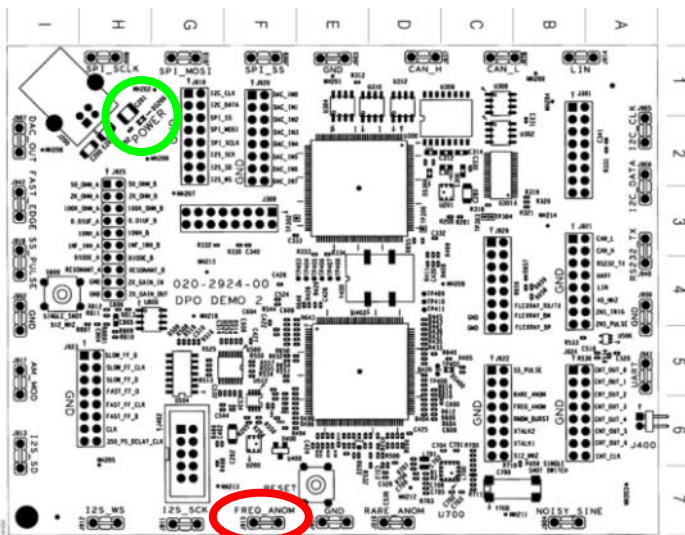
## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a signal with random anomalies which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has a signal with random anomalies which we can use for this lab:



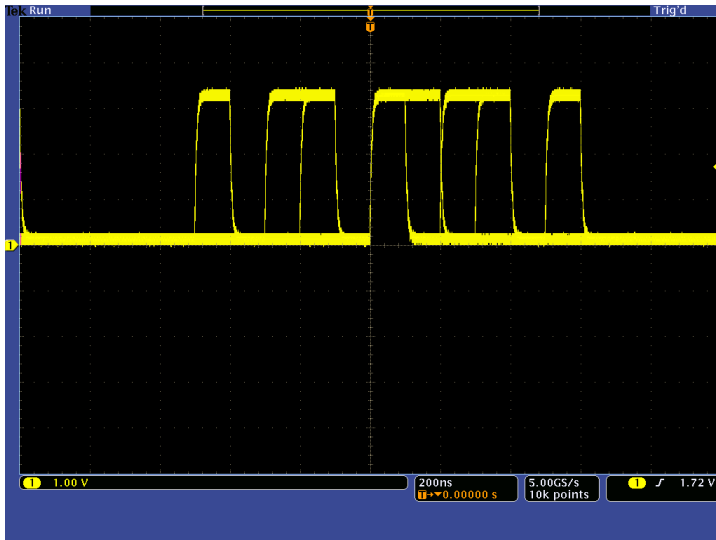
### DPO Demo Board Procedure:

- ❑ Power up the demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **FREQ\_ANOM** test point.

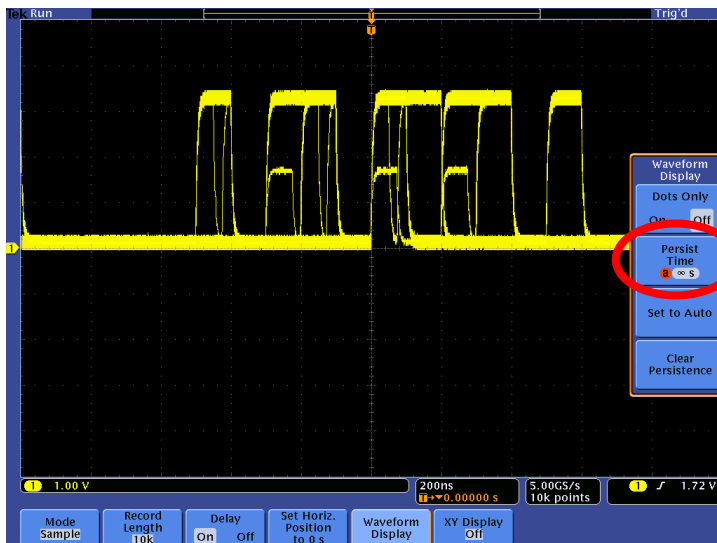
## Discovering Intermittent Errors

### Key Take Away Points

- By default, the oscilloscope is set to capture the signal whenever the signal rises above the trigger level (shown with the arrow along the right side of the display). The numerical trigger level value is also shown in the readout in the lower right corner of the display.
- The display should look about like this:



- Notice that most of the pulses are approximately 100 ns wide or wider.
- Although this digital signal usually has “low” (about 0 Volts) or “high” ( $\geq 3$  Volts) rectangular pulses, you will occasionally see narrow pulses (“glitches”) and low-amplitude pulses (“runt pulses”) on the display. To accumulate all of these anomalies for easier viewing, turn on infinite persistence. The resulting display should look about like this:



### MSO/DPO4000B Series Procedure:

- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Press the front panel **Autoset** button to automatically set up the oscilloscope to get a stable display.
- Press the front panel **Menu Off** button.
- Press the front panel **Intensity** button.
- Turn the Multipurpose a control fully clockwise to set the Waveform Intensity to **100%**.
- Press the front panel **Intensity** button.
  
- Press the front panel **Acquire** button.
- Press the **Waveform Display** bottom bezel button.
- Turn the Multipurpose a control fully clockwise to set the Persist Time to  **$\infty$ s**.
  
- When you are done, press the **Set to Auto** side bezel button.
- Press the **Menu Off** button twice.



## Capturing Intermittent Errors

### Key Take Away Points

- One of the anomalies that clearly appears in the display is a narrow pulse or “glitch”.
- To capture a glitch, the Pulse Width trigger is used. This trigger causes the oscilloscope to capture the signal only when it has a pulse width narrower than a specified value. The pulse width is measured at the amplitude specified by the trigger or Threshold level.



### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Trigger Menu** button.
- ❑ Press the **Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Pulse Width** Trigger Type.
- ❑ Press the **Trigger When** bottom bezel button.
- ❑ Since the normal pulses are about 100 ns wide, set the trigger to find pulse widths that are significantly smaller. Using the Multipurpose **a** control, set the Pulse Width < value to approximately **50 ns**.
- ❑ Press the **Mode** bottom bezel button.
- ❑ Press the **Normal** side bezel button.
- ❑ Notice that the trailing (falling) edge of the narrow pulse is positioned in the center of the display at the orange trigger T indicator.
- ❑ By default, the Pulse Width trigger captures positive pulses. To capture negative pulses, press the **Polarity** bottom bezel button and the **Negative** side bezel button.
- ❑ Notice that the trailing (rising) edge of the narrow pulse is now positioned in the center of the display at the orange trigger T indicator.

## Key Take Away Points

- Another anomaly that appears in the display is a low-amplitude pulse or “runt pulse”.
- To capture a runt pulse, the Runt trigger is used. This trigger causes the oscilloscope to capture the signal only when a pulse back and forth through one threshold level but does not cross through a second threshold level.



## MSO/DPO4000B Series Procedure:

- ❑ Press the **Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Runt** Trigger Type.
- ❑ Press the **Thresholds** bottom bezel button.
- ❑ Since the normal pulses are at least 3V high, and the runt pulses were around half of that, use the Multipurpose **a** control to set the High Threshold value to approximately **2V** and use the Multipurpose **b** control to set the Low Threshold value to approximately **1V**.
- ❑ Notice that the trailing (falling) edge of the runt pulse is positioned at the orange trigger T indicator.
- ❑ By default, the Runt trigger captures positive pulses. To see if there are any negative runt pulses in the signal, press the **Polarity** bottom bezel button and the **Negative** side bezel button.
- ❑ Since the activity on the display stops and the trigger indicator in the upper right corner of the display says “Trig?”, there are apparently no negative runt pulses in this signal.
- ❑ To capture all runt pulses in the signal, press the **Either** side bezel button.

## Searching for Intermittent Errors

### Key Take Away Points

- As you have seen in this lab, triggering provides a way to capture a small time window around every occurrence of a specific anomaly in a signal. Because you have captured only a short time window of the signal and positioned the anomaly in the center of the display, the single anomaly is easy to find.
- But what if you captured a lot of data? How would you find every occurrence of the anomaly, quickly and reliably?
- One way to manually search for a signal event is to horizontally position the waveform on the display by changing the position of the trigger point on the display. When horizontal Delay mode is On (the default), the trigger point starts in the middle of the display and can be moved with the horizontal position control. The time delay between the trigger point and the center of the display is shown in the horizontal readout at the bottom of the display. With Delay mode on, the trigger point can be moved off the display.
- When horizontal Delay mode is turned Off, the trigger point starts near the left side of the display and can be moved with the horizontal position control. The relative position of trigger point on the display (from 0% to 100%) is shown in the horizontal readout at the bottom of the display.
- Another way to manually search through a signal is to capture a long time window and then graphically zoom and pan through the displayed waveform.
- Although the pan/zoom operation is easy with the front panel Wave Inspector controls, finding every occurrence of an anomaly is usually not a fast or reliable process.

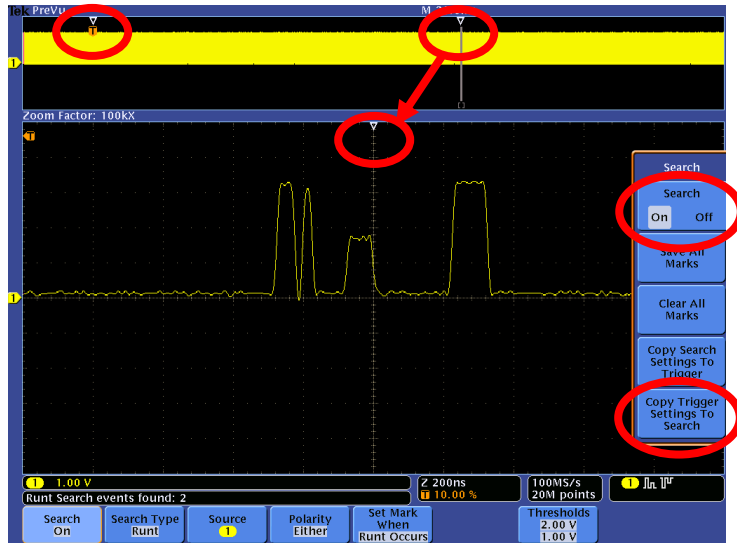


### MSO/DPO4000B Series Procedure:

- ❑ Turn the horizontal **Position** control and notice how the waveform and the trigger point move across the display.
- ❑ Press the front panel **Acquire** button.
- ❑ Repeatedly press the **Delay** bottom bezel button until **Off** is selected. Notice the trigger point moves near the left side of the display, shown as 10% in the orange horizontal readout at the bottom of the display.
- ❑ Press the **Set Horiz. Position to 10%** bottom bezel button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose a control select **20M**.
- ❑ Set the Horizontal **Scale** to **20 ms/div**.
- ❑ Press the front panel **Single** button. At 20 ms/div, this will capture a 0.2 second time window.
- ❑ Turn the inner Wave Inspector control to select a **100kX** zoom.
- ❑ Using the spring-loaded outer Wave Inspector control, pan through the acquisition and see if you can find a runt pulse other than the one which is displayed at the trigger point.

## Key Take Away Points

- The automatic Wave Inspector search quickly and reliably finds every specified occurrence within the acquired signal. The simplest case is to search for the same signal characteristic as the trigger, although it can automatically search on almost any characteristic that it can trigger on.
- The automatic search provides a display like this, including the number of events found:

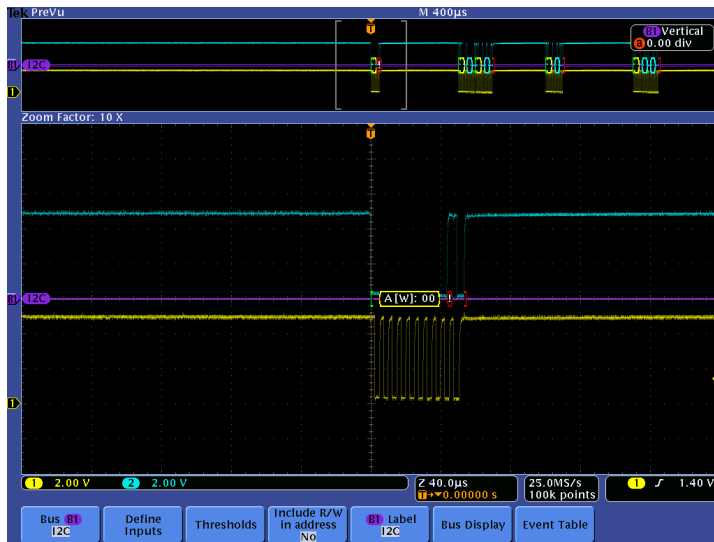


## MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Search** bottom bezel button.
- ❑ Repeatedly press the **Search** side bezel button until **On** is selected.
- ❑ Press the **Copy Trigger Settings To Search** side bezel button.
- ❑ In a matter of seconds, the automatic search finds all occurrences of the specified runt pulse. Notice that each occurrence is marked with a hollow white triangle at the top of the display.
- ❑ Press the front panel ← and → buttons to navigate between the marked runt pulses.
- ❑ Press the **Search Type** bottom bezel button and notice the similarities between the search types and the trigger types you used earlier in the lab.

# MSO4000B/DPO4000B Series

## I<sup>2</sup>C Triggers and Decoding Lab



### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
  - One DPO4EMBD application module
  - Two TPP0500 or TPP1000 passive probes
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]

## Understanding the I<sup>2</sup>C Bus

**I<sup>2</sup>C (Inter-Integrated Circuit)** bus, developed in the early 1980s by Philips, has become a worldwide standard for communications between integrated circuits in a system. This simple two-wire design has found its way into a wide variety of chips and can be found in many of our customers' designs today. I<sup>2</sup>C uses bi-directional serial clock and data lines and supports three bit rates; 100 kbps standard mode, 400 kbps fast mode and 3.4 Mbps high speed mode. Data and clock are sent from the master and the data is clocked on the rising edge of SCLK. I<sup>2</sup>C supports multiple masters and slaves on the bus, but only one master may be active at any one time while slaves can transmit or receive data to the master. Each device is recognized by a unique address and can operate as either a transmitter or receiver, depending on the function of the device.

<b>Start/SRep</b>	<b>Addr</b>	<b>R/W</b>	<b>Ack</b>	<b>Data 0</b>	<b>Ack</b>	<b>Data 1</b>	<b>Ack</b>	<b>.....</b>	<b>Data N</b>	<b>Ack</b>	<b>Stop</b>
1 bit	7-bits	1-bit	1-bit	8-bits	1-bit	8-bits	1-bit	0 – 8 bytes	8-bits	1-bit	1 bit

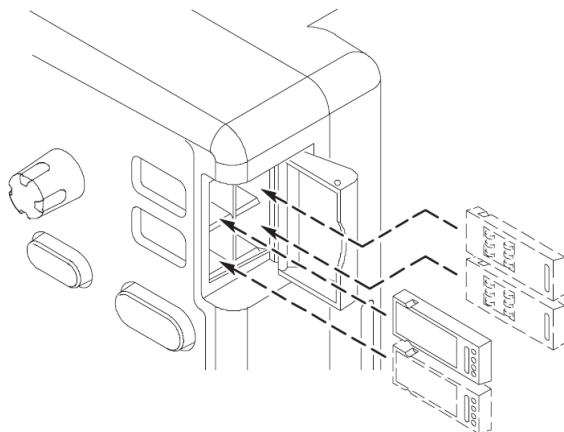
### Objectives

- Obtain a basic understanding of the I<sup>2</sup>C serial bus.
- Learn how customers use oscilloscopes to measure and decode I<sup>2</sup>C.
- Learn how to setup a decoded I<sup>2</sup>C serial bus display and trigger and search on I<sup>2</sup>C bus content with a MSO/DPO4000B Series oscilloscope.

### MSO/DPO4000B Series Lab Setup

#### Key Take Away Points

- I<sup>2</sup>C bus is an industry standard and can be found in many of our customers' designs today.
- Traditional manual decoding methods being used by your customers to decode I<sup>2</sup>C on their oscilloscope are time-consuming.
- With the DPO4EMBD application module installed, the MSO/DPO4000B Series oscilloscope can trigger on, decode, and search I<sup>2</sup>C bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.

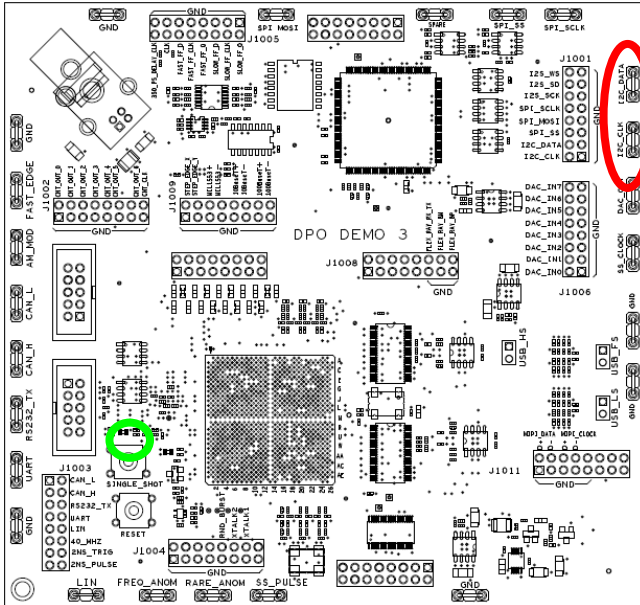


#### MSO/DPO4000B Series Procedure:

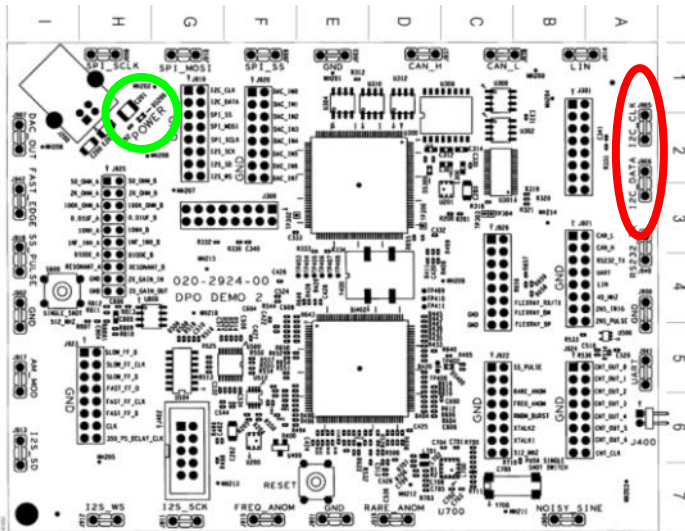
- With the oscilloscope power off, install the **DPO4EMBD** application module into one of the slots on the front panel of the instrument.
- Power up the oscilloscope.
- Press the front panel **Utility** button.
- If necessary, press the **About** bottom bezel button to display the status screen.
- Verify that the **DPO4EMBD Embedded Serial Triggering and Analysis** application module is detected.
- Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has an I<sup>2</sup>C signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has an I<sup>2</sup>C signal which we can use for this lab:



## DPO Demo Board Procedure:

- Power up the demo board.
- Verify the green **POWER** LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **I2C\_CLK** (clock) test point.
- Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **I2C\_DATA** (data) test point.

## Key Take Away Points

- The I<sup>2</sup>C signal display should look about like this:



## MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Set the Horizontal **Scale** to **400µs/div.**
- ❑ Set channel 1 Vertical **Scale** to **2V/div.**
- ❑ Turn on channel 2 by pressing the **2** button.
- ❑ Set channel 2 Vertical **Scale** to **2V/div.**
- ❑ Use the Trigger **Level** control to adjust the trigger level to about **1.7V.**
- ❑ Position channel 1 (clock) so it is below channel 2 (data).
- ❑ Press the **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **100k.**
- ❑ Press the front panel **Menu Off** button to remove the side menu.
- ❑ Press the front panel **Single** button.
- ❑ Turn the inner portion of the Pan / Zoom control and adjust the zoom factor to about **20X** or until one packet fills most of the display horizontally.
- ❑ Turn the outer portion of the Pan / Zoom control to zoom in on the beginning of the packet.



## Manual I<sup>2</sup>C Bus Decoding

### Key Take Away Points

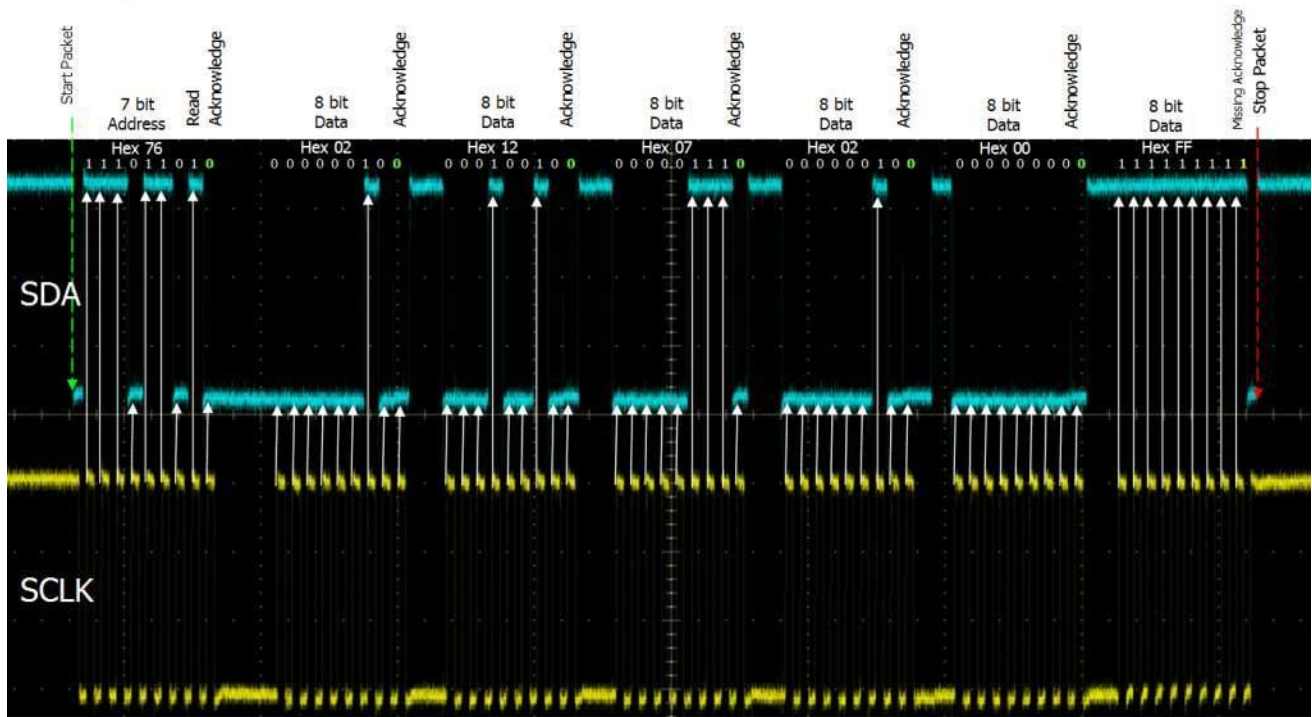
- The I<sup>2</sup>C bus is one of the easiest buses to manually decode. For years, this has been the way your customers have done this task.

### MSO/DPO4000B Series Procedure:

- ❑ Using the I2C Quick Reference Guide below, record the 7 bit binary address of the packet on screen.
- ❑ Record whether the packet is a read or write.
- ❑ Record whether or not the device returned an Acknowledge.

**Conclusion:** Manually decoding I<sup>2</sup>C packets is a time-consuming process. Engineers are looking for a better and faster way to do this.

## I2C Quick Reference Guide



**Read = 1**

**Missing ACK = 1**

**Write = 0**

**ACK = 0**

**Start** A HIGH to LOW transition on the SDA line while SCL is HIGH

**Stop** A LOW to HIGH transition on the SDA line while SCL is HIGH

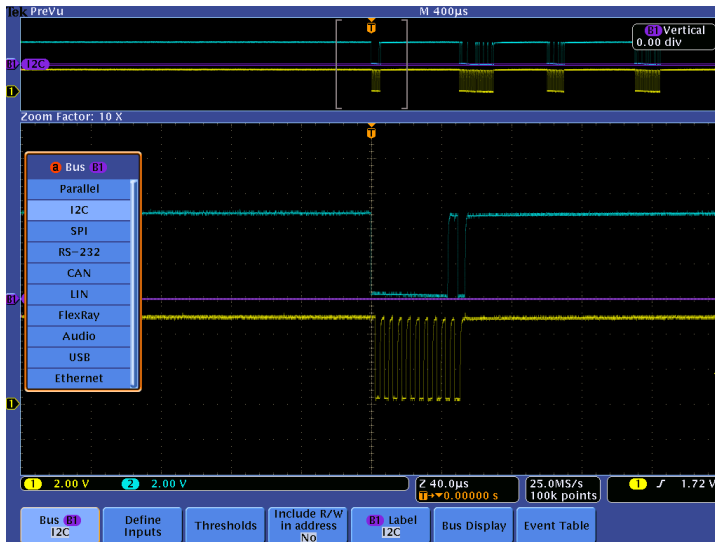
## MSO/DPO4000B Series I<sup>2</sup>C Bus Setup

### Introduction

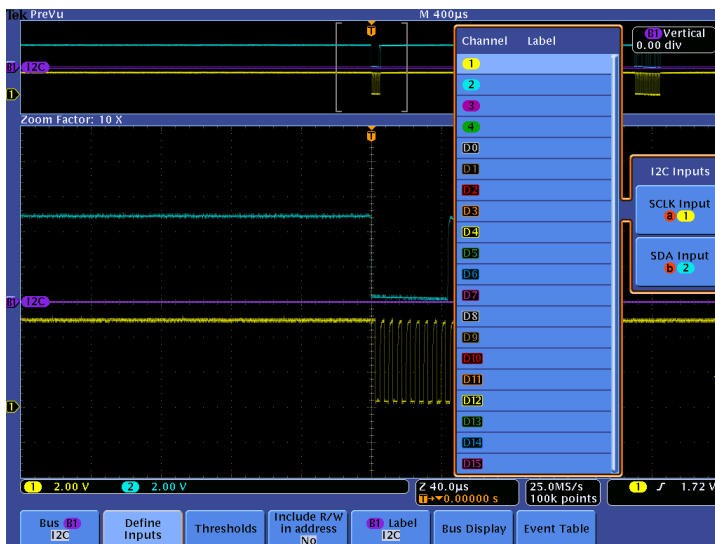
As you personally experienced in the last section, manually decoding I<sup>2</sup>C can be a time-consuming process. In this section we will learn how to use the MSO/DPO4000B Series oscilloscope to automatically decode I<sup>2</sup>C packet content.

### Key Take Away Points

- Setting up a basic I<sup>2</sup>C bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menu guide you through the setup in the left-to-right order across the bottom bezel buttons.
- The I<sup>2</sup>C bus selection menu looks like this:



- Notice that any of the analog or digital input signals can be used as a source for the I<sup>2</sup>C bus:



### MSO/DPO4000B Series Procedure:

- Continue with same setup as previous lab.
- Press the purple Bus **B1** button.
- Press the **Bus B1** bottom bezel button.
- Using the Multipurpose **a** control, select **I2C**.

- Press the **Define Inputs** bottom bezel button. Verify that channel 1 is assigned to SCLK and channel 2 is assigned to SDA.

## Key Take Away Points

- The I<sup>2</sup>C signal threshold menu looks like this:



- The decoded I<sup>2</sup>C signal display should look about like this:



## MSO/DPO4000B Series Procedure:

- Press the **Thresholds** bottom bezel button.
- Using the Multipurpose **a** and **b** controls, set the **Threshold** levels for both signals to **1.4V**.
- Press the **Menu Off** button once.
- Using the Multipurpose **a** control, position the bus above the CH2 waveform.
- Using the Wave Inspector controls, zoom in on one of the packets.
- The green bar symbol represents the start of packet. Start is a high to low transition on the data signal while the clock is high.
- Address packets are shown in yellow boxes. [R] Indicates a read and [W] indicates a write.
- For simplicity, verify that the bottom bezel readout indicates that **Include R/W in address** is set to **No**. If **Include R/W in address** is set to **Yes**, the decoded address value includes the R/W bit in the LSB.
- Data packets are shown in cyan boxes.
- After each packet, the device produces an acknowledge. The MSO/DPO4000B Series only displays missing acknowledges. Missing Acknowledges are indicated by the symbol (!). (Ack = 0, Missing Ack = 1).
- The red bar symbol represents the stop packet. Stop is a low to high transition on the data signal while the clock is high.

## Key Take Away Points

- As seen in the last section, the default I<sup>2</sup>C decoder display format is hexadecimal display of the ID and Parity, and hexadecimal for the Data and Checksum values. These values can also be displayed in binary.
- For many users who are not electrical engineers, the waveform displays may not be familiar. For them, the Event Table format is preferable. This format can also be saved in CSV format and analyzed off-line.



## MSO/DPO4000B Series Procedure:

- ❑ Press the **Bus Display** bottom bezel button.
- ❑ Notice the different bus display options.
- ❑ Press the **Event Table** bottom bezel button.
- ❑ Repeatedly press the **Event Table** side bezel button until **On** is selected.
- ❑ If there are multiple items in the table, you can scroll through the Event Table messages using the Multipurpose **a** control. When you do, notice that the zoom indicators in the overview window indicate the message position in the acquired waveform.
- ❑ Using the **Event Table** side bezel button, select **Off**.
- ❑ Press **Menu Off**.

## MSO/DPO4000B Series I<sup>2</sup>C Cursors

### Key Take Away Points

- The I<sup>2</sup>C serial cursors provide another tool to bridge between the serial waveform and the decoded values, showing absolute timing relative to the trigger, bus values, and relative timing between bus events.
- For this example, we can measure the time from the start of the address to the start of the first data packet:



- Even when you are zoomed out to where you can't read the decoded values on the display, cursor measurements enable you to make timing measurements on buses. Notice that the timing from the start of the address to the start of the second data packet is clearly and easily displayed:



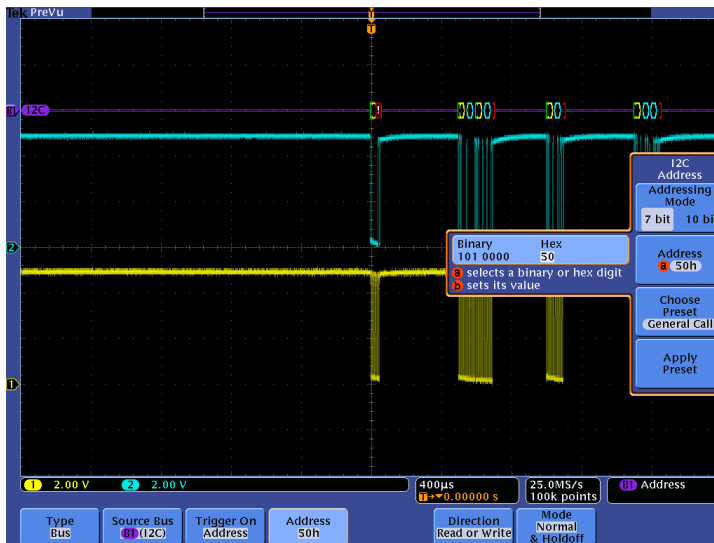
### MSO/DPO4000B Series Procedure:

- ❑ Using the Wave Inspector controls, zoom in on one of the I<sup>2</sup>C messages.
- ❑ Press the **Cursors** front panel button once to turn on vertical bar cursors.
- ❑ Using the Multipurpose **a** control, place the **a** cursor on an event of interest, such as the start of the address.
- ❑ Notice the **a** cursor time and bus value readout in the upper right corner of the display.
- ❑ Using the Multipurpose **b** control, place the **b** cursor on an event of interest, such as the start of the first data packet.
- ❑ Notice the **b** cursor time and bus value readout in the upper right corner of the display.
- ❑ Also notice that we are displaying the time delay between the first and second bus events of interest.
- ❑ Now, turn off zoom. Slowly move the cursors around and notice that you can easily identify the parts of the I<sup>2</sup>C packets and their timing without being able to clearly see the waveforms or the decoded values.
- ❑ Press the **Cursors** front panel button once to turn off cursors.

## MSO/DPO4000B Series I<sup>2</sup>C Bus Triggering

### Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the I<sup>2</sup>C serial bus.
- The MSO/DPO4000B Series can trigger on:
  - Start
  - Repeat Start
  - Stop
  - Missing Ack
  - Address
  - Data (1 – 5 bytes)
  - Address & Data



- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on an I<sup>2</sup>C signal, capturing each occurrence.



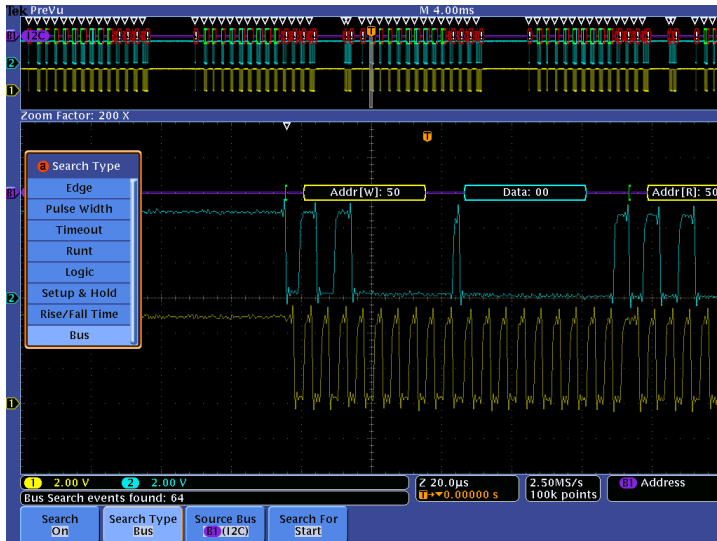
### MSO/DPO4000B Series Procedure:

- Press the front panel Trigger **Menu** button.
- Press the **Type** bottom bezel button.
- Using the Multipurpose **a** control, select **Bus** triggering.
- Press the **Source Bus** bottom bezel button and verify that **B1(I2C)** is selected.
- Press the **Trigger On** bottom bezel button.
- Using the Multipurpose **a** control, select **Address**.
- Press the **Address** bottom bezel button.
- Using the Multipurpose **a** and **b** controls, set the Address to the address you recorded in the last section of this lab (for example, 50 hex).
- Press the front panel **Single** button.
- Press **Menu Off**.
- Adjust the Wave Inspector pan and zoom controls as needed to view the I<sup>2</sup>C packets.

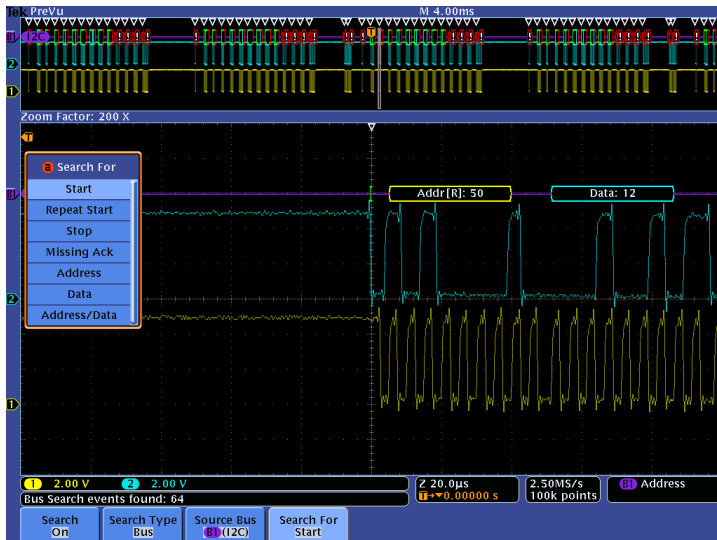
## MSO/DPO4000B Series I<sup>2</sup>C Bus Searching

### Key Take Away Points

- One of the key reasons for using long-record-length oscilloscopes is to be able to capture long time windows at high timing resolution. However, it is difficult to find specific serial signal characteristics in a long acquisition.
- Wave Inspector Search provides an easy way to find all occurrences of a specific signal characteristic, such as Start. The display should look about like this:



- Wave Inspector search allows you to find all occurrences of a specified event, such as Start. The display should look something like this:

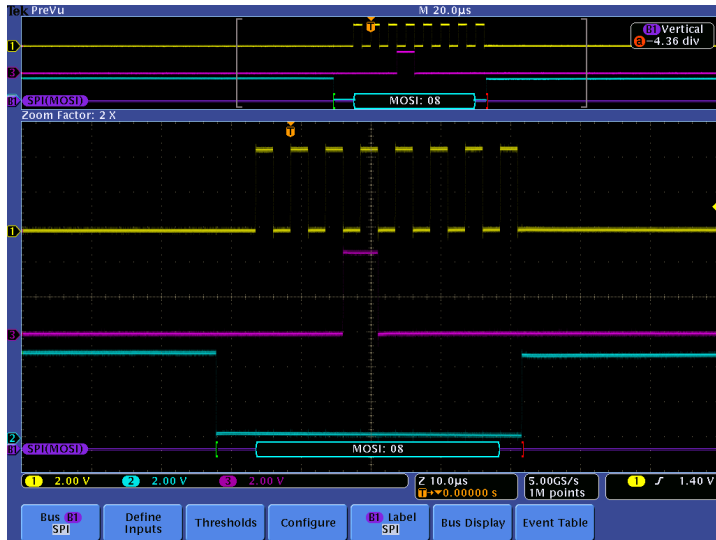


### MSO/DPO4000B Series Procedure:

- Set the Horizontal **Scale** to **4 ms/div**.
- Press the front panel **Single** button.
- Press the front panel **Search** button.
- Press the **Search** bottom bezel button.
- Repeatedly press the **Search** side bezel button until Search is turned **On**.
- Press the **Search Type** bottom bezel button.
- Using the Multipurpose **a** control, select the **Bus** Search Type.
- Press the **Search For** bottom bezel button.
- Using the Multipurpose **a** control, select Search For **Start**.
- Notice all of the hollow white triangular marks appear at the top of the display.
- Press **Menu Off**.
- Navigate between marked occurrences by using the front panel **←** and **→** buttons.
- Press the **Search For** bottom bezel button.
- Using the Multipurpose **a** control, select Search For **Data**.
- Press the **Data** bottom bezel button.
- Repeatedly press the **Data** side bezel button until the Data selection menu appears.
- Using the Multipurpose controls, set the Data pattern to **00** hex.
- Press the front panel **←** and **→** buttons to navigate between search events.

# MSO4000B/DPO4000B Series

## SPI Triggering and Decoding Lab



### Equipment List

One 4-channel MSO/DPO4000B Series oscilloscope with the latest firmware version installed

One DPO4EMBD application module

Three TPP0500 or TPP1000 passive probes

DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or

DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)

[Note: screen shots in this document were made with 020-2924-XX demo board]



## Understanding the SPI Bus

### Introduction

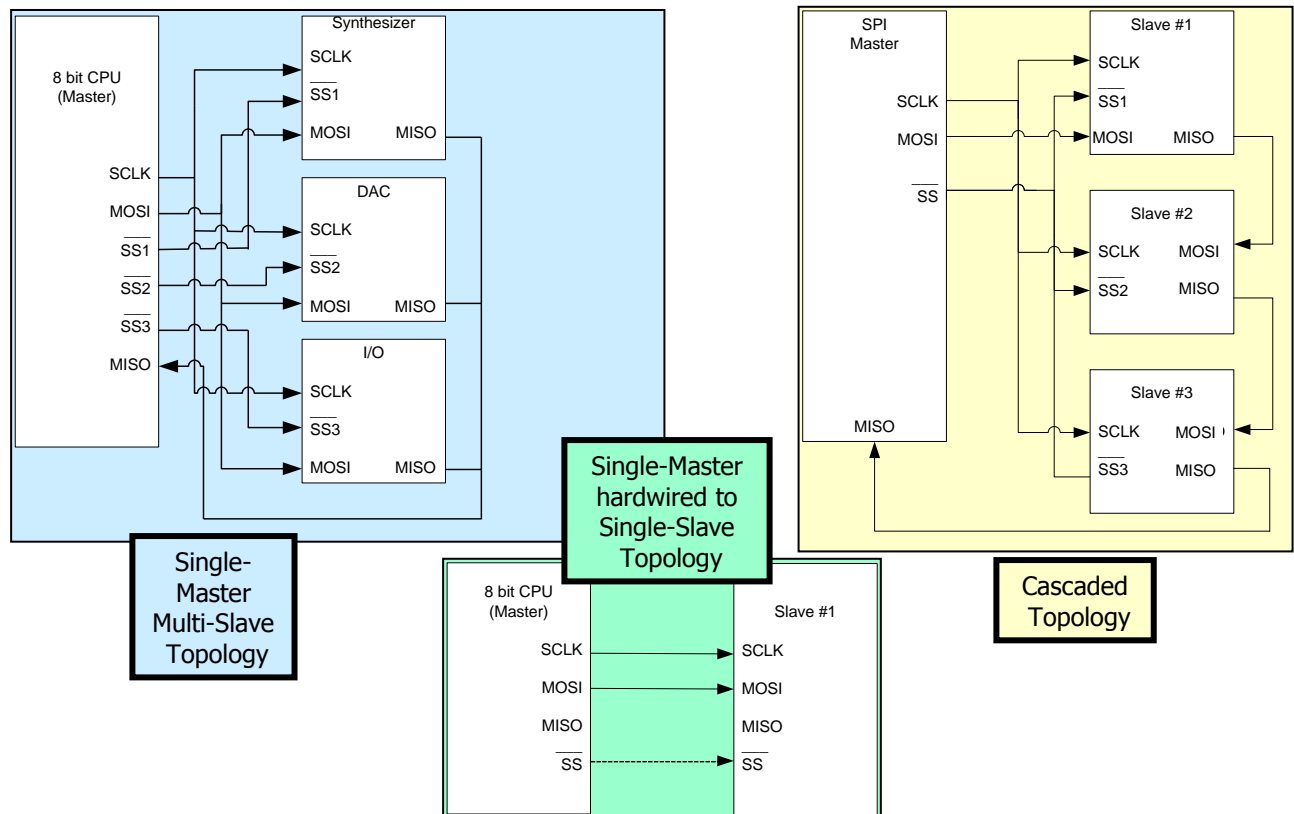
SPI (Serial Peripheral Interface) bus is a 4-wire serial communications interface used primarily in synchronous serial communication for both processors and peripherals. SPI is an interface standard defined by Motorola for use on their microcontrollers. Due to the popularity of the bus other manufacturers have adopted the standard, making a wide variety of parts available in the market. SPI uses a synchronous clock which shifts serial data into and out of the microcontroller, generally in blocks of 8 bits. SPI bus is a master/slave interface. Whenever two devices communicate, one is referred to as the “master” and the other as the “slave”. The master drives the serial clock. When using SPI, data is simultaneously transmitted and received, making it a full-duplex protocol.

As you can see in the following block diagrams, SPI is a flexible interface, supporting several different circuit topologies. In general, the master provides a clock to all slaves. When MOSI, SCLK, and SS are used, it is called the “3-wire” SPI connection.

With the single-master, multi-slave topology, the master provides data (Master Out Slave In or MOSI) directly to each slave and controls them separately with slave select signals. In the case of the “4-wire” SPI connection, the MISO signal is routed from the selected slave back to the master so the master can verify the communication path.

With the cascaded topology, the data (MOSI) from the master is “daisy-chained” through each of the slaves. In the case of the “4-wire” SPI connection, the MISO signal is routed from the last slave back to the master so the master can verify the communication path. The chain of slaves is enabled by a single SS signal, usually generated by the master. However, in the “2-wire” SPI connection, the SS inputs to the slave devices are permanently asserted (e.g. tied to ground).

With the single-master-hardwired-to-single-slave topology, the master provides MOSI and SCLK. MISO is generally not used, and often a “2-wire” connection is used for simplicity.



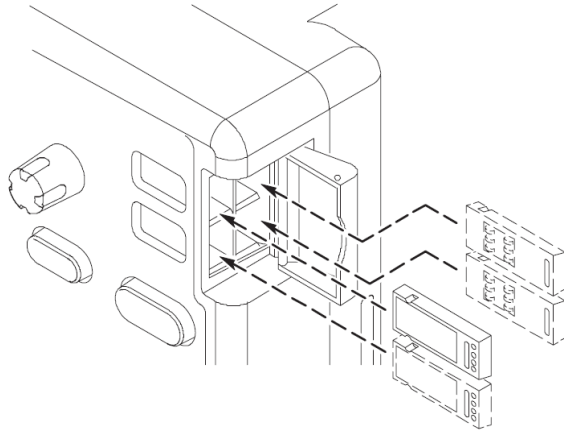
### Lab Objectives

- Obtain a basic understanding of the SPI serial bus.
- Learn how customers use oscilloscopes to measure and decode SPI.
- Learn how to setup a decoded SPI serial bus and trigger and search on SPI packet content with a MSO/DPO4000B Series oscilloscope.

### MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- SPI bus is an industry standard and can be found in many of our customers' designs today.
- Traditional manual decoding methods being used by your customers to decode SPI buses on their oscilloscope are time-consuming.
- With the DPO4EMBD application module installed, the MSO/DPO4000B Series oscilloscope can trigger on, decode, and search SPI bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.

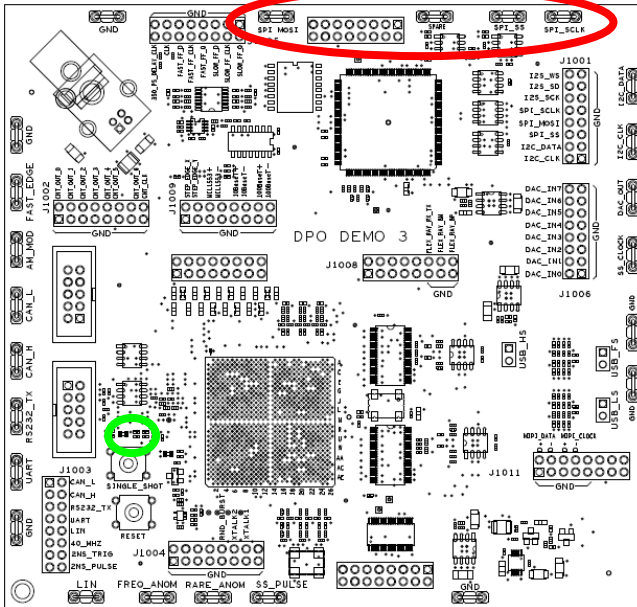


### MSO/DPO4000B Series Procedure:

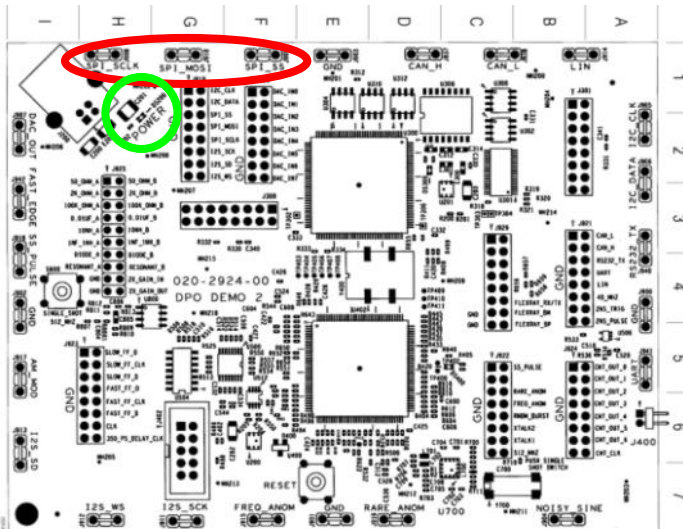
- ❑ With the oscilloscope power off, install the **DPO4EMBD** application module into one of the slots on the front panel of the instrument.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4EMBD Embedded Serial Triggering and Analysis** application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has an SPI signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has an SPI signal which we can use for this lab:

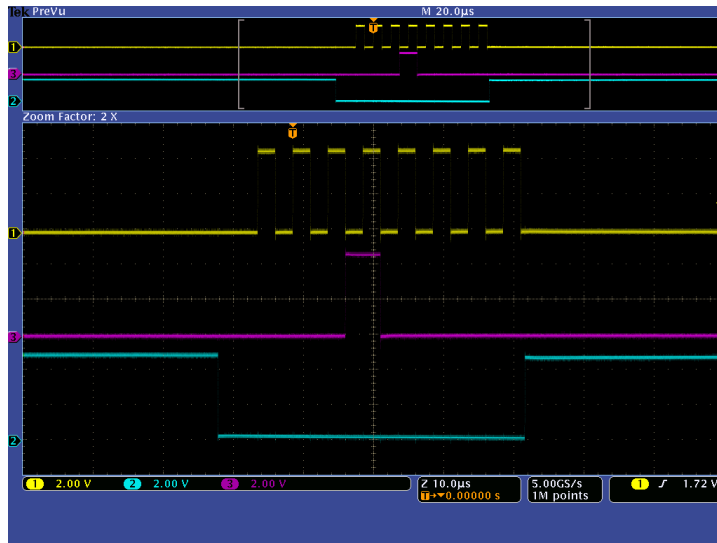


## DPO Demo Board Procedure:

- Power up the demo board.
- Verify the green **POWER** LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **SPI\_SCLK** test point.
- Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **SPI\_SS** test point. Be aware that this signal is called Chip Select (CS) by some and Slave Select (SS) by others.
- Attach a TPP0500 or TPP1000 probe to the Channel 3 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **SPI\_MOSI** test point.

## Key Take Away Points

- The SPI signal display should look about like this:



## MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1M**.
- ❑ Set the Horizontal **Scale** to **20µs/div**.
- ❑ Press the front panel **2** and **3** buttons to turn on channels **2** and **3**.
- ❑ Set the Vertical **Scale** for channels 1, 2, and 3 to **2V/div**.
- ❑ Use the Trigger **Level** control to adjust the trigger level to about **1.7V**.
- ❑ Position the waveforms on the display as shown in the screen shot on the left.
- ❑ Press **Menu Off**.
- ❑ Press the front panel **Single** button.
- ❑ Turn the inner portion of the Pan / Zoom control and adjust the zoom factor to about **2X** to get a single packet in the zoom window.
- ❑ Turn the outer portion of the Pan / Zoom control to zoom in on the beginning of the packet.

## Manual SPI Bus Decoding

### Key Take Away Points

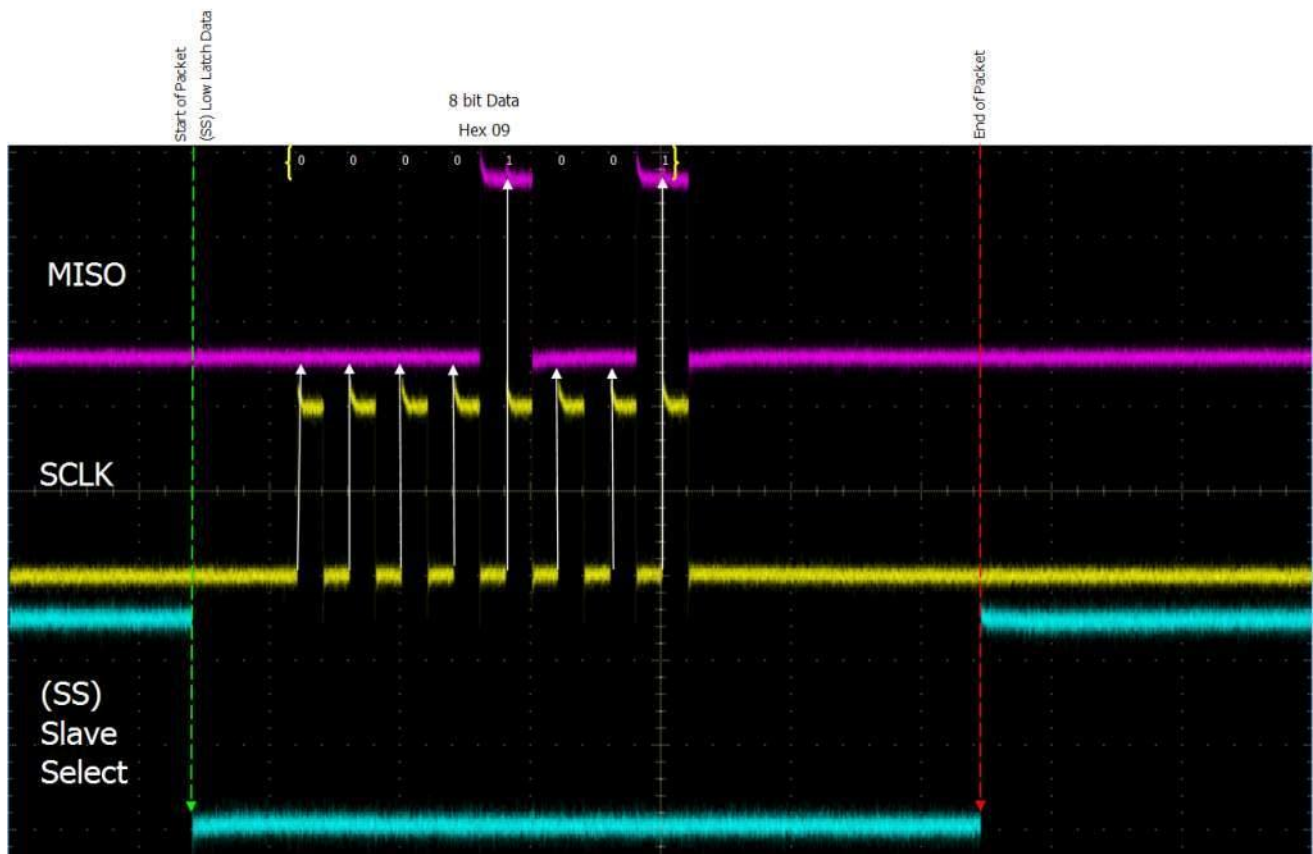
- The SPI bus is fairly easy to manually decode. For years, this has been the way your customers have done this task.

### MSO/DPO4000B Series Procedure:

- ❑ Decode the data bus values by deciding whether the data signal is high or low on each of the rising edges of the clock signal, as shown below.
- ❑ Record the decoded data value.

**Conclusion:** Manually decoding SPI packets is a time-consuming process. Engineers are looking for a better and faster way to do this.

### SPI Quick Reference Guide



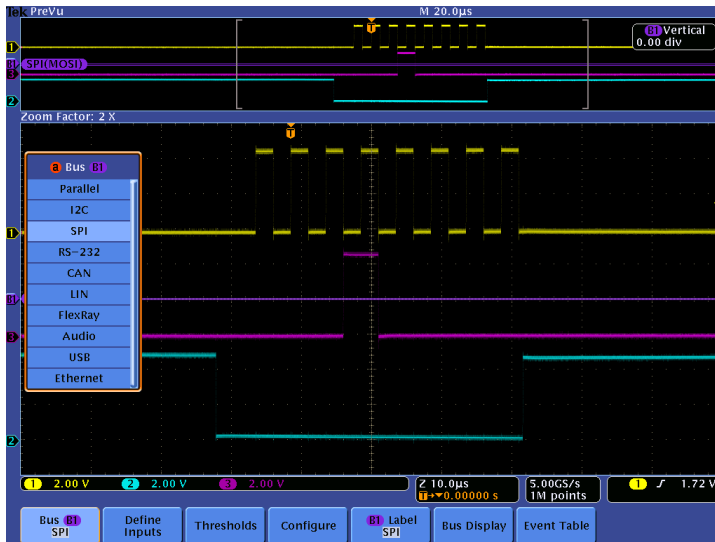
## MSO/DPO4000B Series SPI Bus Setup

### Introduction

As you personally experienced in the last section, manually decoding SPI can be a time-consuming process. In this section we will learn how to use the MSO/DPO4000B Series oscilloscope to automatically decode SPI packet content.

### Key Take Away Points

- Setting up a basic SPI bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menu guide you through the setup in the left-to-right order across the bottom bezel buttons.
- The SPI bus selection menu looks like this:



- Notice that any of the analog or digital input signals can be used as a source for the SPI bus:



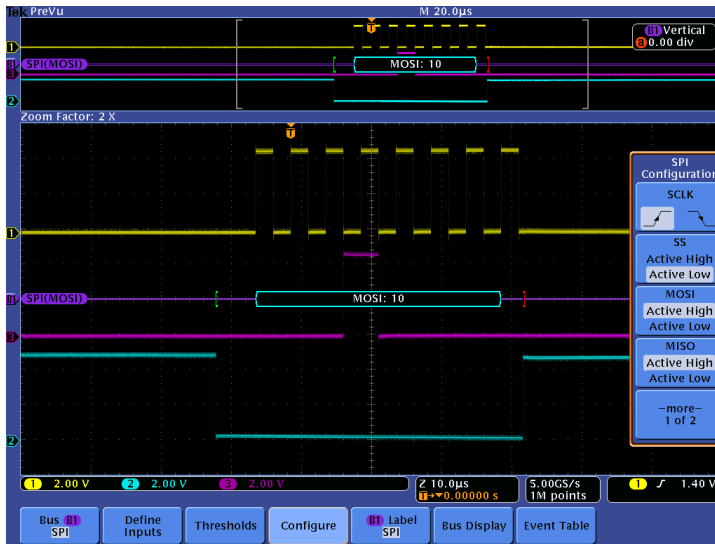
### MSO/DPO4000B Series Procedure:

- ❑ Continue with same setup as previous lab.
- ❑ Press the purple Bus **B1** button.
- ❑ Press the **Bus B1** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **SPI**.

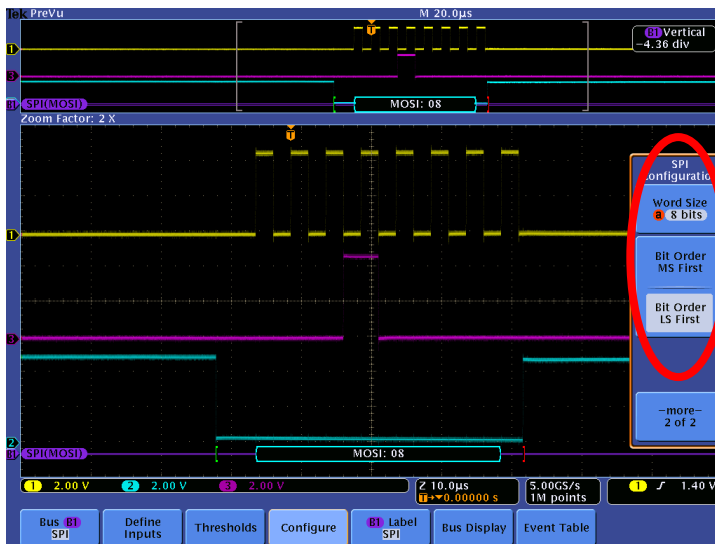
- ❑ Press the **Define Inputs** bottom bezel button. Verify that channel 1 is assigned to SCLK, channel 2 is assigned to SS Input, and channel 3 is assigned to MOSI.

## Key Take Away Points

- The SPI signal Configure menu looks like this:



- The second page of the Configure menu allows the user to specify the number of bits in the SPI packet (any integer from 4 to 32) and to specify the bit order, either most-significant or least-significant bit first.



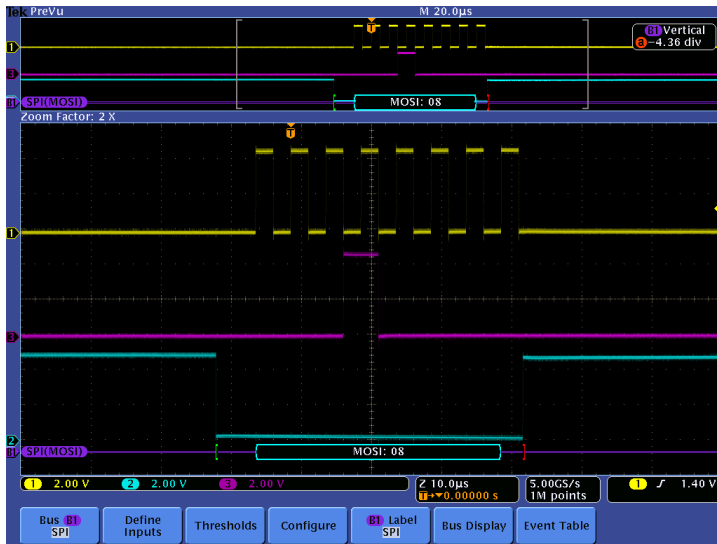
## MSO/DPO4000B Series Procedure:

- Press the **Thresholds** bottom bezel button.
- Using the Multipurpose **a** and **b** controls, set the Threshold levels for all three signals to **1.4V**.
- Press the **Configure** bottom bezel button. Verify that SCLK is set to rising edge, SS is set to Active Low, and MOSI is set to Active High.
- Press the **more- 1 of 2** side bezel button to display the second page of the configuration menu.
- Using the Multipurpose **a** control, you can adjust the number of bits in the packet.
- Press the **Bit Order LS First** side bezel button to swap the order of the bits in the decoded value.
- Note that this order swap affects both the display of the decoded data and the trigger setup.
- Press the **Bit Order MS First** side bezel button to swap the order of the bits in the decoded value.
- Press the **Menu Off** button once.
- Using the Multipurpose **a** control, position the bus near the bottom of the display.

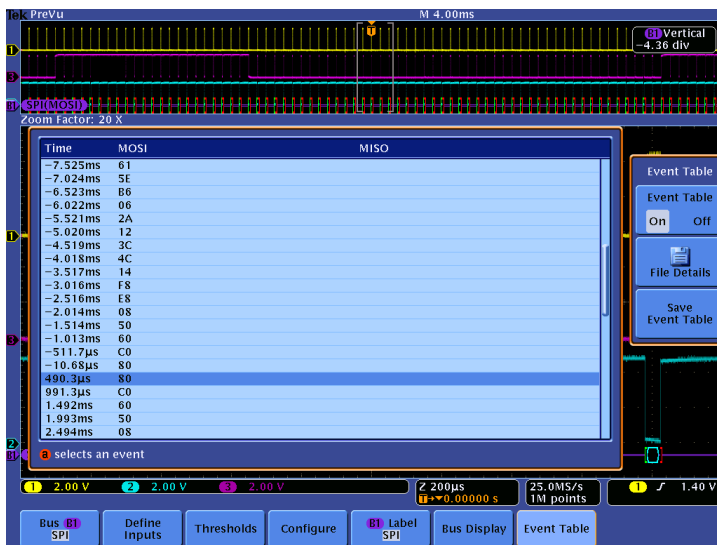


## Key Take Away Points

- The decoded SPI signal display should look about like this:



- As seen in the last section, the default SPI decoder display format is hexadecimal display of the MOSI and MISO, but these values can also be displayed in binary.
- For many users who are not electrical engineers, the waveform displays may not be familiar. For them, the Event Table format is preferable. This format can also be saved in CSV format and analyzed off-line.



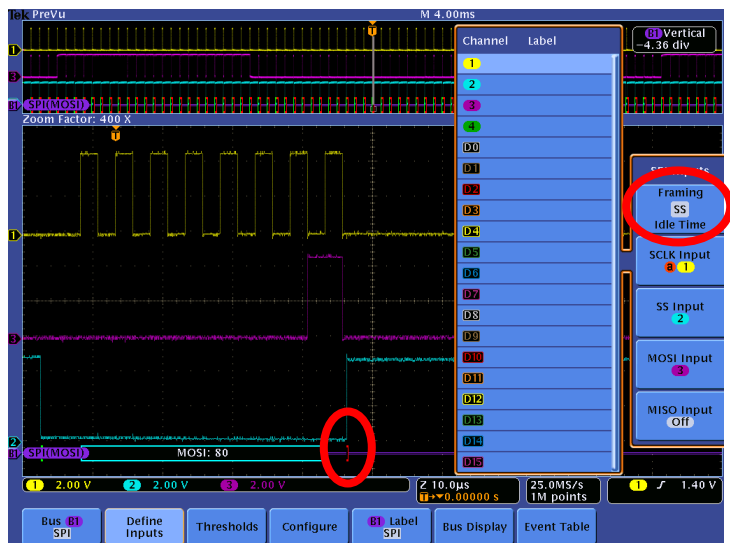
## MSO/DPO4000B Series Procedure:

- Using the Wave Inspector controls, zoom in on one of the packets.
- The green bar symbol represents the start of a packet. Start is a high to low transition on the SS signal.
- Data (MOSI) packets are shown in cyan boxes.
- The red bar symbol represents the end of a packet. This occurs at the low to high transition on the SS signal.
- Set the Horizontal **Scale** to **4 ms/div**.
- Press the front panel **Single** button.
- Press the **Bus Display** bottom bezel button.
- Notice the different bus display options.
- Press the **Event Table** bottom bezel button.
- Repeatedly press the **Event Table** side bezel button until **On** is selected.
- If there are multiple items in the table, you can scroll through the Event Table messages using the Multipurpose **a** control. When you do, notice that the zoom indicators in the overview window indicate the message position in the acquired waveform.
- Using the **Event Table** side bezel button, select **Off**.
- Press **Menu Off**.

## MSO/DPO4000B Series 2-wire SPI Decoding

### Key Take Away Points

- Before continuing on with the main lab, we need to stop and review a special case, “2-wire SPI” which is supported by the MSO/DPO4000B Series.
- Notice the top button in the SPI Define Inputs side menu. The default **Framing SS** provides 3-wire SPI functionality.



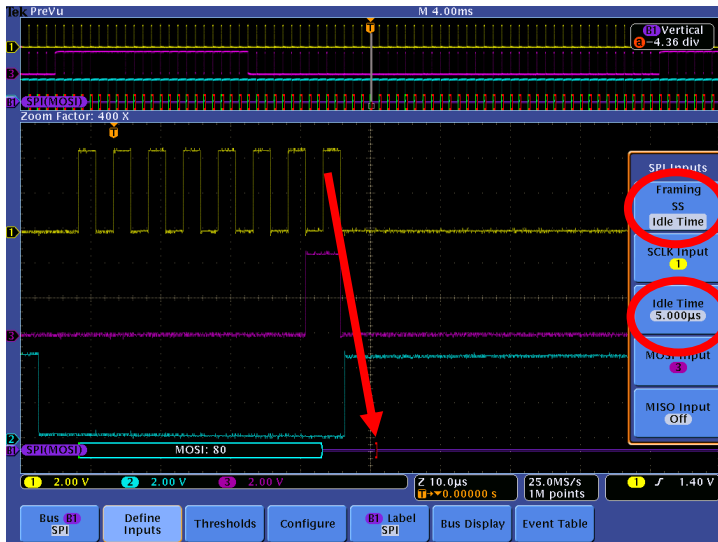
- Notice that the red end of packet indicator corresponds to the rising edge of the SS signal on channel 2.

### MSO/DPO4000B Series Procedure:

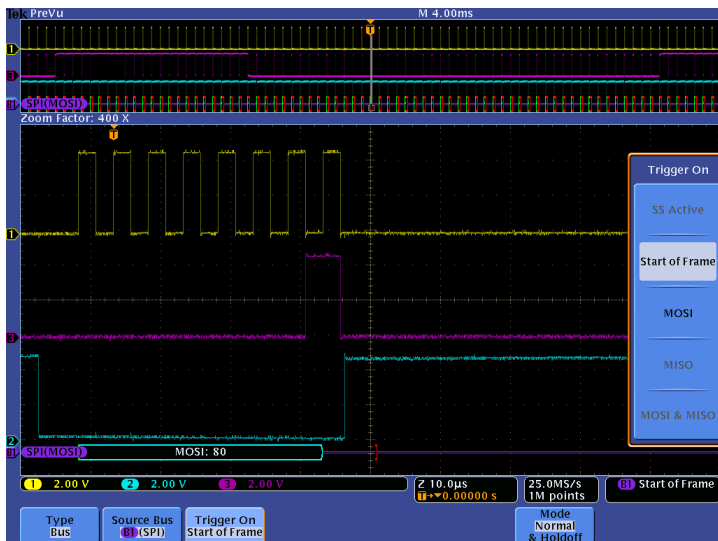
- Press the **Define Inputs** bottom bezel button.

## Key Take Away Points

- In 2-wire SPI, the end of each packet occurs after a specified idle time after the final clock pulse.



- The 2-wire SPI serial trigger's Trigger On menu is shown below. Notice the side menu gives the choice of triggering on the Start of Frame or on the MOSI data value.



- Notice that the side menu does not offer triggering on MISO or MOSI&MISO unless the MISO signal is configured in the Bus Define Inputs menu, simplifying the user interface for the majority of users.

## MSO/DPO4000B Series Procedure:

- Repeatedly press the **Framing** side bezel button until **Idle Time** is selected.
- Press the **Idle Time** side bezel button.
- Using the Multipurpose **a** control, set the **Idle Time** to **5 µs**.

- Press the front panel **Trigger Menu** button.
- Press the **Type** bottom bezel button.
- Using the Multipurpose **a** control, select **Bus**.
- Press the **Trigger On** bottom bezel button.

- When you are done, using the Multipurpose **a** control, select **Edge**.
- Press the blue front panel **B1** button.
- Repeatedly press the **Framing** side bezel button until **SS** is selected.

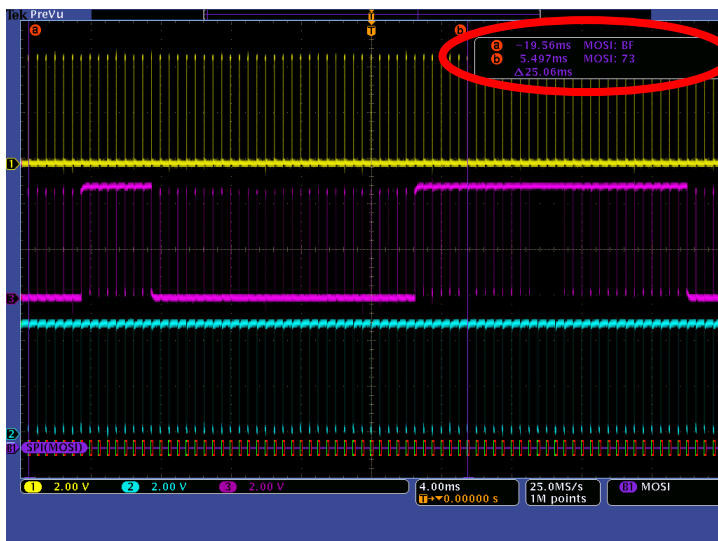
## MSO/DPO4000B Series SPI Cursors

### Key Take Away Points

- The SPI serial cursors provide another tool to bridge between the serial waveform and the decoded values, showing absolute timing relative to the trigger, bus values, and relative timing between bus events.
- For this example, we can measure the time from the start of the address to the start of the first data packet:



- Even when you are zoomed out to where you can't read the decoded values on the display, cursor measurements enable you to make timing measurements on buses. Notice that the timing from the start of the address to the start of the second data packet is clearly and easily displayed:



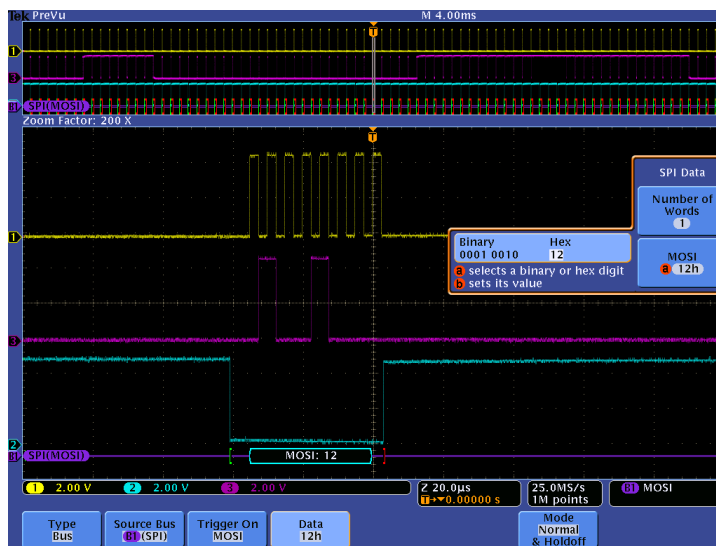
### MSO/DPO4000B Series Procedure:

- ❑ Using the Wave Inspector controls, zoom in on one of the SPI messages.
- ❑ Press the **Cursors** front panel button once to turn on vertical bar cursors.
- ❑ Using the Multipurpose **a** control, place the **a** cursor on an event of interest, such as the start of one data packet.
- ❑ Notice the **a** cursor time and bus value readout in the upper right corner of the display.
- ❑ Using the Multipurpose **b** control, place the **b** cursor on an event of interest, such as the start of the next data packet.
- ❑ Notice the **b** cursor time and bus value readout in the upper right corner of the display.
- ❑ Also notice that we are displaying the time delay between the first and second bus events of interest.
- ❑ Now, turn off zoom. Slowly move the cursors around and notice that you can easily identify the parts of the SPI packets and their timing without being able to clearly see the waveforms or the decoded values.
- ❑ Press the **Cursors** front panel button once to turn off cursors.

## MSO/DPO4000B Series SPI Bus Triggering

### Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the SPI serial bus.
- The MSO/DPO4000B Series can trigger on:
  - SS Active or Start of Frame
  - MOSI
  - MISO or MOSI&MISO (if MISO is set up)
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on an SPI signal, capturing each occurrence.



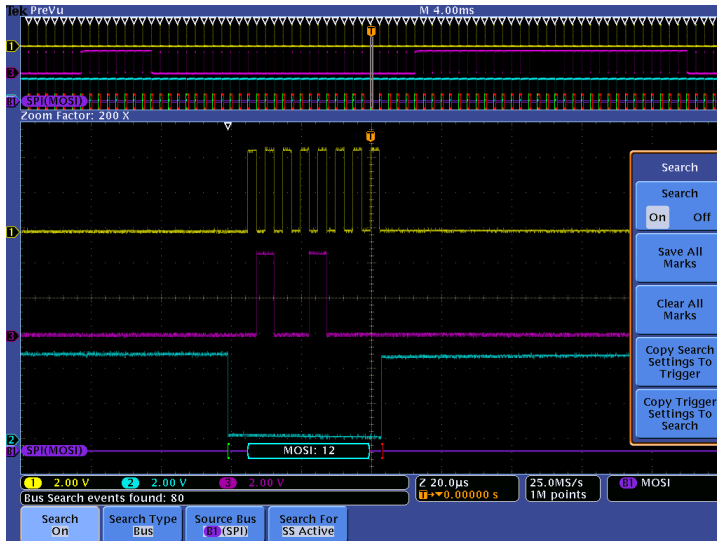
### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel Trigger **Menu** button.
- ❑ Press the **Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **Bus** triggering.
- ❑ Press the **Mode** bottom bezel button.
- ❑ Press the **Normal** side bezel button.
- ❑ Press the **Source Bus** bottom bezel button and verify that **B1(SPI)** is selected.
- ❑ Press the **Trigger On** bottom bezel button.
- ❑ Press the **MOSI** side bezel button.
- ❑ Press the **Data** bottom bezel button.
- ❑ Using the Multipurpose **a** and **b** controls, set the MOSI data value to the address you recorded in the last section of this lab (for example, 1F hex).
- ❑ Press the front panel **Single** button.
- ❑ Press **Menu Off**.
- ❑ Adjust the Wave Inspector pan and zoom controls as needed to view the SPI packets.

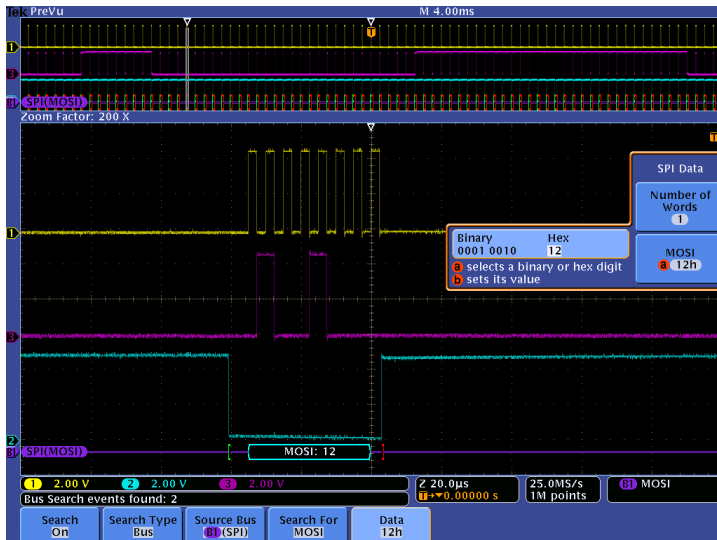
## MSO/DPO4000B Series SPI Bus Searching

### Key Take Away Points

- One of the key reasons for using long-record-length oscilloscopes is to be able to capture long time windows at high timing resolution. However, it is difficult to find specific serial signal characteristics in a long acquisition.
- Wave Inspector Search provides an easy way to find all occurrences of a specific signal characteristic, such as SS Active. The display should look about like this:



- Wave Inspector search allows you to find all occurrences of a specified event, such as a specific data value. The display should look something like this:

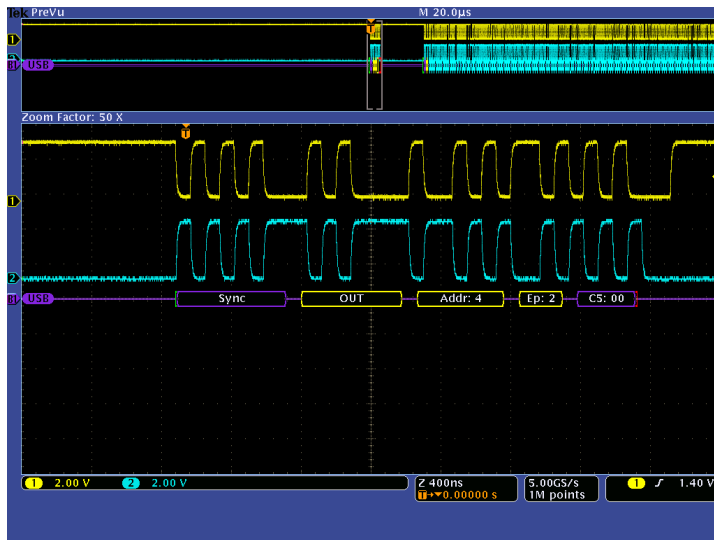


### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Search** bottom bezel button.
- ❑ Repeatedly press the **Search** side bezel button until Search is turned **On**.
- ❑ Press the **Search Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Bus** Search Type.
- ❑ Press the **Search For** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select Search For **SS Active**.
- ❑ Notice all of the white triangular marks appear at the top of the display.
- ❑ Press **Menu Off**.
- ❑ Navigate between marked occurrences by using the front panel ← and → buttons.
- ❑ Press the **Search For** bottom bezel button.
- ❑ Press the **MOSI** side bezel button.
- ❑ Press the **Data** bottom bezel button.
- ❑ Repeatedly press the **MOSI** side bezel button until the **SPI Data** selection menu appears.
- ❑ Using the Multipurpose controls, set the Data pattern to **12 hex**.
- ❑ Press the front panel ← and → buttons to navigate between search events.

# MSO4000B/DPO4000B Series

## USB Triggering and Decoding Lab



### Equipment List

One MSO/DPO4000B Series oscilloscope with the latest firmware version installed

NOTE: An MSO4104B or DPO4104B is required for High-speed USB support

One DPO4USB application module

Two TPP0500 or TPP1000 passive probes

One TDP1000 differential probe

PC with USB2.0 Host ports

DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00)

## Understanding the USB Bus

### Introduction

Universal Serial Bus (USB) has replaced many of the personal computer external serial and parallel buses. USB is a simple and inexpensive interface that brought plug-and-play ease-of-use in connecting and using external devices with the computer. For example, USB devices can be hot-plugged into the computer with dynamically loadable drivers without the need to reboot.

The USB Implementers Forum (USB-IF) manages and promotes USB standards and USB technology. USB specifications are available at the USB-IF web site at [www.usb.org](http://www.usb.org).

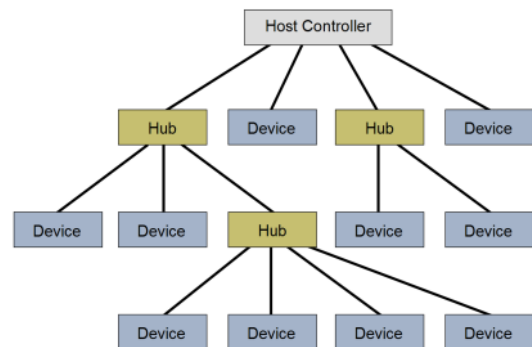
Since the USB introduction in 1995 USB has grown beyond its original personal computer usage and it has become a ubiquitous interface used in many types of electronic devices. For example, the Inter-Chip USB (IC\_USB) and the High-Speed Inter-Chip (HSIC) USB are used for chip-to-chip communications and these implementations do not have connectors, cables, or analog transceivers.

USB 2.0 specifications that were released in 2000 cover most of the USB devices that are being used today. USB 2.0 added a high speed interface to the USB 1.1 specifications. Compliance to USB 2.0 does not require high speed operation. For example, a low-speed USB mouse can be compliant to USB 2.0 and advertise that it is an USB 2.0 device. Supplements to the USB 2.0 specifications cover IC\_USB, HSIC and other enhancements.

### Controller Configuration

The USB configuration is one host controller with 1 to 127 devices. USB is a tiered-star topology with optional hubs to expand the bus, as shown at the right:

The host is the only master and it controls all bus traffic. The host initiates all communications to devices and devices do not have the capability to interrupt the host.



### Enumeration

Enumeration is the configuration process that occurs at power-on or when a device is hot plugged. The host detects the presence of the device on the USB bus. Next, the host polls the device with the SETUP token using address 0 and endpoint 0. Then, the host assigns a unique address to a device in the range of 1 to 127. The host also identifies the device speed and data transfer type, and determines the device's class. The device class defines a device's functionality such as printer, mass storage, video, audio, human interface, etc.



## Electrical

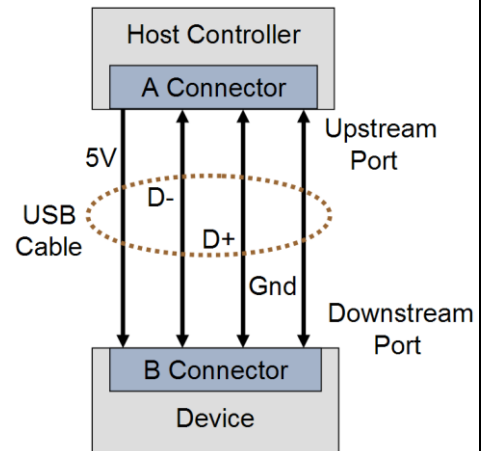
The host uses an upstream “A” connector and devices use a downstream “B” connector.

The USB 2.0 cable has four wires, shown at the right:

Two wires are used for 5 V power (red wire) and ground (black wire) from the host. The connectors are designed so that the power and ground pins are connected before the data pins. The host provides current from 100 mA to 500 mA with intelligent power management. For example, power to a device can be monitored by the host or hub and switched off if an over-current condition occurs.

A twisted differential pair D+ (green wire) and D- (white wire) is used for bidirectional communications using half-duplex, DC-coupled differential signaling controlled by the host. Signal levels are listed in the table below:

USB Speed	Low State	High State
Low Speed	<0.3V	>2.8V
Full Speed	<0.3V	>2.8V
High Speed	0 V±10%	400 mV±10%



The host pulls down both D+ and D- when no device is connected. This is called single-ended zero (SE0) state. As a result, the oscilloscope will show 0 V when probing a USB bus that has no device connected.

Data transmission uses Non-Return-to-Zero-Inverted (NRZI) encoding. A logic ‘0’ is represented by the signal polarity toggling, while a logic ‘1’ is no change. The least significant bit is transmitted first and the most significant bit is transmitted last. To maintain adequate AC signal content, an extra ‘0’ is inserted after six consecutive 1s (called “bit stuffing”).

## Packets

Packets are the fundamental elements of USB communications.

For full-speed and low-speed USB, a packet starts from the idle state with an 8-bit synchronization (SYNC) field. For high-speed USB, a packet starts from the idle state with a 32-bit synchronization (SYNC) field.

Then the Packet Identifier (PID) is transmitted. The PID is composed of a 4-bit PID and its 4-bit PID complement for error checking. A PID encoding error is when the first PID 4-bits do not match the complement of the last PID 4-bits. The PID 4-bit value identifies 17 types of packets, shown in the table at the right:

PIDs are grouped into four Types: token, data, handshake and special.

Finally, the 3-bit end-of-packet (EOP) is transmitted.

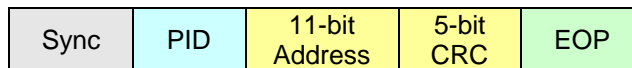
PID Type	PID Name	PID
Token	OUT	0001
	IN	1001
	SOF	0101
	SETUP	1101
Data	DATA0	0011
	DATA1	1011
	DATA2	0111
	MDATA	1111
Handshake	ACK	0010
	NAK	1010
	STALL	1110
	NYET	0110
Special	PRE	1100
	ERR	1100
	SPLIT	1000
	PING	0100
	Reserved	0000

## Handshake Packets

Handshake packets such as data packet accepted (ACK) and data packet not accepted (NAK) are composed of the Sync byte, PID byte and EOP.

## Token Packets

Host-sent token packets are composed of the PID followed by two bytes composed of a 11-bit address and a 5-bit cyclic redundancy check (CRC), as shown here:



OUT, IN and SETUP token packet organization

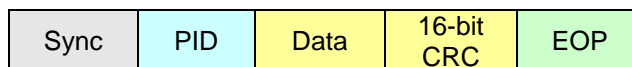
Address zero is special and is for a device that has not been assigned an address at the beginning of the enumeration process. Later in the enumeration process, the host assigns a nonzero address to the device.

All devices have an endpoint zero. Endpoint zero is special and is used for device control and status. Other device endpoints are for data sources and/or sinks.

The host sends an OUT token to a device followed by data packets. The host sends an IN token to a device and expects to receive data packets or handshake packet such as NAK from the device.

## Data Packets

Data packets contain a PID byte, data bytes and 16-bit CRC, as shown here:



Data Packets with the PID defining a DATA0 or DATA1 packet

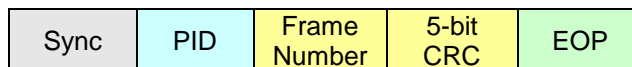
DATA0 and DATA1 packets have a 1-bit sequence number that is used in stop and wait automatic repeat-request handshake. DATA0 and DATA1 packets alternate in error free transmission. Data packets are resent with the same sequence number when a transmission error occurs.

An error free data transaction is when the host sends a DATA0 packet to the device, the device sends a handshake ACK packet, and then the host sends a DATA1 packet.

If the host does not receive a handshake ACK packet, or receives a NAK from the device, it resends the DATA0 packet. If the device sent an ACK packet and receives the data packet with the same sequence number again, the device acknowledges the data packet but ignores the data as a duplicate.

## Start of Frame

Start of Frame (SOF) packet is used to synchronize isochronous and polled data flows. The 11-bit frame number is incremented by one in each consecutive SOF.



Start of Frame Packet

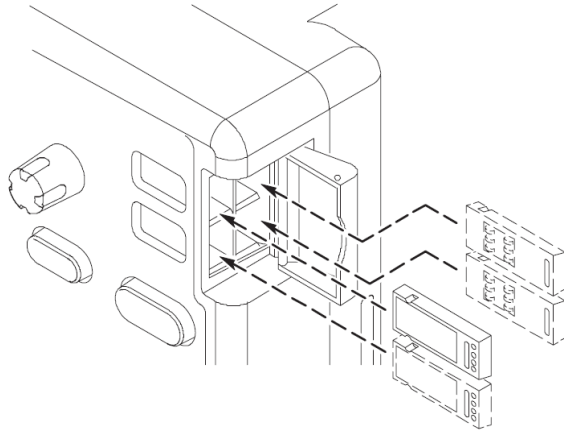
## Lab Objectives

- Obtain a basic understanding of the USB serial bus.
- Learn how customers use oscilloscopes to measure and decode USB.
- Learn how to setup a decoded USB serial bus and trigger and search on USB packet content with a MSO/DPO4000B Series oscilloscope.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- USB bus is an industry standard and can be found in many of our customers' designs today.
- Traditional manual decoding methods being used by your customers to decode USB buses on their oscilloscope are time-consuming.
- With the DPO4USB application module installed, the MSO/DPO4000B Series oscilloscope can trigger on, decode, and search USB bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.

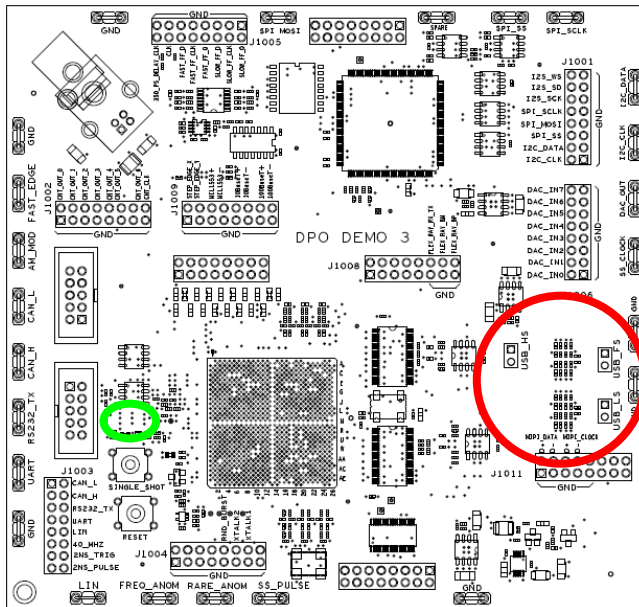


### MSO/DPO4000B Series Procedure:

- ❑ With the oscilloscope power off, install the **DPO4USB** application module into one of the slots on the front panel of the instrument.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4USB USB Serial Triggering and Analysis** application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.

### Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has USB signals which we can use for this lab:



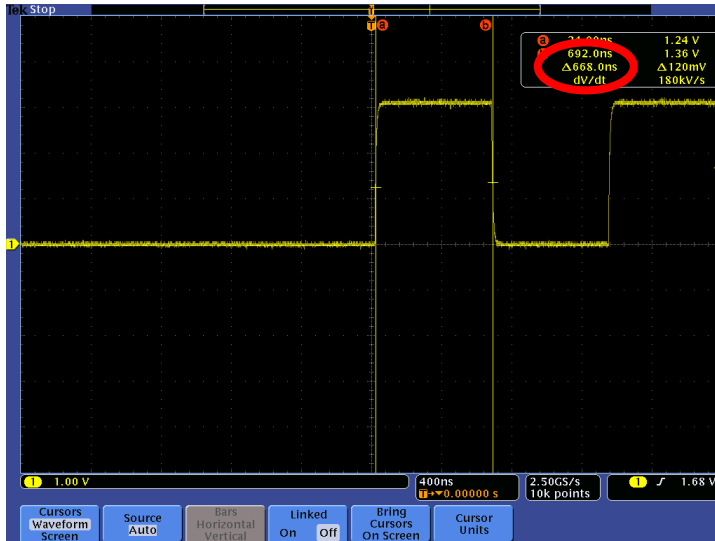
### DPO Demo Board Procedure:

- ❑ Power up the demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ On this board, the three USB signals are differential signals and are available on pairs of square pins. The positive side of the differential signal is on pin 1 of the connector (identified by the silkscreen arrow and the square pad) and the negative side of the differential signal is on pin 2 of the connector.

## Key Take Away Points

### (optional) Determining USB Data Rate

- The data rate of USB signals for commonly-available USB computer mice and USB flash drives may be Low-speed (1.5 Mb/s), Full-speed (12 Mb/s), or High-speed (480 Mb/s). In some cases, the devices may specify the speed at which they operate. However, in general, you may need to determine the data rate using this procedure.
- The display should look about like this:



Minimum Pulse Width	USB Bit Rate	USB Speed
667 ns	1.5 Mb/s	Low-speed
83 ns	12 Mb/s	Full-speed
2.08 ns	480 Mb/s	High-speed

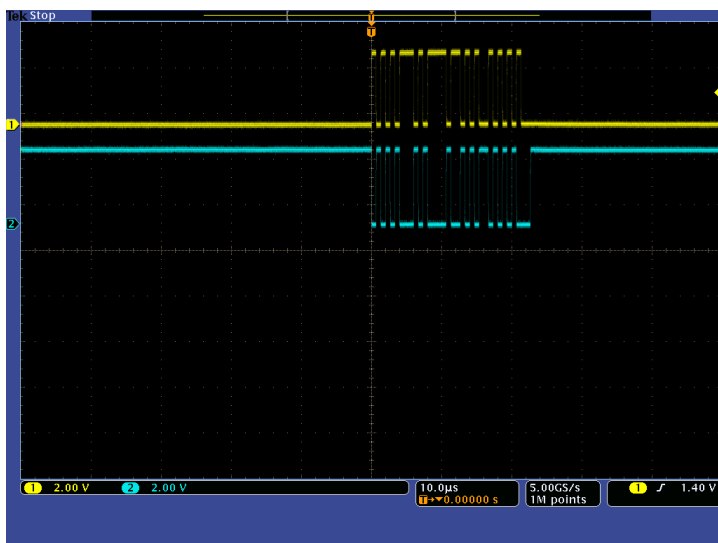
### MSO/DPO4000B Series Procedure:

- For this optional bit rate test only:
- Attach a TPP0500 or TPP1000 passive probe to the Channel 1 input of the oscilloscope.
- Connect the probe tip to the D+ signal on pin 1 of the **USB\_LS** or **USB\_FS** connector and the probe ground to **GND**.
- Press **Autoset**.
- Adjust the **Horizontal Scale** to clearly display individual cycles of the signal.
- Press and hold the front panel **Cursors** button once to turn on vertical bar cursors and to enable the cursor menu.
- Using the Multipurpose controls, measure the width of the narrowest pulse, as shown in the screen shot at the left.
- Read the pulse width ( $\Delta$  time in the cursor readout) and write the value here: \_\_\_\_\_
- Or, you can press the **Cursor Units** bottom bezel button and use the Multipurpose **a** control to select the **Hz** units. Then you can read out the bit rate directly.
- Look up the data rate in the table at the left.

## MSO/DPO4000B Series Low-Speed USB Bus Setup and Decoding

### Key Take Away Points

- NOTE: Low-speed USB triggering and analysis support is offered on all properly-equipped MSO/DPO4000B models. Both single-ended and differential probing of the USB signal is supported. For simplicity, this lab will use single-ended probing with the standard passive probes.
- The Low-speed USB signal display should look about like this:

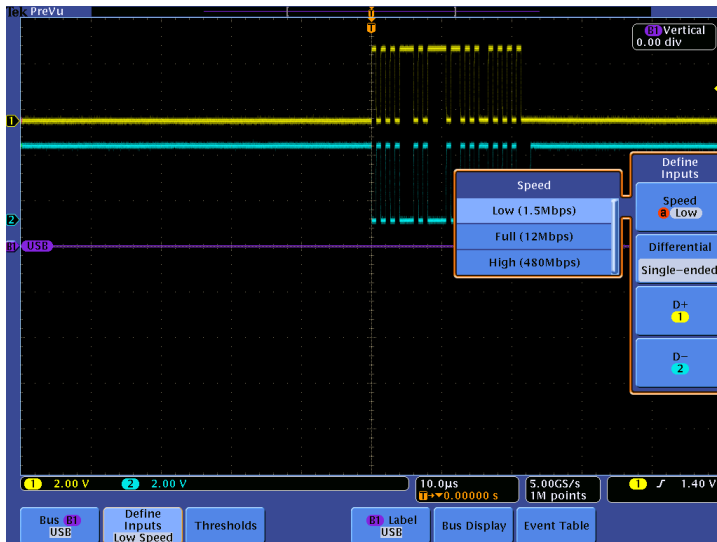


### MSO/DPO4000B Series Procedure:

- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to pin **1** of the **USB\_LS** connector on the demo board.
- Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to pin **2** of the **USB\_LS** connector on the demo board.
- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Press the **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **1M**.
- Set the Horizontal **Scale** to **10us/div**.
- Press the front panel **2** button to turn on channel **2**.
- Set the Vertical **Scale** for channels 1 and 2 to **2V/div**.
- Use the Trigger **Level** control to adjust the trigger level to about **1.4V**.
- Position the waveforms in the top half of the display as shown in the screen shot on the left.
- Press **Menu Off**.
- Press the front panel **Single** button.

## Key Take Away Points

- The USB signal Define Inputs menu looks like this:



- Setting up a basic USB bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menu guide you through the setup in the left-to-right order across the bottom bezel buttons.
- Notice that any of the analog or digital input signals can be used as a source for the USB bus.
- When you zoom in on the decoded USB signals, you should see a display about like this:



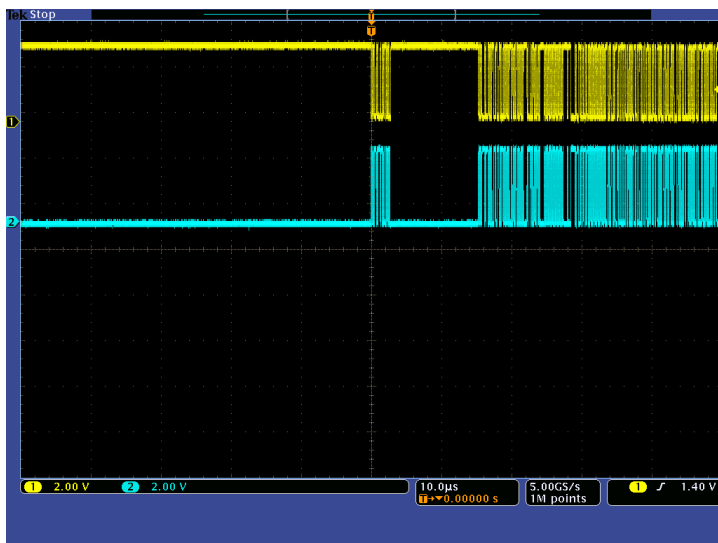
## MSO/DPO4000B Series Procedure:

- Press the purple Bus **B1** button.
- Press the **Bus B1** bottom bezel button.
- Using the Multipurpose **a** control, select **USB**.
- Press the **Define Inputs** bottom bezel button.
- Press the **Speed** side bezel button. Using the Multipurpose **a** control, select **Low (1.5Mbps)**.
- Repeatedly press the second side bezel button until **Single-ended** is selected. Verify that channel 1 is assigned to **D+** and channel 2 is assigned to **D-**.
- Press the **Thresholds** bottom bezel button.
- Using the Multipurpose **a** and **b** controls, set the **Threshold** levels for both signals to **1.4V**.
- Turn the inner portion of the Pan Zoom control and adjust the zoom factor to about 10X to get a single packet in the zoom window.
- Turn the outer portion of the Pan / Zoom control to zoom in on the beginning of the packet.
- Press the **Bus Display** bottom bezel button. Notice the different display formats that are available.
- Press the **Event Table** bottom bezel button. Notice that the Event Table display is available, and that the decoded data can be saved in .CSV format from this menu.
- Press the **Menu Off** button once.

## MSO/DPO4000B Series Full-Speed USB Bus Setup and Decoding

### Key Take Away Points

- NOTE: Full-speed USB support is offered on all properly-equipped MSO/DPO4000B models. Both single-ended and differential probing of the USB signal is supported. For simplicity, this lab will use single-ended probing with the standard passive probes.
- The Full-speed USB signal display should look about like this:

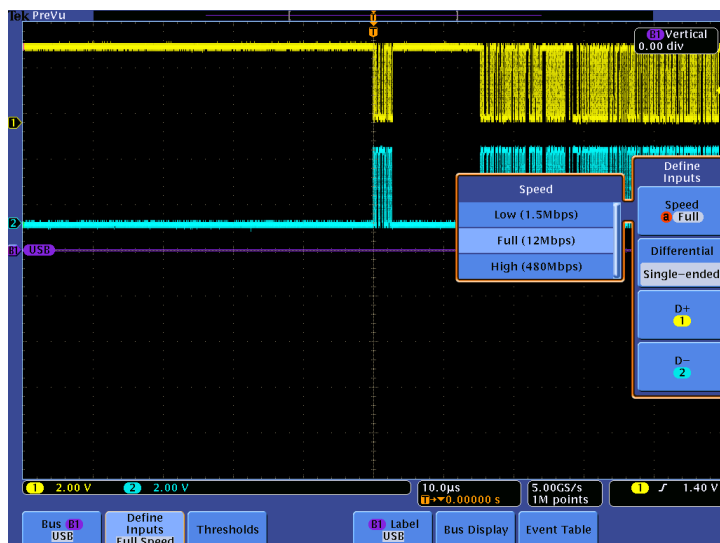


### MSO/DPO4000B Series Procedure:

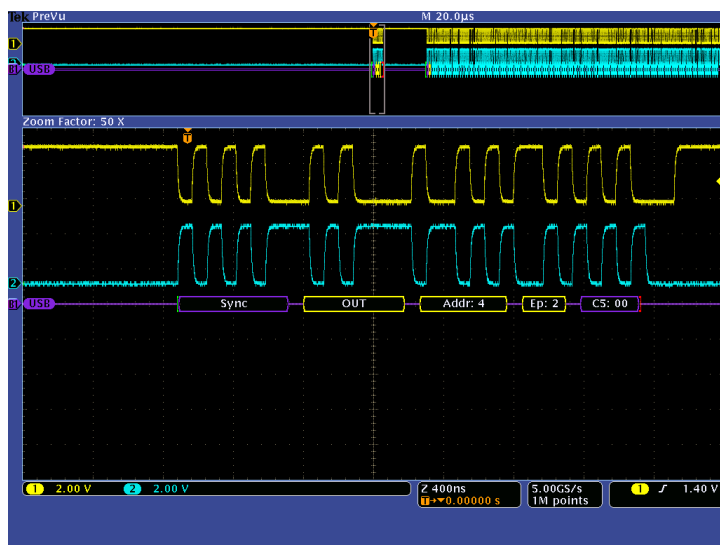
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to pin **1** of the **USB\_FS** connector on the USB test board.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to pin **2** of the **USB\_FS** connector on the USB test board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1M**.
- ❑ Set the Horizontal **Scale** to **10µs/div**.
- ❑ Press the front panel **2** button to turn on channel **2**.
- ❑ Set the Vertical **Scale** for channels 1 and 2 to **2V/div**.
- ❑ Use the Trigger **Level** control to adjust the trigger level to about **1.4V**.
- ❑ Position the waveforms in the top half of the display as shown in the screen shot on the left.
- ❑ Press **Menu Off**.
- ❑ Press the front panel **Single** button.

## Key Take Away Points

- The USB signal Define Inputs menu looks like this:



- Setting up a basic USB bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menu guide you through the setup in the left-to-right order across the bottom bezel buttons.
- Notice that any of the analog or digital input signals can be used as a source for the USB bus.
- When you zoom in on the decoded USB signals, you should see a display about like this:



## MSO/DPO4000B Series Procedure:

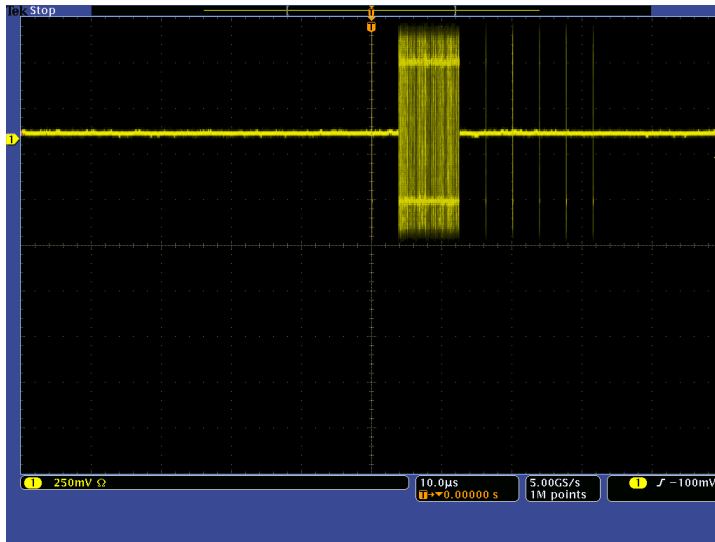
- ❑ Press the purple Bus **B1** button.
- ❑ Press the **Bus B1** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **USB**.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ Press the **Speed** side bezel button. Using the Multipurpose **a** control, select **Full (12Mbps)**.
- ❑ Repeatedly press the second side bezel button until **Single-ended** is selected. Verify that channel 1 is assigned to **D+** and channel 2 is assigned to **D-**.
- ❑ Press the **Thresholds** bottom bezel button.
- ❑ Using the Multipurpose **a** and **b** controls, set the **Threshold** levels for both signals to **1.4V**.
- ❑ Turn the inner portion of the Pan / Zoom control and adjust the zoom factor to about 100X to get a single packet in the zoom window.
- ❑ Turn the outer portion of the Pan / Zoom control to zoom in on the beginning of the packet.
- ❑ Press the **Bus Display** bottom bezel button. Notice the different display formats that are available.
- ❑ Press the **Event Table** bottom bezel button. Notice that the Event Table display is available, and that the decoded data can be saved in .CSV format from this menu.
- ❑ Press the **Menu Off** button once.



## MSO/DPO4000B Series High-Speed USB Bus Setup and Decoding

### Key Take Away Points

- NOTE: High-speed USB support is only offered on the 1 GHz MSO4104B and DPO4104B models, and requires differential probing of the USB signal.
- Also, note that the maximum USB speed is limited by both the host and the device. For example, if you power the USB device from the MSO/DPO4000B's USB host ports, the speed will be limited to Low-speed or Full-speed, even for a High-speed device.
- The High-speed USB signal display should look about like this:

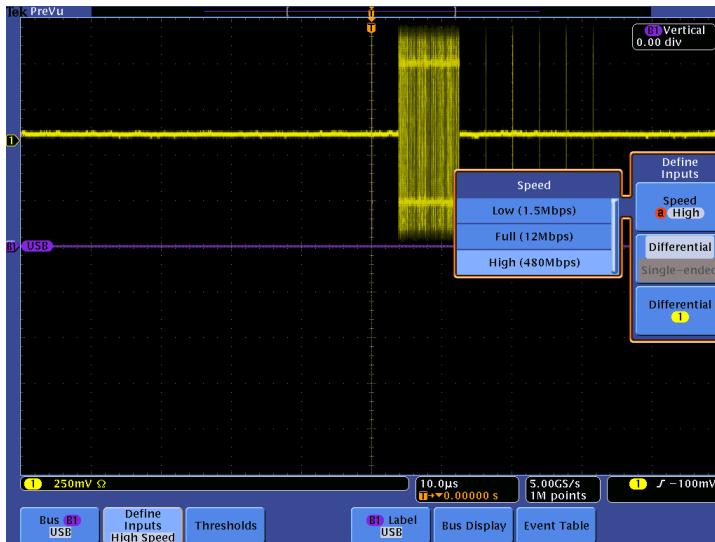


### MSO/DPO4000B Series Procedure:

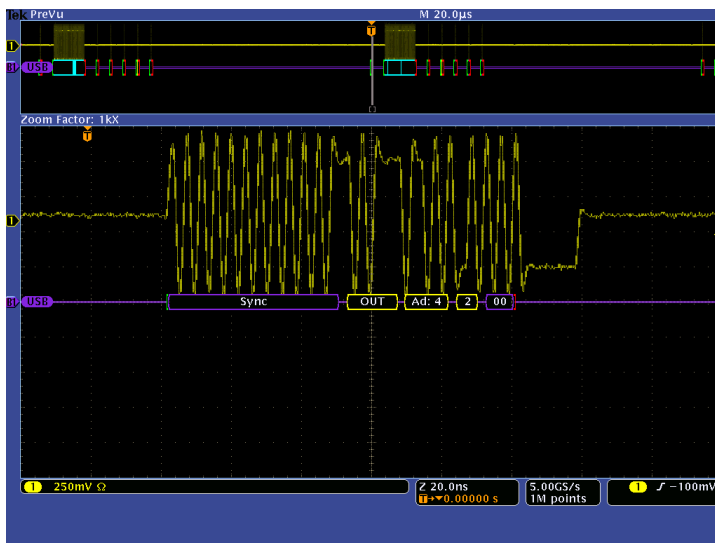
- ❑ Attach a TDP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe + input to pin 1 and the probe – input to pin 2 of the **USB\_HS** connector.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the **Menu** button on the TDP1000.
- ❑ Press the **Range** button on the probe or the side bezel to select **4.25V**.
- ❑ Press the **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1M**.
- ❑ Set the Horizontal **Scale** to **10µs/div**.
- ❑ Set the Vertical **Scale** for channel 1 to **250 mV/div**.
- ❑ Use the Trigger **Level** control to adjust the trigger level to about **-100 mV**.
- ❑ Position the waveform in the top half of the display as shown in the screen shot on the left.
- ❑ Press **Menu Off**.
- ❑ Press the front panel **Single** button.

## Key Take Away Points

- The USB signal Define Inputs menu looks like this:



- Setting up a basic USB bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menu guide you through the setup in the left-to-right order across the bottom bezel buttons.
- Notice that any of the analog or digital input signals can be used as a source for the USB bus.
- When you zoom in on the decoded USB signals, you should see a display about like this:



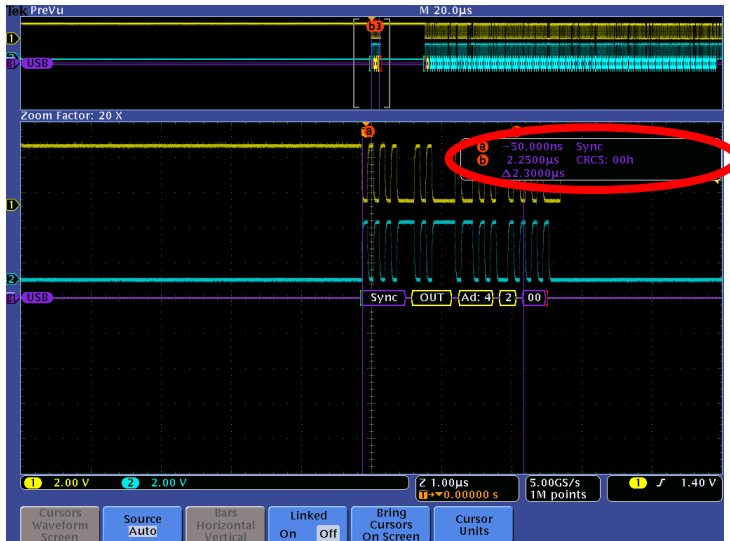
## MSO/DPO4000B Series Procedure:

- Press the purple Bus **B1** button.
- Press the **Bus B1** bottom bezel button.
- Using the Multipurpose **a** control, select **USB**.
- Press the **Define Inputs** bottom bezel button.
- Press the **Speed** side bezel button. Using the Multipurpose **a** control, select **High (480Mbps)**.
- Notice that the second side bezel button indicates that only **Differential** is supported. Verify that the differential input is on channel 1.
- Press the **Thresholds** bottom bezel button.
- Using the Multipurpose **a** control, set the Diff Probe High (1) Threshold level to **100 mV**.
- Use the Multipurpose **b** control to set the Diff Probe Low (1) Threshold level to **-100 mV**.
- Press the **Menu Off** button once.
- Turn the inner portion of the Pan / Zoom control and adjust the zoom factor to about 1000X to get a single packet in the zoom window.
- Turn the outer portion of the Pan / Zoom control to zoom in on the beginning of the packet.
- Press the **Bus Display** bottom bezel button. Notice the different display formats that are available.
- Press the **Event Table** bottom bezel button. Notice that the Event Table display is available, and that the decoded data can be saved in .CSV format from this menu.
- Press the **Menu Off** button once.

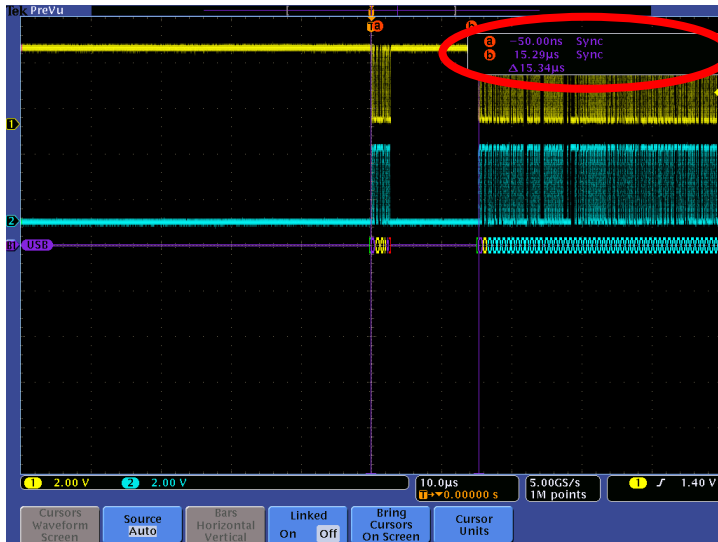
## MSO/DPO4000B Series USB Cursors

### Key Take Away Points

- The USB serial cursors provide another tool to bridge between the serial waveform and the decoded values, showing absolute timing relative to the trigger, bus values, and relative timing between bus events.
- For this example with a Full-speed USB device, we can measure the time from the start of the address to the start of the first data packet:



- Even when you are zoomed out to where you can't read the decoded values on the display, cursor measurements enable you to make timing measurements on buses. Notice that the timing from the first Sync to another Sync in the long acquisition is clearly and easily displayed:



### MSO/DPO4000B Series Procedure:

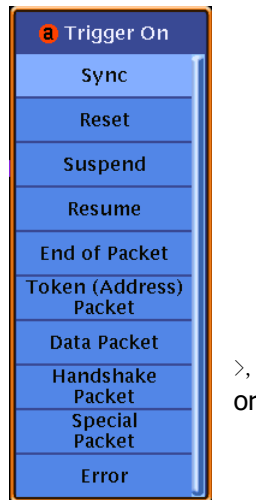
- ❑ NOTE: The remaining sections of this lab can be done with any of the USB speeds.
- ❑ Connect the probe(s) to the USB signal and acquire.
- ❑ Using the Wave Inspector control, zoom in on one of the USB messages.
- ❑ Press and hold the **Cursors** front panel button once to turn on vertical bar cursors and turn on the Cursors menu.
- ❑ Press the **Bring Cursors On Screen** bottom bezel button.
- ❑ Using the Multipurpose **a** control, place the **a** cursor on an event of interest, such as Sync.
- ❑ Notice the **a** cursor time and bus value readout in the upper right corner of the display.
- ❑ Using the Multipurpose **b** control, place the **b** cursor on an event of interest, such as the CRC.
- ❑ Notice the **b** cursor time and bus value readout in the upper right corner of the display.
- ❑ Also notice that we are displaying the time delay between the first and second bus events of interest.
- ❑ Now, turn off zoom.
- ❑ Slowly move the cursors around and notice that you can easily identify the parts of the USB packets and their timing without being able to clearly see the waveforms or the decoded values.
- ❑ Press the **Cursors** front panel button once to turn off cursors.

## MSO/DPO4000B Series USB Bus Triggering

### Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the USB serial bus.
- The MSO/DPO4000B Series can trigger on the following elements of a USB 2.0 bus:

- Sync
- Reset
- Suspend
- Resume
- End of Packet
- Token (address) Packet: Any token type, SOF, OUT, IN, SETUP; Address and End Point can be specified for Any Token, OUT, IN, and SETUP token types. Address can be further specified to trigger on  $\leq$ ,  $<$ ,  $=$ ,  $\geq$ ,  $\neq$  a particular value, or inside outside of a range. Frame number can be specified for SOF token using binary, hex, unsigned decimal and don't care digits.
- Data Packet: Any data type, DATA0, DATA1, DATA2 (HS only), MDATA (HS only). Data can be further specified to trigger on  $\leq$ ,  $<$ ,  $=$ ,  $>$ ,  $\geq$ ,  $\neq$  a particular data value, or inside our outside of a range.
- Handshake Packet: Any handshake type, ACK, NAK, STALL, NYET (HS only).
- Special Packet: Any special type, PRE (LS and FS only), Reserved, ERR (HS only), SPLIT (HS only), PING (HS only). Any special type, ERR, SPLIT, PING, Reserved. SPLIT packet components that can be specified include:
  - Hub Address
  - Start/Complete - Don't care, Start (SSPLIT), Complete (CSPLIT)
  - Port Address
  - Start and End bits - Don't care, Control/Bulk/Interrupt - Full speed device, Control/Bulk/Interrupt - Low speed device, Isochronous - Data is middle, Isochronous - Data is end, Isochronous - Data is start, Isochronous - Data is all
  - Endpoint Type - Don't care, Control, Isochronous, Bulk, Interrupt
- Error: PID check, CRC5 or CRC16, Bit stuffing (LS and FS only).



### MSO/DPO4000B Series Procedure:

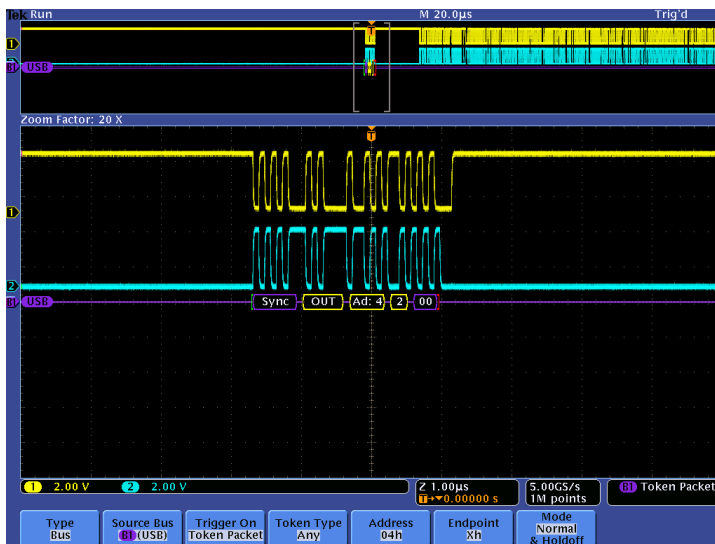
- Press the front panel Trigger **Menu** button.
- Press the **Type** bottom bezel button.
- Using the Multipurpose **a** control, select **Bus** triggering.
- Press the **Mode** bottom bezel button.
- Press the **Normal** side bezel button.
- Press the **Source Bus** bottom bezel button and verify that **B1(USB)** is selected.
- Press the **Trigger On** bottom bezel button.

## Key Take Away Points

- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on an USB signal, capturing each occurrence. For example, this is the setup for triggering on the Sync in a USB Full Speed signal:



- This is an example of triggering on a specific Token (Address) value:



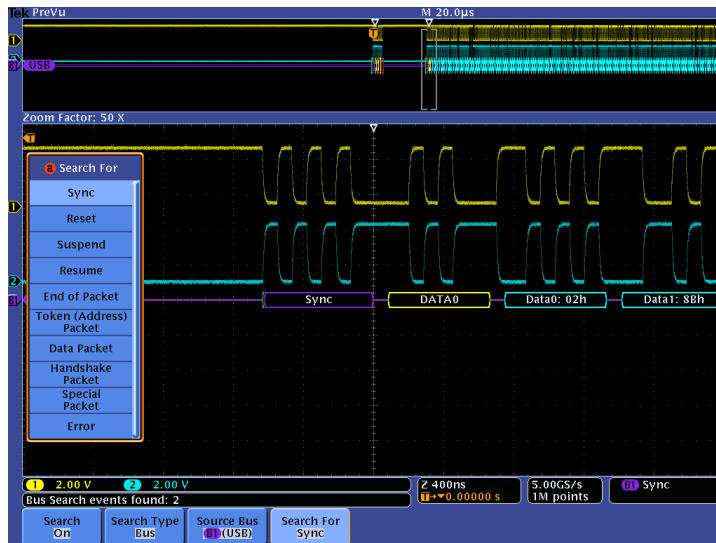
## MSO/DPO4000B Series Procedure:

- Triggering on **Sync** is the default.
- Press the front panel **Single** button.
- Press **Menu Off**.
- Adjust the Wave Inspector pan and zoom controls as needed to view the USB packet at the trigger point.
- Press the **Trigger On** bottom bezel button.
- Using the Multipurpose **a** control, select **Token (Address) Packet**.
- Press the **Address** bottom bezel button.
- Press the **Address** side bezel button.
- Using the Multipurpose **a** control, set the address value to 04 hex.
- Press the front panel **Single** button.
- When you are done, press the **Trigger On** bottom bezel button.
- Using the Multipurpose **a** control, select **Sync**.

## MSO/DPO4000B Series USB Bus Searching

### Key Take Away Points

- One of the key reasons for using long-record-length oscilloscopes is to be able to capture long time windows at high timing resolution. However, it is difficult to find specific serial signal characteristics in a long acquisition.
- Wave Inspector's automatic Search provides an easy way to find all occurrences of a specific USB signal characteristic, such as Sync. The display should look about like this, with the white triangular search marks at the top of the display, and the search event counter in the lower left:

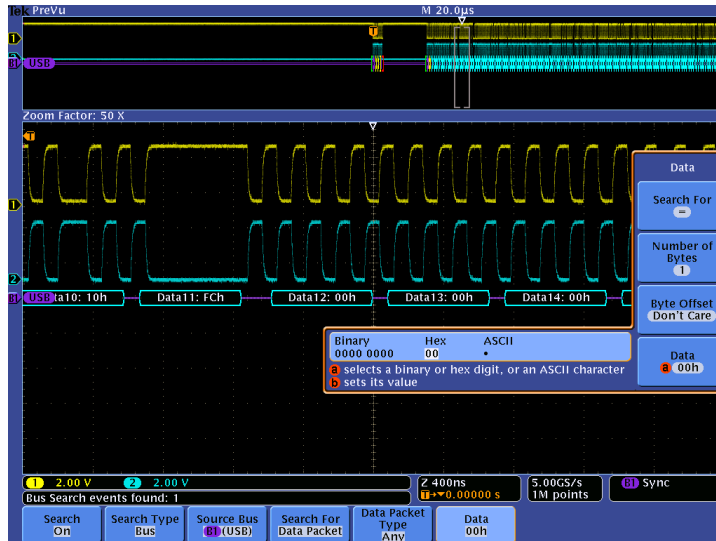


### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Search** bottom bezel button.
- ❑ Repeatedly press the **Search** side bezel button until Search is turned **On**.
- ❑ Press the **Search Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Bus** Search Type.
- ❑ Press the **Search For** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select Search For **Sync**.
- ❑ Notice all of the white triangular marks appear at the top of the display.
- ❑ Press **Menu Off** once.
- ❑ Navigate between marked occurrences by using the front panel **←** and **→** buttons.

## Key Take Away Points

- In general, the list of search criteria matches the trigger criteria. In the case of USB support, the list of search criteria for all USB speeds matches the list of trigger criteria for the Low-speed and Full-speed USB.
- Wave Inspector search allows you to find all occurrences of a specified event, such as a specific data value. The display should look something like this:



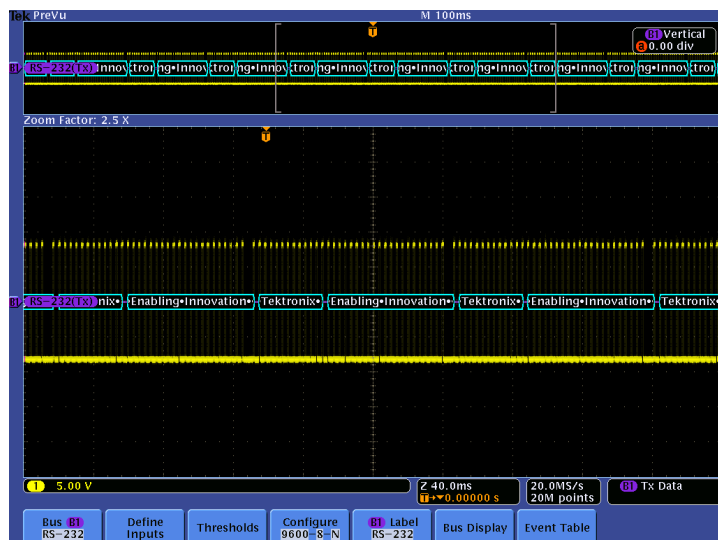
## MSO/DPO4000B Series Procedure:

- ❑ Press the **Search For** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select Search For **Data Packet**.
- ❑ Press the **Data** bottom bezel button.
- ❑ Press the **Data** side bezel button.
- ❑ Using the Multipurpose controls, select a Data value such as **00** hex.
- ❑ Press the front panel **←** and **→** buttons to navigate between search events.

# MSO4000B/DPO4000B Series

## RS-232 / RS-422 / RS-485 / UART

### Triggering and Decoding Lab



#### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
  - One DPO4COMP application module
  - One TPP0500 or TPP1000 passive probe
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]



## Understanding the RS-232 Bus

RS-232 stands for **Recommended Standard 232**, a communication standard from the **Electronic Industries Alliance (EIA)**, which was developed in the early 1960s for interconnection between teletype terminals and modems. The standard was updated to **RS-232C** in 1969 to specify electrical signal characteristics, mechanical interconnects, etc.

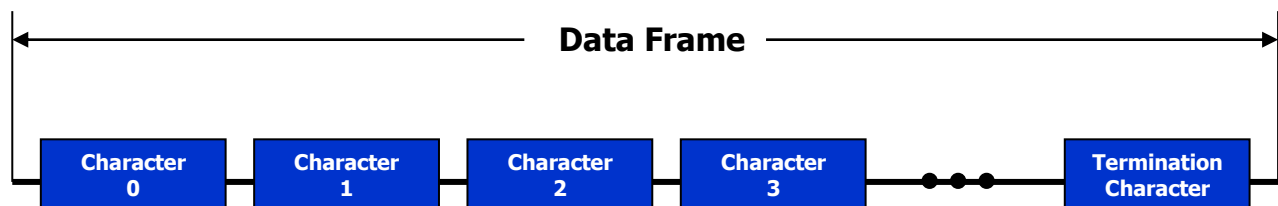
RS-232 provides two single-ended signals for point-to-point, full-duplex communication (simultaneous transmitted and received data). The standard does not specify character encoding, data framing, or protocols. It was designed for short-distance, low-speed serial data communication. Although the maximum cable length is not specified, a distance of less than 15 meters is recommended. The maximum data rate is not also specified, but rates <20 kb/s are recommended.

RS-232 data transmission is asynchronous, meaning that the clock is not transmitted and must be programmed in advance at both the transmitter and the receiver. Each character begins with a start bit, a high value which equates to a logic "0". The character is comprised of 7 or 8 data bits, which must also be programmed. The data bits are transmitted in least-significant to most-significant bit order. The optional Parity bit is next. If not used, the bit is ignored. If used, the polarity must be programmed, and provides simple error detection by indicating whether there are an odd or even number of "1s" in the data word. Finally, the character is usually terminated in one to two stop bits.

<b>Start</b>	<b>Data 0</b>	<b>Data 1</b>	<b>Data 2</b>	<b>Data 3</b>	<b>Data 4</b>	<b>Data 5</b>	<b>Data 6</b>	<b>opt. Data 7</b>	<b>opt. Parity</b>	<b>Stop</b>	<b>opt. Stop</b>
<b>1-bit</b>	<b>1-bit</b>	<b>1-bit</b>	<b>1-bit</b>	<b>1-bit</b>	<b>1-bit</b>	<b>1-bit</b>	<b>1-bit</b>	<b>1-bit</b>	<b>1-bit</b>	<b>1-bit</b>	<b>1-bit</b>

Each RS-232 character can be encoded in various formats, but ASCII format is most commonly used. ASCII, short for **American Standard Code for Information Interchange**, is a 7-bit code (a range from 0 to 127) which is used to represent characters. Of the 128 possible codes, 95 (numbered 32 to 126) represent printable characters. Many of the remaining non-printing characters are control characters which control how text is processed. (Examples of control characters include backspace, tab, carriage return, and line feed.) Since most computer memories are based on 8-bit bytes, the eighth bit of the stored ASCII character can be used for parity, a simple error-detection scheme. (An ASCII conversion chart is included later in this lab document.)

The RS-232 standard does not specify how data content is framed or grouped, but a common technique is to end a data frame with a pre-determined termination character such as carriage return, line feed, or null.



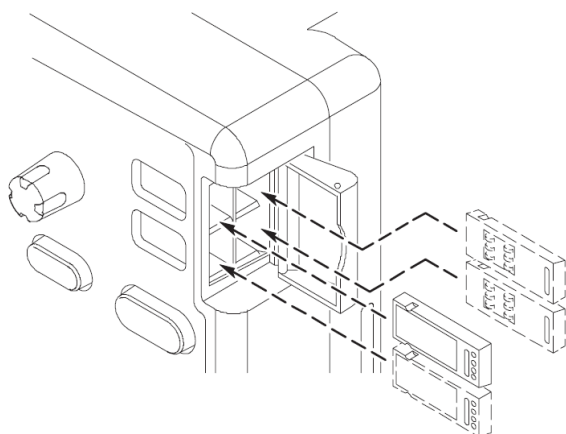
### Lab Objectives

- Obtain a basic understanding of the RS-232 serial bus.
- Learn how customers use oscilloscopes to measure and decode RS-232 signals.
- Learn how to setup an RS-232 serial bus display and trigger and search on RS-232 packet content with a MSO/DPO4000B Series oscilloscope.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- RS-232 and related serial buses are industry standards and can be found in many of our customers' embedded designs today.
- Traditional manual decoding methods being used by your customers to decode these buses on their oscilloscope are time-consuming.
- With the DPO4COMP application module installed, the MSO/DPO4000B Series oscilloscope can trigger on, decode, and search RS-232, RS-422, RS-485, and UART serial bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.

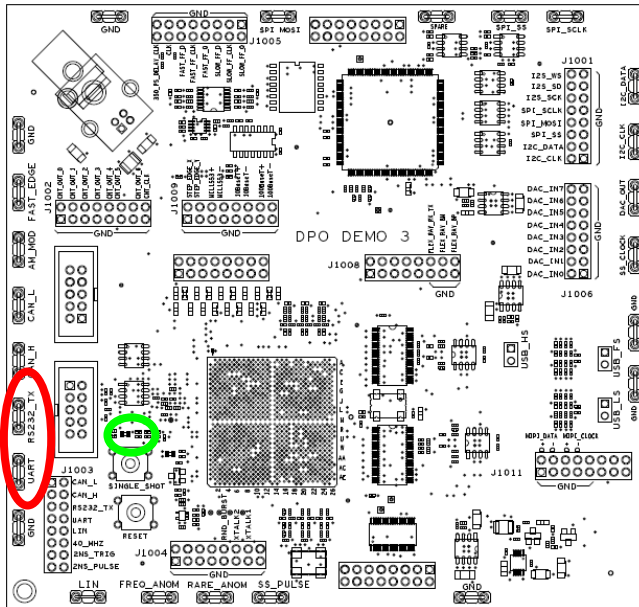


### MSO/DPO4000B Series Procedure:

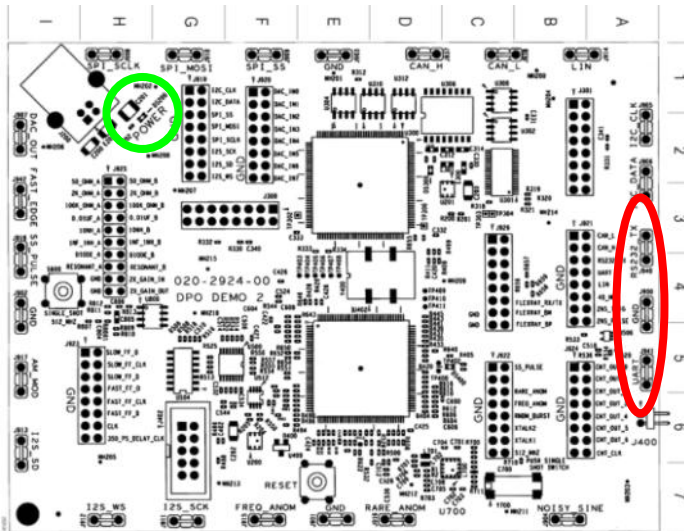
- ❑ With the oscilloscope power off, install the **DPO4COMP** application module into one of the slots on the front panel of the instrument.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4COMP Computer Serial Triggering and Analysis** application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has RS-232 and UART signals which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has RS-232 and UART signals which we can use for this lab:



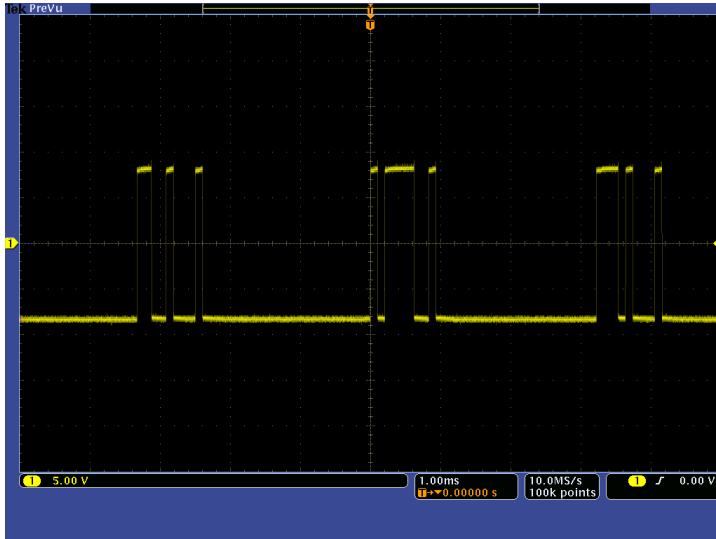
## DPO Demo Board Procedure:

- Power up the demo board.
- Verify the green **POWER** LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **RS232\_TX** test point.

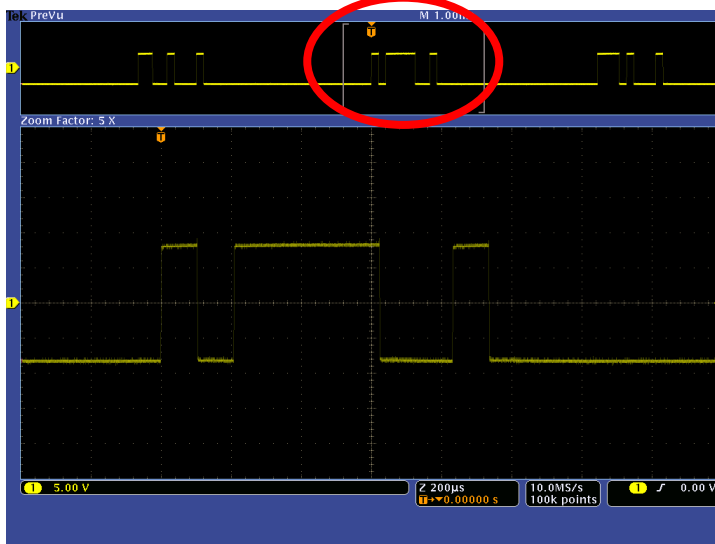
## Manual RS-232 Bus Decoding

### Key Take Away Points

- Notice that RS-232 signals are generally large signals, going positive and negative, with amplitudes from 3V to 15V peak. These large amplitudes provide a very simple immunity from noise.
- The display should look about like this:



- Zoom in on one of the bursts of activity. This is a single RS-232 character. The display should look something like this:

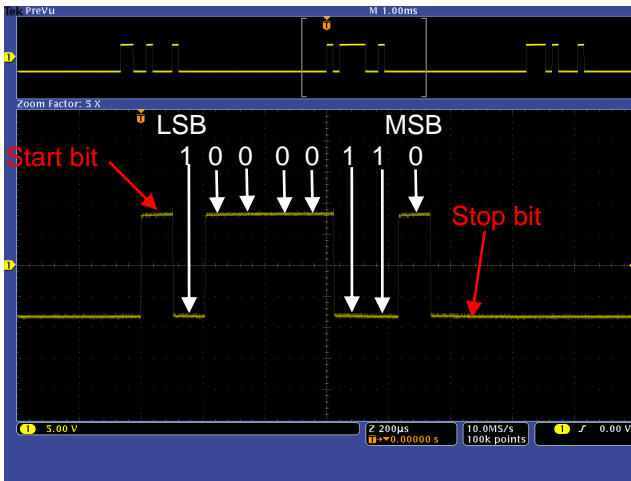


### MSO/DPO4000B Series Procedure:

- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Set the channel 1 Vertical **Scale** to **5V/div**.
- Use the Trigger **Level** control to adjust the trigger level to the center of the waveform, about **0V**.
- Set the Horizontal **Scale** to **1ms/div**. This setting should allow a few bursts (RS-232 characters) to be displayed on screen.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **100k**.
- Press the front panel **Menu Off** button twice to clear the menus.
- Press the front panel **Single** button.
  
- Using the **Wave Inspector** pan and zoom controls, zoom in on one whole burst of signal.

### Key Take Away Points

- Notice the relatively long idle periods between signal bursts where the signal is low.
- The RS-232 character begins with a positive pulse after the idle period.
- The data bits come next, starting with the least-significant bit and ending with the most-significant bit. (In this case, we know that there are 8 data bits and no parity bit.) Low signals are digital 1s and high signals are digital 0s.



- The binary message above, written in most- to least-significant bit order is 01100001. This can also be written as 61 (hex) or ASCII "a", as shown below.
- Most engineers would prefer to use hexadecimal or "hex" notation, rather than binary. You can use the following chart to translate each group of 4 binary bits to a hex character:

Binary	Hex	Binary	Hex
0000	0	1000	8
0001	1	1001	9
0010	2	1010	A
0011	3	1011	B
0100	4	1100	C
0101	5	1101	D
0110	6	1110	E
0111	7	1111	F

- Since RS-232 is often used to transmit text characters, an even more popular code is ASCII. You can use the following chart to translate each hex character to a text character:

### MSO/DPO4000B Series Procedure:

- ❑ Identify the start bit of the RS-232 character.
- ❑ Visually divide the rest of the character into 8 equal sections.
- ❑ If the signal is low in any of the 8 sections, write a "1" in the corresponding space below. If the signal is high in any of the 8 sections, write a "0" in the corresponding space below. (See example at the left.)

LSB MSB

\_\_\_\_\_

- ❑ Now, swap the order of the bits you wrote down, and divide the 8 bits into two 4-bit groups ("nibbles"). This is the binary representation of the RS-232 character. Write the binary character in the reverse order:

MSB LSB

\_\_\_\_\_

- ❑ Now, using the table at the left, translate the character to hex and write the hex value below.

\_\_\_\_\_

- ❑ Finally, using the hex-to-ASCII table, translate the character to hex and write the value below.

\_\_\_\_\_

Dec	Hx	Oct	Char	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL (null)	32	20	040	&#32;	Space	64	40	100	&#64;	@	96	60	140	&#96;	`
1	1	001	SOH (start of heading)	33	21	041	&#33;	!	65	41	101	&#65;	A	97	61	141	&#97;	a
2	2	002	STX (start of text)	34	22	042	&#34;	"	66	42	102	&#66;	B	98	62	142	&#98;	b
3	3	003	ETX (end of text)	35	23	043	&#35;	#	67	43	103	&#67;	C	99	63	143	&#99;	c
4	4	004	EOT (end of transmission)	36	24	044	&#36;	\$	68	44	104	&#68;	D	100	64	144	&#100;	d
5	5	005	ENQ (enquiry)	37	25	045	&#37;	%	69	45	105	&#69;	E	101	65	145	&#101;	e
6	6	006	ACK (acknowledge)	38	26	046	&#38;	&	70	46	106	&#70;	F	102	66	146	&#102;	f
7	7	007	BEL (bell)	39	27	047	&#39;	'	71	47	107	&#71;	G	103	67	147	&#103;	g
8	8	010	BS (backspace)	40	28	050	&#40;	(	72	48	110	&#72;	H	104	68	150	&#104;	h
9	9	011	TAB (horizontal tab)	41	29	051	&#41;	)	73	49	111	&#73;	I	105	69	151	&#105;	i
10	A	012	LF (NL line feed, new line)	42	2A	052	&#42;	*	74	4A	112	&#74;	J	106	6A	152	&#106;	j
11	B	013	VT (vertical tab)	43	2B	053	&#43;	+	75	4B	113	&#75;	K	107	6B	153	&#107;	k
12	C	014	FF (NP form feed, new page)	44	2C	054	&#44;	,	76	4C	114	&#76;	L	108	6C	154	&#108;	l
13	D	015	CR (carriage return)	45	2D	055	&#45;	-	77	4D	115	&#77;	M	109	6D	155	&#109;	m
14	E	016	SO (shift out)	46	2E	056	&#46;	.	78	4E	116	&#78;	N	110	6E	156	&#110;	n
15	F	017	SI (shift in)	47	2F	057	&#47;	/	79	4F	117	&#79;	O	111	6F	157	&#111;	o
16	10	020	DLE (data link escape)	48	30	060	&#48;	0	80	50	120	&#80;	P	112	70	160	&#112;	p
17	11	021	DC1 (device control 1)	49	31	061	&#49;	1	81	51	121	&#81;	Q	113	71	161	&#113;	q
18	12	022	DC2 (device control 2)	50	32	062	&#50;	2	82	52	122	&#82;	R	114	72	162	&#114;	r
19	13	023	DC3 (device control 3)	51	33	063	&#51;	3	83	53	123	&#83;	S	115	73	163	&#115;	s
20	14	024	DC4 (device control 4)	52	34	064	&#52;	4	84	54	124	&#84;	T	116	74	164	&#116;	t
21	15	025	NAK (negative acknowledge)	53	35	065	&#53;	5	85	55	125	&#85;	U	117	75	165	&#117;	u
22	16	026	SYN (synchronous idle)	54	36	066	&#54;	6	86	56	126	&#86;	V	118	76	166	&#118;	v
23	17	027	ETB (end of trans. block)	55	37	067	&#55;	7	87	57	127	&#87;	W	119	77	167	&#119;	w
24	18	030	CAN (cancel)	56	38	070	&#56;	8	88	58	130	&#88;	X	120	78	170	&#120;	x
25	19	031	EM (end of medium)	57	39	071	&#57;	9	89	59	131	&#89;	Y	121	79	171	&#121;	y
26	1A	032	SUB (substitute)	58	3A	072	&#58;	:	90	5A	132	&#90;	Z	122	7A	172	&#122;	z
27	1B	033	ESC (escape)	59	3B	073	&#59;	;	91	5B	133	&#91;	[	123	7B	173	&#123;	{
28	1C	034	FS (file separator)	60	3C	074	&#60;	<	92	5C	134	&#92;	\	124	7C	174	&#124;	
29	1D	035	GS (group separator)	61	3D	075	&#61;	=	93	5D	135	&#93;	]	125	7D	175	&#125;	}
30	1E	036	RS (record separator)	62	3E	076	&#62;	>	94	5E	136	&#94;	^	126	7E	176	&#126;	~
31	1F	037	US (unit separator)	63	3F	077	&#63;	?	95	5F	137	&#95;	_	127	7F	177	&#127;	DEL

Source: [www.LookupTables.com](http://www.LookupTables.com)

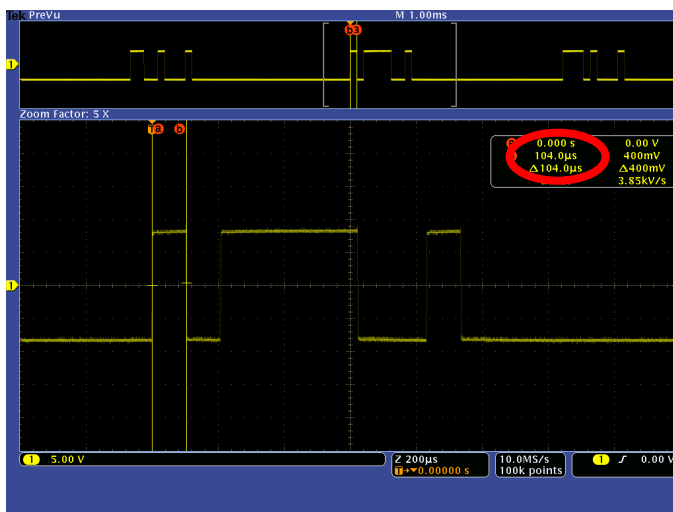
**Conclusion:** Manually decoding RS-232 data is a time-consuming process. Engineers are looking for a better and faster way to do this.

## MSO/DPO4000B Series RS-232 Decoding Setup

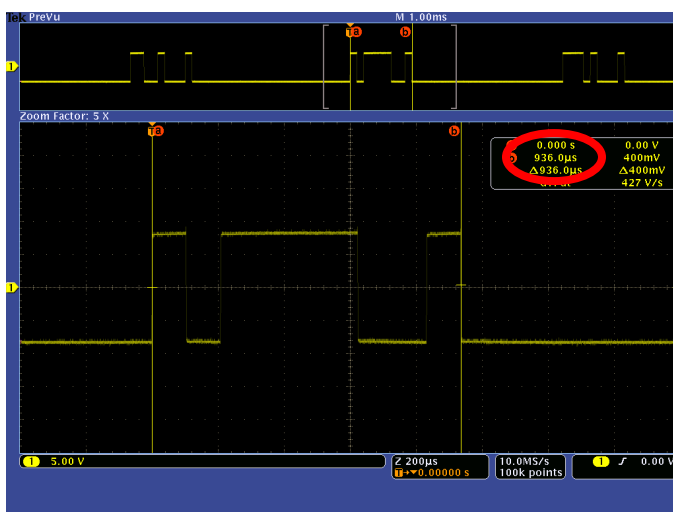
### Key Take Away Points

#### (optional) Determining RS-232 Bus Data Rate

- The data rate of the RS-232 signal on both of the DPO demo boards is 9600 bits/second (also sometimes called “9600 baud”). However, in general, you may need to determine the data rate using this procedure.
- In addition to the long list of preset bit rate values from 50 bps to 2764800 bps, the custom bit rate control allows the user to set the bit rate to any value between 50 bps and 10 Mbps in fine steps (which vary with the setting of the front panel Fine mode and also vary with the baud rate).
- The display should look about like this:



- Since the minimum pulse width is 104  $\mu$ s, the data rate is verified to be 9600 bits/second. The display should look about like this:



- This signal uses 8 data bits with no parity.

### MSO/DPO4000B Series Procedure:

- Using the **Wave Inspector** controls, zoom in on the narrowest pulse on the display.
- Press the front panel **Cursors** button once.
- Using the Multipurpose controls, measure the width of the narrowest pulse by positioning the cursor cross-hairs near the center of the rising and falling edges of the pulse.
- Read the pulse width ( $\Delta$  time in the cursor readout) and write the value here: \_\_\_\_\_
- Look up the data rate in the table below:

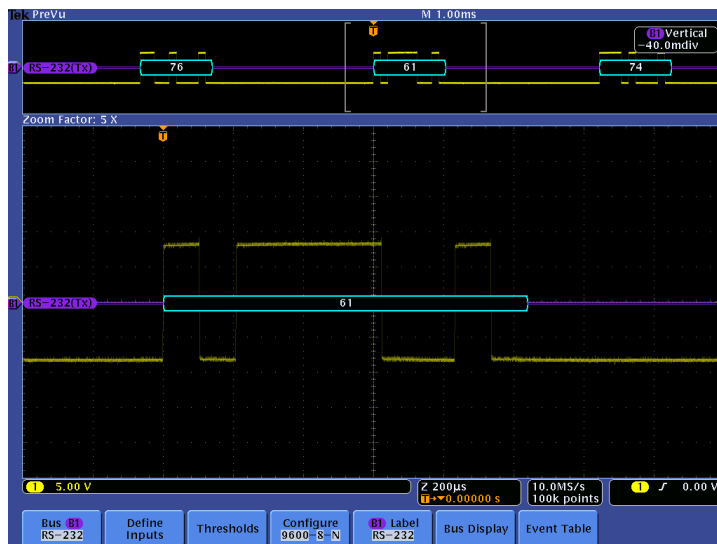
Minimum Pulse Width	Data Rate (bits / sec)
26 $\mu$ s	38400
52 $\mu$ s	19200
104 $\mu$ s	9600
139 $\mu$ s	7200
208 $\mu$ s	4800
417 $\mu$ s	2400
500 $\mu$ s	2000
556 $\mu$ s	1800
833 $\mu$ s	1200
1.7 ms	600
3.3 ms	300
6.7 ms	150
9.1 ms	110
13.3 ms	75

- Zoom in on one whole burst of signal. Using the Multipurpose controls, measure the width of the burst.
- Read the burst width ( $\Delta$  time in the cursor readout) and write the value here: \_\_\_\_\_
- Divide this value by the pulse width value you recorded earlier, and subtract one (for the Start Bit). Assuming that there is no Parity bit being used, the result is the number of data bits (7 or 8).  
\_\_\_\_\_
- Press the front panel **Cursors** button once to turn off cursors.

## MSO/DPO4000B Series RS-232 Bus Decoding

### Key Take Away Points

- As you personally experienced in the last part of the lab, manually decoding RS-232 signals can be a time-consuming process. In this section, you will learn how to use the MSO/DPO4000B Series to automatically decode RS-232 packet content.
- Setting up a basic RS-232 bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menu guide you through the setup in the left-to-right order across the bottom bezel buttons.
- Notice that any of the analog or digital input signals can be used as a source for the RS-232 bus.
- The default RS-232 bus values in the MSO/DPO4000B Series were chosen to match the signal on the DPO demo board, so many of the steps to the right have already been done for you.
- The display should now look about like this, with the hexadecimal decoded value shown in the bus waveform:



- A lot simpler than manually decoding the data!

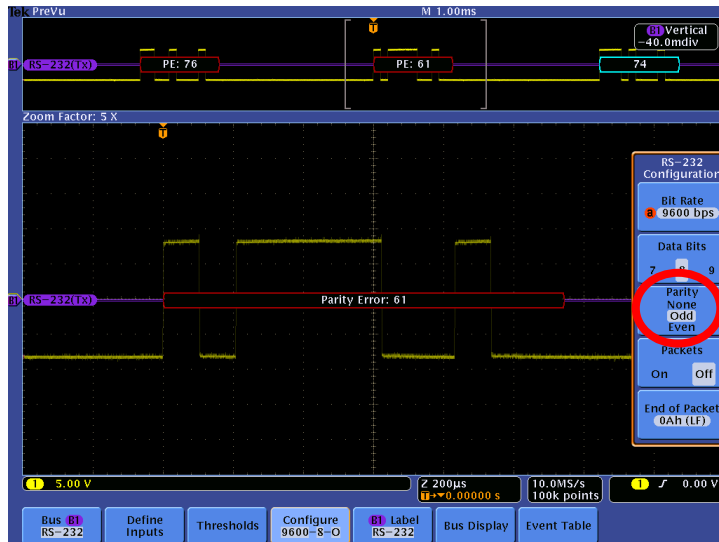
### MSO/DPO4000B Series Procedure:

- Press the front panel **Bus B1** button.
- Press the **Bus B1** bottom bezel button.
- Using the Multipurpose **a** control, select the **RS-232** Bus Type.
- Press the **Define Inputs** bottom bezel button.
- Using the Multipurpose **a** control, select channel **1** as the **Tx** Input.
- For RS-232 transmitted signals, press the **Polarity Normal (High = 0)** side bezel button. For RS-422, RS-485, and UART signals, press the **Polarity Inverted (High = 1)** side bezel button.
- Press the **Thresholds** bottom bezel button.
- Using the Multipurpose **a** control, set the Channel **1** Threshold value to the center of the signal, usually about **0 V** for RS-232 signals.
- Press the **Configure** bottom bezel button.
- Using the Multipurpose **a** control, set the Bit Rate to **9600** bps.
- Using the **Data Bits** side bezel button, select **8** bits.
- Using the **Parity** side bezel button, select **None**.
- If desired, you can edit the label on the bus. Press the **B1 Label** bottom bezel button and enter the desired label.
- Press the **Bus Display** bottom bezel button.
- Verify that the **Hex** side bezel button has been selected to enable hexadecimal decoding.
- Press **Menu Off** once to remove the side menu.



## Key Take Away Points

- Notice the way the display clearly indicates that an error has been detected, and displays the decoded value.



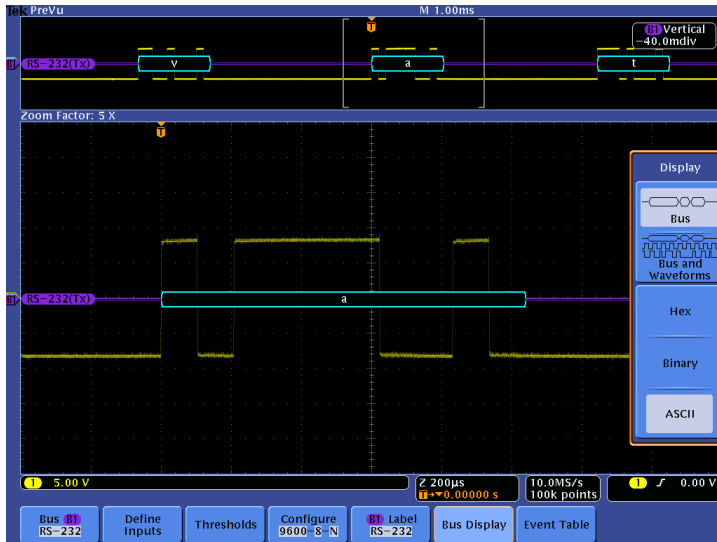
- This decoded data and parity error information is also shown in the Event Table display.

## MSO/DPO4000B Series Procedure:

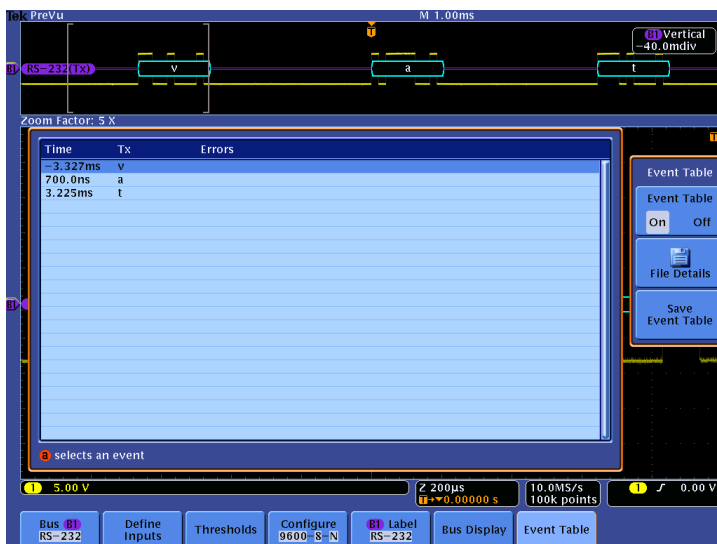
- ❑ The demo board does not produce RS-232 signals with parity errors, but we can simulate them with the following steps:
  - ❑ While in the RS-232 Configure menu, repeatedly press the **Parity** side bezel button until **Odd** is selected. Since the hex number **61** has an odd number of 1 digits, this produces a parity error.
  - ❑ When you are done examining parity errors, return the **Parity** control to **None**.

## Key Take Away Points

- Although the bus waveform display is very familiar to most hardware engineers, there are another display formats that other engineers, such as software engineers, may find more useful.
- The first is the ASCII display, since RS-232 is often used to transmit text messages. The display should now look something like this, with the ASCII decoded value shown in the bus waveform:



- For large quantities of data, and for those who are not comfortable with waveform displays, you can also use the Event Table to display the RS-232 data (in the selected format) along with the time stamps. The display should now look something like this:



- Notice that, from the Event Table menu, you can also save the Event Table data in .CSV format with a single button

## MSO/DPO4000B Series Procedure:

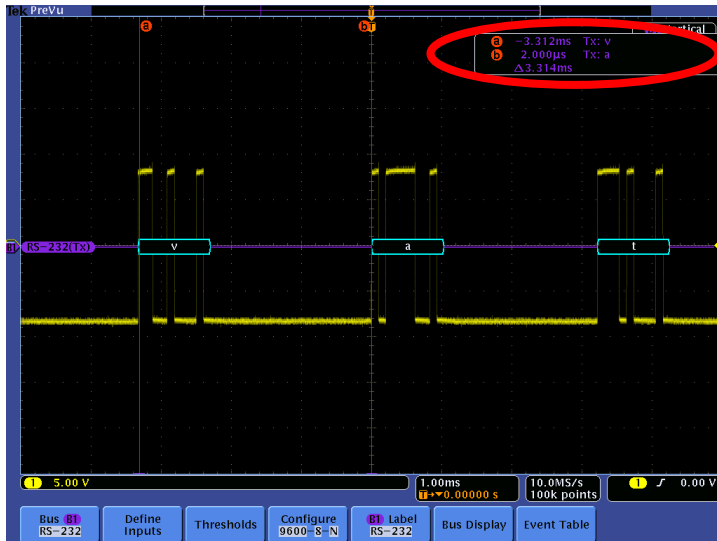
- Press the **Bus Display** bottom bezel button.
- Press the **ASCII** side bezel button.
- Press the **Event Table** bottom bezel button.
- Using the **Event Table** side bezel button, select **On**.
- Press the **Save Event Table** side bezel button to save the Event Table in CSV format to the pre-selected mass storage device.
- Using the **Event Table** side bezel button, select **Off**.

press.

## MSO/DPO4000B Series RS-232 Cursors

### Key Take Away Points

- The RS-232 serial cursors provide another tool to bridge between the serial waveform and the decoded values, showing absolute timing relative to the trigger, bus values, and relative timing between bus events.
- For this example, we can measure the time from the start of one character to the start of the next:



- Even when you are zoomed out to where you can't read the decoded values on the display, cursor measurements enable you to make timing measurements on buses.

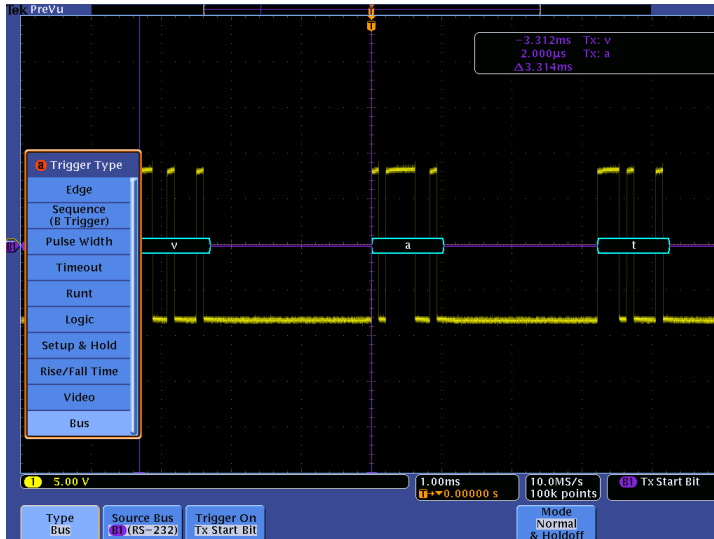
### MSO/DPO4000B Series Procedure:

- ❑ Using the Wave Inspector controls, zoom in on one of the RS-232 messages.
- ❑ Press the **Cursors** front panel button once to turn on vertical bar cursors.
- ❑ Using the Multipurpose **a** control, place the **a** cursor on an event of interest, such as the start of the first character.
- ❑ Notice the **a** cursor time and bus value readout in the upper right corner of the display.
- ❑ Using the Multipurpose **b** control, place the **b** cursor on an event of interest, such as the start of the second character.
- ❑ Notice the **b** cursor time and bus value readout in the upper right corner of the display.
- ❑ Also notice that we are displaying the time delay between the first and second bus events of interest.
  
- ❑ Press the **Cursors** front panel button once to turn off cursors.

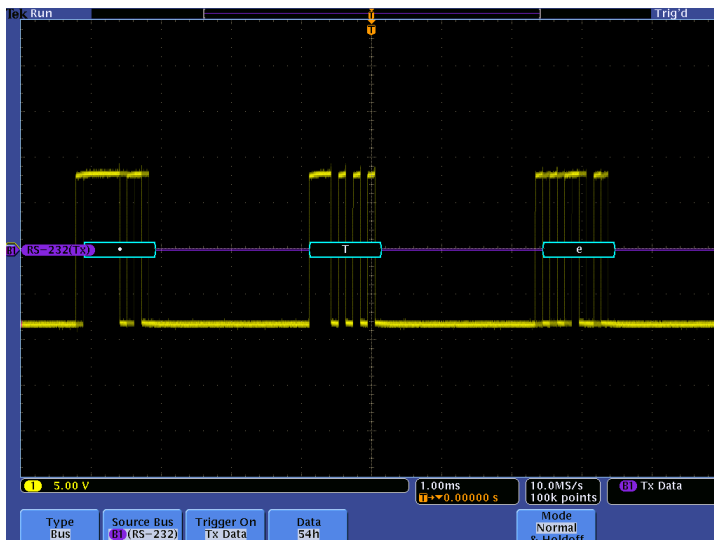
## MSO/DPO4000B Series RS-232 Bus Triggering

### Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the RS-232 serial bus.



- The MSO/DPO4000B Series can trigger on the Start Bit, End of Packet, Data value for either the transmitted (Tx) or received (Rx) serial signal, or Tx or Rx Parity Error.
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern, capturing each occurrence.



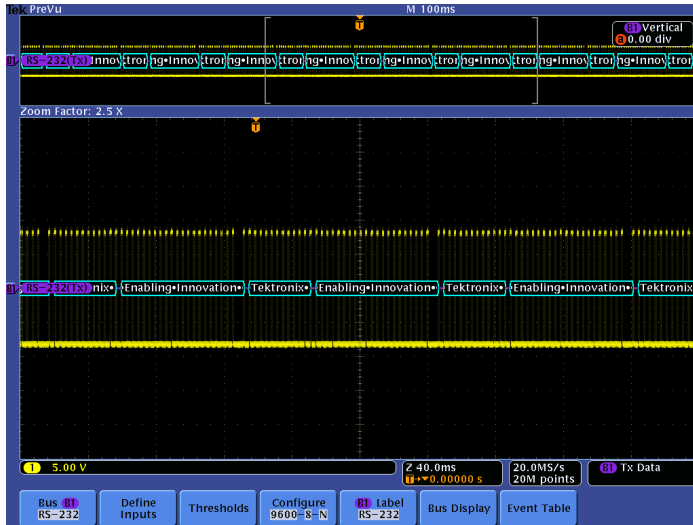
### MSO/DPO4000B Series Procedure:

- Press the front panel Trigger **Menu** button.
  - Press the **Type** bottom bezel button.
  - Using the Multipurpose **a** control, select the **Bus** Trigger Type.
- 
- Press the **Trigger On** bottom bezel button.
  - Using the Multipurpose **a** control, set the oscilloscope to Trigger On **Tx Data**.
  - Press the **Data** bottom bezel button.
  - Repeatedly press the **Data** side bezel button until the Data selection menu appears.
  - Using the Multipurpose controls, set the Data pattern to **54** hex or an ASCII **T** to capture the start of the "Tektronix" message.
  - Press **Menu Off**.
  - Press the **Mode** bottom bezel button.
  - Press the **Normal** side bezel button.
  - Press the front panel **Run/Stop** button.
  - Adjust the Wave Inspector **Pan** control as needed.

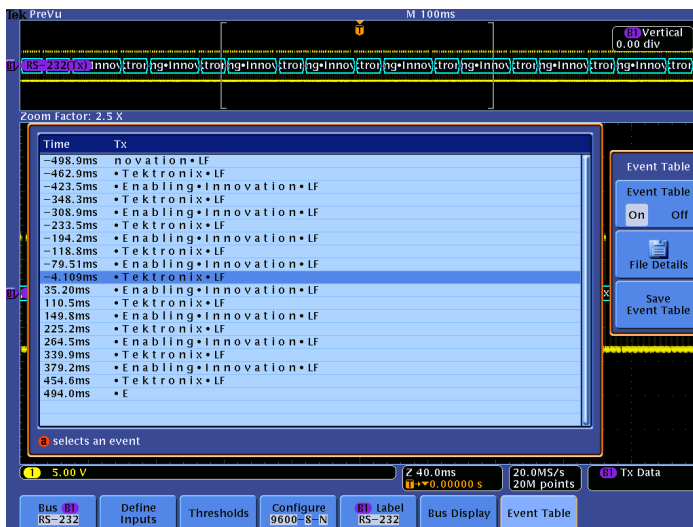
## MSO/DPO4000B Series RS-232 Packet Mode Decoding

### Key Take Away Points

- As you work with large amounts of RS-232 serial data, you may find that you want to focus less on the timing characteristics of the bus waveform and more on the data content. This is the purpose of the Packet mode decoding.
- Notice the way the data stream has been divided into a few messages (blue packets). Notice how the text characters are displayed in an easily readable format in the zoom window. The display should now look something like this:



- Each text packet is delimited by a character, such as Null, Line Feed, Carriage Return, Space, or hex FF. In the case of the DPO demo board, each message is terminated with a Carriage Return (CR) and Line Feed (LF).
- The Event Table also displays the packets of messages, if possible, one per line. The display should look like this:



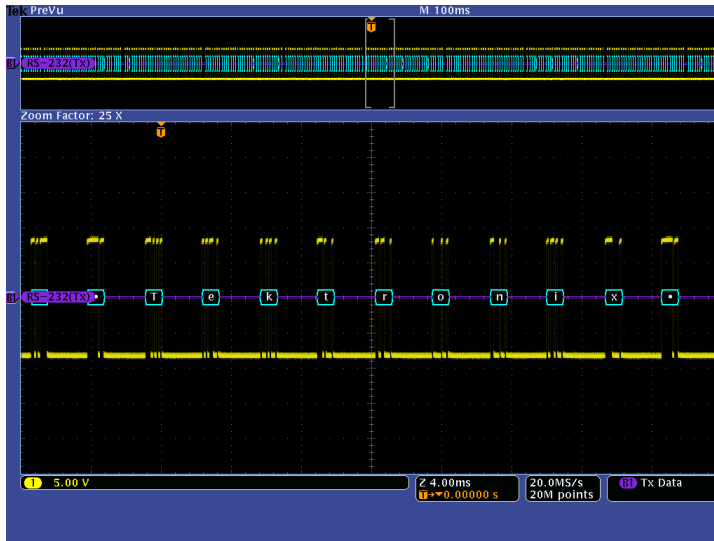
### MSO/DPO4000B Series Procedure:

- Press the front panel zoom button to turn zoom off.
- Set the Horizontal **Scale** to **100ms/div** to display a few packets of RS-232 characters.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **20M**.
- Press the front panel **Menu Off** button.
- Press the front panel **Single** button.
- Press the front panel Bus **B1** button.
- Press the **Configure** bottom bezel button.
- Repeatedly press the **Packets** side bezel button until **On** is selected.
- Repeatedly press the **End of Packet** side bezel button until the selection menu is displayed.
- Using the Multipurpose **a** control, select the Line Feed **0Ah (LF)** End of Packet character.
- Using the Wave Inspector **Pan** and **Zoom** controls, zoom in so you can read the decoded characters in the main display window.
- Press the **Event Table** bottom bezel button.
- Using the **Event Table** side bezel button, select **On**.
- When you are done, using the **Event Table** side bezel button, select **Off**.

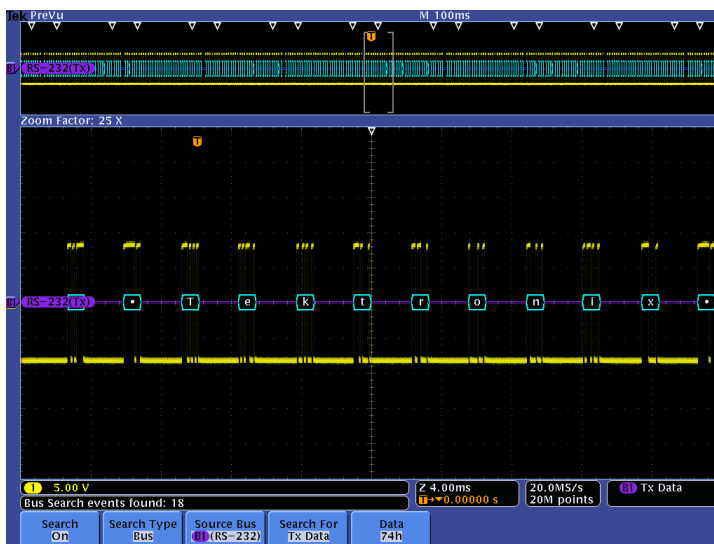
## MSO/DPO4000B Series RS-232 Bus Searching

### Key Take Away Points

- One of the key reasons for using long-record-length oscilloscopes is to be able to capture long time windows at high timing resolution.
- Capture a long time window (1 second). The display should look about like this:



- Wave Inspector automatic search allows you to find all occurrences of a specified event, such as the letter 't'. The display should look something like this:

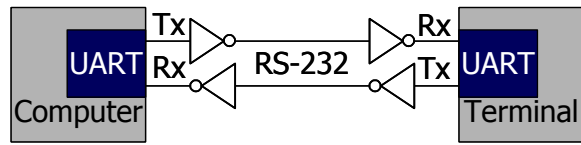


### MSO/DPO4000B Series Procedure:

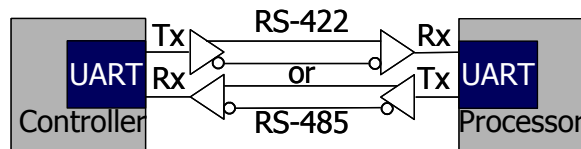
- Press the **Configure** bottom bezel button.
- Press the **Packets** side bezel button until **Off** is selected.
- Press the front panel **Search** button.
- Press the **Search** bottom bezel button.
- Repeatedly press the Search side bezel button until Search is turned **On**.
- Press the **Search Type** bottom bezel button.
- Using the Multipurpose **a** control, select the **Bus** Search Type.
- Press the **Search For** bottom bezel button.
- Using the Multipurpose **a** control, select Search For **Tx Data**.
- Press the **Data** bottom bezel button.
- Repeatedly press the **Data** side bezel button until the Data selection menu appears.
- Using the Multipurpose controls, set the Data pattern to **74** hex (ASCII 't', one of the most common letters in the English language).
- Notice all of the white triangular marks appear at the top of the display.
- Press **Menu Off**.
- Navigate between marked occurrences by using the front panel ← and → buttons.

## MSO/DPO4000B Series Support for RS-232-related Standards

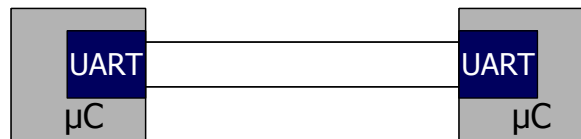
The initial introduction of RS-232 triggering and analysis with the DPO4COMP application key was targeted at transmitted RS-232. This is primarily focused on applications where these serial signals are transmitted between modules, over cables, and between products. These RS-232 signals are transmitted single-ended, at relatively high voltage (up to  $\pm 15V$ ), and inverted (so a digital 0 is a positive voltage and a 1 is a negative voltage).



RS-232 application example



Audio / video application example



Embedded communication application example

There are two other types of variants on the RS-232 family that are addressed with the DPO4COMP.

The first is differential signaling, such as with the RS-422 and RS-485 standards. These standards specify transmission of a lower-voltage differential signal which is not inverted. Although one side of these differential signals can be probed with a passive probe, the TDP0500 and TDP1000 differential probes will provide better signal fidelity, especially in noisy environments.

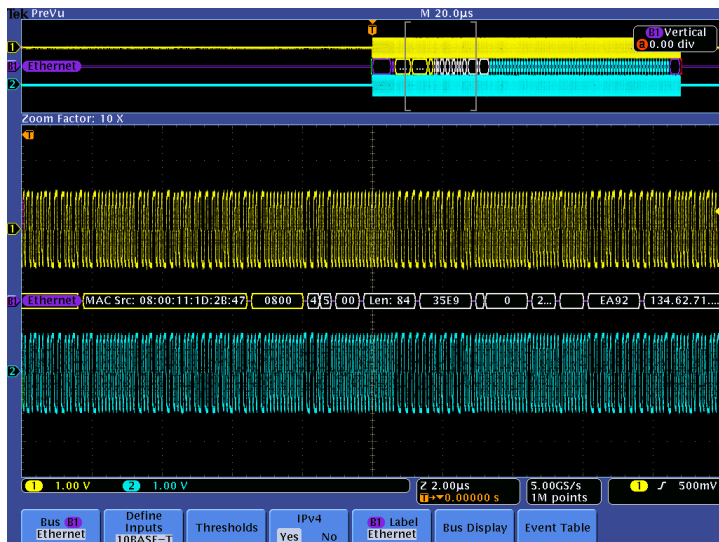
The second variant on RS-232 signals is the transmission of these serial signals between components on a single circuit board. This embedded system application, most commonly communication between a microcontroller and a Universal Asynchronous Receiver / Transmitter (UART) or RS-232 driver/receiver IC. These signals are single-ended and non-inverted, with standard logic levels.

For both of these non-inverting RS-232 variants, you need to select the Polarity Inverted (High = 1) side bezel button in the Bus Define Inputs Menu. Otherwise, the signals are treated like RS-232 signals.

# MSO4000B/DPO4000B Series

## 10 / 100-BaseT Ethernet

### Triggering and Decoding Lab



#### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
- One DPO4ENET application module
- Two TPP0500 or TPP1000 passive probes
- One TDP0500 or TDP1000 differential probe
- DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00)



## Understanding the 10/100BASE-T Ethernet Bus

Ethernet is the versatile networking technology at heart of the vast majority of wired local area computer networks (LANs). The technology is so universal that it has been standardized as IEEE 802.3. Common Ethernet networks use cost-effective twisted pair (TP) cabling to connect many data centers and computers.

Ethernet is a family of frame-based computer networking technologies for local area networks (LANs), initially developed at Xerox PARC in the early 1970s. The first standard draft was published in 1980 by the Institute of Electrical and Electronics Engineers (IEEE). Approval of IEEE 802.3 CSMA/CD occurred in 1982 and the international ISO/IEEE 802/3 standard was approved in 1984.

Two of the most common versions of Ethernet are 10BASE-T and 100BASE-TX which are found on most personal computers. The leading number represents the data rate in Mb/s. BASE indicates that the signals are baseband signals and there is no RF signal modulation. The T denotes the twisted pair wires that are in the LAN cable that is used between network nodes.

The popularity of 10BASE-T and 100BASE-TX and its decreasing hardware implementation cost has caused it to be incorporated in an increasing number of embedded systems designs.

Ethernet provides peer-to-peer packet-based communication, enabling direct point-to-point communication. At the physical layer, the 10BASE-T and 100BASE-TX signals transport address, control, data, and clock information. The data is transferred in sequences of data bytes called packets. Ethernet packets can carry other, higher-level protocol packets inside of them. For example, an Ethernet packet may contain an Internet Protocol (IP) packet, which in turn may contain a Transmission Control Protocol (TCP) packet. This signal complexity makes isolating events of interest difficult when analyzing 10BASE-T and 100BASE-TX waveforms.

With rapid adoption of Ethernet standards, you face constant pressure in validating the physical layer of Ethernet devices and developing and debugging Ethernet-based systems. Tektronix offers comprehensive, integrated tool sets for debugging complex systems, and analog validation, compliance test, and device characterization of Ethernet PHYs, quickly and efficiently.

The popularity of 10BASE-T and 100BASE-TX and its decreasing hardware implementation cost has caused it to be incorporated in an increasing number of embedded systems designs. The 10base-T and 100base-TX twisted pair signals transport address, control, data, clock and higher level protocols such as TCP and IPv4 between network nodes. This signal complexity makes isolating events of interest difficult when analyzing 10base-T and 100base-TX waveforms. MSO/DPO4000B Series Oscilloscopes with the DPO4ENET Serial Application Module are a robust 10base-T and 100base-TX verification and debugging tool with automatic trigger, decode, and search.

Debugging Ethernet-based embedded systems designs provides some complex measurement and analysis challenges:

- Capturing specific Ethernet addresses and data
- Displaying the elements of the Ethernet message in an understandable format, in a variety of formats, for a wide variety of engineers and technicians
- Time-correlating Ethernet messages with analog and digital signals in the embedded system
- Capture long time windows of Ethernet traffic and then find specific events within the acquired data

The DPO4ENET application module, installed in an MSO/DPO4000B Series oscilloscope, provides a robust set of tools for debugging embedded systems with 10BASE-T and 100BASE-TX Ethernet, including:

- Automated Serial Triggering, Decode, and Search for Ethernet 10base-T and 100base-TX
- Trigger on all the critical elements of an Ethernet 10base-T and 100base-TX such as address, data, etc.
- Trigger on and Decode IPv4 internet protocol and TCP transport protocol
- Decode all the critical elements of each message. No more counting 1s and 0s!
- Search through long acquisitions using user defined criteria to find specific messages
- Event Table shows decoded serial bus activity in a tabular, time-stamped format for quick summary

The Ethernet data frame format is defined by the IEEE 802.3 standard and contains seven fields, as shown below:=

Type	Preamble	Start-of-frame Delimiter	Destination Address	Source Address	Length/Type	Data + Pad	Frame check sequence
Bytes	7	1	6	6	2	46-1500	4

IEEE 802.3 standard Ethernet Frame Format

The Preamble is seven bytes long consisting of an alternating pattern of ones and zeros for synchronization.

The Start-of-frame Delimiter is a single byte with alternating ones and zeros but ending in two ones.

The Destination and Source Media Access Control (MAC) Addresses are each six bytes long, transmitted in most-significant to least-significant bit order. Each Ethernet node is assigned a unique MAC address which is used to specify both the destination and the source of each data packet. It thus forms the basis of most of the Link layer (OSI Layer 2) networking upon which upper layer protocols rely to produce complex, functioning networks.

The Length/Type field is a two-byte value. If the decimal value of Length/Type is  $\leq 1500$ , it represents the number of data bytes in the data field. If the value of Length/Type is  $> 1536$  (0x0600), it is an EtherType value which specifies the protocol that is encapsulated in the payload of the Ethernet frame. (For example, EtherType is set to 0x0800 for IPv4.)

The Data packet contains 46 to 1500 bytes. If the data is less than 46 bytes long, the data field is padded to be 46 bytes long.

The Frame Check Sequence is a 32-bit cyclic redundancy check (CRC) and provides error checking across the Destination Address, Source Address, Length/Type and Data fields.

Finally, after each frame has been sent, transmitters are required to transmit a minimum of 12 bytes of idle characters before transmitting the next frame, or they must remain idle for an equal amount of time by de-asserting the transmit enable signal.

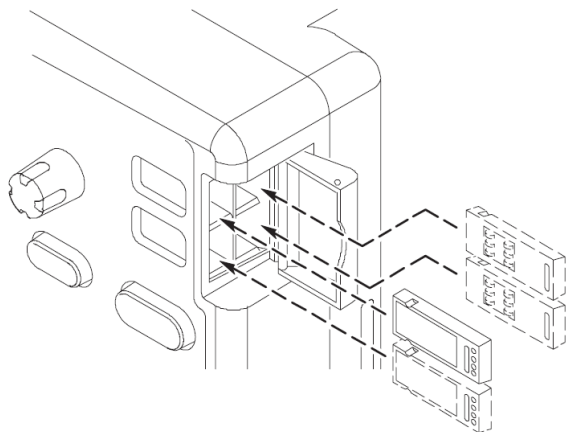
### Lab Objectives

- Obtain a basic understanding of the Ethernet serial bus.
- Learn how customers use oscilloscopes to acquire and decode 10BASE-T and 100BASE-TX Ethernet signals.
- Learn how to set up an Ethernet serial bus display and trigger and search on Ethernet packet content with a MSO/DPO4000B Series oscilloscope.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- Ethernet and related serial buses are industry standards and can be found in many of our customers' embedded designs today.
- Traditional manual decoding methods being used by your customers to decode these buses on their oscilloscope are time-consuming.
- With the DPO4ENET application module installed, the MSO/DPO4000B Series oscilloscope can trigger on, decode, and search Ethernet serial bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.

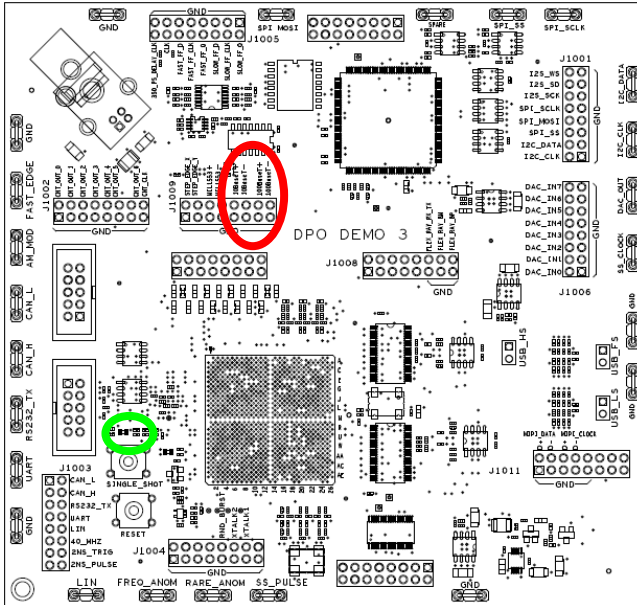


### MSO/DPO4000B Series Procedure:

- ❑ With the oscilloscope power off, install the **DPO4ENET** application module into one of the slots on the front panel of the instrument.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4ENET Ethernet Serial Triggering and Analysis** application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has Ethernet signals which we can use for this lab:



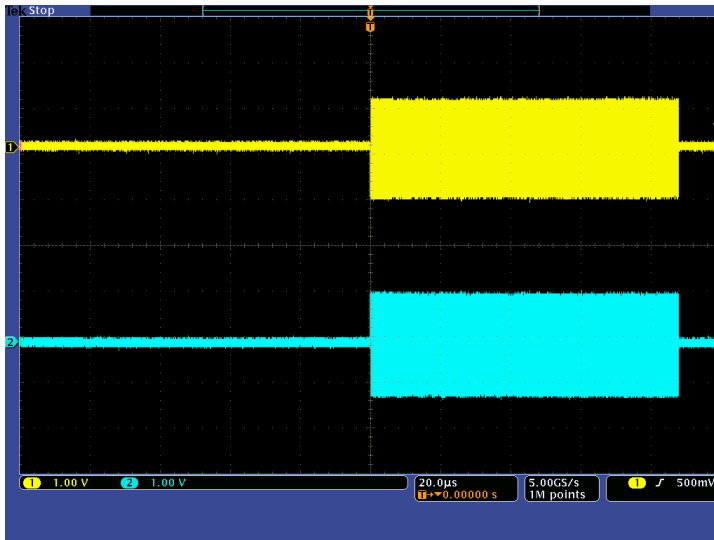
## DPO Demo 3 Board Procedure:

- Power up the demo board.
- Verify the green **POWER** LED is lit.
- On this board, the two Ethernet signals are differential signals and are available on pairs of square pins. But also notice that the other side of the connector is all tied to ground, so you can easily use a differential probe to probe each side of the differential pair relative to ground, as well as probing the differential signal.

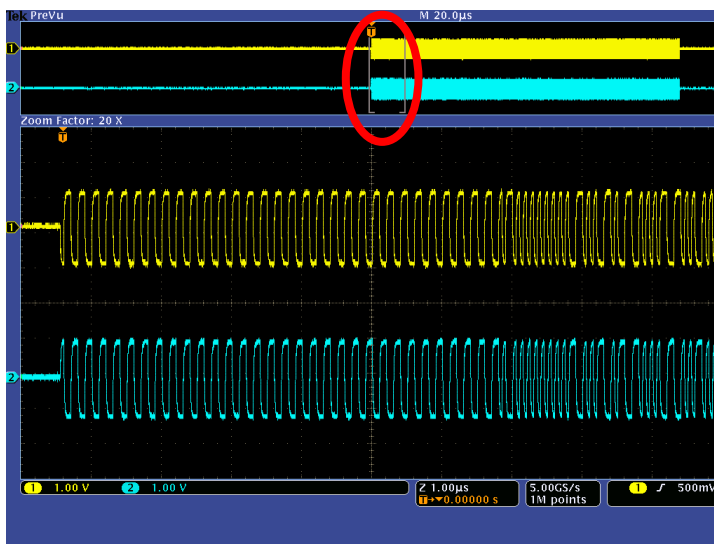
## MSO/DPO4000B Series 10BASE-T Ethernet Bus Setup and Decoding

### Key Take Away Points

- NOTE: 10BASE-T Ethernet triggering and analysis support is offered on all properly-equipped MSO/DPO4000B models. Both single-ended and differential probing of the Ethernet signal is supported. For simplicity, this lab will use single-ended probing with the standard passive probes.
- The display should look about like this:



- Zoom in on the start of the bursts of activity. The display should look something like this:

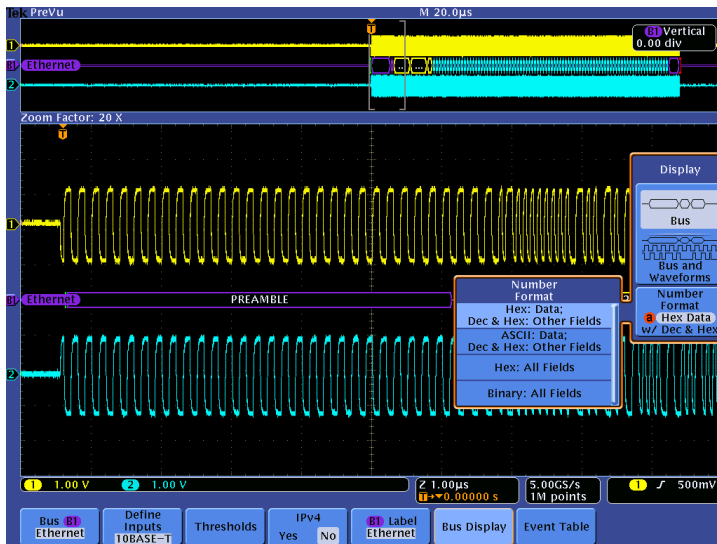


### MSO/DPO4000B Series Procedure:

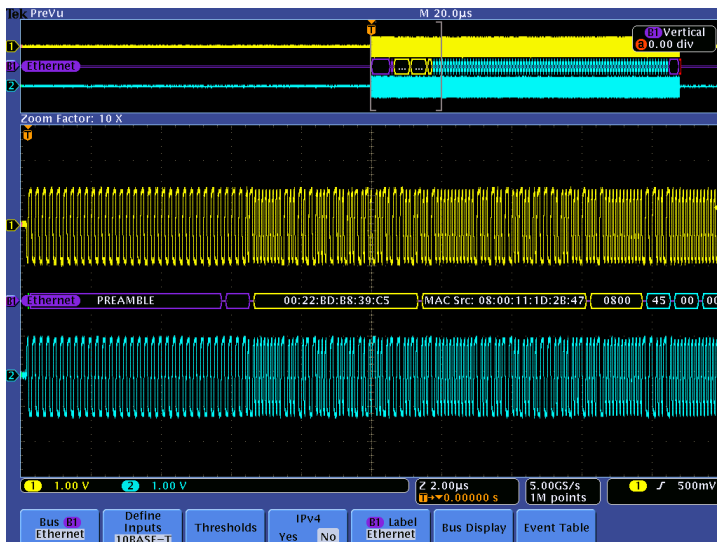
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **10BaseT+** test point.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **10BaseT-** test point.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **2** button to turn on channel **2**.
- ❑ Set the Vertical **Scale** for channels 1 and 2 to **1V/div**.
- ❑ Use the Trigger **Level** control to adjust the trigger level to about **500mV**.
- ❑ Position the waveforms as shown in the screen shot on the left.
- ❑ Set the Horizontal **Scale** to **20µs/div**.
- ❑ Press the **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1M**.
- ❑ Press **Menu Off**.
- ❑ Press the front panel **Single** button.
- ❑ Using the **Wave Inspector** pan and zoom controls, zoom in on one whole burst of signal.

## Key Take Away Points

- Setting up a basic Ethernet bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menu guide you through the setup in the left-to-right order across the bottom bezel buttons.
- Notice that any of the analog input channels can be used to acquire the Ethernet bus signal.
- For 10BASE-T Ethernet, you can probe the bus with a pair of passive probes or a differential probe. For simplicity, this lab will use single-ended probing with the standard passive probes.
- The Ethernet bus setup menu should look about like this:



- The display should now look about like this, with the hexadecimal decoded value shown in the bus waveform:



## MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Bus B1** button.
- ❑ Press the **Bus B1** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Ethernet** Bus Type.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ Repeatedly press the **Type** side bezel button until **10BASE-T** is selected.
- ❑ Repeatedly press the next side bezel button until **Single-ended** is selected.
- ❑ Using the Multipurpose **a** control, select channel **1** as the **D+** Input.
- ❑ Using the Multipurpose **b** control, select channel **2** as the **D-** Input.
- ❑ Press the **Thresholds** bottom bezel button.
- ❑ Using the Multipurpose **a** and **b** controls, set the **D+** and **D-** Threshold values to about **500mV** for single-ended 10BASE-T signals.
- ❑ Verify that the **IPv4** bottom bezel button shows that **No** is selected.
- ❑ If desired, you can edit the label on the bus. Press the **B1 Label** bottom bezel button and enter the desired label.
- ❑ Press the **Bus Display** bottom bezel button.
- ❑ Verify that the **Number Format** side bezel button indicates that hexadecimal data decoding has been selected.
- ❑ Press **Menu Off** once to remove the side menu.

## Key Take Away Points

- Although the bus waveform display is very familiar to most hardware engineers, there are another display formats that other engineers, such as software engineers, may find more useful.
- For large quantities of data, and for those who are not comfortable with waveform displays, you can also use the Event Table to display the Ethernet data (in the selected format) along with the time stamps. The display should now look something like this:



- The decoded information includes the Preamble, the SFD, the MAC Destination Address, MAC Source Address, the MAC Type, and all of the data values.
- Notice that, from the Event Table menu, you can also save the Event Table data in .CSV format with a single button press.

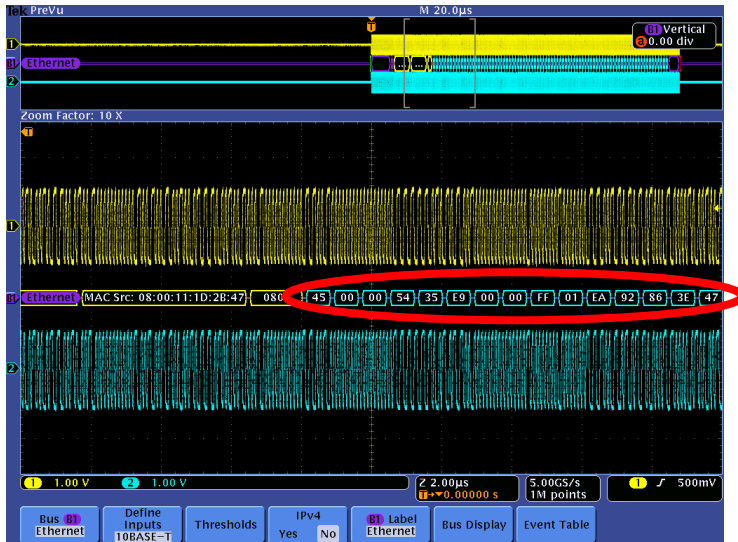
## MSO/DPO4000B Series Procedure:

- ❑ Press the **Event Table** bottom bezel button.
- ❑ Using the **Event Table** side bezel button, select **On**.

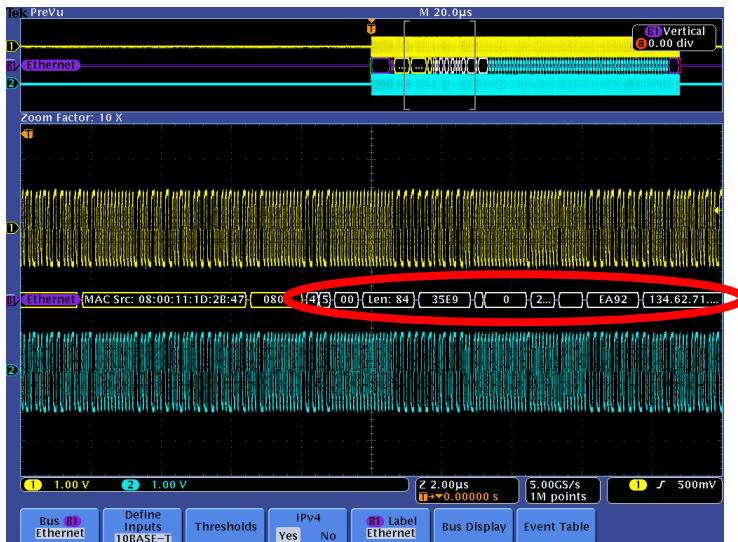
- ❑ Press the **Save Event Table** side bezel button to save the Event Table in CSV format to the pre-selected mass storage device.
- ❑ Using the **Event Table** side bezel button, select **Off**.

## Key Take Away Points

- With IPv4 set to No, the decoded display looks about like this, where all of the payload data is simply shown as hex values in cyan boxes:



- With IPv4 set to Yes, notice that some of the payload data has been decoded and this information is shown in white boxes:



- In the case of the demo board signal, ICMP transport layer protocol is used. With IPv4 set to Yes, most of the payload data is presented in hex format. (This can be more clearly seen in the Event Table format, shown on the next page.)

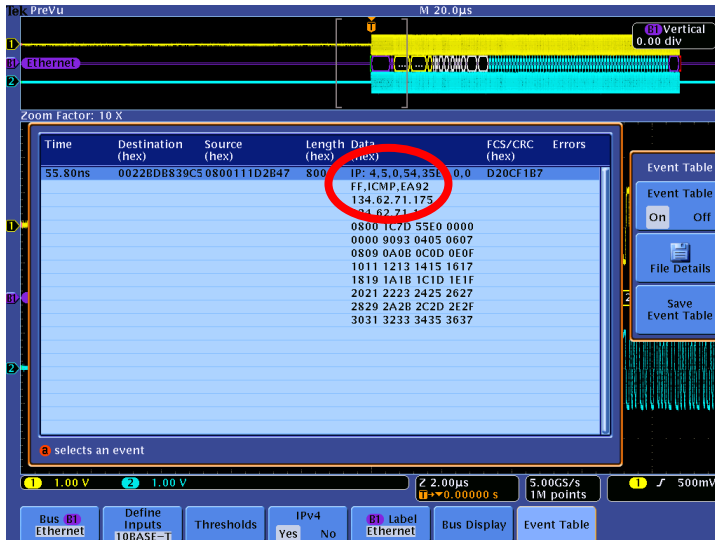
## MSO/DPO4000B Series Procedure:

- Press the **IPv4** bottom bezel button until **Yes** is selected.

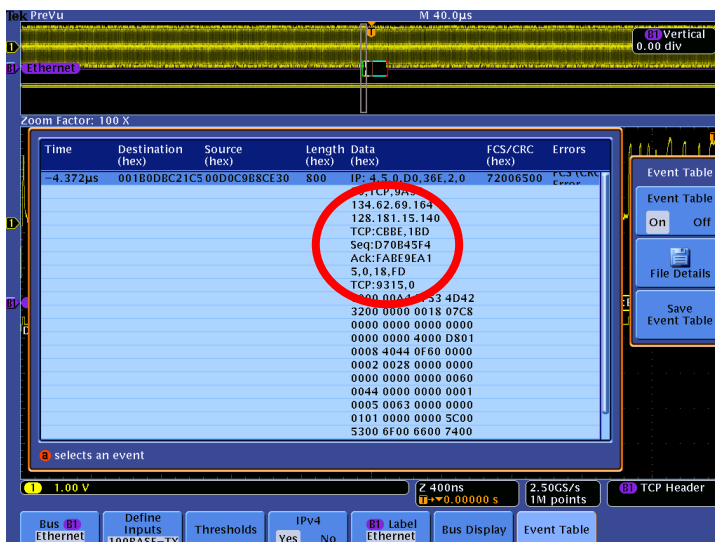


## Key Take Away Points

- With IPv4 decoding enabled, the decoded information includes the Preamble, the SFD, the MAC Destination Address, MAC Source Address, the MAC Type, the Version (4), the Header Length, Diff Services, Total Length, Identification, Flags, Fragment Offset, Time To Live, ICMP, Header Checksum, Source IP Address, Destination IP Address, and then all of the data values.
- With IPv4 decoding enabled, the event table looks like this:



- In the special case of a signal with TCP transport layer protocol, when IPv4 decoding is enabled, the decoded data stream will include the decoded TCP port addresses and the TCP information is shown in cinnamon-colored boxes on the bus waveform.



## MSO/DPO4000B Series Procedure:

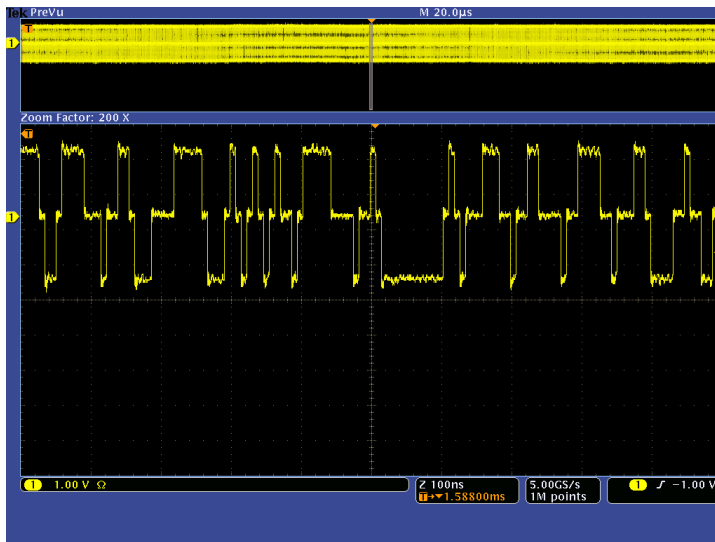
- Using the Wave Inspector controls, pan through the white IPv4 decoded information.
- Using the **Event Table** side bezel button, select **On**.

- Using the **Event Table** side bezel button, select **Off**.

## MSO/DPO4000B Series 100BASE-TX Ethernet Bus Setup and Decoding

### Key Take Away Points

- For 100BASE-TX Ethernet signals, any of the analog input channels can be used to acquire the Ethernet bus signal.
- You can probe the bus with a pair of passive probes or a differential probe. For better signal fidelity at these speeds, this lab will use differential probing.
- The display should now look about like this:



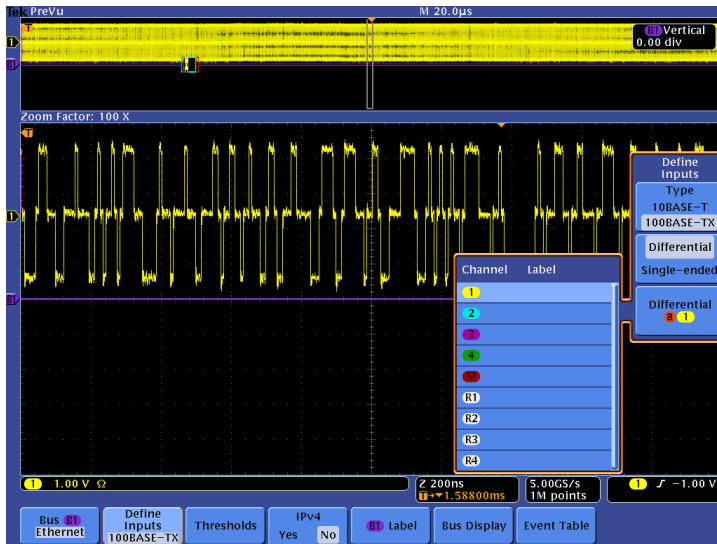
- Notice that the 100BASE-TX signal is almost constantly transitioning because of the scrambling that is used, even in the idle state. You do not want to try to manually decode this signal!

### MSO/DPO4000B Series Procedure:

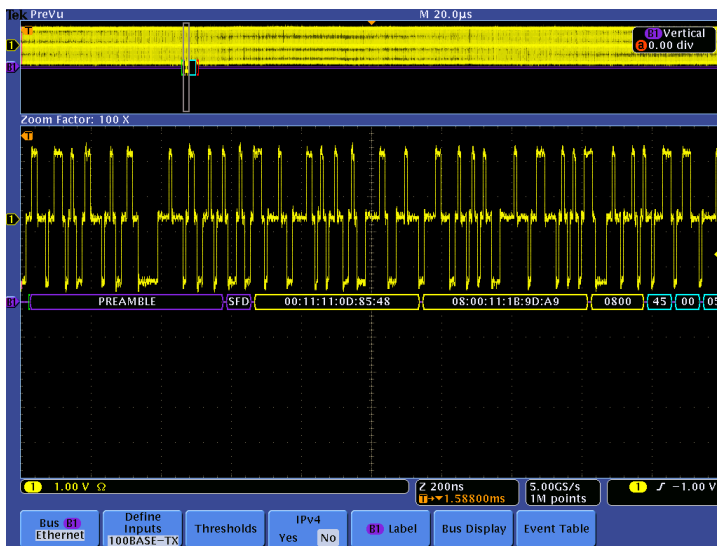
- ❑ Attach a TDP0500 or TDP1000 probe to the Channel 1 input of the oscilloscope.
- ❑ Connect the probe + input to the **100BaseT+** test point and the probe – input to the **100BaseT-** test point.
- ❑ Set the Vertical **Scale** to **1V/div**.
- ❑ Position the waveform as shown in the screen shot on the left.
- ❑ Use the Trigger **Level** control to adjust the trigger level to the lower half of the waveform, about **-1V**.
- ❑ Set the Horizontal **Scale** to **20µs/div**.
- ❑ Press the **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1M**.
- ❑ Press the front panel **Menu Off** button.
- ❑ Press the front panel **Single** button.
- ❑ Using the **Wave Inspector** pan and zoom controls, zoom in on part of the signal.

## Key Take Away Points

- The 100BASE-TX bus setup display should now look about like this:



- The display should now look about like this, with the hexadecimal decoded value shown in the bus waveform:



## MSO/DPO4000B Series Procedure:

- Press the front panel **Bus B1** button.
- Press the **Bus B1** bottom bezel button.
- Using the Multipurpose **a** control, select the **Ethernet** Bus Type.
- Press the **Define Inputs** bottom bezel button.
- Repeatedly press the **Type** side bezel button until **100BASE-TX** is selected.
- Repeatedly press the next side bezel button until **Differential** is selected.
- Using the Multipurpose **a** control, select channel **1** as the differential input.
- Press the **Thresholds** bottom bezel button.
- Using the Multipurpose **a** and **b** controls, set the D+ Threshold value to about **1V** and D- Threshold value to about **-1V** for differential 100BASE-TX signals.
- If desired, you can edit the label on the bus. Press the **B1 Label** bottom bezel button and enter the desired label.
- Press the **Bus Display** bottom bezel button.
- Verify that the **Hex** side bezel button has been selected to enable hexadecimal decoding.
- Press **Menu Off** once to remove the side menu.

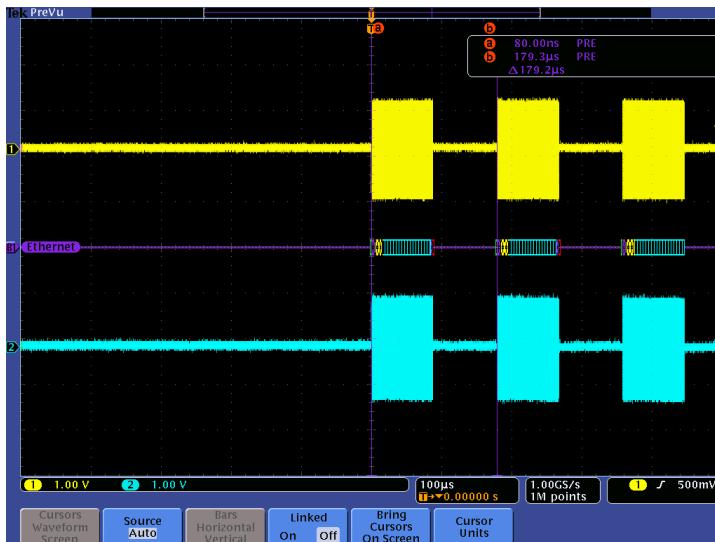
## MSO/DPO4000B Series Ethernet Cursors

### Key Take Away Points

- The Ethernet serial cursors provide another tool to bridge between the serial waveform and the decoded values, showing absolute timing relative to the trigger, bus values, and relative timing between bus events. For example, on 10BASE-T Ethernet signals:



- For this example, we can measure the time from the start of one packet to the start of the next:



- Even when you are zoomed out to where you can't read the decoded values on the display, cursor measurements enable you to make timing measurements on buses.

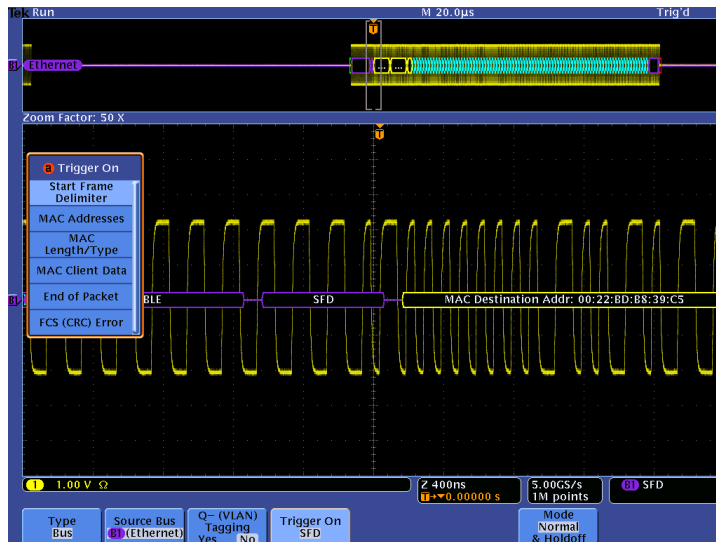
### MSO/DPO4000B Series Procedure:

- NOTE: The remaining sections of this lab can be done with either of the Ethernet speeds.
- Press the front panel **Run/Stop** button to start acquisitions.
- Adjust the Horizontal **Scale** control until 2 or more packets are displayed.
- Using the Wave Inspector controls, zoom in on the start of one of the Ethernet packets.
- Press and hold the **Cursors** front panel button to turn on vertical bar cursors and the cursor menu.
- Using the Multipurpose **a** control, place the **a** cursor on an event of interest, such as the start of the preamble.
- Notice the **a** cursor time and bus value readout in the upper right corner of the display.
- Using the Multipurpose **b** control, place the **b** cursor on an event of interest, such as the MAC address.
- Notice the **b** cursor time and bus value readout in the upper right corner of the display.
- Also notice that we are displaying the time delay between the first and second bus events of interest.
- Turn off zoom.
- Using the Multipurpose **b** control, place the **b** cursor on an event of interest in another packet, such as the start of the preamble of the second packet.
- Press the **Cursors** front panel button once to turn off cursors.

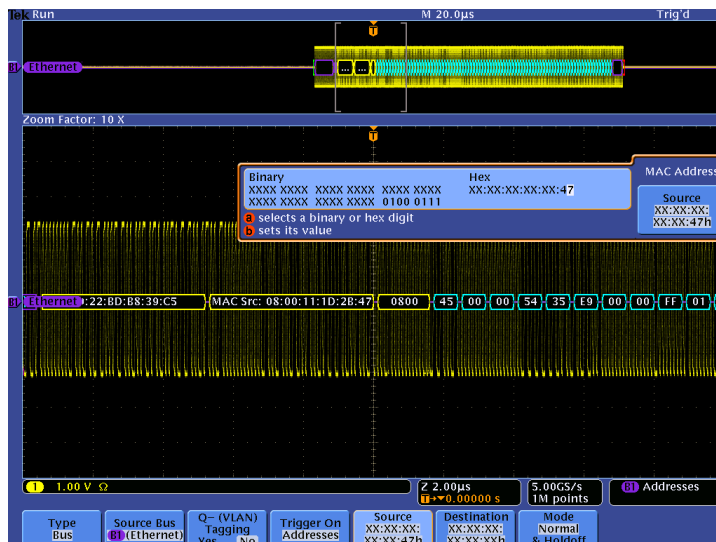
## MSO/DPO4000B Series Ethernet Bus Triggering

### Key Take Away Points

- We'll use a differential probe for this section of the lab, since it provides much better signal integrity for triggering.
- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the Ethernet serial bus.



- The MSO/DPO4000B Series can trigger on the Start Frame Delimiter, MAC Addresses, Q-Tag Control Information, MAC Length/Type, MAC Client Data, IP Header, TCP Header, TCP-IPv4 Client Data, End of Packet, Idle, or FCS (CRC) Error. By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern, capturing each occurrence.



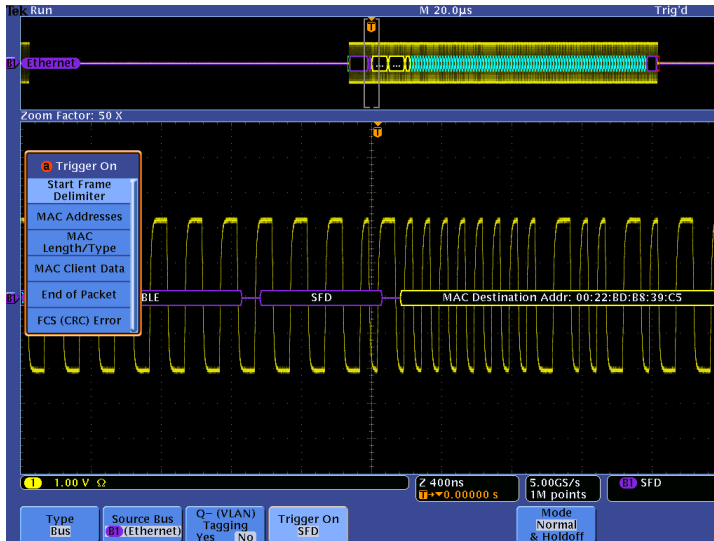
### MSO/DPO4000B Series Procedure:

- Press the front panel **Trigger Menu** button.
- Press the **Type** bottom bezel button.
- Using the Multipurpose **a** control, select the **Bus** Trigger Type.
- Press the **Trigger On** bottom bezel button.
- Using the Multipurpose **a** control, select **Start Frame Delimiter**.
- Using the Multipurpose **a** control, set the oscilloscope to Trigger On **MAC Addresses**.
- Press the **Source** bottom bezel button.
- Repeatedly press the **Source** side bezel button until the Source selection menu appears.
- Using the Multipurpose controls, set the least-significant bits of the MAC source address to **47** hex.
- Press **Menu Off**.
- Press the front panel **Run/Stop** button.
- Adjust the Wave Inspector **Pan** control as needed.

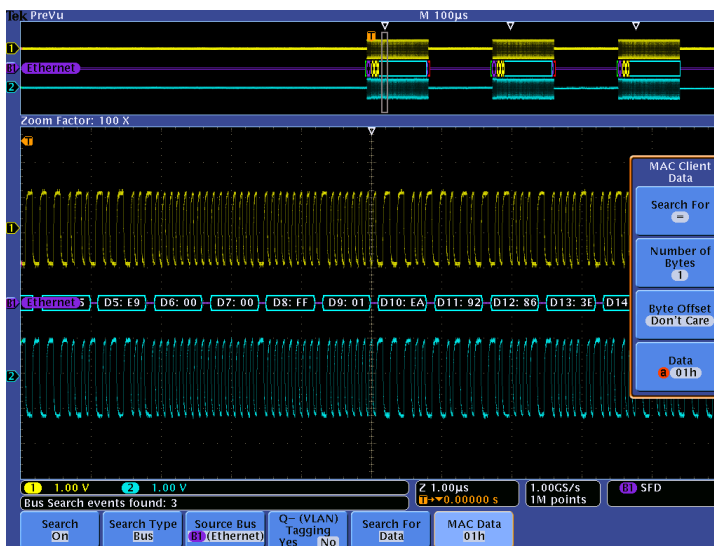
## MSO/DPO4000B Series Ethernet Bus Searching

### Key Take Away Points

- One of the key reasons for using long-record-length oscilloscopes is to be able to capture long time windows at high timing resolution.
- Capture a long time window. The display should look about like this:



- Wave Inspector search allows you to find all occurrences of a specified event, such as the data value '1'. The display should look something like this:



### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Search** button.
  - ❑ Press the **Search** bottom bezel button.
  - ❑ Repeatedly press the Search side bezel button until Search is turned **On**.
  - ❑ Press the **Search Type** bottom bezel button.
  - ❑ Using the Multipurpose **a** control, select the **Bus** Search Type.
  - ❑ Press the **Search For** bottom bezel button.
  - ❑ Using the Multipurpose **a** control, select Search For **Start Frame Delimiter**.
  - ❑ Notice all of the white triangular marks appear at the top of the display.
  - ❑ Navigate between marked occurrences by using the front panel ← and → buttons.
- 
- ❑ Using the Multipurpose **a** control, select Search For **MAC Client Data**.
  - ❑ Press the **Data** bottom bezel button.
  - ❑ Repeatedly press the **Data** side bezel button until the Data selection menu appears.
  - ❑ Using the Multipurpose controls, set the Data pattern to **01** hex.
  - ❑ Notice all of the white triangular marks appear at the top of the display.
  - ❑ Press **Menu Off**.
  - ❑ Navigate between marked occurrences by using the front panel ← and → buttons.

# MSO4000B/DPO4000B Series

## CAN Triggering and Decoding Lab



### Equipment List

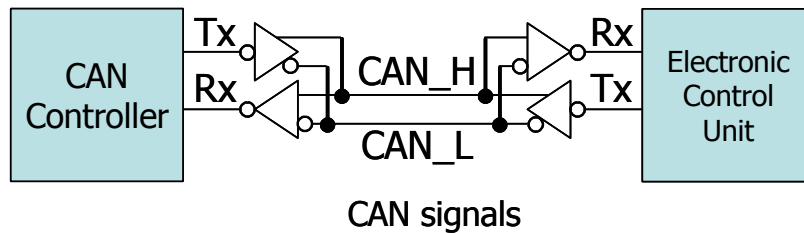
- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
  - One TPP0500 or TPP1000 passive probe
  - One DPO4AUTO or DPO4AUTOMAX application module
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]

## Understanding the CAN Bus

**CAN (Controller Area Network)** was developed by the Robert Bosch GmbH, in Germany, during the late 1980's. The need to specifically control and communicate with electronic control devices (ECUs) in electrically noisy environments was a driving force behind CAN. In 1992, Mercedes-Benz became the first automobile manufacturer to employ CAN in their higher end cars. Today almost every car manufacturer in the world employs CAN controllers and networks in systems such as windshield wiper motor controllers, rain sensors, airbags, door locks, engine timing controls, anti-lock braking systems, power train controls and electric windows, to name a few. CAN is rapidly expanding into other applications like industrial control, marine, medical, and aerospace.

CAN is a two-wire, half-duplex, high-speed serial communications bus. It is a layered protocol where the transmission and physical layers are of primary interest here. Because CAN is an asynchronous the bus can be utilized as a differential balanced line similar to RS-232 but allows multiple masters on the same network. Data rates range from 10 Kbps (<6km) to 1Mbps (<40m) with a tradeoff between speed and bus length, decreasing the bit rate allows for longer bus lengths. Typically CAN is used for system-to-system communication between nodes (transceivers and receivers) which communicate on the bus by messages similar to Ethernet.

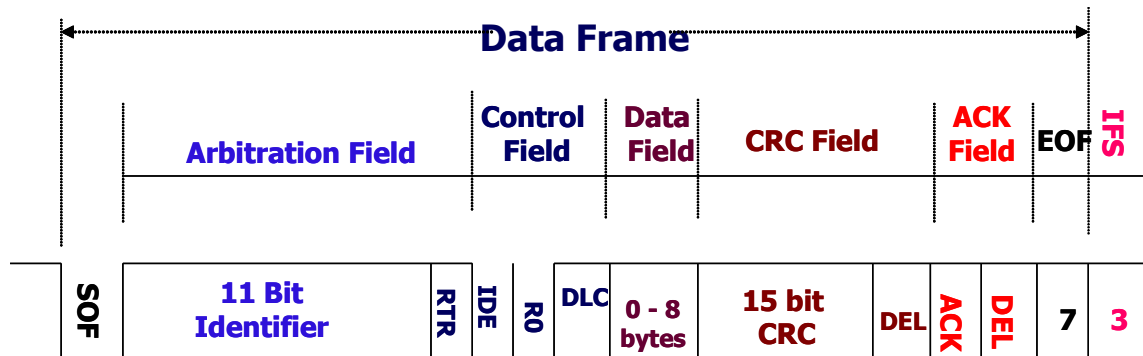
There are a variety of CAN signals, as shown in the figure below. The transmitted data (Tx) and received data (Rx) signals are single-ended digital signals which are found at the inputs and outputs of devices such as CAN controllers and Electronic Control Units (ECUs). The messages transmitted between modules and products are carried on an inverted differential signal. The differential signal can be measured, or the individual signals (CAN\_H and CAN\_L) can be measured individually (if the signal-to-noise ratio is adequate). Because the signal amplitudes, polarities, and DC offsets vary between these different signals, you need to adjust your measurement setup and decoding method accordingly.





## Identifiers, Arbitration and Frames

CAN data messages are transmitted from any node by identifier (ID) not by address or data. Before a node sends a message out to another node it checks if the bus is busy – two nodes on the same network are not allowed to send messages at the same time – a node can detect if it has lost arbitration and stops transmitting, letting the other node, with the higher priority transmit uninterrupted. A CAN message is created using frames. The frames of interest are: Data Frames, Standard (11 bit ID) and Extended (29 bit ID). Both Data Frames can hold 0 to 8 bytes of data and are used when a node wants to transmit data on the network. Remote Frames are used to request information and the node having the information should then respond by sending it on the network. Error Frames are used to signal an error and can be transmitted by any node. Overloaded Frames are used to provide extra delay between data and remote frames when a node is busy.



### Bit stuffing

In CAN frames a bit of opposite polarity is inserted after five consecutive bits of the same polarity. This practice is called bit stuffing, and is due to the Non-Return-to-Zero (NRZ) coding. The “stuffed” data frames are un-stuffed by the receiver. Since bit stuffing is used, six consecutive bits of the same type (111111 or 000000) are considered an error. The bits in a CAN message are sent either high or low: high bits are recessive; low bits are dominant.

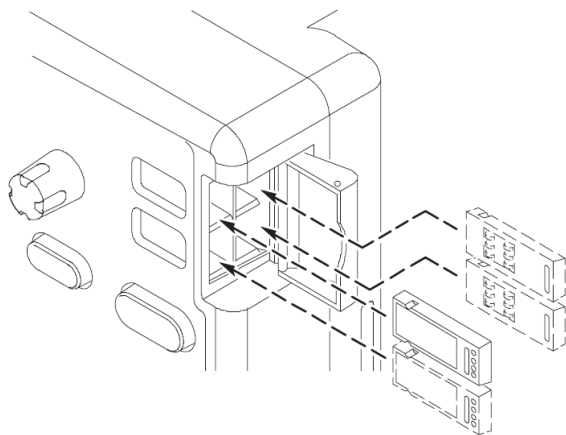
### Lab Objectives

- Obtain a basic understanding of the CAN serial bus.
- Learn how customers use oscilloscopes to measure and decode CAN signals.
- Learn how to setup a CAN serial bus display, and trigger and search on CAN bus content.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- CAN serial buses are industry standards and can be found in many of our customers' embedded designs today.
- Traditional manual decoding methods being used by your customers to decode these buses on their oscilloscope are time-consuming.
- With the DPO4AUTO or DPO4AUTOMAX application module installed, the MSO/DPO4000B Series oscilloscope can trigger on, decode, and search CAN bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.

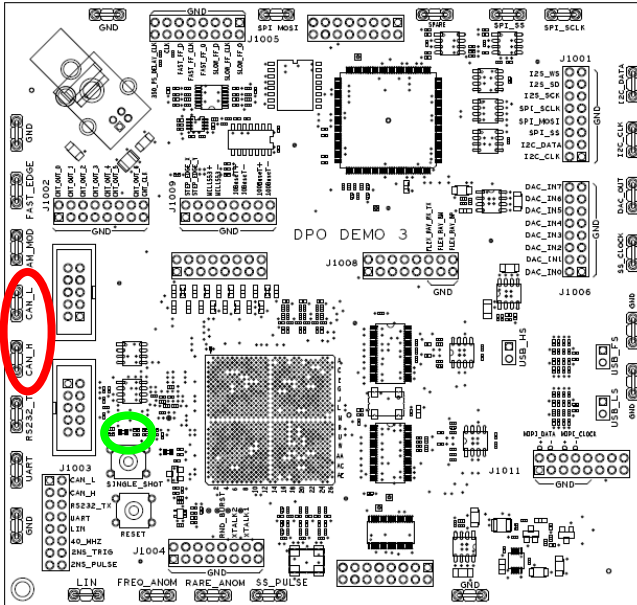


### MSO/DPO4000B Series Procedure:

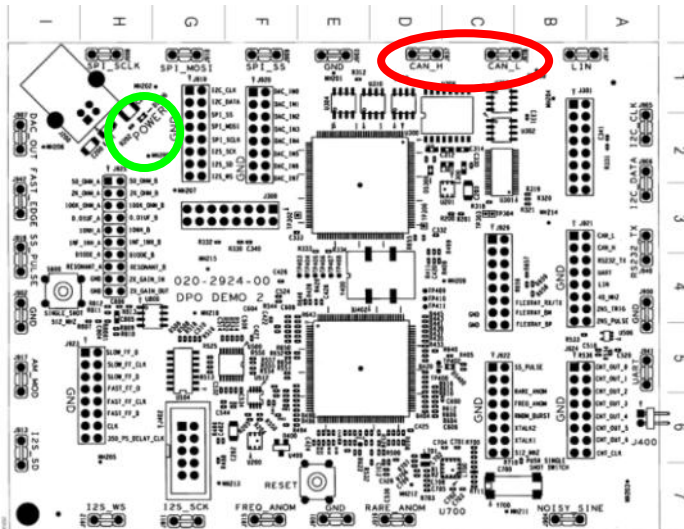
- ❑ With the oscilloscope power off, install the **DPO4AUTO** or **DPO4AUTOMAX** into one of the application module slots on the front panel of the instrument.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4AUTO Automotive Serial Triggering and Analysis** or **DPO4AUTOMAX Extended Automotive Serial Triggering and Analysis** application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has CAN signals which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has CAN signals which we can use for this lab.



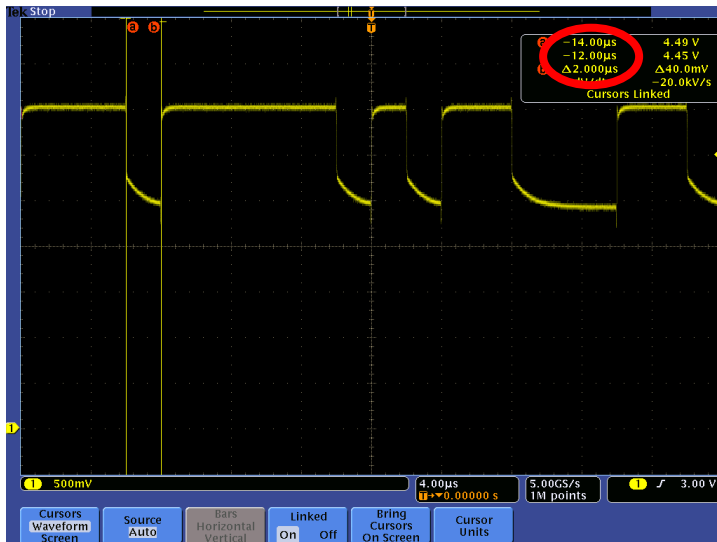
## DPO Demo board Procedure:

- Power up the demo board.
- Verify the power LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.
- Attach the probe ground to the **GND** test point on the demo board.
- Connect the probe tip to the **CAN\_H** test point on the demo board.

## Manual CAN Bit Rate Measurement

### Key Take Away Points

- On the DPO Demo 3 board (679-6506-XX) and the DPO Demo 2 board (020-2924-XX), the CAN bit rate is 500 kbps.
- In addition to the long list of preset bit rate values from 10 kbps to 1 Mbps, the custom bit rate control allows the user to set the bit rate to any value between 10 kbps and 1 Mbps in 10 bps steps (with the front panel Fine mode selected) and in 100 bps steps (with the Fine mode deselected).
- However, in general, you may not know what the bit rate is. Because CAN is an asynchronous bus, you must accurately determine the bit rate before the bus can be properly decoded. This section of the lab explains how to measure the CAN bit rate. The display should look about like this:



- The cursor measurement of the pulse width of the narrowest pulse indicates a 50 µs minimum pulse width. Compare this pulse width with the values in the following chart to determine the CAN bit rate:

Minimum CAN Pulse Width	CAN Bit Rate
1 µs	1 Mbps
1.25 µs	800 kbps
2 µs	500 kbps
4 µs	250 kbps
8 µs	125 kbps
12 µs	83.3 kbps
16 µs	62.5 kbps
20 µs	50 kbps
30 µs	33.3 kbps
50 µs	20 kbps
100 µs	10 kbps

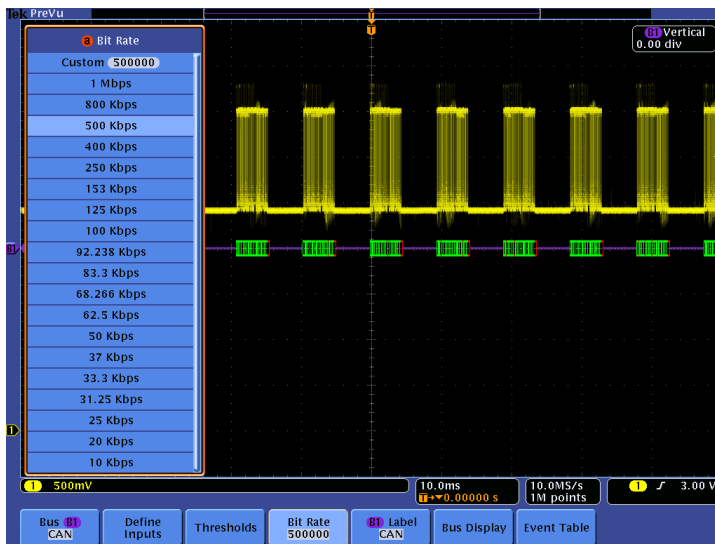
### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Default Setup** button.
- ❑ Set the channel 1 Vertical **Scale** to **500mV/div**.
- ❑ Position the channel 1 waveform near the bottom of the display.
- ❑ Press the Trigger **Menu** button.
- ❑ Press the **Mode** bottom bezel button.
- ❑ Press the **Normal** side bezel button.
- ❑ Use the Trigger **Level** control to adjust the trigger level to the center of the waveform, about **3V**.
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1M**.
- ❑ Press the front panel **Menu Off** button.
- ❑ Press the front panel **Single** button.
- ❑ Press and hold the front panel **Cursors** button to turn on cursors and display the cursor control menu.
- ❑ Using the Multipurpose **a** and **b** controls, position the cursors on the rising and falling edge of a narrow pulse to measure the pulse width.
- ❑ When done, press the front panel **Cursors** button once.

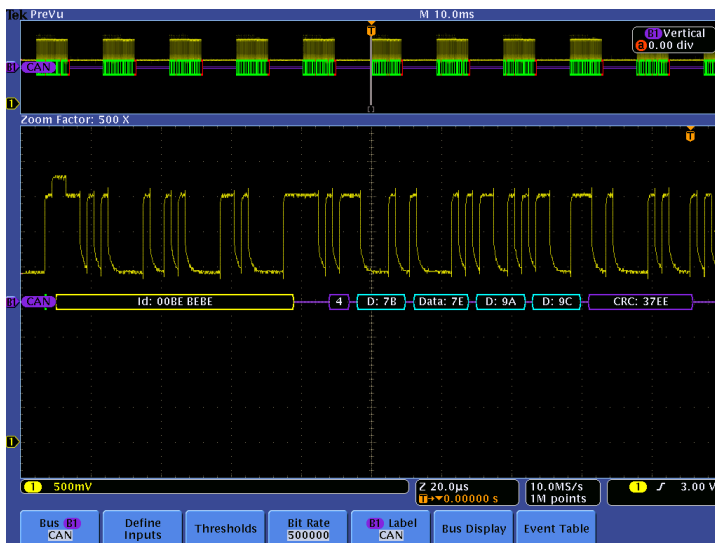
## MSO/DPO4000B Series CAN Bus Decoding

### Key Take Away Points

- In this section, you will learn how to use the MSO/DPO4000B Series to automatically decode CAN frame content. Setting up a basic CAN bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menus guide you through the setup in the left-to-right order across the bottom bezel buttons.
- Notice that any of the analog or digital input signals can be used as a source for the CAN bus.
- Notice that the list of available CAN bit rates has been increased, including a Custom bit rate setting. This control allows you to set the CAN bit rate to any integer value from 10 kbps to 1 Mb/s.



- The display should now look about like this, with the hexadecimal decoded value shown in the bus waveform:

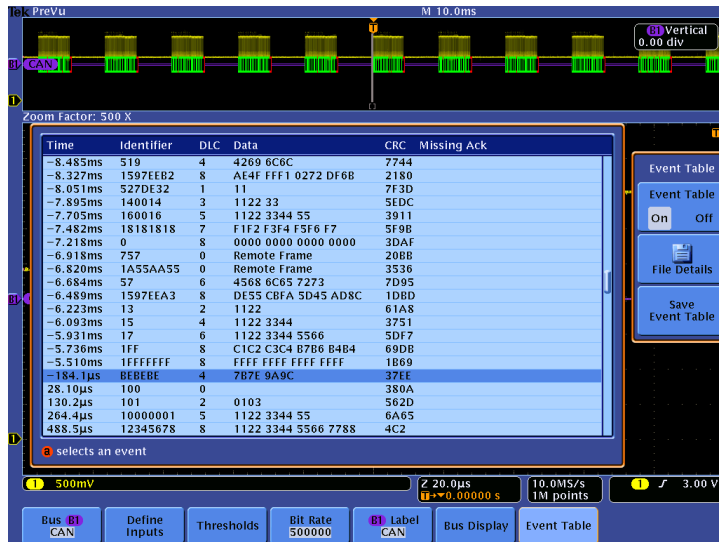


### MSO/DPO4000B Series Procedure:

- ❑ Set the Horizontal **Scale** to **10ms/div**.
- ❑ Press the front panel Bus **B1** button.
- ❑ Press the **Bus B1** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **CAN** Bus Type.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ Verify that the CAN input is on channel **1**, that the Signal Type is **CAN\_H**, and the Sample Point is set to **50%**.
- ❑ Press the **Thresholds** bottom bezel button.
- ❑ Using the Multipurpose **a** control, set the Channel **1** Threshold value to the center of the signal, about **3 V**.
- ❑ Press the **Bit Rate** bottom bezel button.
- ❑ Using the Multipurpose **a** control, set the Bit Rate to the appropriate value.
- ❑ If desired, you can edit the label on the bus. Press the **B1 Label** bottom bezel button and enter the desired label.
- ❑ Press the **Bus Display** bottom bezel button.
- ❑ Verify that the **Hex** side bezel button has been selected to enable hexadecimal decoding.
- ❑ Press **Menu Off** once to remove the side menu.
- ❑ Press the front panel **Single** button.
- ❑ Using the **Wave Inspector** pan and zoom controls, zoom in on one frame of the signal.

## Key Take Away Points

- Although the bus waveform display is very familiar to most hardware engineers, there are another display formats that other engineers, such as software engineers, may find more useful.
- For large quantities of data, and for those who are not comfortable with waveform displays, you can also use the Event Table to display the CAN data (in the selected format) along with the time stamps. The display should now look something like this:



- Notice that, from the Event Table menu, you can also save the Event Table data in .CSV format with a single button press.

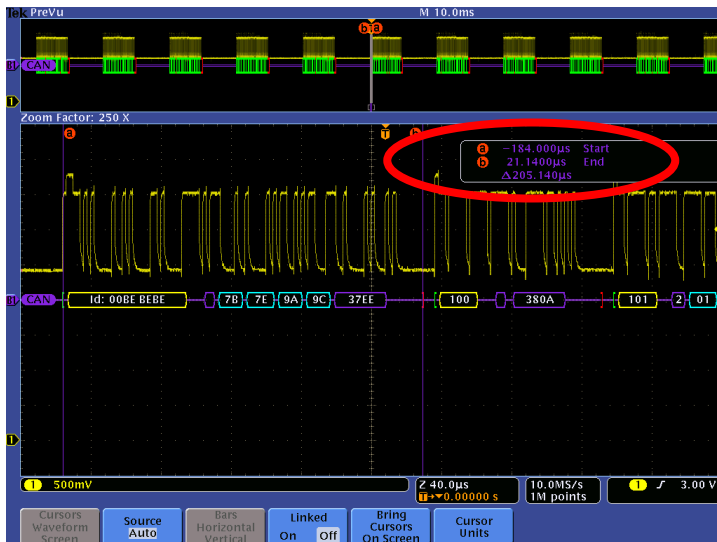
## MSO/DPO4000B Series Procedure:

- ❑ Press the **Event Table** bottom bezel button.
- ❑ Repeatedly press the **Event Table** side bezel button until it is set to **On**.
- ❑ Using the Multipurpose **a** control, scroll through Event Table messages. Notice that the zoom indicators in the overview window indicate the message position in the acquired waveform.
- ❑ Press the **Save Event Table** side bezel button to save the Event Table in CSV format to the pre-selected mass storage device.
- ❑ When you are done using the Event Table display, press the **Event Table** side bezel button to select **Off**.

## MSO/DPO4000B Series CAN Bus Cursors

### Key Take Away Points

- The CAN serial cursors provide another tool to bridge between the serial waveform and the decoded values, showing absolute timing relative to the trigger, bus values, and relative timing between bus events.
- For this example, we can measure the time from the start to the end of one frame:



- Even when you are zoomed out to where you can't read the decoded values on the display, cursor measurements enable you to make timing measurements on buses, such as between the starts of two distant packets:



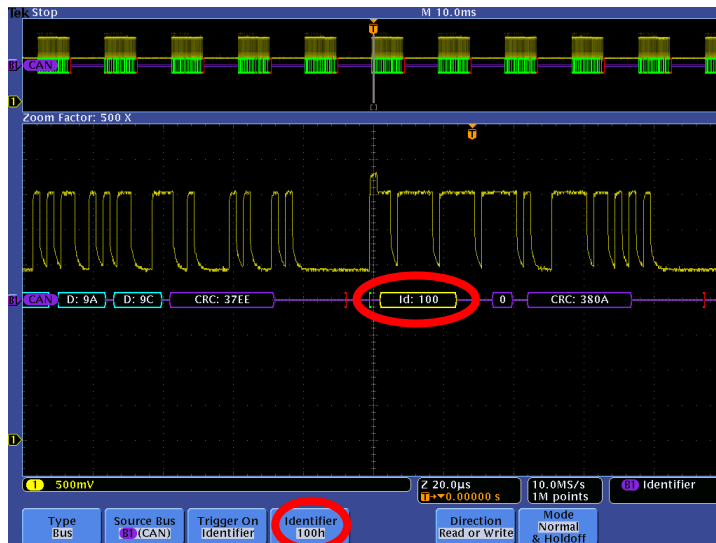
### MSO/DPO4000B Series Procedure:

- ❑ Using the Wave Inspector controls, zoom in on one of the CAN frames.
- ❑ Press the **Cursors** front panel button once to turn on vertical bar cursors.
- ❑ Using the Multipurpose **a** control, place the **a** cursor on an event of interest, such as the start of a frame.
- ❑ Notice the **a** cursor time and bus value readout in the upper right corner of the display.
- ❑ Using the Multipurpose **b** control, place the **b** cursor on an event of interest, such as the end of the same frame.
- ❑ Notice the **b** cursor time and bus value readout in the upper right corner of the display.
- ❑ Also notice that we are displaying the time delay between the first and second bus events of interest.
- ❑ Now, turn off zoom. Slowly move the cursors around and notice that you can easily identify the parts of the CAN messages and their timing without being able to clearly see the waveforms or the decoded values.
- ❑ When you are done, press the **Cursors** front panel button once to turn off cursors.

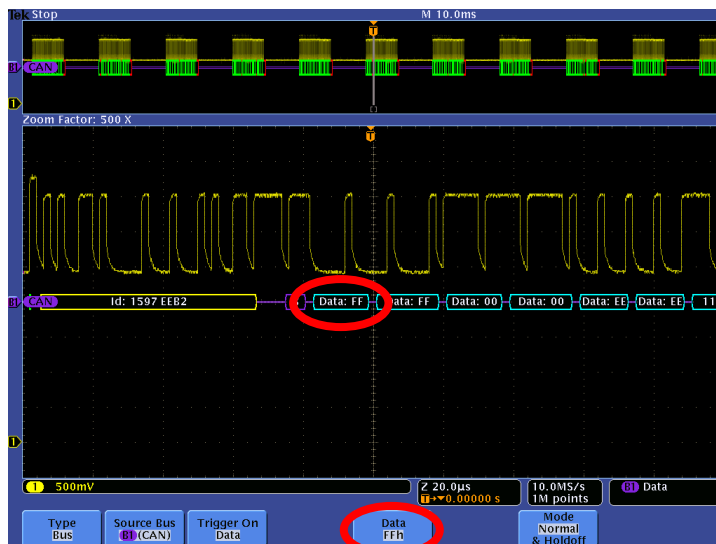
## MSO/DPO4000B Series CAN Bus Triggering

### Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the CAN serial bus.
- The MSO/DPO4000B Series can trigger on the Start of Frame, Type of Frame, Identifier, Data, ID & Data, End of Frame, Missing Ack, or Bit Stuffing Error. This is an example of triggering on a partially-specified Identifier value:



- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern, capturing each occurrence. Here is an example of triggering when the first data value is FF Hex:



### MSO/DPO4000B Series Procedure:

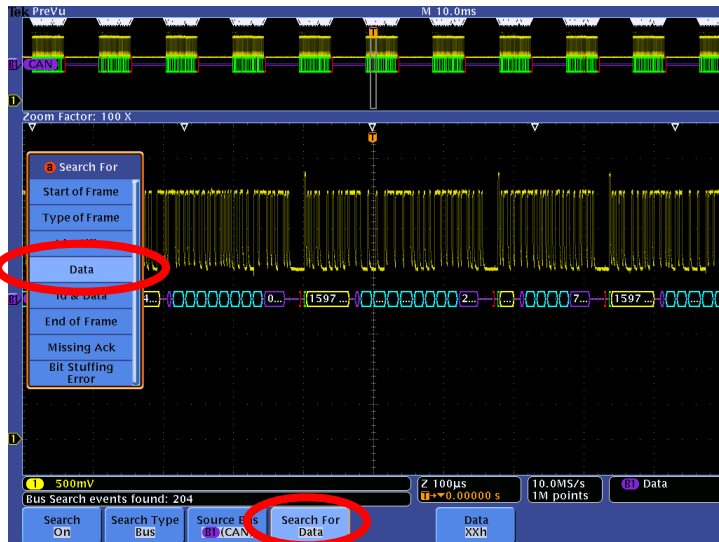
- Press the front panel **Trigger Menu** button.
  - Press the **Type** bottom bezel button.
  - Using the Multipurpose **a** control, select the **Bus** Trigger Type.
  - Press the **Trigger On** bottom bezel button.
  - Using the Multipurpose **a** control, select **Identifier**.
  - Press the **Identifier** bottom bezel button.
  - If necessary, press the **Identifier** side bezel button to make the Identifier selection menu appear.
  - Using the Multipurpose **a** control, set the Identifier to **100** Hex.
  - Press **Menu Off**.
  - Press the front panel **Single** button.
  - Adjust the Wave Inspector pan and zoom controls as needed to view the CAN message and the trigger event.
- 
- Press the **Trigger On** bottom bezel button.
  - Using the Multipurpose **a** control, set the oscilloscope to Trigger On **Data**.
  - Press the **Data** bottom bezel button.
  - If necessary, press the **Data** side bezel button to make the Identifier selection menu appear.
  - Using the Multipurpose **a** control, set the Identifier to **FF** Hex.
  - Press **Menu Off**.
  - Press the front panel **Single** button.



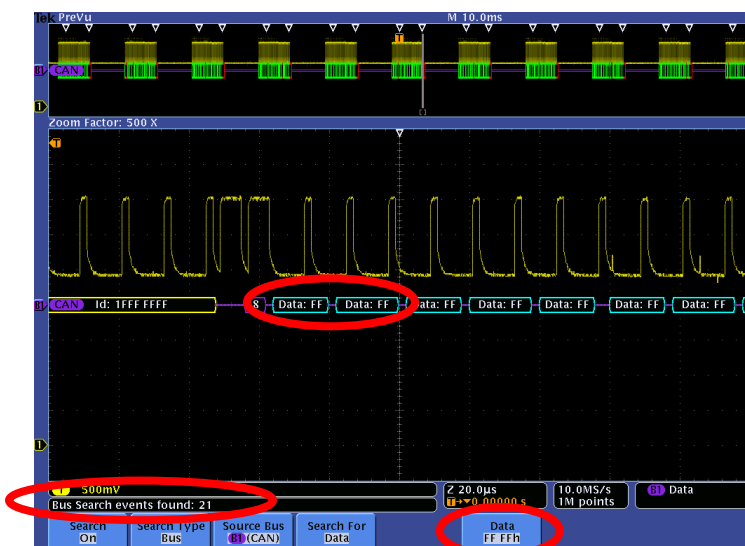
## MSO/DPO4000B Series CAN Bus Searching

### Key Take Away Points

- One of the key reasons for using long-record-length oscilloscopes is to be able to capture long time windows at high timing resolution.
- Search is similar to triggering, but it finds all matching events within the current acquisition. As you select different search criteria, the white triangles at the top of the display indicate each of the events that were found. The display should look about like this:



- Wave Inspector search allows you to find all occurrences of a specified event, such as the data value FFFF hex. The display should look something like this:

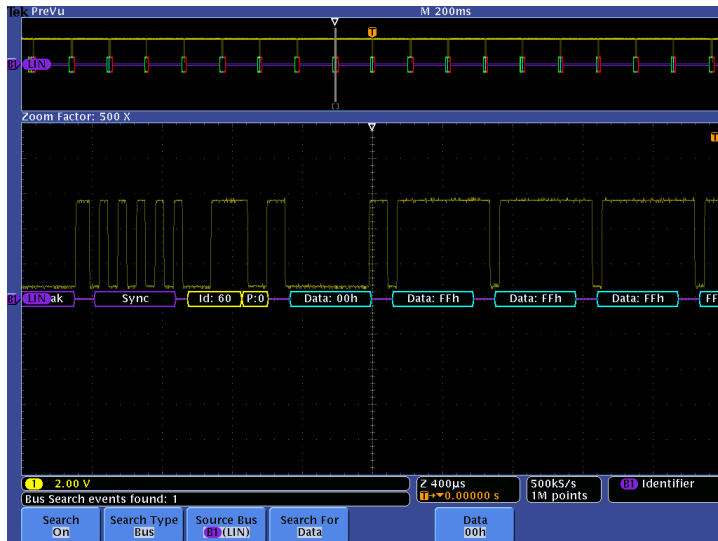


### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Search** bottom bezel button.
- ❑ Repeatedly press the **Search** side bezel button until Search is turned **On**.
- ❑ Press the **Search Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Bus** Search Type.
- ❑ Press the **Search For** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select Search For **Data**.
- ❑ Press the **Data** bottom bezel button.
- ❑ Press the **Number of Bytes** side bezel button.
- ❑ Using the Multipurpose **a** control, select **2** bytes.
- ❑ Press the **Data** side bezel button to display the Data selection menu.
- ❑ Using the Multipurpose controls, set the Data pattern to **FFFF** hex.
- ❑ Notice the white triangular marks changing at the top of the display as you change values.
- ❑ Navigate between marked occurrences by using the front panel **←** and **→** buttons.

# MSO4000B/DPO4000B Series

## LIN TrIGGERING and Decoding Lab



### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
  - One TPP0500 or TPP1000 passive probe
  - One DPO4AUTO or DPO4AUTOMAX application module
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]

## Understanding the LIN Bus

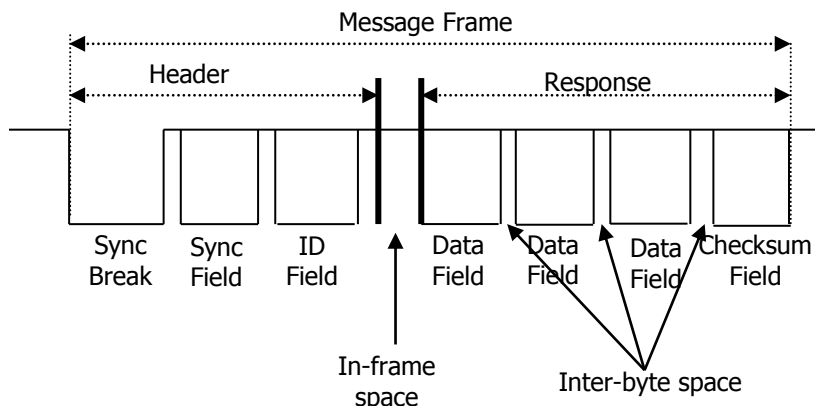
**Local Interconnect Network (LIN)** is one of the older low-speed serial standards for the automotive industry, developed by the LIN consortium in 1999 as a lower-cost alternative to the CAN bus for applications where CAN's cost, versatility, and speed were overkill. LIN applications typically include communications between intelligent sensors and actuators such as window controls, door locks, rain sensors, windshield wiper controls, and climate control, to name a few. However, due to its electrical noise tolerance, error-detection capabilities, and high speed data transfer, CAN is still used today for engine timing controls, anti-lock braking systems, power train controls and more.

The LIN bus is a low-cost, single-wire implementation based on the Enhanced ISO9141 standard. LIN networks have a single master and one or more slaves. LIN signals can be transmitted over distances up to 40 meters. All messages are initiated by the master with only one slave responding to each message, so collision detection and arbitration capabilities are not needed as they are in CAN. Communication is based on UART/SCI with data being sent in eight-bit bytes along with a start bit, stop bit and no parity. Data rates range from 1kb/s to 20kb/s. While this may sound slow, it is suitable for the intended applications and minimizes EMI.

LIN support is optional and is enabled by either the DPO4AUTO or DPO4AUTOMAX application module. This lab will walk you through the most significant of the capabilities of the product.

The LIN bus is always in one of two states: active or sleep. When it's active, all nodes on the bus are awake and listening for relevant bus commands. Nodes on the bus can be put to sleep by either the Master issuing a Sleep Frame or the bus going inactive for longer than a predetermined amount of time. The bus is then awakened by any node requesting a wake up or by the master node issuing a break field.

LIN frames consist of two main parts, the header and the response. The header is sent by the master while the response is sent by the slave. The LIN message frame looks like this:



#### Header Components:

- Sync Break – marks the beginning of the Message Frame. It activates and instructs all slave devices to listen to the remainder of the header.
- Sync Field – an alternating bit pattern which is used by the slave nodes for determination of the baud rate being used by the master node and synchronize themselves accordingly.
- Identifier Field – specifies which slave device is to take action. The ID Field contains four elements:
  - Message Identifier: identifies the sender, the receiver, the purpose, and data field length 6 Bit
  - 4 classes of 2/4/8 data bytes
  - 16 identifiers
  - 2 parity bits

#### Response Components:

- Data – the specified slave device responds with one to eight bytes of data
- Checksum – computed field used to detect errors in data transmission. The LIN standard has evolved through several versions that have used two different forms of checksums. Classic checksums are calculated only over the data bytes and are used in version 1.x LIN systems. Enhanced checksums are calculated over the data bytes and the identifier field and are used in version 2.x LIN systems.

The LIN bus transmits signals in three ways:

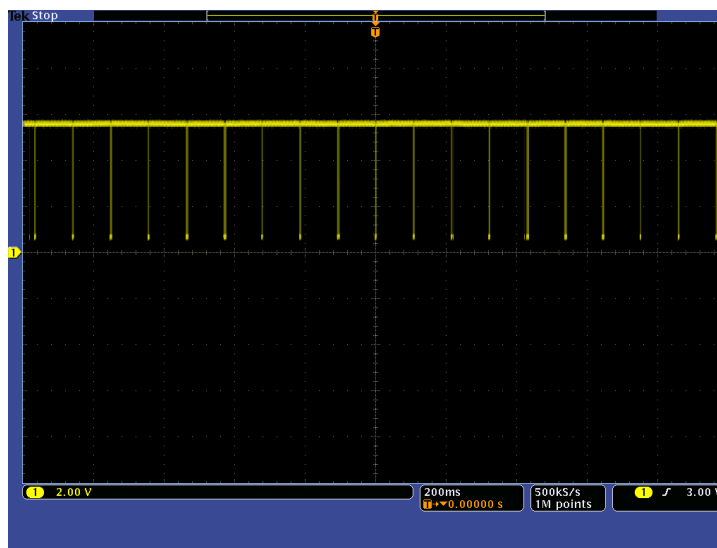
- **Unconditional:** The most typical LIN frame where the bus master sends the frame header in a scheduled frame slot and the designated slave node fills the frame with data.
- **Event-triggered:** Receives maximum information from slave nodes without overloading bus. Event Triggered Frames can be filled with data from multiple slave nodes.
- **Sporadic:** Sent only from master when a signal is updated in a slave node. Usually the master fills the data bytes of the frame and slave nodes receive information.

#### Lab Objectives

- Obtain a basic understanding of the LIN serial bus.
- Learn how customers use oscilloscopes to measure and decode LIN signals.
- Learn how to setup a LIN serial bus display and trigger and search on LIN bus content with a MSO/DPO4000B Series oscilloscope.

## Key Take Away Points

- The LIN signal on the demo board looks about like this:

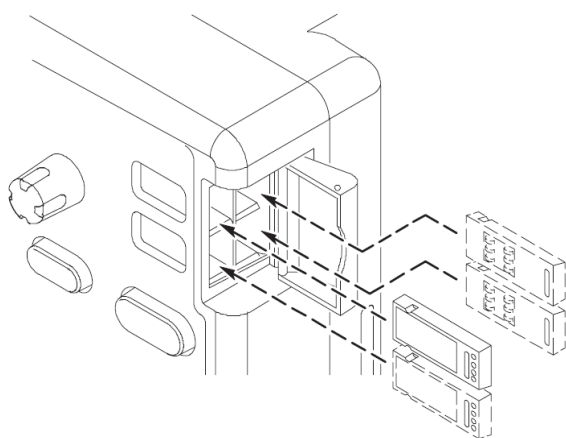


- LIN signal level are defined as follows:
  - Recessive (high)  $\geq 0.6$  \* system supply voltage
  - Dominant (low)  $\leq 0.4$  \* system supply voltage

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- With the DPO4AUTO or DPO4AUTOMAX application module installed, the MSO/DPO4000B Series oscilloscope can trigger on, decode, and search LIN bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.

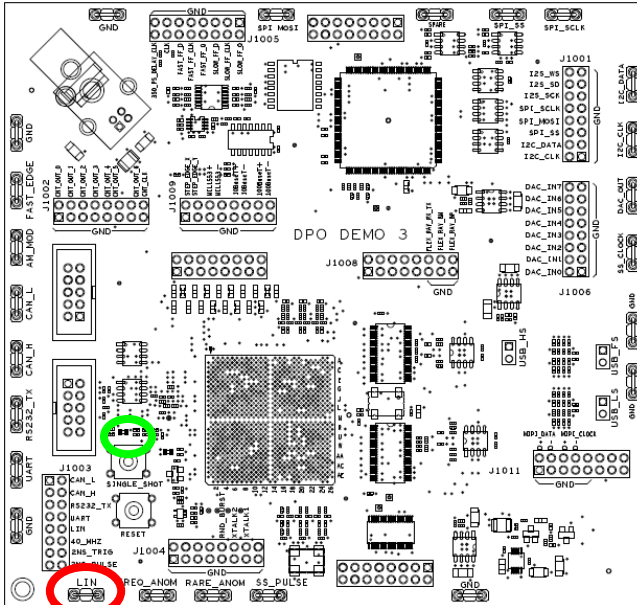


### MSO/DPO4000B Series Procedure:

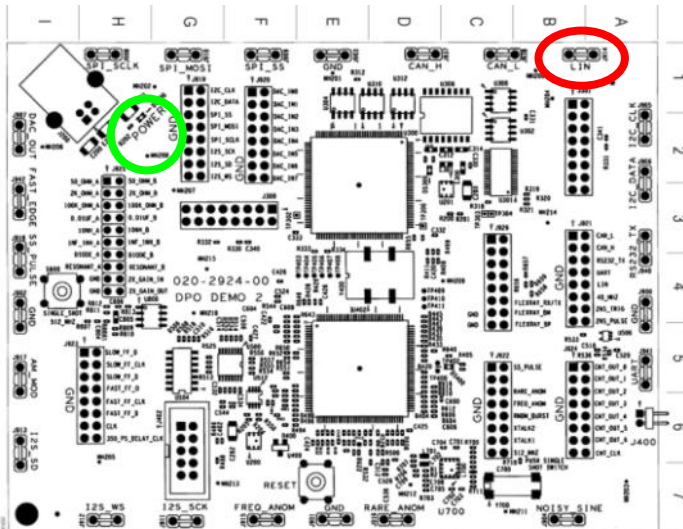
- With the oscilloscope power off, install the **DPO4AUTO** or **DPO4AUTOMAX** into one of the application module slots on the front panel of the instrument.
- Power up the oscilloscope.
- Press the front panel **Utility** button.
- If necessary, press the **About** bottom bezel button to display the status screen.
- Verify that the **DPO4AUTO Automotive Serial Triggering and Analysis** or **DPO4AUTOMAX Extended Automotive Serial Triggering and Analysis** application module is detected.
- Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a LIN signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has a LIN signal which we will use for this lab.



## DPO Demo Board Procedure:

- Power up the demo board.
- Verify the power LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.
- Attach the probe ground to the **GND** test point on the demo board.
- Connect the probe tip to the **LIN** test point on the demo board.

## Key Take Away Points

### (optional) Determining LIN Bus Data Rate

- The data rate of the LIN signal on the DPO demo board is about 19200 bits/second and this is the default setting in the oscilloscope, as you will soon see. However, in general, you may need to determine the data rate using this procedure.
- In addition to the preset bit rate values of 1.2 kbps, 2.4 kbps, 4.8 kbps, 9.6 kbps, 10.417 kbps, and 19.2 kbps, the custom bit rate control allows the user to set the bit rate to any value between 800 bps and 100 kbps in 10 bps steps (with the front panel Fine mode selected) and in 100 bps steps (with the Fine mode deselected).
- Since LIN slaves depend upon the average bit rate in the sync field, let's measure that. The measurement below indicates that the average single bit width (423  $\mu$ s / 8 bits) is between 52 and 53  $\mu$ s, so the bit rate is verified to be about 19.2kbps.
- The display should look about like this:



- Look up the data rate in this table:

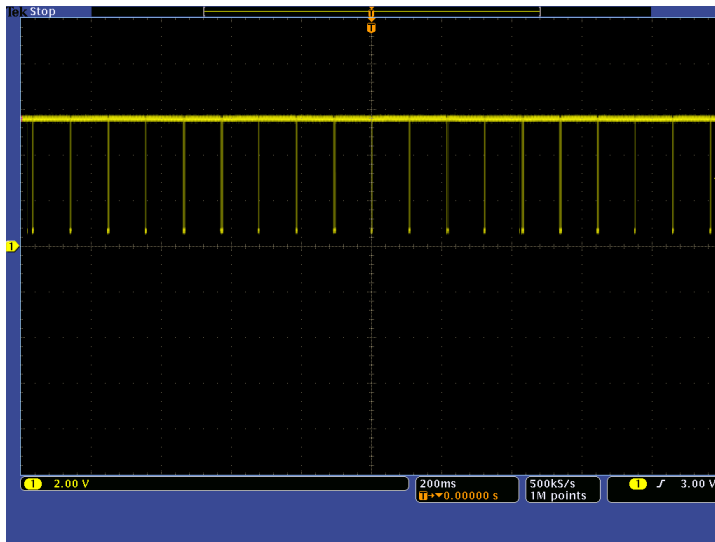
Average Sync Bit Width	Data Rate (bits / sec)
50 $\mu$ s	20000
52.1 $\mu$ s	19200
66.7 $\mu$ s	15000
100 $\mu$ s	10000
200 $\mu$ s	5000
1 ms	1000
2 ms	500

### MSO/DPO4000B Series Procedure:

- Press the front panel **Default Setup** button.
- Set the channel 1 Vertical **Scale** to **2V/div**.
- Set the **Horizontal Scale** to **200 $\mu$ s/div**.
- Use the **Trigger Level** control to adjust the trigger level below the center of the waveform, about **3V**.
- Trigger on the sync break by triggering on a relatively long negative pulse.
  - Press the front panel **Trigger Menu** button.
  - Press the **Type** bottom bezel button and select **Pulse Width** using the Multipurpose **a** control.
  - Press the **Polarity** bottom bezel button and the **Negative** side bezel button.
  - Press the **Trigger When** bottom bezel button and select **Pulse Width >** in the side menu. Set the pulse width to **~500 $\mu$ s/div** with the Multipurpose **a** control.
- Press the front panel **Cursors** button once to turn on vertical bar cursors.
- Using the Multipurpose controls, measure the width of the 8-bit sync field (01010101), starting with the negative edge, as shown in the screen shot at the left.
- Read the sync field burst width ( $\Delta$  time in the cursor readout) and write the value here: \_\_\_\_\_
- Divide the burst width by 8 to get the average sync bit width and write the value here: \_\_\_\_\_
- Look up the data rate in the table at the left and write the value here: \_\_\_\_\_

## Key Take Away Points

- The LIN signal should look about like this:



## MSO/DPO4000B Series Procedure:

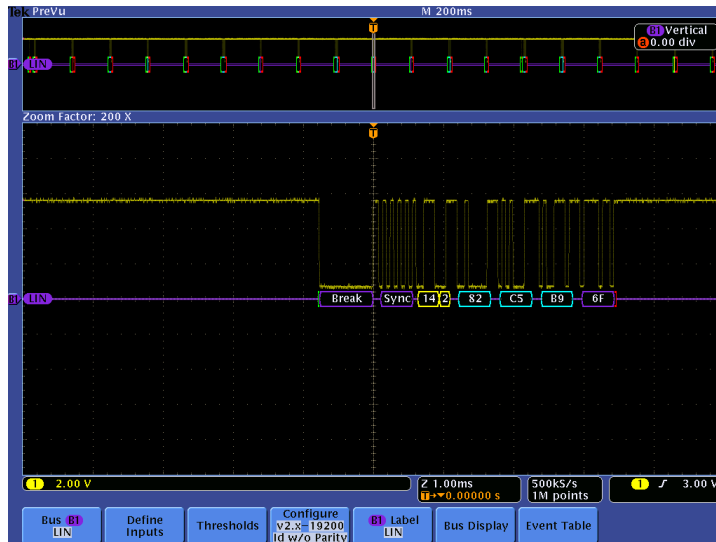
- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Set the channel 1 Vertical **Scale** to **2V/div**.
- Use the **Trigger Level** control to adjust the trigger level below the center of the waveform, about **3V**.
- Set the **Horizontal Scale** to **200ms/div**.
- Press **Trigger Menu** button.
- Press the **Mode** bottom bezel button.
- Press the **Normal** side bezel button to turn off Roll Mode.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **1M**.
- Press the front panel **Menu Off** button twice.
- Press the front panel **Single** button.



## MSO/DPO4000B Series LIN Decoding Setup

### Key Take Away Points

- Setting up a basic LIN bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menus guide you through the setup in the left-to-right order across the bottom bezel buttons.
- Notice that any of the analog or digital input signals can be used as a source for the LIN bus.
- The MSO/DPO4000B Series can trigger and decode LIN signals at the preset bit rates from 1.2 to 19.2 kbps, or at any user-selectable value from 800 bps to 100 kbps.
- The MSO/DPO4000B Series supports LIN versions 1.3, 2.0, and 2.1.
- The default LIN bus values in the MSO/DPO4000B Series were chosen to match the signal on the demo board, so many of the steps to the right have already been done for you.
- The display should now look about like this, with the decoded values shown in the bus waveform:



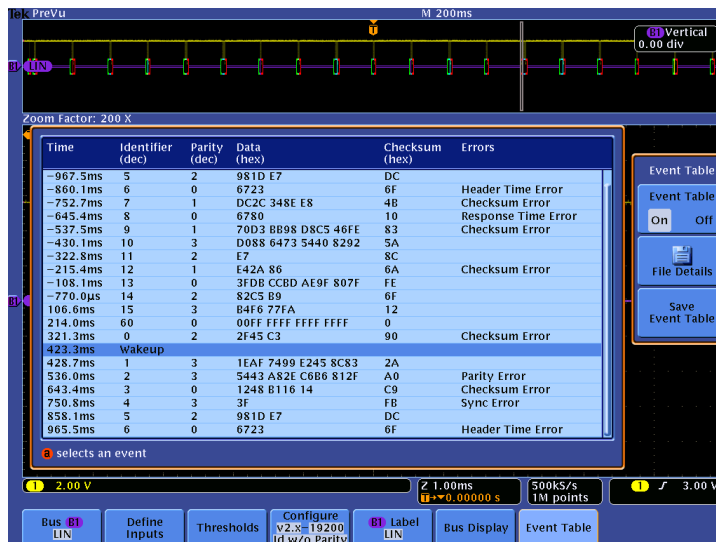
- Notice that the decoded bus waveform shows Start of Frame in green, Sync Break and Sync Field in purple, the Identifier and Parity in yellow, the data values in cyan, the checksum in purple, and the End of Frame in red. Errors are all shown in red.

### MSO/DPO4000B Series Procedure:

- Press the front panel **B1** button.
- Press the **Bus B1** bottom bezel button.
- Using the Multipurpose **a** control, set Bus type to **LIN**.
- Press the **Define Inputs** bottom bezel button.
- Verify that the LIN Input is on channel **1**, Sample Point is set to **50%**, and the **Polarity Normal** is selected.
- Press the **Thresholds** bottom bezel button.
- Using the Multipurpose **a** control, set the Threshold to **3 V**.
- Press the **Configure** bottom bezel button.
- Press the **Bit Rate** side bezel button.
- Using the Multipurpose **a** control, set the Bit Rate to **19200**. You can also use the **Custom Bit Rate** control to select the bit rate. Because this control has very fine resolution, you will want to press the front panel **Fine** button until it is turned off whenever you are making large changes in bit rate.
- Press the **LIN Standard** side bezel button.
- Using the Multipurpose **a** control, set the LIN Standard to **v2.x**.
- Verify that the **Include Parity Bits with Id** selection is set to **No**.
- Press the front panel **Menu Off** button once.
- Using the Wave Inspector controls, zoom in on one of the LIN messages.

## Key Take Away Points

- As seen in the last section, the default LIN decoder display format is decimal display of the ID and Parity, and hexadecimal for the Data and Checksum values. These values can also be displayed in hexadecimal and binary.



- For many users who are not electrical engineers, the waveform displays may not be familiar. For them, the Event Table format is preferable. This format can also be saved in CSV format and analyzed off-line.

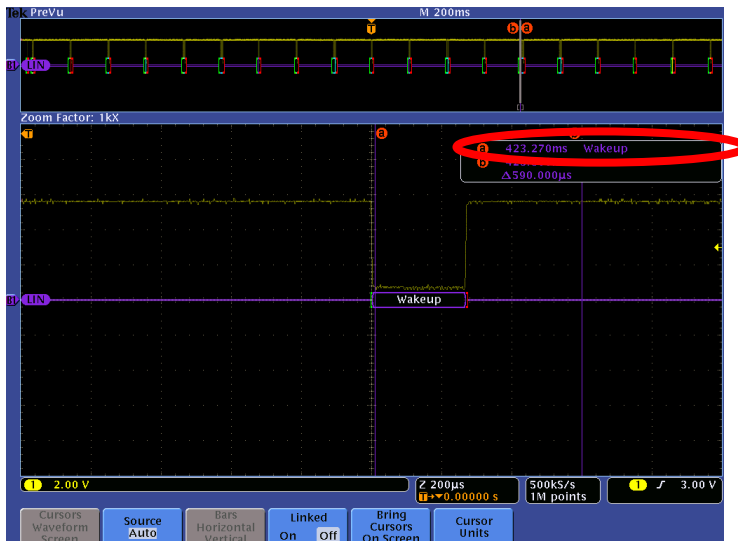
## MSO/DPO4000B Series Procedure:

- Press the **Bus Display** bottom bezel button.
- Notice the different bus display options.
- Press the **Event Table** bottom bezel button.
- Repeatedly press the **Event Table** side bezel button until it is set to **On**.
- Using the Multipurpose **a** control, scroll through Event Table messages. Notice that the zoom indicators in the overview window indicate the message position in the acquired waveform.
- When you are done using the Event Table display, press the **Event Table** side bezel button to select **Off**.

## MSO/DPO4000B Series LIN Cursors

### Key Take Away Points

- The LIN serial cursors provide another tool to bridge between the serial waveform and the decoded values, showing absolute timing relative to the trigger, bus values, and relative timing between bus events.
- For this example, we want to measure the time from the start of the Wakeup frame to the start of the next LIN message. Cursor **a** is placed at the beginning of the Wakeup message. The **a** readout indicates the time and the value.



- Cursor **b** is placed at the beginning of the Sync Break of the next LIN message. Notice that the timing from Wakeup to Break is clearly and easily displayed.



### MSO/DPO4000B Series Procedure:

- ❑ Using the Wave Inspector controls, zoom in on one of the LIN messages.
- ❑ Press and hold the **Cursors** front panel button once to turn on vertical bar cursors and to display the cursor menu.
- ❑ Using the Multipurpose **a** control, place the **a** cursor on an event of interest.
- ❑ Notice the **a** cursor time and bus value readout in the upper right corner of the display.
  
- ❑ Using the Wave Inspector controls, zoom in on another of the LIN messages.
- ❑ Using the Multipurpose **b** control, place the **b** cursor on an event of interest.
- ❑ Notice the **b** cursor time and bus value readout in the upper right corner of the display.
- ❑ Also notice that we are displaying the time delay between the first and second bus events of interest.
  
- ❑ Now, turn off zoom. Slowly move the cursors around and notice that you can easily identify the parts of the LIN messages and their timing without being able to clearly see the waveforms or the decoded values.
- ❑ Press the **Cursors** front panel button once to turn off cursors.

## MSO/DPO4000B Series LIN Bus Triggering

### Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the LIN serial bus.
- The MSO/DPO4000B Series can trigger on:
  - Sync
  - Identifier
  - Data (=, ≠, <, ≤, ≥, >, inside range, outside range)
  - ID & Data
  - Wakeup Frame
  - Sleep Frame
  - Error (Sync, Parity, Checksum)
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on a LIN signal, capturing each occurrence.



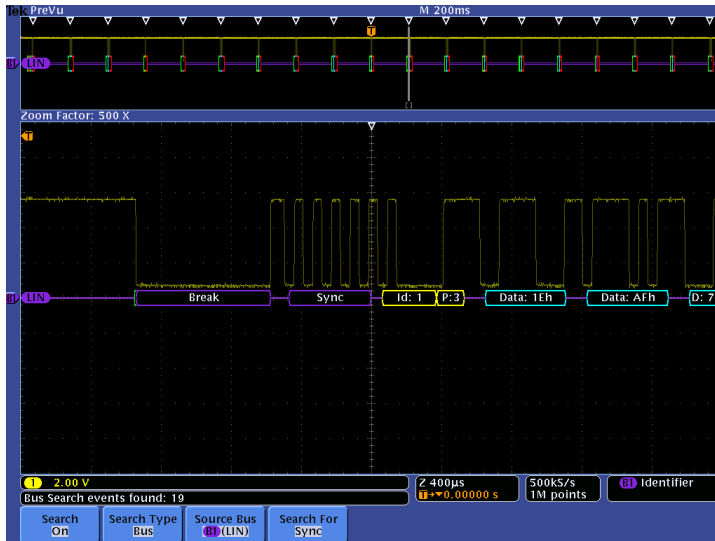
### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Trigger Menu** button.
- ❑ Press the **Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Bus** Trigger Type.
- ❑ Press the **Trigger On** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **Identifier**.
- ❑ Press the **Identifier** bottom bezel button.
- ❑ Using the Multipurpose **a** control, set the Identifier to **00** Hex.
- ❑ Press **Menu Off**.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the Wave Inspector pan and zoom controls as needed to view the LIN message.

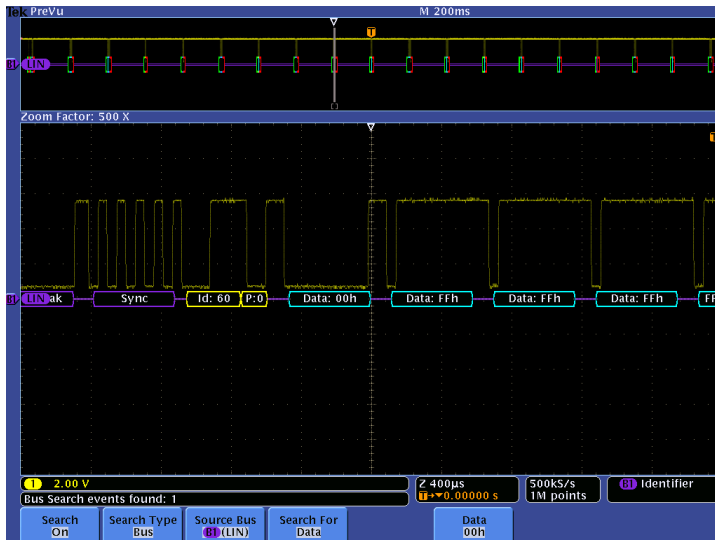
## MSO/DPO4000B Series LIN Bus Searching

### Key Take Away Points

- One of the key reasons for using long-record-length oscilloscopes is to be able to capture long time windows at high timing resolution. However, it is difficult to find specific serial signal characteristics in a long acquisition.
- Wave Inspector Search provides an easy way to find all occurrences of a specific signal characteristic, such as the Sync Field. The display should look about like this:



- Wave Inspector search allows you to find all occurrences of a specified event, such as the data value 00 hex. The display should look something like this:

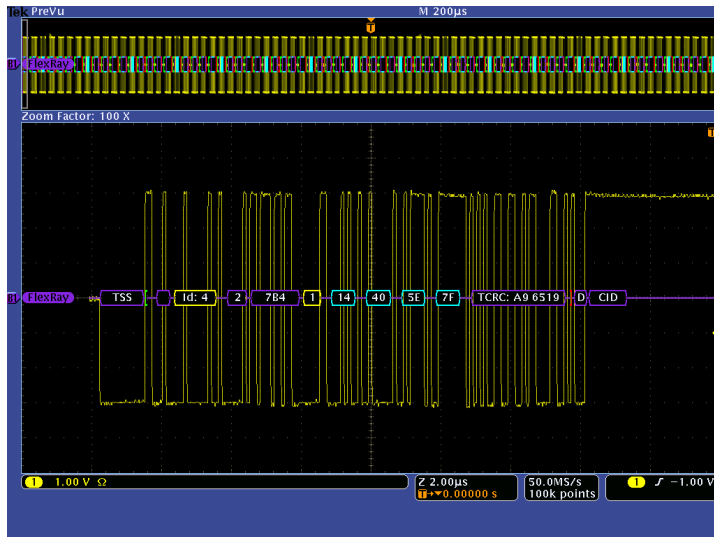


### MSO/DPO4000B Series Procedure:

- Press the front panel **Search** button.
  - Press the **Search** bottom bezel button.
  - Repeatedly press the **Search** side bezel button until Search is turned **On**.
  - Press the **Search Type** bottom bezel button.
  - Using the Multipurpose **a** control, select the **Bus** Search Type.
  - Press the **Search For** bottom bezel button.
  - Using the Multipurpose **a** control, select Search For **Sync**.
  - Press **Menu Off**.
  - Notice all of the white triangular marks appear at the top of the display.
  - Navigate between marked occurrences by using the front panel ← and → buttons.
- 
- Press the **Search For** bottom bezel button.
  - Using the Multipurpose **a** control, select Search For **Data**.
  - Press the **Data** bottom bezel button.
  - Repeatedly press the **Data** side bezel button until the Data selection menu appears.
  - Using the Multipurpose controls, set the Data pattern to **00** hex.
  - Press the front panel ← and → buttons to navigate between search events.

# MSO4000B/DPO4000B Series

## FlexRay Triggering and Decoding Lab



### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
  - Two TPP0500 or TPP1000 passive probes
  - (optional) One TDP0500 or TDP1000 differential probe
  - One DPO4AUTOMAX application module
  - PC with PDF-D FlexRay Protocol Analysis software, TekVISA ( $\geq$  version 3.3), and .NET ( $\geq$  version 2.0)
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
  - USB cable (174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]

## Understanding the FlexRay Bus

FlexRay is the most significant of several emerging low-speed serial standards for the automotive industry. FlexRay is still being developed by a group of leading automotive companies and suppliers known as the FlexRay Consortium. As cars get smarter and electronics find their way into more and more automotive applications, manufacturers are finding that existing automotive serial standards such as CAN and LIN do not have the speed, reliability, or redundancy required to address X-by-wire applications such as brake-by-wire or steer-by-wire.

Today, these functions are dominated by mechanical and hydraulic systems. In the future they will be replaced by a network of sensors and highly reliable electronics that will not only lower the cost of the automobile, but also significantly increase passenger safety due to intelligent electronic-based features such as anticipatory braking, collision avoidance, adaptive cruise control, etc.

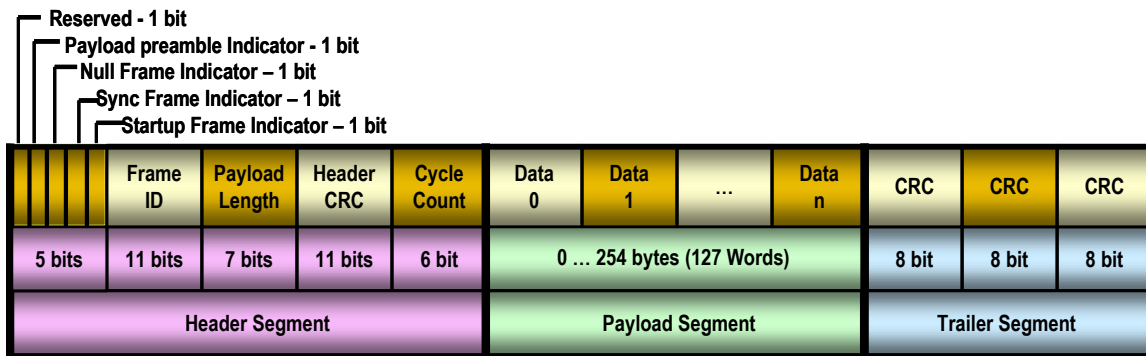
The DPO4AUTOMAX application module for the MSO/DPO4000B Series provides optional serial triggering and analysis for FlexRay. This lab will walk you through the most significant of the capabilities of the product.

### Lab Objectives

- Obtain a basic understanding of the FlexRay serial bus.
- Learn how customers use oscilloscopes to measure and decode FlexRay signals.
- Learn how to set up a FlexRay serial bus display and trigger and search on FlexRay packet content with a MSO/DPO4000B Series oscilloscope.
- Learn how to do eye diagram testing on a FlexRay bus.

FlexRay is a differential automotive serial bus which transmits data at rates up to 10 Mbps. The FlexRay information is transmitted over unshielded twisted-pair (UTP) cables and shielded twisted-pair (STP) cables (for better EMC performance). This is significantly faster than LIN's 20 kb/s or CAN's 1 Mb/s rates. FlexRay uses a dual channel architecture which has two major benefits. First, the two channels can be configured to provide redundant communication in safety critical applications such as x-by-wire to ensure the message gets through. Second, the two channels can be configured to send unique information on each at 10 Mb/s, giving an overall bus transfer rate of 20 Mb/s in less safety critical applications.

FlexRay uses a time-triggered protocol that incorporates the advantages of prior synchronous and asynchronous protocols via communication cycles that include both static and dynamic frames. Static frames are time slots of predetermined length allocated for each device on the bus to communicate during each cycle. Each device on the bus is also given a chance to communicate during each cycle via a Dynamic frame which can vary in length (and time).



The FlexRay frame is made up of three major recurring segments (Header, Payload, and Trailer), separated by idle periods. At the end of the idle period there is a:

- **TSS** (Transmission Start Sequence): 3-15 bits, which initiates network connection setup
- **FSS** (Frame Start Sequence): 1 bit which immediately follows TSS.

Then Header Segment is 5 bytes long and contains:

- Indicator Bits: 5 bits which provide Header Segment preamble information. The combination of the bits specify the type of frame:
  - Null / Normal / Payload
  - Sync / Startup
- Frame Id (Frame Identifier): 11 bits which define the slot in which the frame is transmitted. Frame IDs range from 1 to 2047 with any individual frame ID being used no more than once on each channel in a communication cycle.
- Payload Length: 7 bits which specify the number of data words being transferred in the frame.
- Header CRC (Header Cyclic Redundancy Code): error-detection protection for part of the Header Segment, calculated over the sync frame indicator, the startup frame indicator, the frame ID and the payload length.
- Cycle Count: the value of the current communication cycle, which can range from 0-63. This value is incremented at the start of each communication cycle.

The Payload Segment contains the data transferred by the frame. The Payload Segment has a variable length, from 0 to a maximum payload length of 127 words (254 bytes). For frames transmitted in the static segment the first 0 to 12 bytes of the payload segment may optionally be used as a network management vector. The payload preamble indicator in the frame header indicates whether the payload segment contains the network management vector. For frames transmitted in the dynamic segment the first two bytes of the payload segment may optionally be used as a message ID field, allowing receiving nodes to filter or steer data based on the contents of this field. The payload preamble indicator in the frame header indicates whether the payload segment contains the message ID.

The Trailer Segment contains a single 24-bit CRC to provide error-detection protection for the Header and Payload segments.

Each frame is delimited with a bus idle signal.

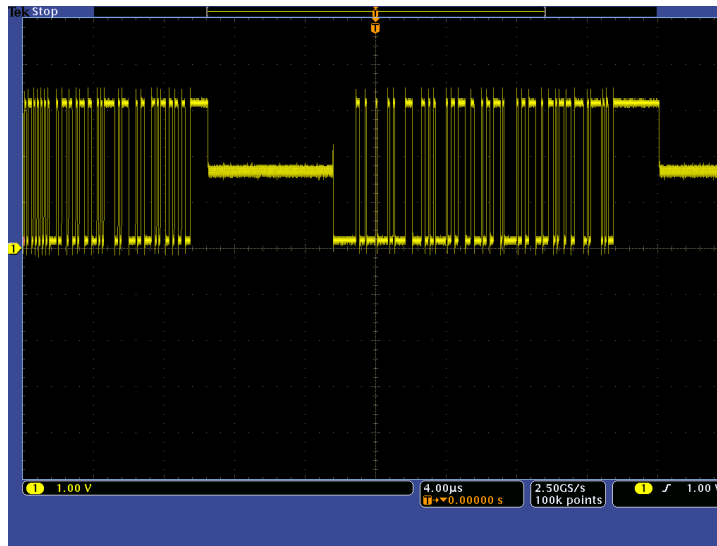
- **FES** (End of Frame): 2 bits, immediately following the Trailer CRC.
- **DTS** (Dynamic Trailing Sequence): follows a dynamic frame and prevents premature channel idle detection by the bus receivers.

**CID** (Channel Idle Delimiter): minimum of 11 bits which indicate the beginning of the idle period.

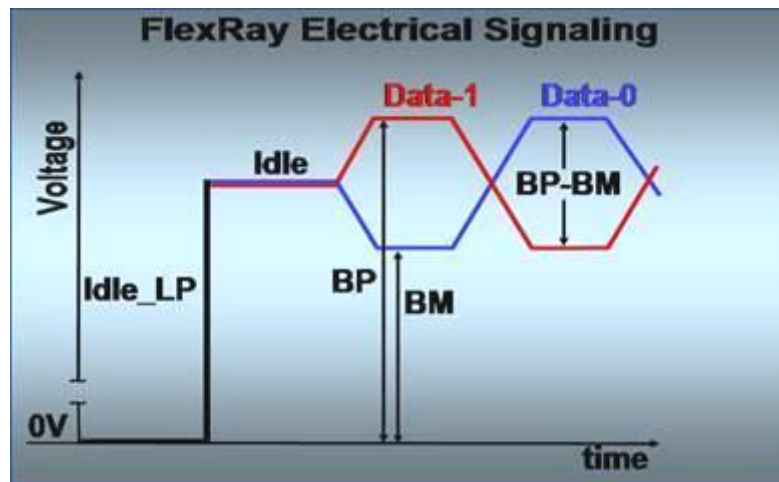


## Key Take Away Points

- The FlexRay signal on the demo board looks about like this:



- Notice that FlexRay signals are relatively large signals, with multiple voltage levels.
- FlexRay signal levels are defined as follows:

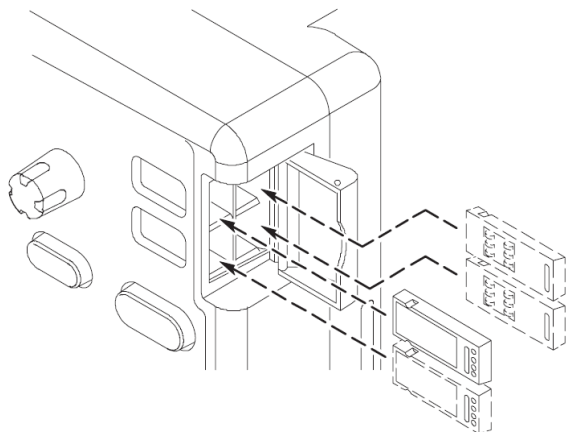


- BP** (Bus Plus): the positive side of the differential FlexRay signal.
- BM** (Bus Minus): the negative side of the differential FlexRay signal.
- Data\_1**: positive differential voltage between BP and BM.
- Data\_0**: negative differential voltage between BP and BM.
- Idle**: biased to a mid-level voltage, BP=BM.
- Idle\_LP** (Low Power): biased to ground. No current to BP or BM.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- With the DPO4AUTOMAX application module installed, the MSO/DPO4000B Series oscilloscope can trigger on, decode, and search FlexRay bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.

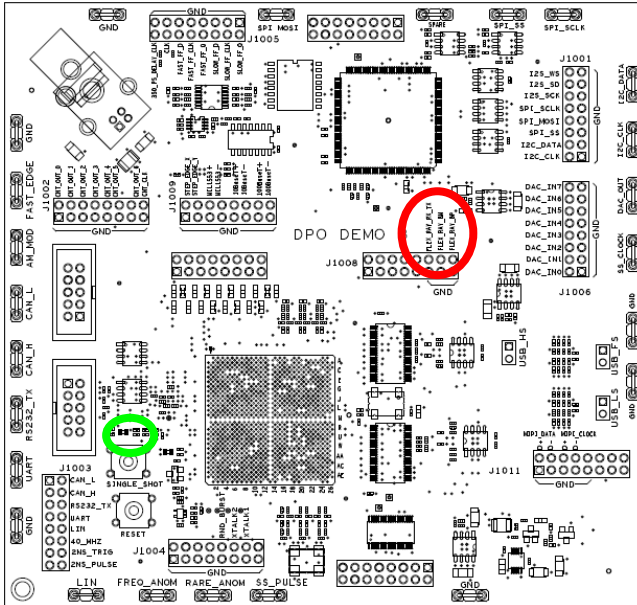


### MSO/DPO4000B Series Procedure:

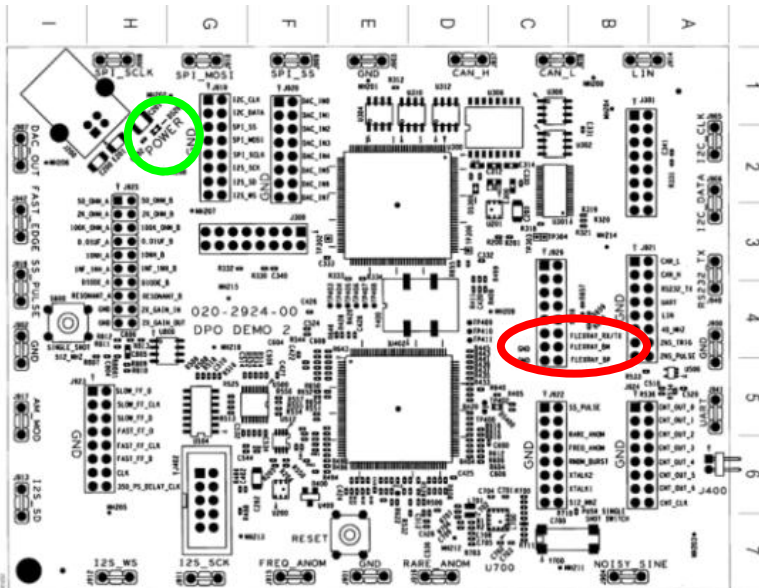
- ❑ With the oscilloscope power off, install the **DPO4AUTOMAX** into one of the application module slots on the front panel of the instrument.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4AUTOMAX Extended Automotive Serial Triggering and Analysis** application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has FlexRay signals which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) has FlexRay signals which we will use for this lab.

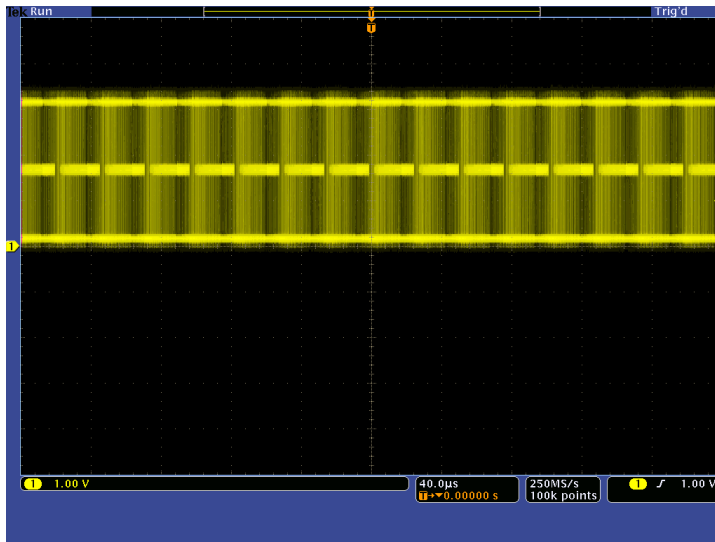


## DPO Demo Board Procedure:

- Power up the demo board.
- Verify the power LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.
- Attach the probe ground to the **GND** test point on the demo board.
- Connect the probe tip to the **FlexRay\_BP** test point on the demo board.

## Key Take Away Points

- The FlexRay signal should look about like this:



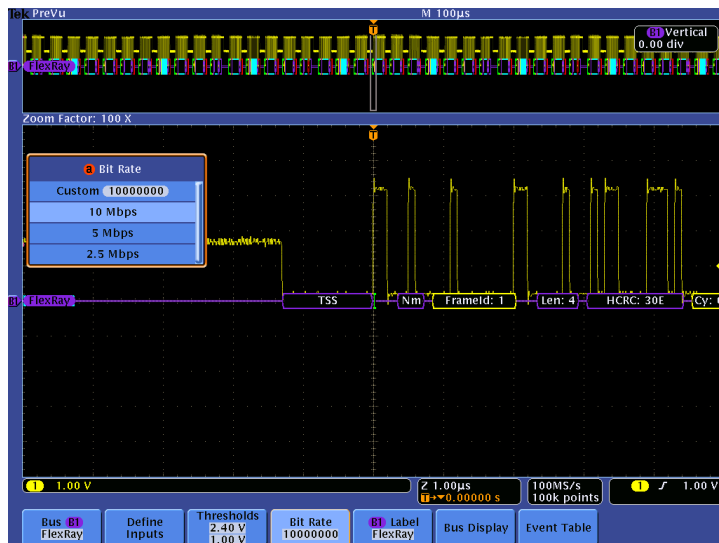
## MSO/DPO4000B Series Procedure:

- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Set the **Vertical Scale** to **1V/div**.
- Use the **Vertical Position** control to set the channel 1 ground level indicator about one division above center of the display.
- Use the **Trigger Level** control to adjust the trigger level below the center of the waveform, about **1V**.
- Set the **Horizontal Scale** to **100µs/div**.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **100k**.
- Press **Trigger Menu** button.
- Press the **Mode** bottom bezel button.
- Press the **Normal** side bezel button.
- Press the front panel **Menu Off** button.
- Press the front panel **Single** button.

## MSO/DPO4000B Series FlexRay Decoding Setup

### Key Take Away Points

- Setting up a basic FlexRay bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menu guide you through the setup in the left-to-right order across the bottom bezel buttons.
- Notice that any of the analog or digital input signals can be used as a source for the FlexRay bus.
- The MSO/DPO4000B Series can trigger and decode FlexRay signals at the preset bit rates of 2.5, 5, and 10 Mbps, or at any user-selectable value from 1 Mbps to 10 Mbps (in 10 kbps increments with the front panel Fine mode selected and 100 kbps increments with the Fine mode deselected).
- The default FlexRay bus values in the MSO/DPO4000B Series were chosen to match the signal on the demo board, so many of the steps to the right have already been done for you.
- The display should now look about like this, with the decimal decoded value shown in the bus waveform:

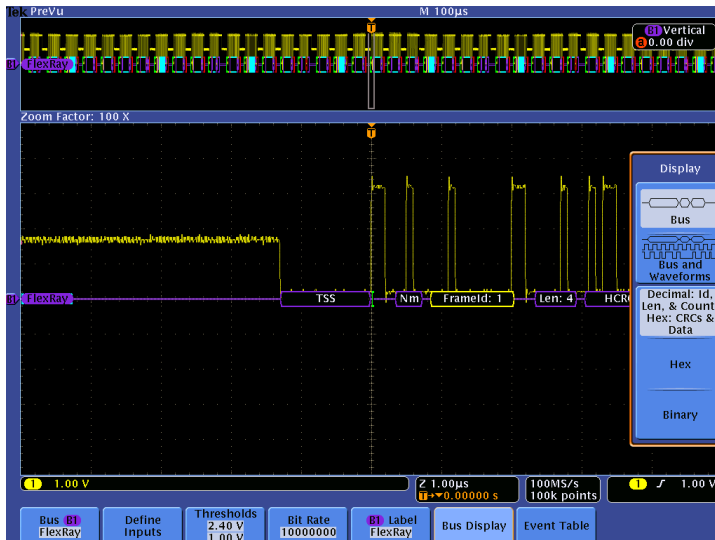


### MSO/DPO4000B Series Procedure:

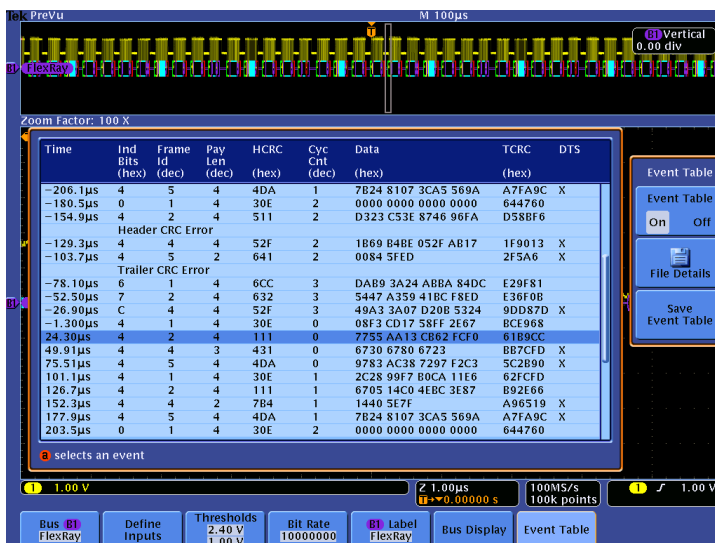
- ❑ Press the front panel **B1** button.
- ❑ Press the **Bus B1** bottom bezel button.
- ❑ Using the Multipurpose **a** control, set Bus type to **FlexRay**.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ Since you have connected the FlexRay\_BP signal to channel 1, verify that the FlexRay Input is on channel **1**, that it is FlexRay channel type **A**, and that **Bdiff or BP (Polarity Normal)** is selected.
- ❑ Press the **Thresholds** bottom bezel button.
- ❑ Using the Multipurpose **a** control, set the High Threshold to **2.4 V**.
- ❑ Using the Multipurpose **b** control, set the Low Threshold to **1V**.
- ❑ Press the **Bit Rate** bottom bezel button.
- ❑ Press the **10Mbps** side bezel button. You can also use the **Custom Bit Rate** control to select the bit rate. Because this control has very fine resolution, you will want to press the front panel **Fine** button until it is turned off whenever you are making large changes in bit rate.
- ❑ Using the Wave Inspector controls, zoom to **1µs/div (100X zoom, not a horizontal scale change)**.

## Key Take Away Points

- As seen in the last section, the default FlexRay decoder display format is a decimal display of the numerical values. These values can also be displayed in hexadecimal and binary.



- Notice that TSS appears in purple, followed by the green start of frame bar. The Header segment begins with the indicator bits in purple, followed by the frame ID in yellow, the payload length and header CRC in purple, and the cycle count in yellow. The data in the Payload segment are shown in cyan. Finally, the Trailer CRC, DTS, and CID are shown in purple and the end of frame bar is red. Errors are shown in red.
- For many users who are not electrical engineers, the waveform displays may not be familiar. For some, the Event Table format is preferable. This format can also be saved in CSV format and analyzed off-line.



## MSO/DPO4000B Series Procedure:

- Press the **Bus Display** bottom bezel button.
- Notice the different display formats.
- Press the **Event Table** bottom bezel button.
- Repeatedly press the **Event Table** side bezel button until it is set to **On**.
- Using the Multipurpose a control, scroll through Event Table messages. Notice that the zoom indicators in the overview window indicate the message position in the acquired waveform.
- Using the **Event Table** side bezel button, select **Off**.
- Press **Menu Off**.

## MSO/DPO4000B Series FlexRay Bus Cursors

### Key Take Away Points

- The FlexRay serial cursors provide another tool to bridge between the serial waveform and the decoded values, showing absolute timing relative to the trigger, bus values, and relative timing between bus events.
- For this example, we want to measure the time from the start of TSS on one frame to the start of TSS on the next frame. Cursor **a** is placed at the beginning of TSS. The **a** readout indicates the time and the value.



- Cursor **b** is placed at the beginning of the Sync Break of the next FlexRay message. Notice that the timing from one TSS to the next is clearly and easily displayed.



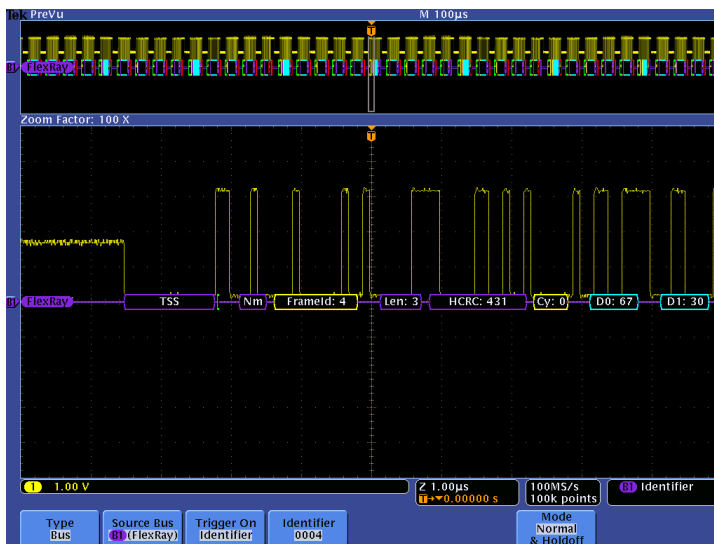
### MSO/DPO4000B Series Procedure:

- ❑ Using the Wave Inspector controls, zoom in on one of the FlexRay frames.
- ❑ Press and hold the **Cursors** front panel button once to turn on vertical bar cursors and to display the cursor control menu.
- ❑ Press the **Bring Cursors On Screen** bottom bezel button.
- ❑ Using the Multipurpose **a** control, place the **a** cursor on an event of interest.
- ❑ Notice the **a** cursor time and bus value readout in the upper right corner of the display.
- ❑ Using the Wave Inspector controls, zoom in on another of the FlexRay frames.
- ❑ Using the Multipurpose **b** control, place the **b** cursor on an event of interest.
- ❑ Notice the **b** cursor time and bus value readout in the upper right corner of the display.
- ❑ Also notice that we are displaying the time delay between the first and second bus events of interest.
- ❑ Now, turn off zoom. Slowly move the cursors around and notice that you can easily identify the parts of the FlexRay messages and their timing without being able to clearly see the waveforms or the decoded values.
- ❑ Press the **Cursors** front panel button once to turn off cursors.

## MSO/DPO4000B Series FlexRay Bus Triggering

### Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the FlexRay serial bus.
- The MSO/DPO4000B Series can trigger on:
  - Start of Frame
  - Indicator Bits (Normal, Null, Payload, Sync, Startup)
  - Identifier (=, ≠, <, ≤, ≥, >, inside range, outside range)
  - Cycle Count (=, ≠, <, ≤, ≥, >, inside range, outside range)
  - Header Fields
  - Data Identifier (=, ≠, <, ≤, ≥, >, inside range, outside range)
  - ID & Data
  - End of Frame
  - Error (Header CRC, Trailer CRC, Null Frame, Sync Frame, Startup Frame)
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on a FlexRay signal, capturing each occurrence.



### MSO/DPO4000B Series Procedure:

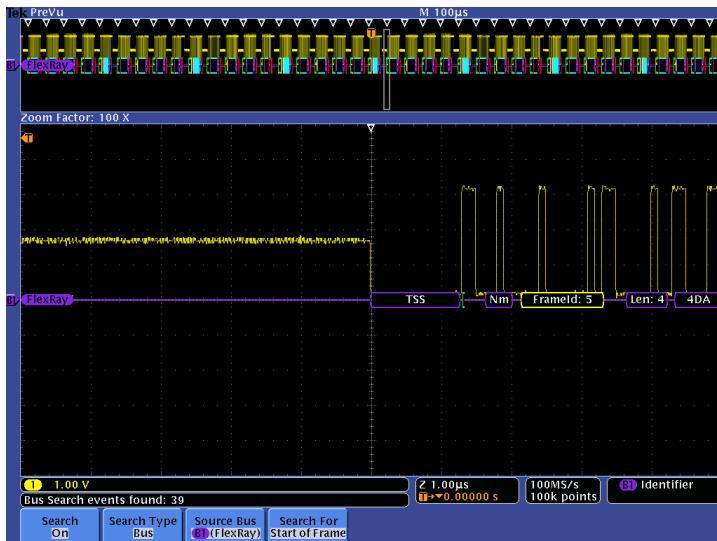
- ❑ Press the front panel **Trigger Menu** button.
- ❑ Press the **Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Bus** Trigger Type.
- ❑ Press the **Trigger On** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **Identifier**.
- ❑ Press the **Identifier** bottom bezel button.
- ❑ Verify that **Trigger When** is set to **=**.
- ❑ Press the **Identifier** side bezel button.
- ❑ Using the Multipurpose **a** control, set the Identifier to **004** Hex.
  
- ❑ Press **Menu Off**.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the Wave Inspector pan control as needed to examine the FlexRay frame where the trigger occurred.



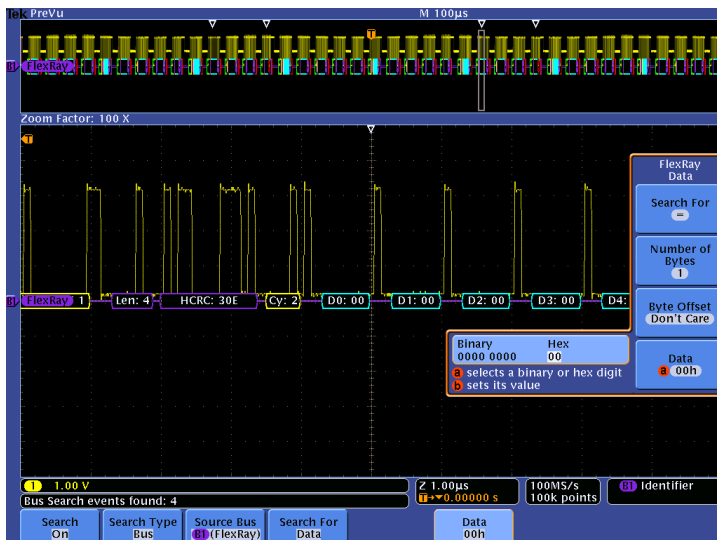
## MSO/DPO4000B Series FlexRay Bus Searching

### Key Take Away Points

- One of the key reasons for using long-record-length oscilloscopes is to be able to capture long time windows at high timing resolution. However, it is difficult to find specific serial signal characteristics in a long acquisition.
- Wave Inspector Search provides an easy way to find all occurrences of a specific signal characteristic, such as the start of each frame. The display should look about like this:



- Wave Inspector search allows you to find all occurrences of a specified event, such as the data value 00 hex. The display should look something like this:



### MSO/DPO4000B Series Procedure:

- Press the front panel **Search** button.
  - Press the **Search** bottom bezel button.
  - Repeatedly press the **Search** side bezel button until Search is turned **On**.
  - Press the **Search Type** bottom bezel button.
  - Using the Multipurpose **a** control, select the **Bus** Search Type.
  - Press the **Search For** bottom bezel button.
  - Using the Multipurpose **a** control, select Search For **Start of Frame**.
  - Press **Menu Off**.
  - Notice all of the white triangular marks appear at the top of the display.
  - Navigate between marked occurrences by using the front panel ← and → buttons.
- 
- Press the **Search For** bottom bezel button.
  - Using the Multipurpose **a** control, select Search For **Data**.
  - Press the **Data** bottom bezel button.
  - Repeatedly press the **Data** side bezel button until the Data selection menu appears.
  - Using the Multipurpose controls, set the Data pattern to **00** hex.
  - Press **Menu Off**.
  - Press the front panel → button.

## FlexRay Eye Diagram Analysis

Unlike the other serial standards presented earlier in this lab, FlexRay is in earlier phases of implementation and operates at a significantly higher frequency. These issues combine to increase the importance of compliance testing in the form of eye diagram testing and time interval analysis which is really not required or used on most other lower-speed serial standards.

The DPO4AUTOMAX application module for the MSO/DPO4000B Series provides FlexRay eye diagram testing with a PC application called PDF-D. This application connects to any MSO/DPO4000B Series oscilloscope equipped with the DPO4AUTOMAX application module.

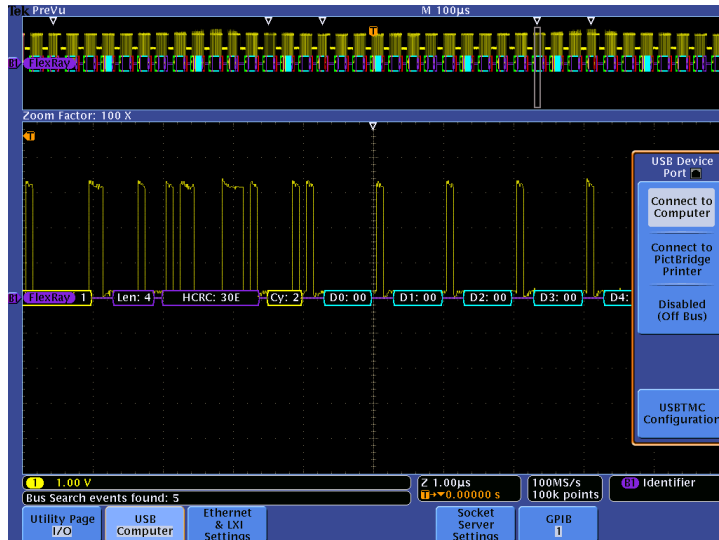
The PDF-D FlexRay Protocol Analysis software provides displays of decoded data overlaid on the waveform and protocol decode table which highlights the header CRC, end CRC, and eye diagram error frames (frames causing eye diagram failure) in red.

FlexRay Electronic Control Units (ECUs) must work in extreme operating conditions, such as in an automobile. To ensure correct and reliable performance, FlexRay physical layer signals must have adequate design margins. The PDF-D software provides advanced analysis features such as eye diagram analysis, time interval error plot, and sync measurements, enabling the user to evaluate eye opening and jitter in the FlexRay design.

## PDF-D Lab Setup

### Key Take Away Points

- For this part of the lab, we will be using the differential FlexRay signal on the demo board. We can acquire this signal with a pair of TPP0500 or TPP1000 passive probes or with a differential probe such as a TDP0500.
- The DPO4AUTOMAX application module must be installed in one of the four application module slots on the front panel of the instrument.
- This lab is based on USB connection between the PC and oscilloscopes. However, you can use Ethernet instead. If you are on a DHCP Ethernet network and are using a regular Ethernet cable to connect, you will need to set DHCP to On. If you are using a cross-over Ethernet cable, you will need to set DHCP to Off and enter a hard-coded TCP/IP address.
- Verify that the USB Device Port is set up correctly:

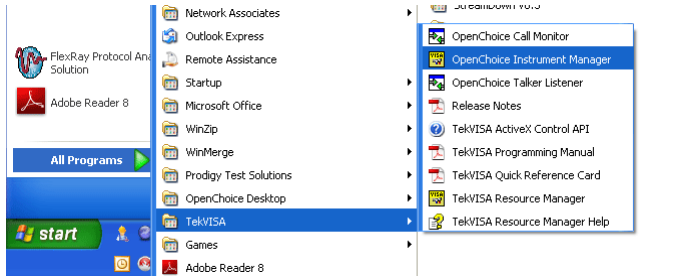


### MSO/DPO4000B Series Procedure:

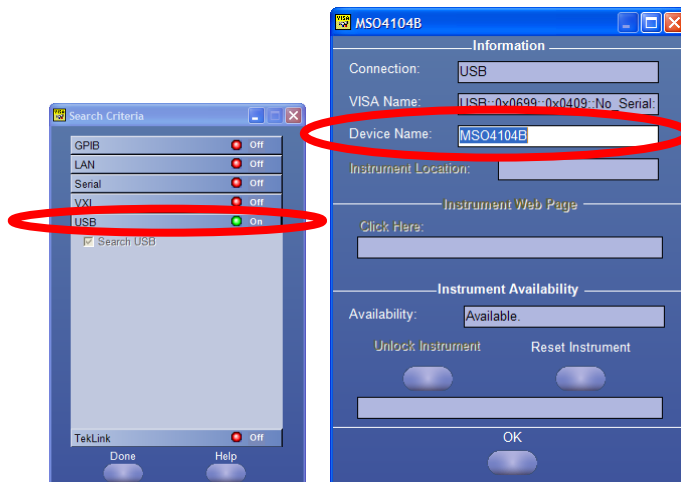
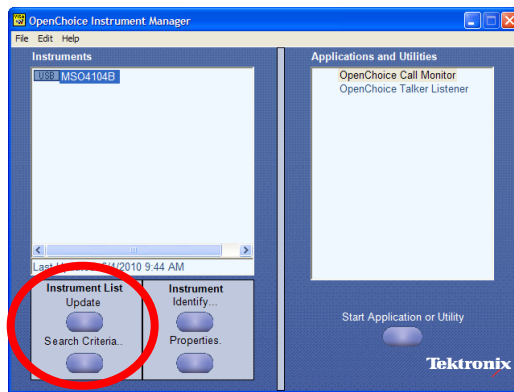
- ❑ If you are using a differential probe:
  - ❑ Attach the differential probe to the Channel 1 input of the oscilloscope.
  - ❑ Connect the positive probe input to the **FlexRay\_BP** test point and the negative probe input to the **FlexRay\_BM** test point on the demo board.
- ❑ If you want to use passive probes instead:
  - ❑ Attach the TPP0500 or TPP1000 probes to the Channel 1 and 2 inputs of the oscilloscope.
  - ❑ Attach the probe grounds to the **GND** test point.
  - ❑ Connect the channel 1 probe tip to the **FlexRay\_BP** test point.
  - ❑ Connect the channel 2 probe tip to the **FlexRay\_BM** test point.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4AUTOMAX Extended Automotive Serial Triggering and Analysis** application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.
- ❑ Press the **Config** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **I/O**.
- ❑ Press the **USB** bottom bezel button.
- ❑ Verify that the USB device port is set to **Connect to Computer**.

## Key Take Away Points

- The PC must be running Windows 2000 SP4, Windows XP SP2, or Windows Vista operating system and have at least 512 MB of RAM and 10 MB of available hard disk space, as well as a display resolution of at least 1024 X 768 (XGA).
- The PDF-D software, .NET 2.0 Framework SP2, and a current version of TekVISA must be installed on the PC.



- Then you need to configure TekVISA.

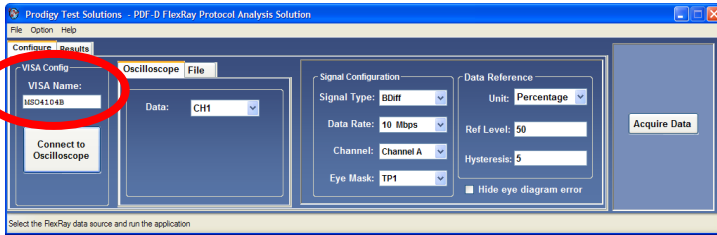


## PC Setup Procedure (first time only):

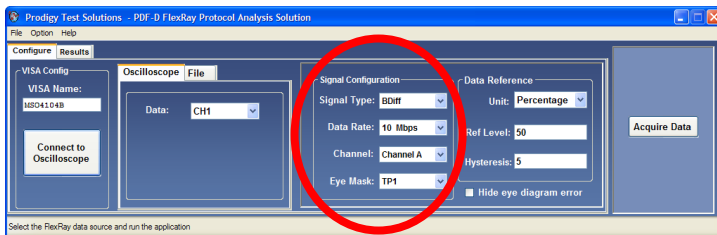
- ❑ Insert the **PDF-D** CD into the drive on the PC.
- ❑ When the splash screen appears, press the Install button for each of the three software packages: the PDF-D software, the .NET framework, and TekVISA version 3.3 or higher. You must install all three for this software to work.
- ❑ Connect a USB cable from the USB device port on the rear of the oscilloscope to a USB host port on the PC.
- ❑ Open the TekVISA Instrument Manager from **Start Menu > All Programs > TekVISA > OpenChoice Instrument Manager** as shown.
- ❑ Click the **Search Criteria...** button to configure the type of connection.
- ❑ Verify that **USB** search is enabled. If you are using Ethernet, select **LAN**. (If you know the specific IP address, enter it in the Add LAN Search Location text box.)
- ❑ Click the **Done** button.
- ❑ Click the **Update** button to identify the connected instrument.
- ❑ To get a VISA name that is easier to recognize, select the instrument from the list at the left of the window and click **Properties**.
- ❑ Provide a **Device Name** and click **OK**.
- ❑ Click the **Update** button to display the newly-named instrument.

## Key Take Away Points

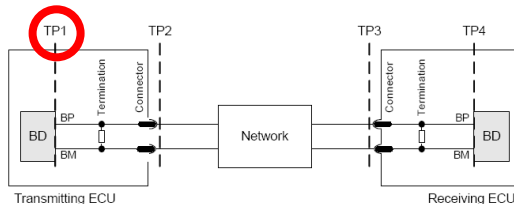
- Connection from the PDF-D application to the oscilloscope is done through TekVISA:



- PDF-D allows you to input a FlexRay signal using CH1-CH4, Ref1-Ref4 or the Math channel on a MSO/DPO4000B Series oscilloscope.
- A FlexRay signal is a differential signal. You can probe the differential signal using a differential probe or with two single-ended probes and the Ch1-Ch2 math function.
- PDF-D can also analyze previously saved FlexRay waveforms. This is not addressed in the step-by-step lab, but you can try it by loading the stored FlexRay signals (.ISF files) into any of the reference channels of MSO/DPO4000B Series oscilloscope and selecting those reference channels as inputs in the PDF-D Software. Or you can analyze the FlexRay signals directly from a file by loading the signal files using the file menu of PDF-D. PDF-D supports .ISF and .CSV files.
- The Signal Configuration section enables you to input the FlexRay signal characteristics and test point information:



- The FlexRay standard recommends eye diagram testing at test points TP1 and TP4, and PDF-D provides masks for both of these test points. For the demo board, TP1 most closely corresponds to the correct test point in the network.



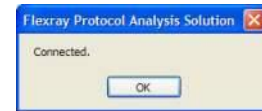
## PC Procedure:

- ❑ Launch the **PDF-D** application by clicking the icon on your PC desktop:



FlexRay Protocol Analysis Solution.lnk

- ❑ Select the **Configure** tab.
- ❑ In the **VISA Config** section, provide the VISA device name (see previous section) in the **VISA Name** text box and click the **Connect to Oscilloscope** button.

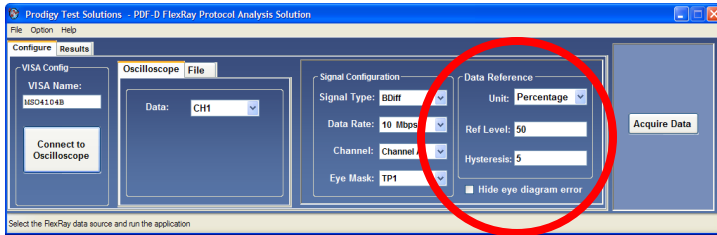


- ❑ Select the **Oscilloscope** tab.
- ❑ If you are using a differential probe, select **CH1** as the FlexRay input. If you are using passive probes, select **Math** as the FlexRay input.

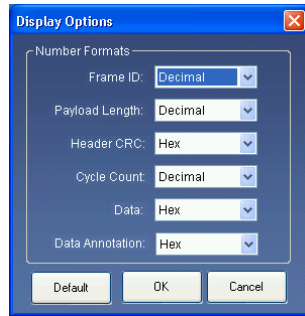
- ❑ In the **Signal Configuration** section:
  - ❑ Select the **Bdiff** Signal Type.
  - ❑ Select the **10 Mbps** Data Rate.
  - ❑ Select FlexRay **Channel A**.
  - ❑ Select the **TP1** Eye Mask.

## Key Take Away Points

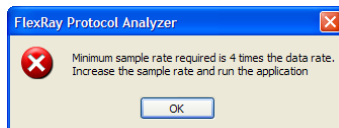
- To correctly analyze the FlexRay signals, the reference levels must be specified:



- In the percentage mode, the PDF-D software measures the maximum and minimum amplitude of the FlexRay signal. If the 'Ref level' is set as 50%, then any transition above 50% of amplitude is considered as logical '1' and below 50% of amplitude as logical '0'.
- Any aberration within the hysteresis band around the reference level is not considered a logical transition. The hysteresis level helps in isolating voltage transitions in the hysteresis region.
- The Display Options menu allows you to configure the view of decoded FlexRay frame contents in different numerical formats. You can configure Frame ID, payload length, header CRC, cycle count, data and data annotation in hexadecimal, decimal, binary or octal numerical formats.



- NOTE:** The following instrument setup instructions should be correct for the demo board's FlexRay signal. However, if you use longer record lengths and/or slower time/div settings (which may have the effect of lowering the oscilloscope's sample rate), you may see the following error message:



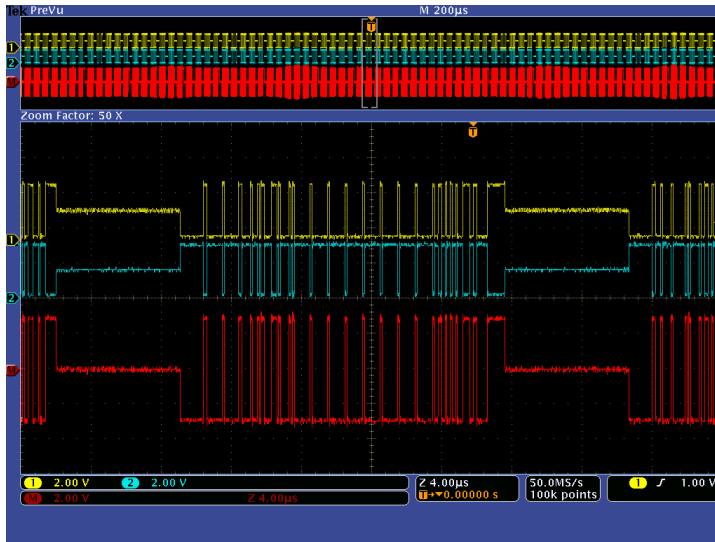
- If you get this error message, use a faster time/div or shorter record length setting to assure that the oscilloscope's sample rate is at least 4 times the data rate.

## PC Procedure:

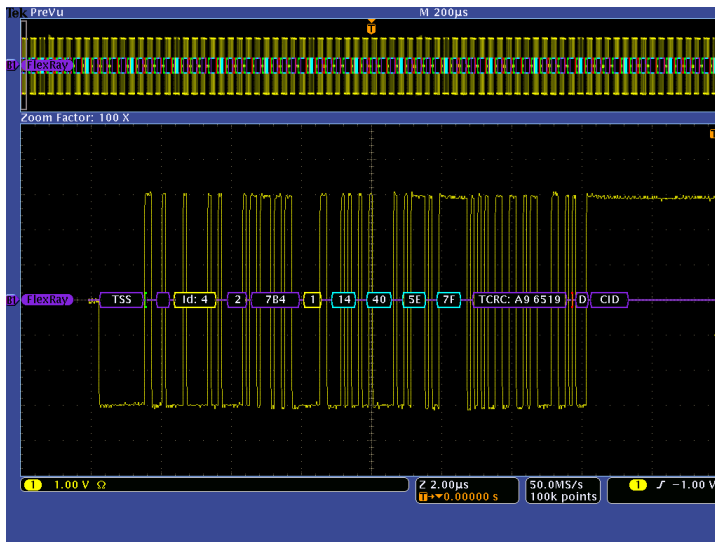
- In the **Data Reference** section:
  - Select **Percentage** units.
  - Select a **50 % Ref Level**.
  - Select a **10 % Hysteresis** band.
- Select **Option -> Display Options**.
- To match the default display formats in the MSO/DPO4000B Series, select **Decimal** for Frame ID, Payload Length, and Cycle Count, and **Hex** for Header CRC, Data, and Data Annotation.

## Key Take Away Points

- Using a pair of passive probes and a math calculation of the voltage difference between the channels, this is what an oscilloscope acquisition should look like:



- If you are using a differential probe, you can also display the decoded information from the differential signal. You can then compare the decoded information on the oscilloscope with the decoded information in the PDF-D displays. The oscilloscope display should look about like this:



## MSO/DPO4000B Series Procedure:

- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Use the **Trigger Level** controls to adjust the trigger level below the center of the waveform.
- If you are using passive probes:
  - Press the front panel **2** button to turn on channel 2.
  - Press the red front panel **M** button to enable math.
  - Press the **Dual Wfm Math** bottom bezel button.
  - Press the **Operator** side bezel button until the '-' (minus) operator is selected.
- Set the **Horizontal Scale** to **200μs/div**.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **100k**.
- Press **Trigger Menu** button.
- Press the **Mode** bottom bezel button.
- Press the **Normal** side bezel button.
- Press the front panel **Menu Off** button twice.
- Using the inner Wave Inspector control, zoom in on a single packet (zoom, not a horizontal scale change) so you can verify that the differential signal waveform looks correct.
- If you are using the differential probe, you can also display the decoded bus:
  - Press the **B1** button and select **FlexRay**.
  - Set the **Thresholds** to **~±1V**.

## PDF-D Decode Table Displays

### Key Take Away Points

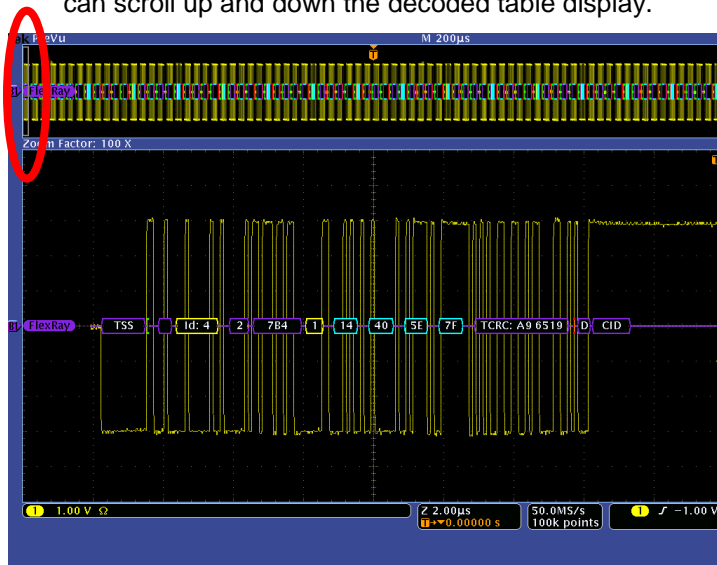
- The basic PDF-D Decoded FlexRay frame display contains the following information:

Header	Description
Frame Type (FT)	Static Frame (S) or Dynamic Frame (D)
Reserved Bit (RB)	Value of the Reserved Bit
Payload Preamble (PP)	Payload Preamble in the Frame Header
Null Frame Indicator (NI)	Null Frame Indicator in the Frame Header
Sync Frame Indicator (Sy)	Sync Frame Indicator in the Frame Header
Start up Frame Indicator (St)	Start up Frame Indicator in the Frame Header
Frame ID (F ID)	Frame ID
Payload Length (PL)	Frame Payload Length
Header CRC (H CRC)	Decoded Header CRC value
Cycle Count (CC)	Decoded Cycle Count
Time	Time of the Start of the frame time relative to the Trigger Position
Data	Payload Data

- The PDF-D Decode Table Display looks like this:

FT	RB	PP	NI	Sy	St	F ID	PL	H CRC	CC	Time	Data
D	0	0	1	0	0	4	2	784h	1	-999.70 µs	14h, 40h, 5Eh, 7Fh, ...
D	0	0	1	0	0	5	4	40Ah	1	-974.11 µs	78h, 24h, 81h, 7h, 3...
S	0	0	0	0	0	1	4	30Eh	2	-948.52 µs	0h, 0h, 0h, 0h, 0h, 0...
S	0	0	1	0	0	2	4	511h	2	-922.92 µs	03h, 23h, C5h, 26h, ...
D	0	0	1	0	0	4	4	52Fh	2	-897.32 µs	18h, 69h, 84h, BEh, 5...
D	0	0	1	0	0	5	2	641h	2	-871.70 µs	0h, 84h, 5Fh, EDh, ...
S	0	0	1	1	1	1	4	6CCh	3	-846.10 µs	DAh, 89h, 3Ah, 24h, ...
S	0	0	1	1	1	2	4	632h	3	-820.50 µs	54h, 47h, A3h, 59h, ...
D	0	1	1	0	0	4	4	52Fh	3	-794.92 µs	49h, A3h, 3Ah, 7h, D...

- After the PDF-D application completes the decoding, it zooms and places the cursors in the oscilloscope waveform around the first decoded frame in the decode table. You can scroll up and down the decoded table display.



### PC Procedure:

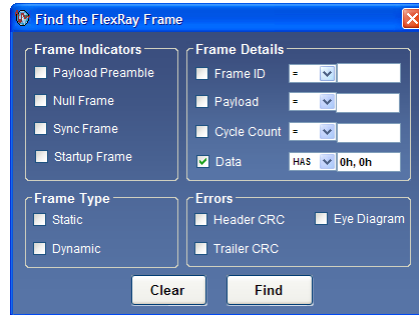
- Click on the **Acquire Data** button to acquire data from the oscilloscope using the current instrument setup.
- View the Decode Table analysis on the **Results** tab.

- Notice that the oscilloscope waveform related to this frame is zoomed and cursors are placed at the start and end of the frame in the oscilloscope display.
- If you want to view the waveform for a particular FlexRay frames in decoded table, click on the frame in the table.



## Key Take Away Points

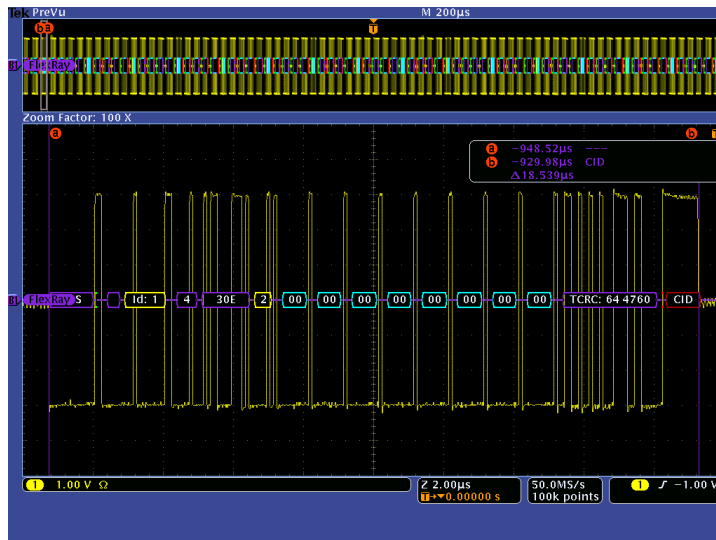
- You can also automatically find FlexRay frames within the acquired data using the built-in search capabilities.



- PDF-D searches for the specified information (in this case, data 00 hex) and highlights the location in the table:

FT	RB	PP	NI	Sy	ST	FID	PL	H CRC	CC	Time	Data
D	0	0	1	0	0	4	2	78Ah	1	-999.70 μs	14h, 40h, 56h, 7Fh, ...
D	0	0	1	0	0	5	4	40Ah	1	-974.11 μs	78h, 24h, 81h, 7h, 3...
S	0	0	0	0	1	4	30Eh	2	2	-948.52 μs	0h, 0h, 0h, 0h, 0h, 0...
S	0	0	1	0	0	2	4	511h	2	-922.92 μs	03h, 23h, C5h, 3Eh, ...
D	0	0	1	0	0	4	4	52Fh	2	-897.32 μs	18h, 69h, B4h, BEh, 5...
D	0	0	1	0	0	5	2	641h	2	-871.70 μs	0h, 84h, 5Fh, EDh, ...
S	0	0	1	1	1	1	4	6CCh	3	-846.10 μs	DAh, 89h, 3Ah, 24h, ...
S	0	0	1	1	1	2	4	632h	3	-820.50 μs	54h, 47h, A3h, 59h, ...
D	0	1	1	0	0	4	4	52Fh	3	-794.92 μs	49h, A3h, 3Ah, 7h, D...

- Notice that the oscilloscope display now shows the FlexRay frame which matched the search criteria.



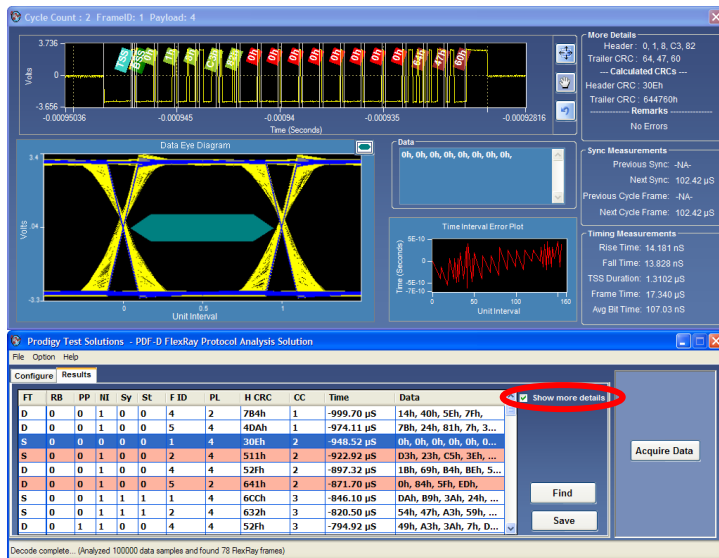
- From the Results tab, you can also save the decoded data in .CSV format to the PC hard drive.

## PC Procedure:

- Click on the **Find** button.
- To search for a specific (partial) data value, check the **Data** box, select **"HAS"** in the drop-down menu, and type in the data value(s) to search for (in the format shown in the decode table above).
- Click on the **Find** button in the Find the FlexRay Frame menu.
- Close the Find the FlexRay Frame menu when you are done searching.

## Key Take Away Points

- The Show More Details view provides a more comprehensive analysis of the FlexRay frame:
  - Overlay of decoded message on the waveform
  - Eye diagram analysis
  - TIE plot
  - Timing measurements
  - Sync Measurements
- The display should now look something like this:



- Notice the different views of the FlexRay signal presented in the displays. The top display shows the decoded values overlaid on the waveform of the selected FlexRay frame.
- Details for that frame are shown in the readouts in the upper right corner, with sync and timing measurements shown below.
- The decoded data values are shown in a table below the waveform display, and the time interval errors across the frame are shown below that.
- Finally, the eye diagram for the entire acquisition is shown. We'll look at each of these areas in more detail on the next few pages.

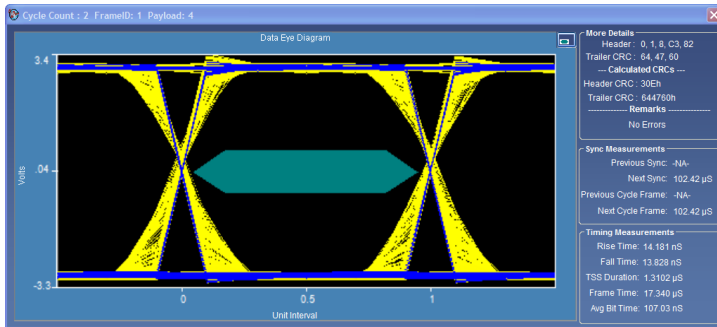
## PC Procedure:

- Click the **Show more details** check box in the Results panel.

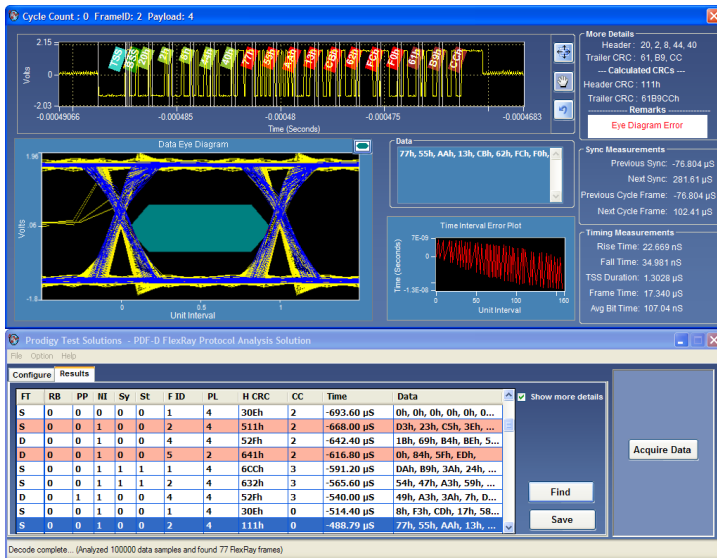
# PDF-D FlexRay Eye Diagrams

## Key Take Away Points

- The following is a detailed view of the Eye Diagram plot:



- The eye diagram, shown in yellow, is built from all the FlexRay frames acquired in a single acquisition on the MSO/DPO4000B Series oscilloscope. The blue trace in the eye diagram is the eye for the selected frame in the decode table.
- Eye diagram failures are highlighted in red, as shown in the following figure. The FlexRay frames causing these eye diagram failures are also highlighted in red in the decode table as shown below.



## PC Procedure:

- To maximize the eye diagram plot area, click the maximize button:



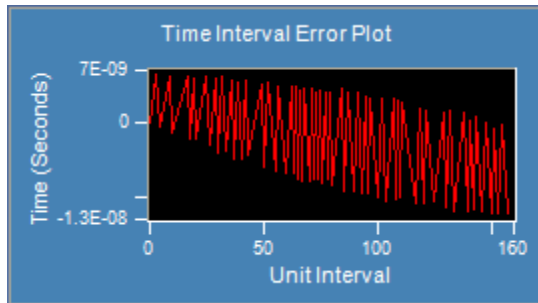
- To minimize the eye diagram plot area, click the minimize button:



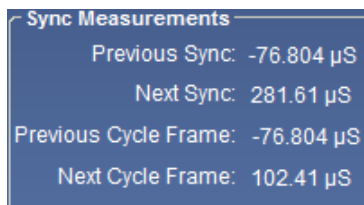
## PDF-D FlexRay Timing Measurements

### Key Take Away Points

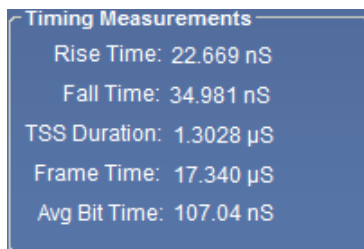
- The Time Interval Error Plot (TIE Plot) component of the Detail view looks like this:



- A TIE plot shows the time difference between the real clock and an ideal clock (specified by the FlexRay standard) for each Unit Interval (UI) for the FlexRay frame selected in the decode table.
- The TIE plot allows you to quickly observe UI time variations. This variation may indicate transmission of data through different segments of the network, the impact of oscillator frequency variation, or electrical noise.
- The Sync Measurements display shows timing relationships between the selected frame and the adjacent frames like this:



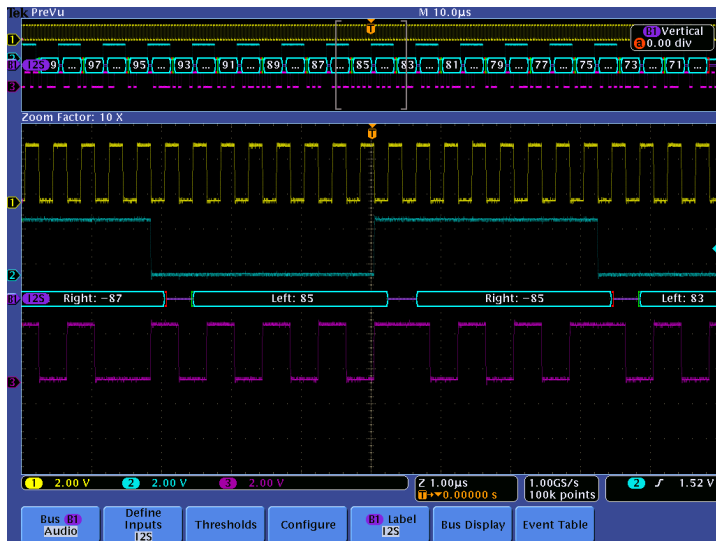
- The Timing Measurements display shows timing measurements for the selected frame like this:



- Rise and fall times are measured between the 20% and 80% points of each of the signal transitions in the waveform and the average value is displayed.

# MSO4000B/DPO4000B Series

## Serial Audio Triggering and Decoding Lab



### Equipment List

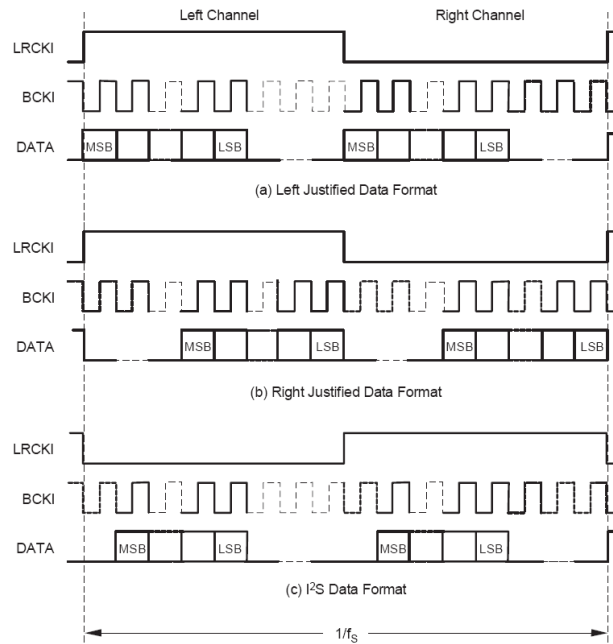
- One 4-channel MSO/DPO4000B Series oscilloscope with the latest firmware version installed
  - Three TPP0500 or TPP1000 passive probes
  - One DPO4AUDIO application module
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]

## Serial Audio Bus Overview

Digital audio information is usually transmitted via specialized serial buses. There are many different standards, but all are designed to provide high-fidelity (high-resolution, low jitter, etc.) audio transmission at low cost for consumer electronic equipment (low speed signals, few IC pins, minimal circuit board space).

The DPO4AUDIO solution provides optional triggering and analysis for the following serial audio bus standards:

1. I<sup>2</sup>S
2. Left Justified
3. Right Justified
4. TDM



This document will provide an overview of each, and then a detailed lab to go through the operation of the I<sup>2</sup>S support (since this is the signal that is available on the demo board). The extension of this lab to the other supported audio standards should be straightforward.

### Lab Objectives

- Obtain a basic understanding of the serial audio buses.
- Learn how customers use oscilloscopes to measure and decode serial audio signals.
- Learn how to setup an I<sup>2</sup>S serial bus display and trigger and search on serial audio packet content with a MSO/DPO4000B Series oscilloscope.

## Understanding the I<sup>2</sup>S Bus

Inter-IC Sound (I<sup>2</sup>S) is a bidirectional, synchronous electrical serial bus interface standard primarily used for connecting stereo digital audio devices together, such as between the CD transport and the D/A converter in a CD player. The I<sup>2</sup>S bus was introduced in 1986 by Philips.

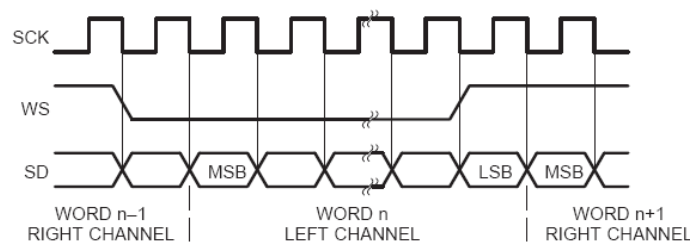
The bus consists of at least three lines:

1. Bit Clock
2. Word Select
3. Data

The bit clock frequency is equal to the number of bits per channel times the number of channels times the audio sample rate. As an example, CD Audio with a sample frequency of 44.1kHz and 32 bits of precision per 2 (stereo) channels will have a bit clock frequency of 2.8224MHz.

The polarity of the word select clock signifies whether the transmitted data is from channel 1 or channel 2, and the word select clock transitions indicate the start-of-word and occur at the sample frequency. For the CD Audio example above, the word select clock will be a 44.1 kHz square wave. Normally, the word select line is low to indicate that channel 1 (left) is being transmitted and high to indicate that channel 2 (right) is being transmitted.

I<sup>2</sup>S data is transmitted in two's complement format in MSB-to-LSB order, starting at the edge of the word select clock, with one bit clock delay. Since the MSB is transmitted first, transmitting and receiving devices do not have to be concerned about the number of bits of audio precision. (If the 32-bit-precision data is sent to a device with only 24 bits of precision, the receiver may simply ignore the extra LSBs. If 16-bit-precision data is sent to a device with 24 bits of precision, the receiver will simply zero-fill the missing bits.)



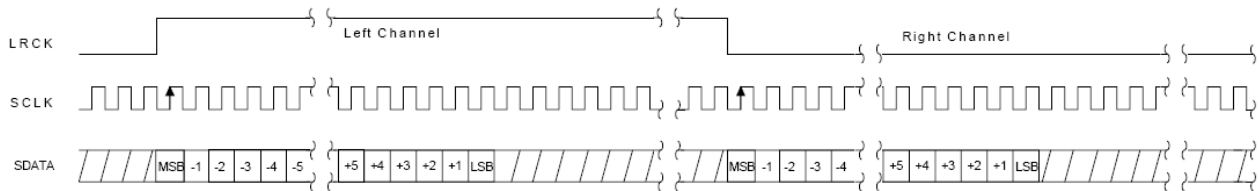
For more information on I<sup>2</sup>S, please see [http://www.nxp.com/acrobat\\_download/variou/I2SBUS.pdf](http://www.nxp.com/acrobat_download/variou/I2SBUS.pdf).

## Understanding the Left Justified and Right Justified Buses

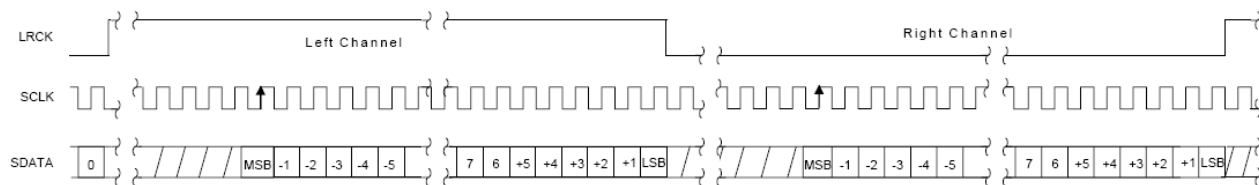
There are two common de facto stereo audio buses that are very similar to I<sup>2</sup>S: Left Justified (LJ) and Right Justified (RJ). Each of these buses consist of three lines:

1. Serial Clock (Bit Clock)
2. Left/Right clock (Word Select)
3. Data

Left Justified is the most similar to I<sup>2</sup>S, where the data is transmitted MSB first and left-justified in the channel time slot. The format is word-length independent and can support audio resolution of 16 to 32 bits, assuming that there are enough clock cycles per left/right period. However, Left Justified format differs from I<sup>2</sup>S in that it uses the opposite polarity of signal for left/right channel selection and there is no one-clock delay from the channel selection edge, as shown below:



Right Justified format is very similar to the Left Justified format except the placement of the audio word within the frame, where the trailing edge of the LSB is coincident with the trailing edge of the Left/Right clock. The other important difference is that the RJ interface is not word-length independent, so any receiver of RJ data must be aware of the transmitted audio word length.



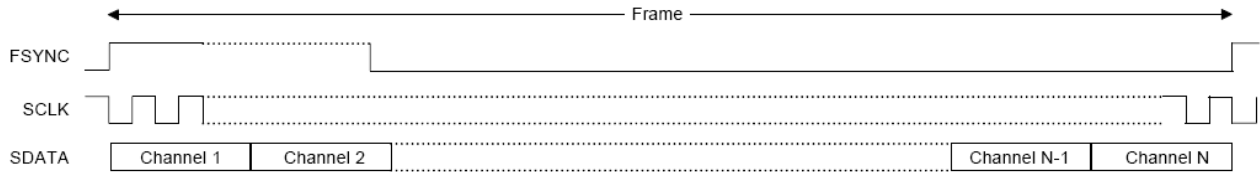


## Understanding the TDM Audio Bus

The I<sup>2</sup>S, LJ, and RJ buses are primarily used to transmit stereo (two-channel) audio information. The Time Division Multiplex (TDM) bus is more general and allows for transmissions of many more (often 4-8) channels of audio data in a frame of data on a single data line.

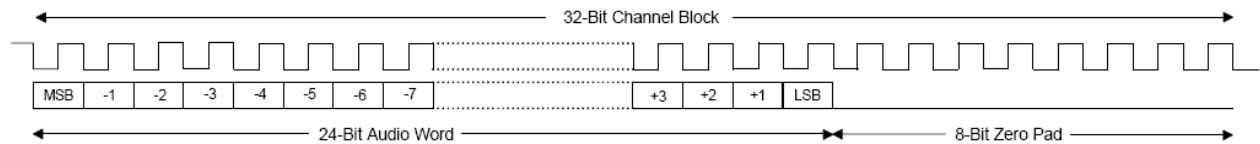
The TDM bus consists of three lines:

1. Frame Sync
2. Serial Clock (Bit Clock)
3. Data



Each frame of channel data is delimited by the Frame Sync pulse, which always occurs at the audio sample rate (44.1 kHz, 48 kHz, etc.). The rising edge of the pulse indicates the start of the frame, and most TDM implementations ignore the falling edge, so the shape of the signal is not necessarily critical or consistent from design to design.

Channel blocks are either aligned with the rising edge of the Frame Sync or delayed one period of the serial clock. The two's complement audio data within each 32-bit block is typically transmitted MSB first with the remainder of the data bits set to zero.

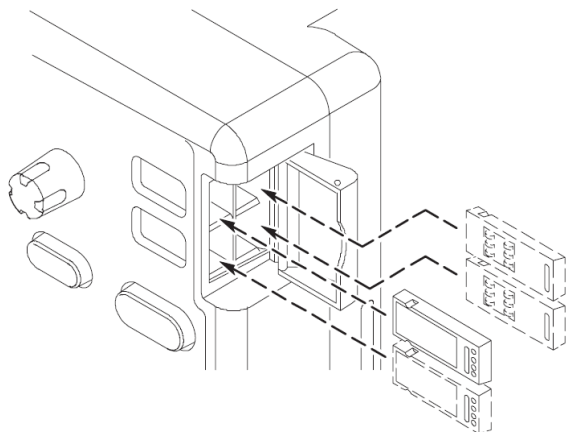


The serial clock is used to shift audio data into or out of the serial audio ports. Its frequency is directly proportional to the audio sample rate, the number of channel blocks in a frame, and the number of bits per channel block. As an example, an 8-channel frame with 32-bit channel blocks operating at 48 kHz requires a 12.288 MHz serial clock.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- With the DPO4AUDIO application module installed, the MSO/DPO4000B Series oscilloscope can trigger on, decode, and search I<sup>2</sup>S, LJ, RJ, and TDM serial audio bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.

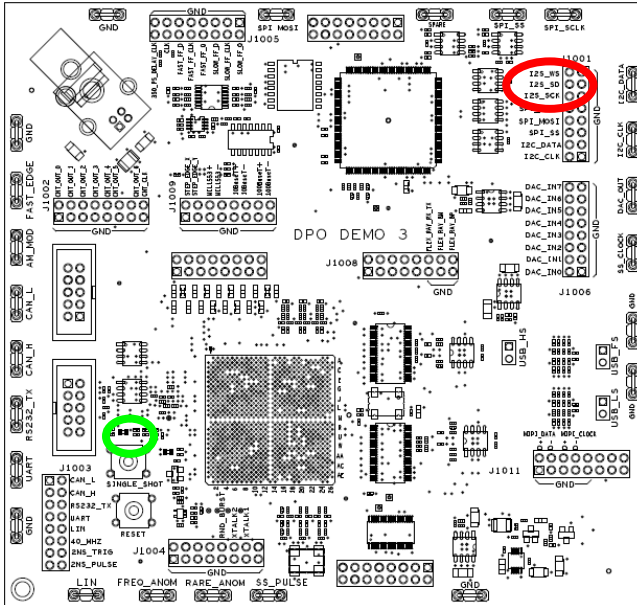


### MSO/DPO4000B Series Procedure:

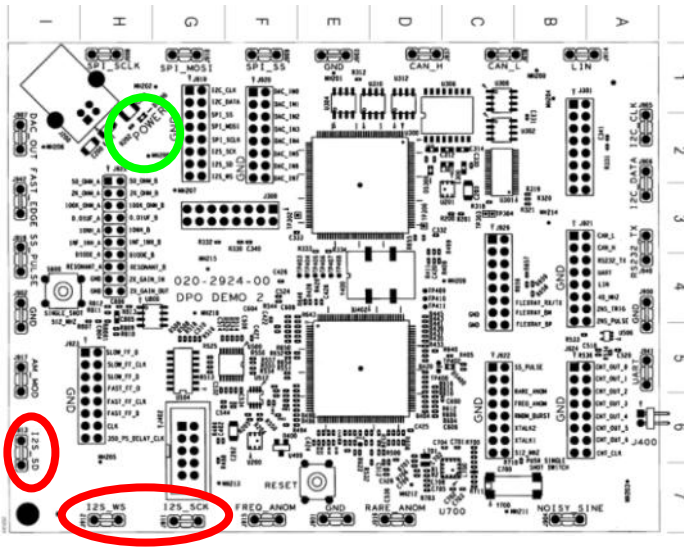
- ❑ With the oscilloscope power off, install the **DPO4AUDIO** one of the application module slots on the front panel of the instrument.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4AUDIO Audio Serial Triggering and Analysis** application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has an I<sup>2</sup>S signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) has an I<sup>2</sup>S signal which we can use for this lab.

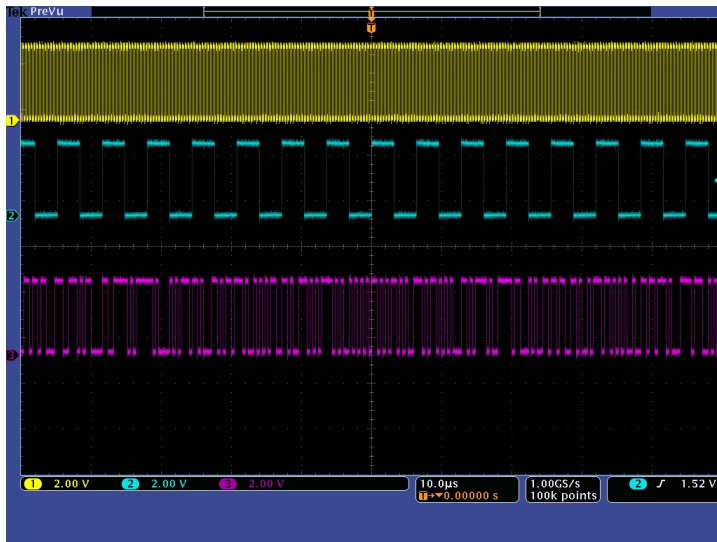


## DPO Demo Board Procedure:

- Power up the demo board.
- Verify the power LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **I2S\_SCK** test point on the demo board.
- Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **I2S\_WS** test point on the demo board.
- Attach a TPP0500 or TPP1000 probe to the Channel 3 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **I2S\_SD** test point on the demo board.

## Key Take Away Points

- The display should look about like this:



- Here you can see the I<sup>2</sup>S bus signals, but it is difficult to interpret the values of the serial data from this display.
- Let's look at an easier way to interpret the serial data.

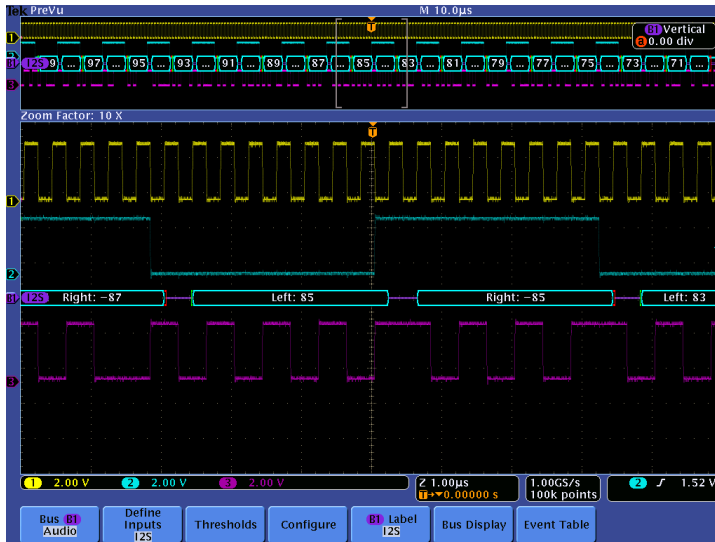
## MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Turn on channels 2 and 3 by pressing the front panel **2** and **3** buttons.
- ❑ Set the **Vertical Scales** for channels 1, 2, and 3 to **2V/div**.
- ❑ Position the waveforms on the display with the **Vertical Position** controls.
- ❑ Press the **Trigger Menu** button.
- ❑ Press the **Source** bottom bezel button and select channel **2** with the Multipurpose **a** control.
- ❑ With the front panel **Trigger Level** control, set the trigger level to the middle of the Word Select signal, or about **1.5V**.
- ❑ Set the Horizontal **Scale** to **10 μs/div**.
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **100k**.
- ❑ Press the front panel **Menu Off** button twice.
- ❑ Press the front panel **Single** button.

## MSO/DPO4000B Series I<sup>2</sup>S Decoding Setup

### Key Take Away Points

- Setting up a basic I<sup>2</sup>S bus waveform display takes only a few simple steps with the MSO/DPO4000B Series. After turning on a bus with a front panel button, the menu guide you through the setup in the left-to-right order across the bottom bezel buttons.
- Notice that any of the analog or digital input signals can be used as a source for the I<sup>2</sup>S bus.
- Most of the default I<sup>2</sup>S bus values in the MSO/DPO4000B Series were chosen to match the signal on the demo board, so many of the steps to the right have already been done for you.
- The display should now look about like this, with the decoded values shown in the bus waveform:



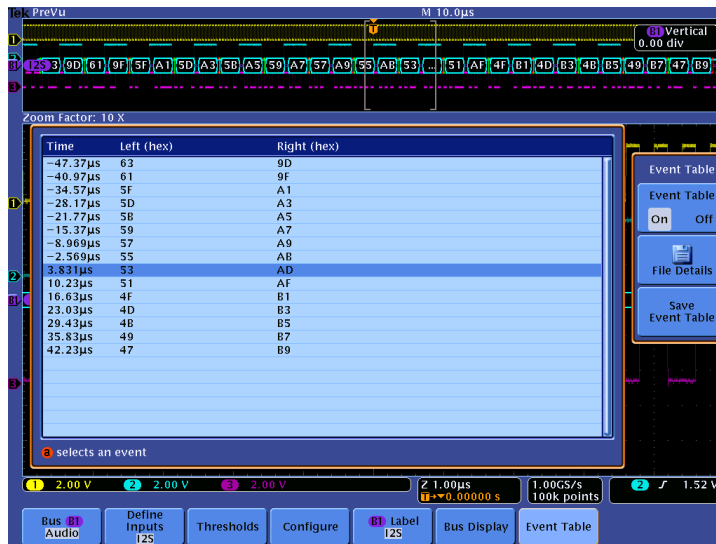
- Notice that the decoded bus waveform shows Start of Frame in green, Left data and then Right data values in cyan, and the End of Frame in red.

### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **B1** button.
- ❑ Press the **Bus B1** bottom bezel button.
- ❑ Using the Multipurpose **a** control, set Bus type to **Audio**.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ Verify that the **Audio Bus Type** is set to **I2S**, the Bit Clock is on channel **1**, Word Select is on channel **2**, and Data is on channel **3**.
- ❑ Press the **Thresholds** bottom bezel button.
- ❑ Using the Multipurpose controls, set the **Thresholds** for channels 1-3 to approximately **1.5 V**.
- ❑ Press the **Configure** bottom bezel button.
- ❑ Using the Multipurpose **a** control, set the **Word Size** to **8 bits**. Note that Word Size setting must be set to match the signal so that the serial data trigger will work correctly and that the decoded values are displayed as expected.
- ❑ Verify that the **Bit Clock** is set to rising edge and the **WS Polarity** is set to **Normal**.
- ❑ Press the **-more-** side bezel button.
- ❑ Verify that the **Data Polarity** is set to **High = 1** and the **Bit Order** is set to **MS First**.
- ❑ Using the Wave Inspector controls, zoom in on one of the I<sup>2</sup>S messages.

## Key Take Away Points

- As seen in the last section, the default I<sup>2</sup>S decoder display format is a signed decimal display of the audio data. These values can also be displayed in hexadecimal and binary.



- For many users who are not electrical engineers, the waveform displays may not be familiar. For them, the Event Table format is preferable. This format can also be saved in CSV format and analyzed off-line.

## MSO/DPO4000B Series Procedure:

- Press the **Bus Display** bottom bezel button.
- Notice the different bus display options. Press the **Hex** side bezel button.
- Press the **Event Table** bottom bezel button.
- Repeatedly press the **Event Table** side bezel button until it is set to **On**.
- Using the Multipurpose **a** control, scroll through Event Table messages. Notice that the zoom indicators in the overview window indicate the message position in the acquired waveform.
- When you are done using the Event Table display, press the **Event Table** side bezel button to select **Off**.

## MSO/DPO4000B Series I<sup>2</sup>S Cursors

### Key Take Away Points

- The I<sup>2</sup>S serial cursors provide another tool to bridge between the serial waveform and the decoded values, showing absolute timing relative to the trigger, bus values, and relative timing between bus events.
- For this example, we want to measure the time between two specific data values in the left channel. The **a** and **b** cursor readouts indicate the time and the bus value at each cursor, as well as the time between the cursors.



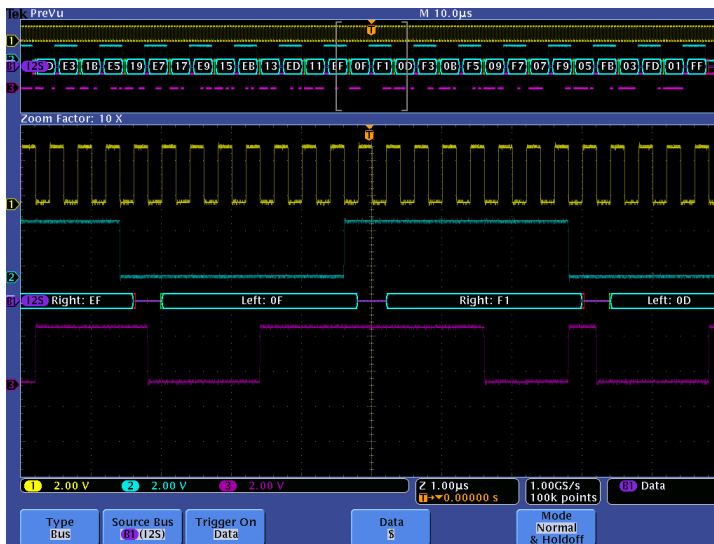
### MSO/DPO4000B Series Procedure:

- ❑ Using the Wave Inspector controls, zoom in on one of the I<sup>2</sup>S messages.
- ❑ Press the **Cursors** front panel button once to turn on vertical bar cursors.
- ❑ Using the Multipurpose **a** control, place the **a** cursor on an event of interest.
- ❑ Notice the **a** cursor time and bus value readout in the upper right corner of the display.
- ❑ Using the Wave Inspector controls, zoom in on another of the I<sup>2</sup>S messages.
- ❑ Using the Multipurpose **b** control, place the **b** cursor on an event of interest.
- ❑ Notice the **b** cursor time and bus value readout in the upper right corner of the display.
- ❑ Also notice that we are displaying the time delay between the first and second bus events of interest.
  
- ❑ Now, turn off zoom. Slowly move the cursors around and notice that you can easily identify the parts of the I<sup>2</sup>S messages and their timing without being able to clearly see the waveforms or the decoded values.
- ❑ Press the **Cursors** front panel button once to turn off cursors.

## MSO/DPO4000B Series I<sup>2</sup>S Bus Triggering

### Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the I<sup>2</sup>S serial bus.
- The MSO/DPO4000B Series can trigger on:
  - Word Select
  - Data (=, ≠, <, ≤, ≥, >, inside range, outside range; on left, right, or either data word)
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on an I<sup>2</sup>S signal, capturing each occurrence.



- NOTE: You will notice that the left channel data values count down by two each frame, while the right channel data values count up by two each frame. However, the I<sup>2</sup>S signal on the Demo II board provides somewhat random starting data values, so it is highly recommended that you specify the data trigger values with “don’t care” (X) conditions in the least significant digit to get a reliable demo.

### MSO/DPO4000B Series Procedure:

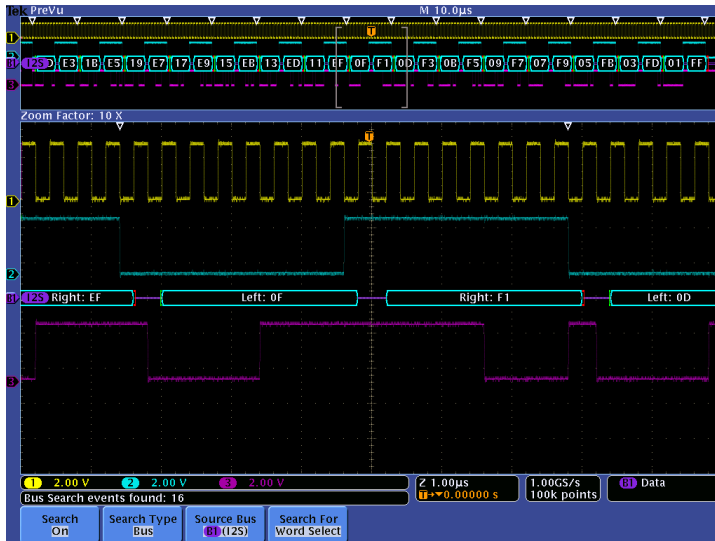
- Press the front panel **Trigger Menu** button.
- Press the **Type** bottom bezel button.
- Using the Multipurpose **a** control, select the **Bus** Trigger Type.
- Press the **Trigger On** bottom bezel button.
- Press the **Data** side bezel button.
- Press the **Data** bottom bezel button.
- Verify that **Trigger When** is set to **=** and **Either Word** is selected.
- Press the **Data** side bezel button.
- Using the Multipurpose **a** control, set the **Data Word** to **0X** Hex.
- Press the **Mode** bottom bezel button.
- Press the **Normal** side bezel button.
- Press **Menu Off**.
- Press the front panel **Single** button.
- Adjust the Wave Inspector pan and zoom controls as needed to view the I<sup>2</sup>S message at the trigger point.



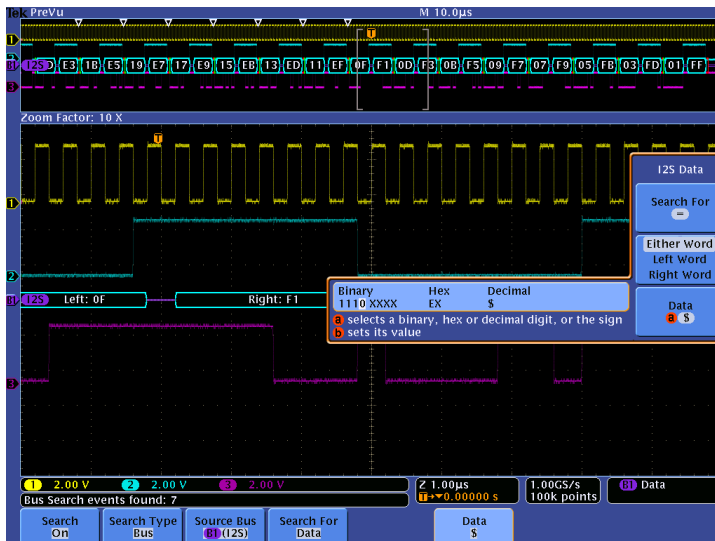
## MSO/DPO4000B Series I<sup>2</sup>S Bus Searching

### Key Take Away Points

- One of the key reasons for using long-record-length oscilloscopes is to be able to capture long time windows at high timing resolution. However, it is difficult to find specific serial signal characteristics in a long acquisition.
- Wave Inspector Search provides an easy way to find all occurrences of a specific signal characteristic, such as the Word Select. The display should look about like this:



- Wave Inspector search allows you to find all occurrences of a specified event, such as the data pattern which starts with the binary value 11111. The display should look something like this:

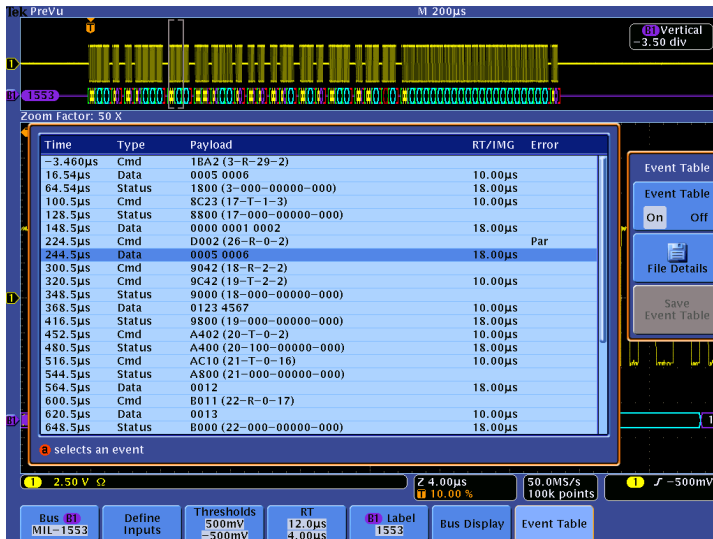


### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Search** bottom bezel button.
- ❑ Repeatedly press the **Search** side bezel button until Search is turned **On**.
- ❑ Press the **Search Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Bus** Search Type.
- ❑ Press **Menu Off**.
- ❑ By default, Search is identifying all occurrences of Word Select. Notice all of the white triangular marks appear at the top of the display.
- ❑ Navigate between marked occurrences by using the front panel **←** and **→** buttons.
- ❑ Press the **Search For** bottom bezel button.
- ❑ Press the **Data** side bezel button.
- ❑ Press the **Data** bottom bezel button.
- ❑ Repeatedly press the **Data** side bezel button until the Data selection menu appears.
- ❑ Using the Multipurpose controls, adjust the Data pattern until you see several white triangles at the top of the display.
- ❑ Press the front panel **←** and **→** buttons to navigate between search events.

# MSO4000B/DPO4000B Series

## MIL-STD-1553 Triggering and Decoding Lab



### Equipment List

- One 4-channel MSO/DPO4000B Series oscilloscope with the latest firmware version installed
- One DPO4AERO application module
- One TDP0500 or TDP1000 differential probe
- DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or a MIL-STD-1553 reference waveform

[Note: screen shots in this document were made with the DPO Demo 3 board]

## Understanding the MIL-STD-1553 Bus

Similar to the computer industry's LAN, MIL-STD-1553 is a military standard that defines the electrical and protocol characteristics of a serial bus initially designed for data communication in avionics applications.

MIL-STD-1553 began with the development of the A2-K draft standard by the Society of Automotive Engineers (SAE) in 1970. After government and military reviews and revisions, it was released as MIL-STD-1553 (USAF) in 1973. MIL-STD-1553A was released in 1975 to support all of the branches of the military, and the SAE then released and froze the MIL-STD-1553B standard to enable component manufacturers to build compliant products. The most recent changes, documented as Notice 2, was released in 1986 to provide a common set of operational characteristics. The standard is now overseen by SAE as commercial document AS15531.

Although the standard was widely used in US military applications, it has also been used commercially in mass-transportation, spacecraft, and manufacturing applications, and has been accepted and implemented by NATO and many other governments.

The DPO4AERO application module for the MSO/DPO4000B Series provides optional serial triggering and analysis for MIL-STD-1553. This lab will walk you through the most significant of the capabilities of the product.

MIL-STD-1553 asynchronously transmits messages of up to thirty-two 16-bit data words at bit rates of up to 10 Mb/s over shielded twisted-pair and twinax cabling. A 1553 network uses time-division multiplexed half-duplex communication to transmit data over a single cable. For safety-critical applications, dual redundant buses are commonly used to provide higher-reliability communications. Manchester II bi-phase encoding is used to allow direct or transformer coupling. Manchester encoding is self-clocking, independent of the bit sequence, and is DC-balanced. Because the information in Manchester coded signals is actually contained in the polarity and timing of the zero-crossings, the 1553 bus is tolerant of large variations in signal levels.

MIL-STD-1553 defines three distinct word types: Command words, Data words, and Status words. All are twenty-bit structures, with a 3-bit synchronization field, a 16-bit information field, and finally an odd parity bit for simple error detection. The sync field is an invalid Manchester signal, with a single transition in the middle of the second bit time. A command/status sync has a negative transition in the middle, while a data sync has a positive transition.

Command words, sent by the active bus controller, specify the function that a remote terminal is to perform. The 16-bit information field contains a 5-bit terminal address which uniquely identifies the terminal, a transmit/receive bit, 5 bits of sub-address or mode, and 5 bits of word count or mode code.

Command Word	Sync	Terminal Address	T/R	Subaddress / Mode	Word Count / Mode Code	Parity
Bits	3	5	1	5	5	1

Data words, transmitted by either a bus controller or remote terminal, are sent with the most-significant-bit first.

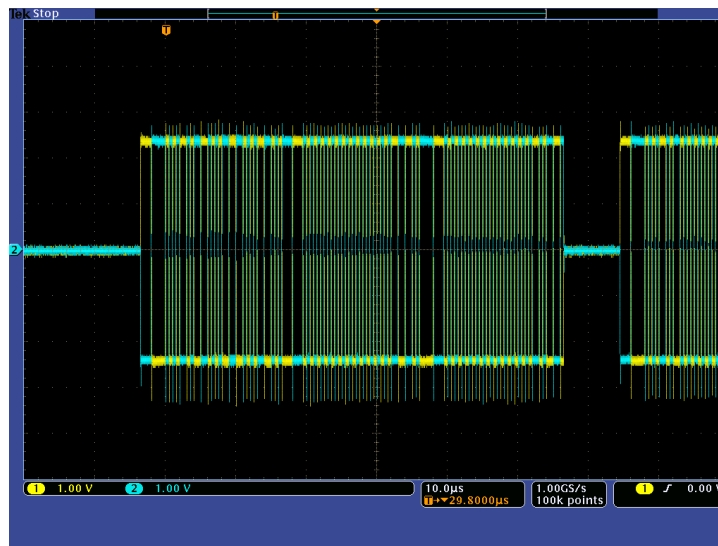
Data Word	Sync	Data (D15 – D0)	Parity
Bits	3	16	1

Status words are returned by remote terminals in response to a valid message from the controller to acknowledge receipt of a message or to convey the remote terminal status. The first 5 bits of the 16-bit information field are the terminal address. The remaining bits represent specific status information, including Message Error, Instrumentation Bit, Service Request, Broadcast Command Received, Busy, Subsystem Flag, Dynamic Bus Acceptance, and Terminal Flag.

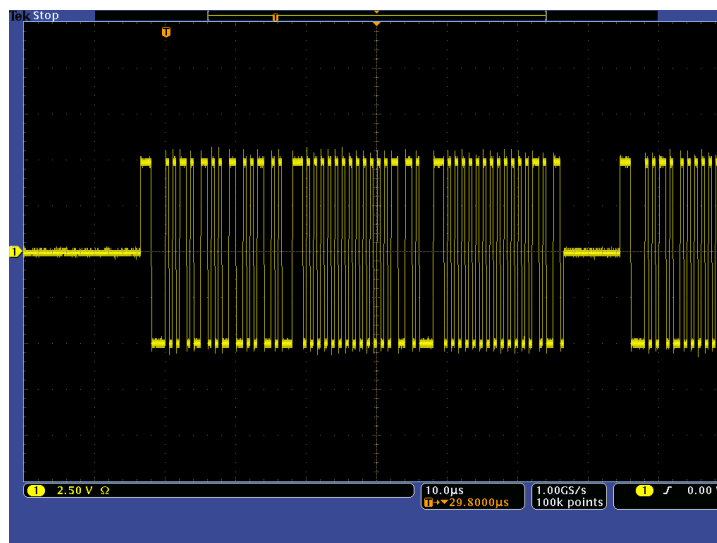
Status Word	Sync	Terminal Address	ME	IB	SR	Re-served	BCR	Busy	SF	DBA	TF	Parity
Bits	3	5	1	1	1	3	1	1	1	1	1	1

## Key Take Away Points

- The MIL-STD-1553 signals on the demo board look about like this, where the yellow channel 1 signal is the positive MIL1553+ and the cyan channel 2 signal is the negative MIL1553-:



- Notice that the individual MIL-STD-1553 signals are relatively large signals, about  $\pm 2.5V_{pk-pk}$ , with multiple voltage levels.
- These MIL-STD-1553 signals transmit information differentially, and the DPO4AERO decoder is designed to work with a single differential signal, so the remainder of this lab will focus on the differential signal, captured with a differential probe, as shown below:



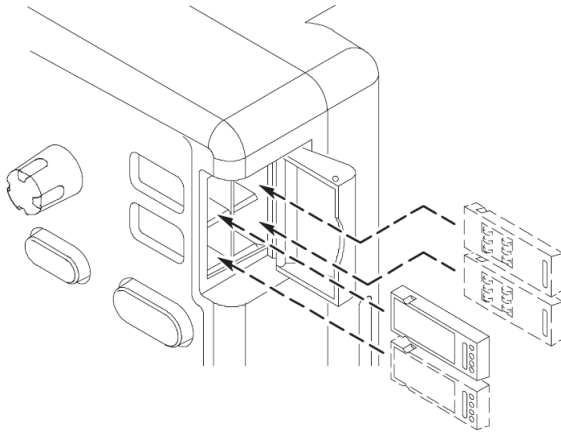
## Lab Objectives

- Obtain a basic understanding of the MIL-STD-1553 serial bus.
- Learn how to use oscilloscopes to measure and decode MIL-STD-1553 signals.
- Learn how to setup a MIL-STD-1553 serial bus display and trigger and search on MIL-STD-1553 bus content with an MSO/DPO4000B Series oscilloscope.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

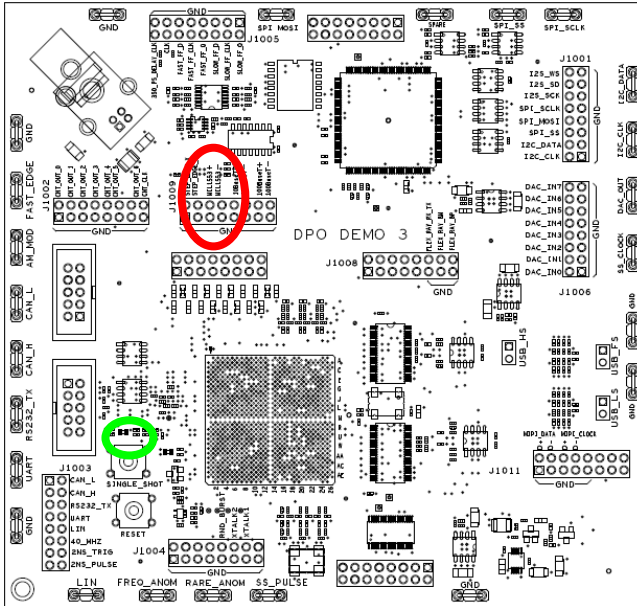
- With the DPO4AERO application module installed, the MSO/DPO4000B Series oscilloscope can trigger on, decode, and search MIL-STD-1553 serial bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.



- ❑ With the oscilloscope power off, install the **DPO4AERO** one of the application module slots on the front panel of the instrument.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4AERO: Aerospace Serial Triggering and Analysis** application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a MIL-STD-1553 signal which we can use for this lab:



- You can also load a MIL-STD-1553 signal into a reference memory for use in this lab to demonstrate decoding and searching. However, the rest of this lab assumes a live signal.

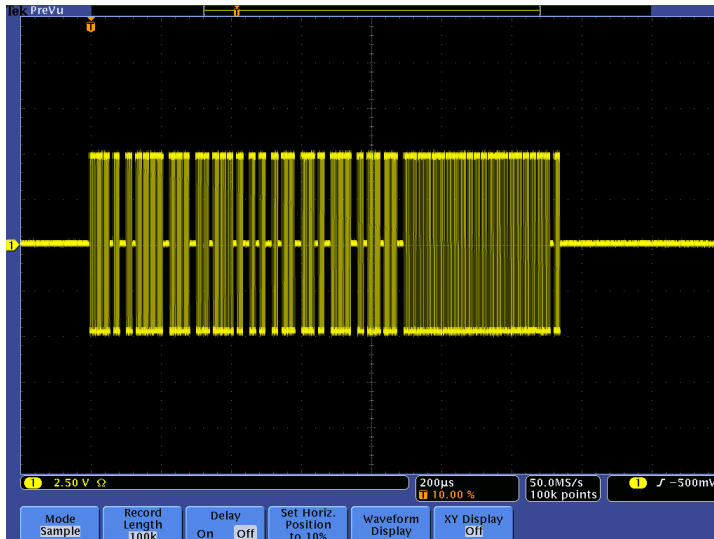
## DPO Demo Board Procedure:

- Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- Verify the green **POWER** LED is lit.
- Attach a TDP0500 or TDP1000 differential probe to the Channel 1 input of the oscilloscope. Then connect the probe's + input to **MIL1553+** and connect the probe's - input to the **MIL1553-** test point.
- Using the **Range** button on the probe, select the **4.25V** range.
- For your reference, to load a reference waveform for decoding, after setting up the scope:
  - Plug USB flash drive with waveform file into the oscilloscope.
  - Press the front panel Save/Recall **Menu** button.
  - Press the **Recall Waveform** bottom bezel button.
  - Using the Multipurpose **a** control (and the Select button if necessary to select drives and folders), select the waveform file.
  - Press the **Recall to R1** side bezel button.

## MSO/DPO4000B Series MIL-STD-1553 Bus Setup and Decoding

### Key Take Away Points

- The MIL-STD-1553 signal should look about like this when set up correctly:



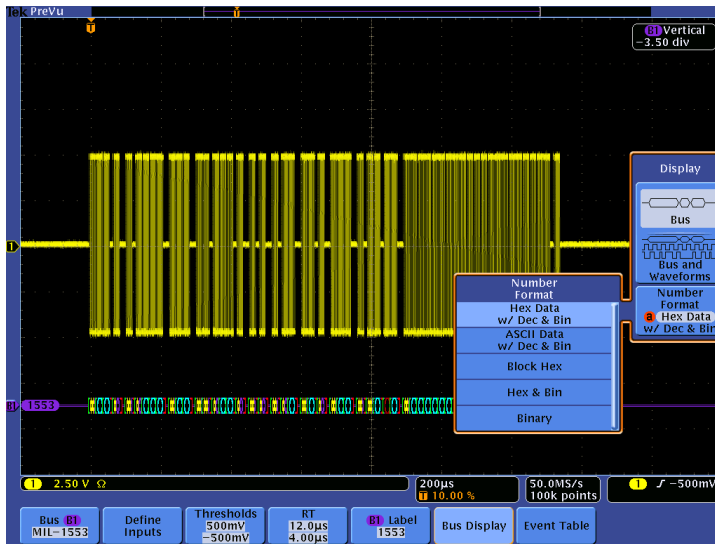
- Setting up a basic MIL-STD-1553 bus waveform display takes only a few simple steps with the MSO/DPO4000B Series.
- Notice that any of the analog or reference signals can be used as a source for the MIL-STD-1553 bus.

### MSO/DPO4000B Series Procedure:

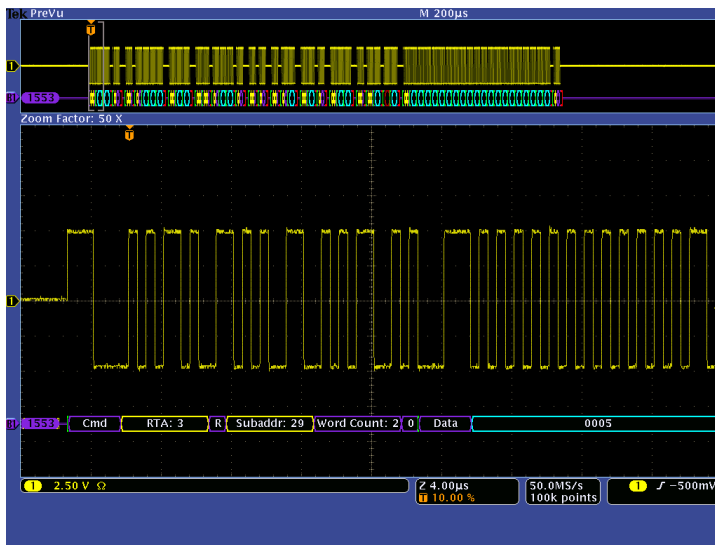
- ❑ Set channel 1 Vertical **Scale** to **2.5V/div**.
- ❑ Use the **Trigger Level** control to adjust the trigger level below the center of the waveform, about **-1V**.
- ❑ Set the **Horizontal Scale** to **200μs/div**.
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **100k**.
- ❑ Press the **Delay** bottom bezel button until **Off** is selected.
- ❑ Press the **Set Horiz. Position** to **10%** bottom bezel button.
- ❑ Press the front panel **Single** button.
- ❑ Press the purple front panel **Bus B1** button.
- ❑ Press the **Bus B1** bottom bezel button.
- ❑ Using the Multipurpose **a** control, set Bus type to **MIL-STD-1553**.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ Verify that the **1553 Input** is set to channel **1** and the **Polarity** is set to **Normal**.
- ❑ Press the **Thresholds** bottom bezel button.
- ❑ Using the Multipurpose **a** control, set the **Threshold High** value to **+500 mV**.
- ❑ Using the Multipurpose **b** control, set the **Threshold Low** value to **-500 mV**.

## Key Take Away Points

- The MIL-STD-1553 Bus Setup menu looks like this:



- When you zoom in to see the details, the MIL-STD-1553 bus display looks like this:



- The green bar symbol represents the start of packet and the red bar symbol represents the end of packet.
- Notice that the Sync Word Type, R/T bit, Word Count, Status Bits, and Parity appear in purple. Address bits appear in yellow. Data values are shown in cyan. Errors are shown in red.

## MSO/DPO4000B Series Procedure:

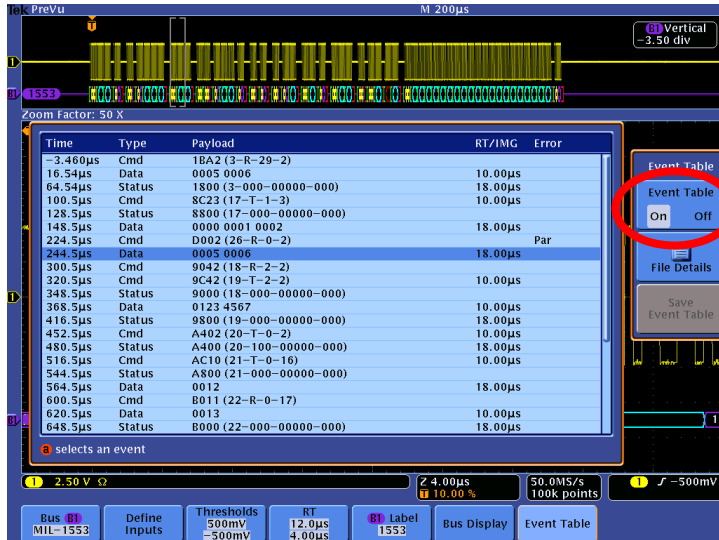
- Press the front **Menu Off** button once.
- Using the Multipurpose **a** control, position the bus waveform below the MIL-STD-1553 waveform as desired.
- Press the **Bus Display** bottom bezel button.
- Under **Display**, verify that **Bus** is selected.
- Using the Multipurpose **a** control, select **Hex Data w/ Dec & Bin**.
- Using the front panel Wave Inspector controls, zoom in on the signal until you can read the individual decoded signal elements.
- Press the front panel **Menu Off** button.
- Pan through the display to see what the decoded signal elements look like.



## MSO/DPO4000B Series MIL-STD-1553 Bus Event Tables

### Key Take Away Points

- Setting up a basic MIL-STD-1553 bus event table display takes only a few simple steps with the MSO/DPO4000B Series.
- The MIL-STD-1553 bus event table display looks like this:



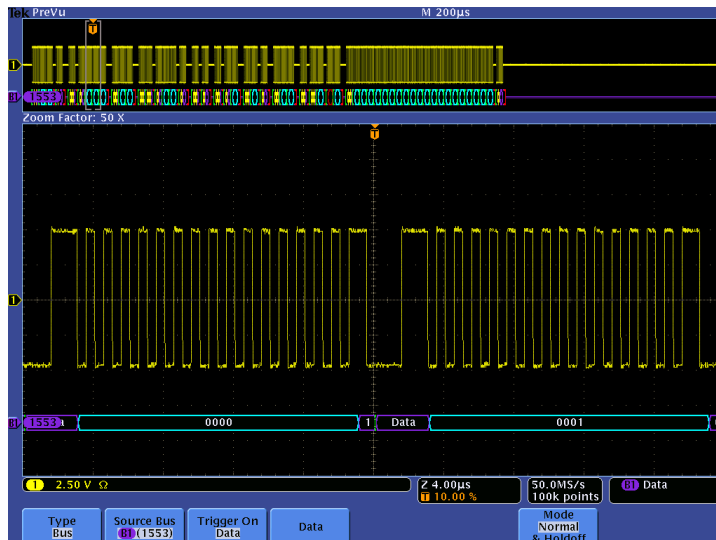
### MSO/DPO4000B Series Procedure:

- ❑ Press the purple front panel Bus **B1** button.
- ❑ Press the **Event Table** bottom bezel button.
- ❑ Press the **Event Table** side bezel button to turn Event Table **On**.
- ❑ Using the Multipurpose **a** control, scroll through the rows in the Event Table and notice the zoom box is repositioned to correspond to the selected row.
- ❑ When you are done with the setup, press the **Event Table** side bezel button to turn the Event Table **Off**.

## MSO/DPO4000B Series MIL-STD-1553 Bus Triggering

### Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the MIL-STD-1553 serial bus.
- The MSO/DPO4000B Series can trigger on:
  - Sync
  - Command Word (set RT Address (=, ≠, <, >, ≤, ≥, inside range, outside range), T/R, Sub-address/Mode, Data Word Count/Mode Code, and Parity individually)
  - Status Word (set RT Address (=, ≠, <, >, ≤, ≥, inside range, outside range), Message Error, Instrumentation, Service Request Bit, Broadcast Command Received, Busy, Subsystem Flag, Dynamic Bus Control Acceptance (DBCA), Terminal Flag, and Parity individually)
  - Data (user-specified 16-bit data and parity values)
  - Idle Time (< Minimum, > Maximum, Inside Range, Outside Range)
  - Error (Parity Error, Sync Error, Manchester Error, Non-Contiguous Data)
- NOTE: Trigger selection of Command Word will trigger on Command and ambiguous Command/Status words. Trigger selection of Status Word will trigger on Status and ambiguous Command/Status words.
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on a MIL-STD-1553 signal, capturing each occurrence.



### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel Trigger **Menu** button.
- ❑ Press the **Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **Bus**.
- ❑ Notice that the Source Bus is set to **B1 (1553)**.
- ❑ Notice that, by default, Trigger On is set to **Sync**.
- ❑ Press the **Trigger On** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **Data**.
- ❑ Press the **Data** bottom bezel button.
- ❑ Using the Multipurpose controls, set the Data value to **0000** hex. As you enter the values, notice that the values in the other radices are also updated.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the MultiView Zoom pan and zoom controls as needed to view the MIL-STD-1553 packets at the trigger point.

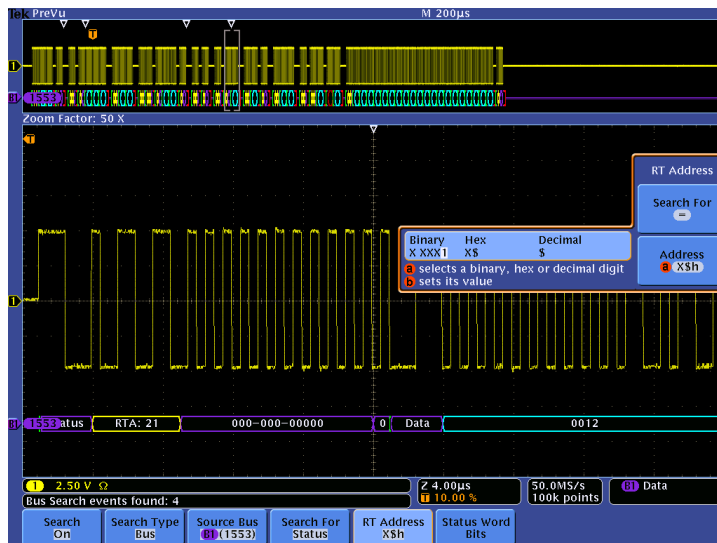
## MSO/DPO4000B Series MIL-STD-1553 Bus Searching

### Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific content over the MIL-STD-1553 serial bus.



- The MSO/DPO4000B Series can search on Sync, Command Word, Status Word, Data, Idle Time, and Error.
- By following this simple procedure, you can easily search an acquisition for a specified serial pattern on a MIL-STD-1553 signal, marking each occurrence:



### MSO/DPO4000B Series Procedure:

- Press the front panel **Search** button.
- Press the **Search** bottom bezel button.
- Press the **Search** side bezel button to turn on search.
- Press the Search Type bottom bezel button.
- Using the Multipurpose **a** control select **Bus** Search Type.
- Press the **Search For** bottom bezel button.
- Notice that, by default, Search For **Sync** is selected.
- Using the Multipurpose **a** control, select Search For **Status** Word.
- Press the **RT Address** bottom bezel button.
- Press the Address side bezel button.
- Using the Multipurpose controls, enter the binary value **X XXX1**. As you enter the values, notice that the values in the other radices are also updated.
- Using the front panel left and right arrows, navigate between search events.

# MSO4000B Series

## Parallel Bus Triggering and Decoding Lab



### Equipment List

- One 4-channel MSO4000B Series oscilloscope with the latest firmware version installed
  - One P6616 MSO probe
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]

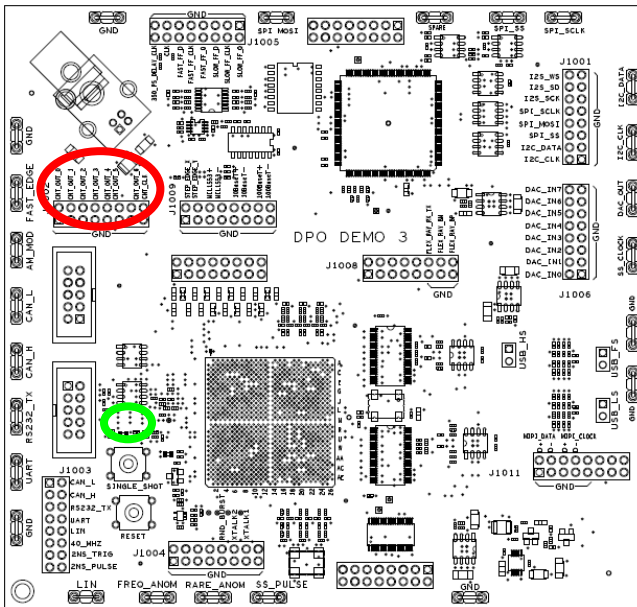
## Lab Objectives

- Learn how to set up a parallel serial bus display and trigger and search on parallel bus content with an MSO4000B Series mixed-signal oscilloscope.
- Learn how to use setup & hold triggering to identify timing errors in synchronous buses.
- Learn how to use the MagniVu acquisition mode to maximize measurement timing resolution.

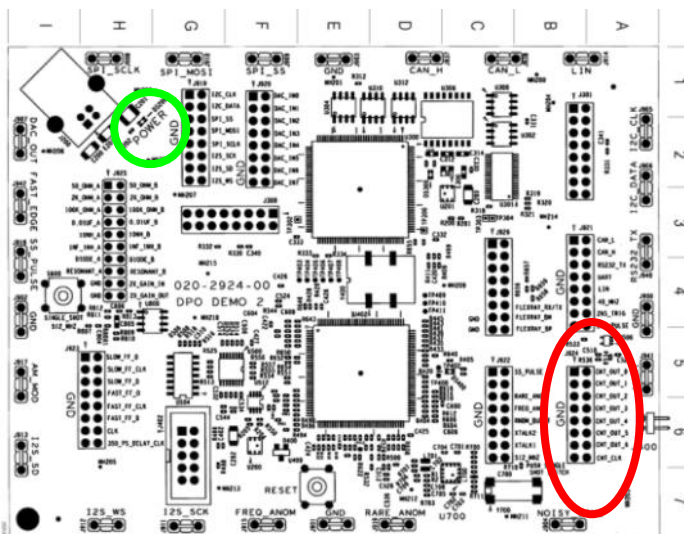
## MSO4000B Series Lab Setup

### Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a parallel bus signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) has a parallel bus signal which we can use for this lab.

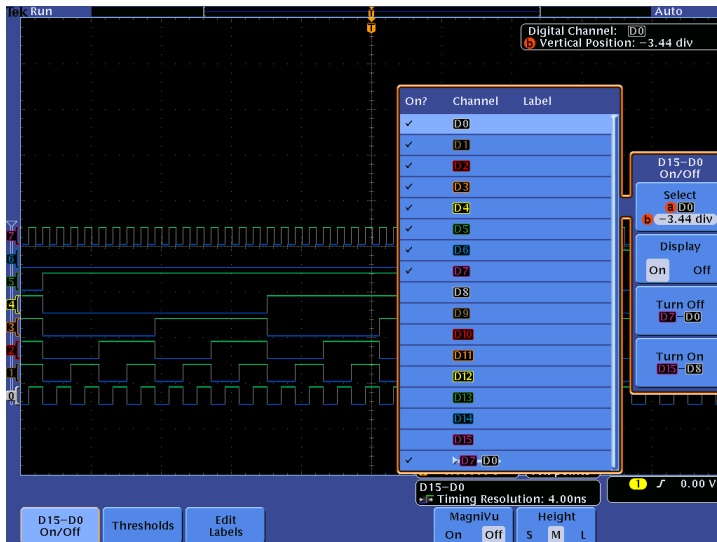


### DPO Demo Board Procedure:

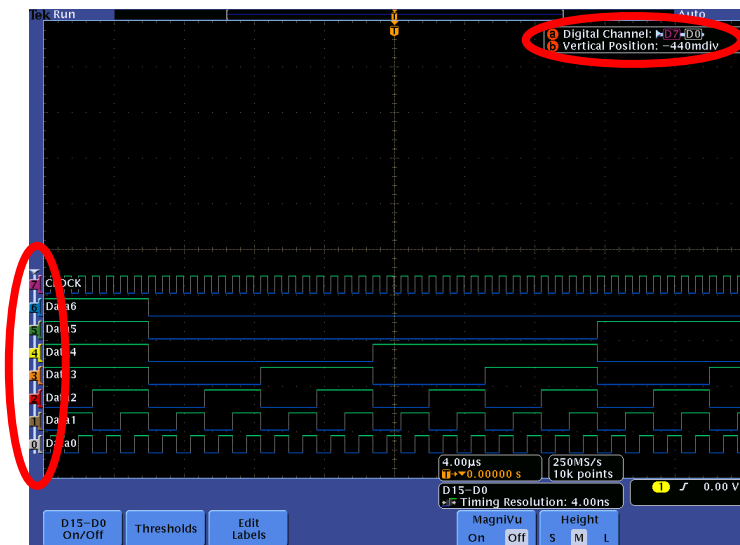
- ❑ Power up the demo board.
- ❑ Verify the power LED is lit.
- ❑ Attach a P6616 MSO probe to the D15-D0 input on the front of the oscilloscope.
- ❑ On Group 1 of the MSO probe, connect the **D0** input to the **CNT\_OUT0** square pin, with the probe ground on the ground pin on the left side of the connector. Similarly, connect inputs **D1** through **D6** to the **CNT\_OUT1** through **CNT\_OUT6** signals.
- ❑ Connect the **D7** input to the **CNT\_CLK** pin.

## Key Take Away Points

- The display should look about like this:



- There are several key next-generation digital display characteristics to notice in the display. When digital signals are **low**, the waveforms are **colored blue**. When the signals are **high**, the waveforms are **colored green**.
- Digital channels can be grouped together to simplify operations such as modifying vertical position or thresholds:



- As the number of signals on the display increases, it becomes increasingly valuable to be able to attach text labels to the waveforms. There are three ways to add labels:
  - Select one of the Preset Labels from the list.
  - Enter the label using an attached USB keyboard.
  - Enter the label, character by character, using the Multipurpose controls and bezel buttons.

## MSO4000B Series Procedure:

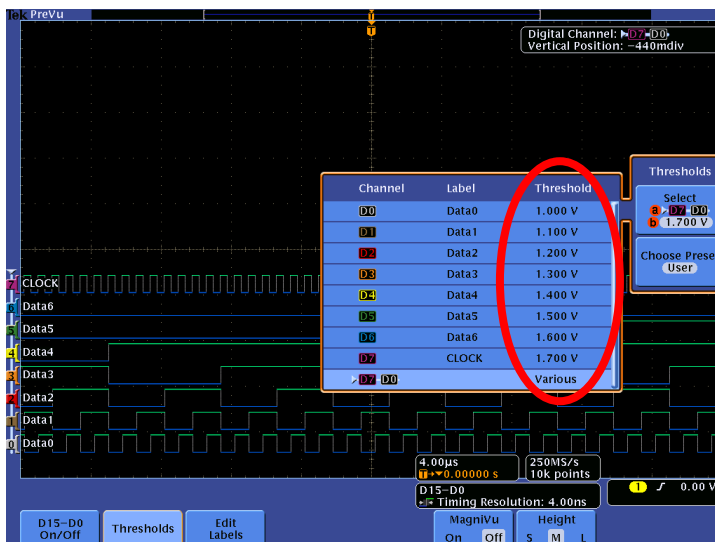
- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Repeatedly press the front panel **1** button until channel 1 is turned off.
- Press the blue **D15-D0** front panel button to display the digital channel menu.
- Press the **D15-D0 On/Off** bottom bezel button.
- Press the **Turn On D7-D0** side bezel button.
- Press the **Menu Off** button once to remove the side menu.
- Turn the Multipurpose **a** control fully clockwise. Notice that a white bar appears behind the waveform labels at the left side of the display, indicating that you have selected a group of adjacent digital channels.
- Turn the Multipurpose **b** control counter-clockwise to position the group of channels in the lower half of the display.
- Press the **Edit Labels** bottom bezel button.
- Notice the different ways to attach text labels to the channels.
- Press **Menu Off** to exit.

## Key Take Away Points

- Many digital and mixed signal designs also contain multiple logic families. The signal on each input to the digital logic probe is compared with a threshold value to determine if the input signal is high or low.
- Most MSO products only allow the user to set a single logic threshold per group of 8 channels. If the application has multiple logic families, this would require using channels from each group to acquire the waveform. If more than two logic families are used, another instrument would be needed. The MSO4000B series allows the user to set a unique logic threshold for every digital channel.
- The Thresholds display should look about like this:



- When the digital group is selected, the threshold value is set for all signals in the group. When individual channels are selected, the threshold values can be set independently and the threshold value for the group is indicated as "various".



## MSO4000B Series Procedure:

- Press the **Thresholds** bottom bezel button.
- With the D7-D0 group selected, turn Multipurpose **b** control to adjust the digital threshold on all channels at once.
- If you select a single channel with the Multipurpose **a** control, you can then adjust its threshold value independently.

- Turn the Multipurpose **a** control fully clockwise.
- Press the **Choose Preset** side bezel button and select **TTL** using the Multipurpose **a** control.

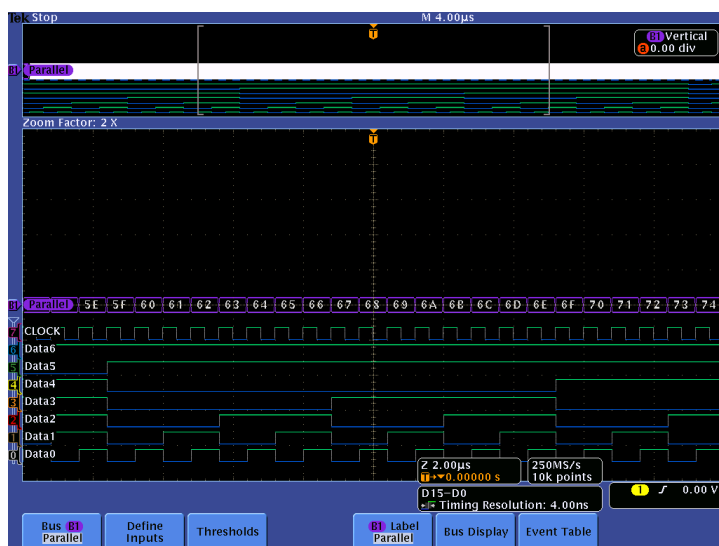
## MSO4000B Series Parallel Bus Decoding Setup

### Key Take Away Points

- Setting up a basic parallel bus waveform display takes only a few simple steps with the MSO4000B Series. After turning on a bus with a front panel button, the menu guide you through the setup in the left-to-right order across the bottom bezel buttons.



- Notice that any of the analog or digital input signals can be used as a source for the parallel bus. To keep this demo simple, we will only use one group of 8 digital signals.
- Also notice another display feature, the bright white bus display. Bright white edges and buses are clues that you need to zoom in to see more detail.
- The display should now look about like this, with the decoded values shown in the bus waveform:



### MSO4000B Series Procedure:

- Press the front panel **B1** button.
- Press the **Bus B1** bottom bezel button.
- Using the Multipurpose **a** control, set Bus type to **Parallel**.
- Press the **Define Inputs** bottom bezel button.
- Repeatedly press the **Clocked Data** side bezel button until **Yes** is selected.
- Verify that the **Clock Edge** is set to rising edge.
- Using the Multipurpose **a** control, set the **Number of Data Bits** to **7**.
- Press the **Define Bits** side bezel button.
- Using the Multipurpose **b** control, select **D7** as the clock.
- Press the **Menu Off** button once to remove the side menu.
- Press the front panel **Run/Stop** button.
- Using the Wave Inspector controls, zoom in on the decoded data values.

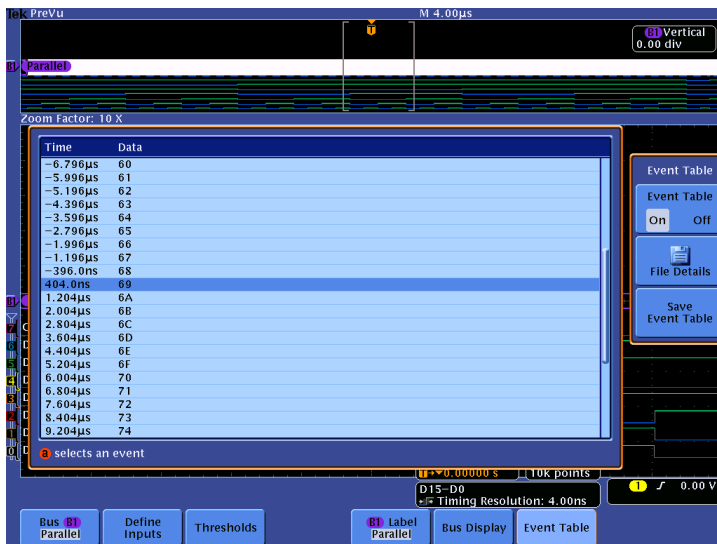


## Key Take Away Points

- As seen in the last section, the default parallel decoder display format is hexadecimal, but the values can also be shown in binary format on the bus display.



- Notice that we used a clocked bus format, and the bus transitions are coincident with the rising edge of the clock signal. Clocked buses are the best choice when you are interested in the transmitted data values on the bus.
- For many users who are not electrical engineers, the waveform displays may not be familiar. For them, the Event Table format is preferable. This format can also be saved in CSV format and analyzed off-line.



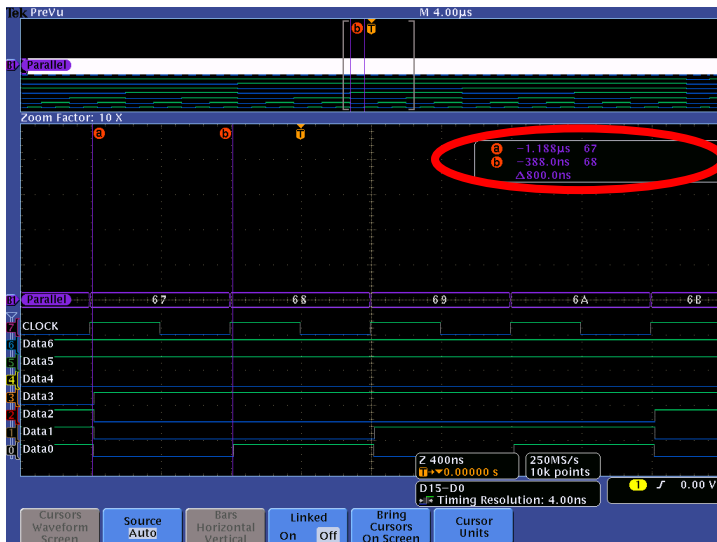
## MSO4000B Series Procedure:

- Press the **Bus Display** bottom bezel button.
  - Notice the different bus display options. Press the **Binary** side bezel button.
  - You may need to adjust the zoom scale to display the binary values (since there are more characters to display).
- 
- Press the **Hex** side bezel button.
  - Press the **Event Table** bottom bezel button.
  - Repeatedly press the **Event Table** side bezel button until it is set to **On**.
  - Using the Multipurpose **a** control, scroll through Event Table messages. Notice that the zoom indicators in the overview window indicate the message position in the acquired waveform.
  - When you are done using the Event Table display, press the **Event Table** side bezel button to select **Off**.

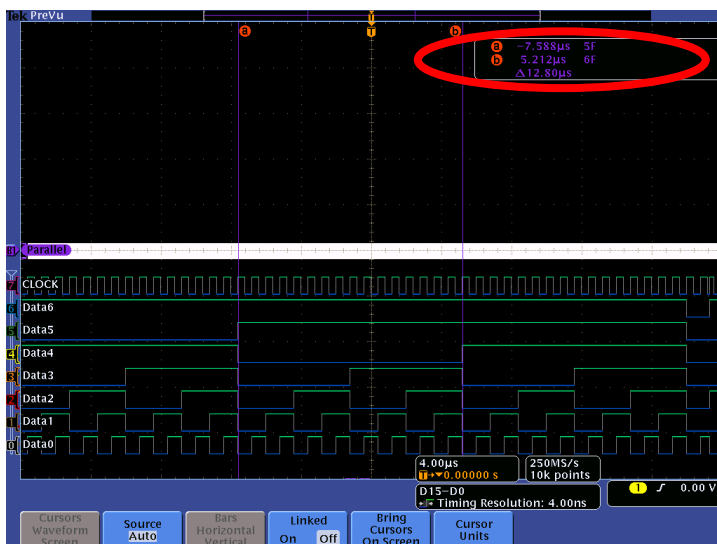
## MSO4000B Series Parallel Cursors

### Key Take Away Points

- The parallel bus cursors provide another tool to bridge between the digital channel waveforms and the decoded parallel bus values, showing absolute timing relative to the trigger, bus values, and relative timing between bus events.
- When the parallel bus is selected, the cursor readouts indicate the bus values and the timing measurements:



- If the digital channels were selected, then the cursor readouts would indicate the values of the individual digital channels (MSB on the left, LSB on the right) and the timing measurements. Note that digital cursors read out the digital values in probe channel order, not by screen position.
- Even with zoom turned off, cursors provide a way to measure the time between distant parallel bus events:



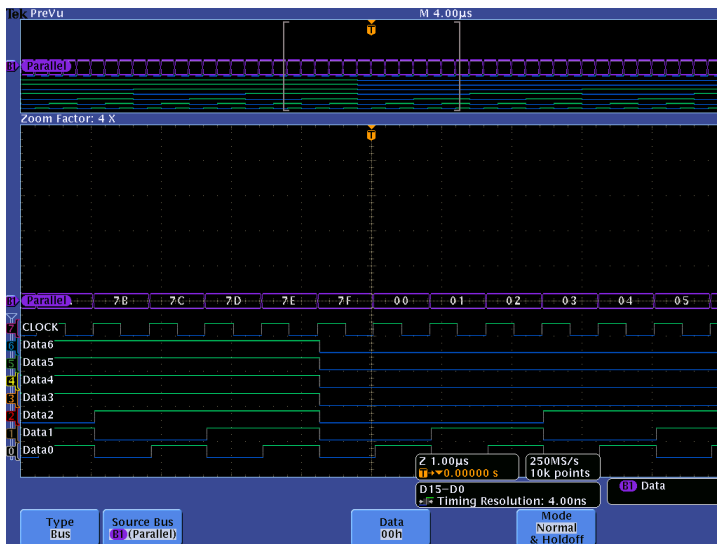
### MSO4000B Series Procedure:

- ❑ Press and hold the **Cursors** front panel button once to turn on vertical bar cursors and to display the cursors control menu.
- ❑ Press the **Bring Cursors On Screen** bottom bezel button.
- ❑ Using the Multipurpose **a** control, place the **a** cursor on an event of interest.
- ❑ Notice the **a** cursor time and bus value readout in the upper right corner of the display.
- ❑ Using the Multipurpose **b** control, place the **b** cursor on an event of interest.
- ❑ Notice the **b** cursor time and bus value readout in the upper right corner of the display.
- ❑ Also notice that we are displaying the time delay between the first and second bus events of interest.
- ❑ Now, turn off zoom. Slowly move the cursors around and notice that you can easily identify the parallel bus values and their timing without being able to clearly see the waveforms or the decoded values.
- ❑ Press the **Cursors** front panel button once to turn off cursors.

## MSO4000B Series Parallel Bus Triggering

### Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the data value on the parallel bus.
- You can use Logic triggering, setting up the desired digital trigger pattern bit-by-bit. However, since the parallel bus is already set up, it is much easier to use parallel bus triggering.
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on a parallel bus signal, capturing each occurrence.
- When you zoom into the trigger point, you can verify that the trigger occurred as expected.



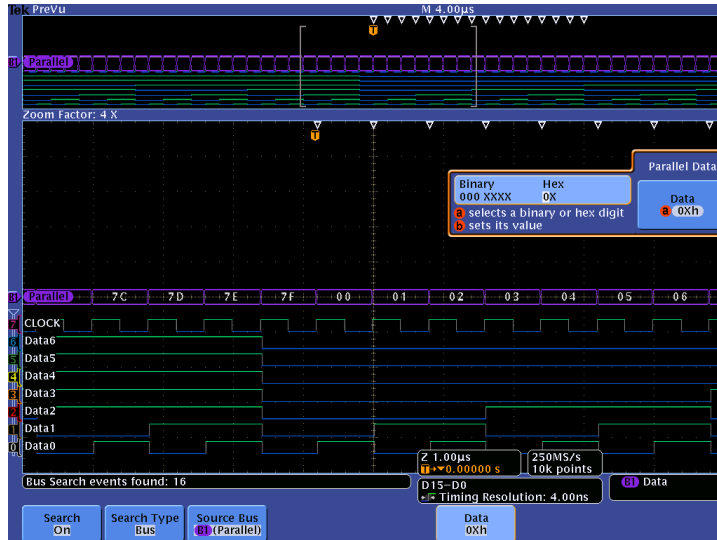
### MSO4000B Series Procedure:

- ❑ Press the front panel **Trigger Menu** button.
  - ❑ Press the **Type** bottom bezel button.
  - ❑ Using the Multipurpose **a** control, select the **Bus** Trigger Type.
  - ❑ Press the **Data** bottom bezel button.
  - ❑ Using the Multipurpose **a** control, set the **Data** to **0X** Hex.
  - ❑ Press the **Mode** bottom bezel button.
  - ❑ Press the **Normal** side bezel button.
  - ❑ Press **Menu Off**.
  - ❑ Press the front panel **Single** button.
- 
- ❑ Adjust the Wave Inspector pan and zoom controls as needed to view the parallel bus value at the trigger point.

## MSO4000B Series Parallel Bus Searching

### Key Take Away Points

- One of the key reasons for using long-record-length oscilloscopes is to be able to capture long time windows at high timing resolution. However, it can be difficult to quickly find specific parallel bus values in a long acquisition.
- Wave Inspector Search provides an easy way to find all occurrences of a specific value, such as all hex values starting with the value 0. The display should look about like this:



### MSO4000B Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Search** bottom bezel button.
- ❑ Repeatedly press the **Search** side bezel button until Search is turned **On**.
- ❑ Press the **Search Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Bus** Search Type.
- ❑ Press the **Data** bottom bezel button.
- ❑ Using the Multipurpose **a** control, set the **Data** value to **0X** hex.
- ❑ Press **Menu Off**.
- ❑ Navigate between marked occurrences by using the front panel ← and → buttons.
- ❑ When you are done with Search, press the **Search** bottom bezel button and press the **Search** side bezel button until **Off** is selected.

## MSO4000B Series Bus Setup and Hold Triggering

### Key Take Away Points

- When debugging a synchronous digital system, one of the most critical issues is the setup and hold time, the timing between the clock and data signals. Setup and hold violations occur when the device receiving the signal is not guaranteed to correctly determine whether the data bit is a one or a zero. To guarantee correct operation, the data must be stable a minimum amount of time before the clock edge (setup time) and stable a minimum amount of time after the clock edge (hold time).
- Some oscilloscopes such as the DPO4000B series allow you to capture setup and hold violations between a data signal and a clock.
- With the MSO4000B series, you can trigger on and capture setup and hold violations on up to 20 data lines relative to a clock.
- By following this simple procedure, you can easily trigger the oscilloscope on any setup and hold violations across a parallel bus:



- Wave Inspector search can also be used to detect all setup & hold violations in an acquisition.

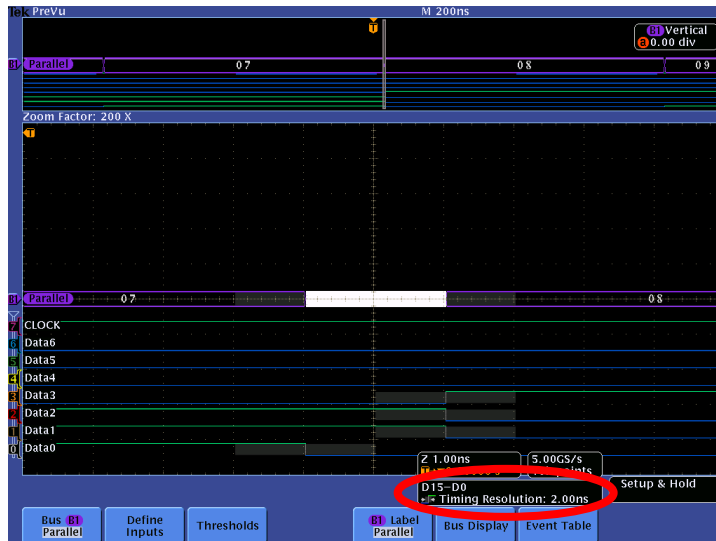
### MSO4000B Series Procedure:

- ❑ Press the front panel **Trigger Menu** button.
- ❑ Press the **Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Setup & Hold** Trigger Type.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **D0** and press the **Data** side bezel button. Repeat for channels **D1** through **D6**.
- ❑ Using the Multipurpose **a** control, select **D7** and press the **Clock** side bezel button.
- ❑ Press the **Times** bottom bezel button.
- ❑ Using the Multipurpose controls, set the **Setup Time** and **Hold Time** to approximately **24.00ns**. (This is a very large range, but it should assure that you get some triggers with these counter outputs.)
- ❑ Press the front panel **Run/Stop** button to start acquisitions.
- ❑ Adjust the Wave Inspector pan and zoom controls as needed to view the parallel bus value at the trigger point.

## MSO4000B Series MagniVu Acquisition

### Key Take Away Points

- The normal sample rate for the MSO4000B digital channels is 500 MS/s per channel (2 ns timing resolution) over the 20M record length. This sample rate provides adequate sample rate for most applications involving widely-spaced digital signals.
- Notice the gray blocks around the signal edges. These blocks indicate the sample timing uncertainty resulting from the digital timing resolution (which is displayed at the bottom of the screen):



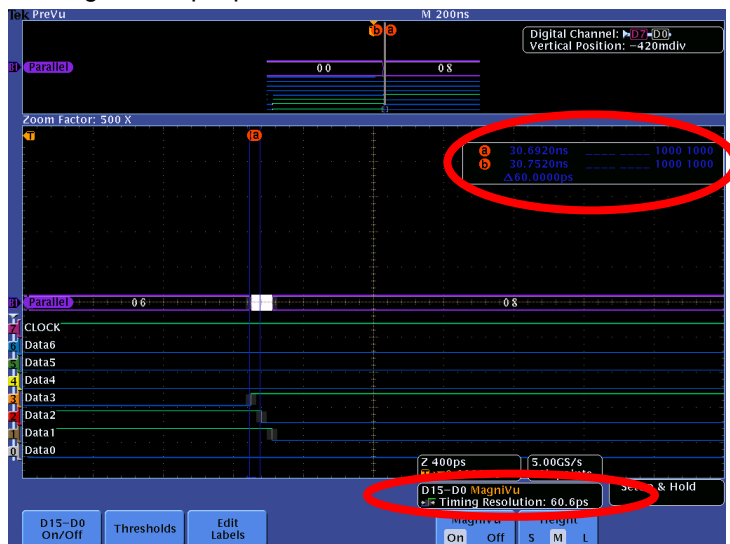
- As mentioned before, the bright white area on the bus waveform indicates that you should zoom in for more detail. Unfortunately in this case, zoom does not improve upon the timing uncertainties which result from the maximum 2 ns digital timing resolution, as indicated by the gray blocks around the digital edges.

### MSO4000B Series Procedure:

- ❑ Press the front panel magnifying glass button to turn off zoom.
- ❑ Set the horizontal Scale to **10 ns/div**. As you change the scale, notice that the digital sample rate reaches a maximum 500 MS/s (2 ns timing resolution, indicated in the readout at the bottom of the display).
- ❑ Press the front panel **B1** button.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ Repeatedly press the **Clocked Data** side bezel button until **No** is selected.
- ❑ Notice that intermediate decoded bus values may appear on the display, and the bus transitions occur where the data bit values change, not on the clock edges. You can use zoom to look at these intermediate values in more detail.

## Key Take Away Points

- For high-resolution timing measurements between timing events that are close together, such as setup & hold time or propagation delay measurements, MagniVu acquisition mode provides the highest timing resolution available in a mixed signal oscilloscope. MagniVu provides up to 16.5 GS/s sample rate (60.6 ps timing resolution) over a 10k record length centered around the trigger point.
- Notice how much smaller the timing uncertainty is with MagniVu acquisition, as indicated by the gray blocks around the digital edges. With the higher MagniVu timing resolution, you can now accurately measure the timing differences between edges that occur within a single 2 ns digital sample period.



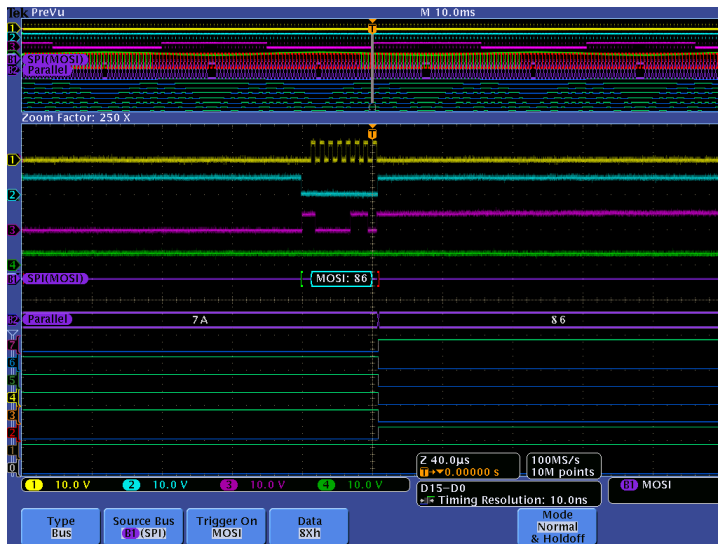
- And, because normal and MagniVu acquisitions are always taken at the same time, you can switch back and forth between acquisition modes, even after acquisitions are stopped.

## MSO4000B Series Procedure:

- ❑ Press the blue front panel **D15-D0** button.
- ❑ Press the **MagniVu** bottom bezel button.
- ❑ Notice the 60.6 ps digital timing resolution in the readout at the bottom of the display.
- ❑ Press the **Cursors** front panel button once to turn on vertical bar cursors.
- ❑ Using the Multipurpose controls, place the **a** and **b** cursors on events of interest.
- ❑ Notice that we are displaying the time delay between the edges, with single-pixel timing resolution.

# MSO4000B Series

## Mixed Signal Demo Lab



### Equipment List

- One 4-channel MSO4000B Series oscilloscope with the latest firmware version installed
  - Four TPP0500 or TPP1000 passive probes
  - One P6616 MSO probe
  - One DPO4EMBD application module
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]

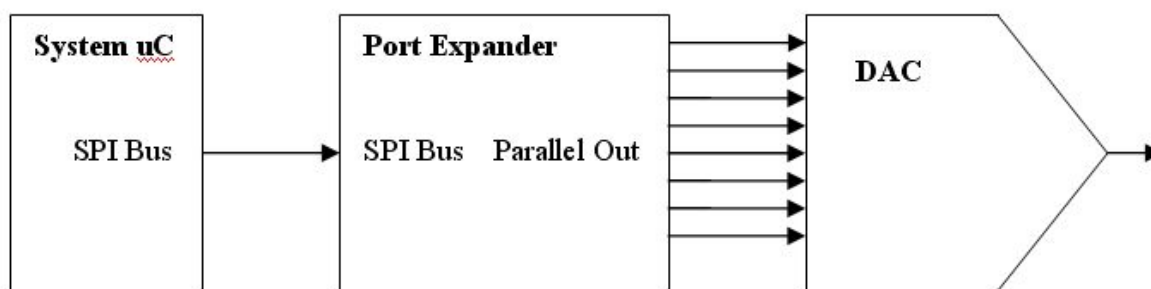


## A Mixed-Signal Application Circuit

The demo board has a circuit which enables you to do a demo of a complete, fairly typical embedded mixed-signal application.

The system microcontroller generates digital waveform values and sends them out over the SPI serial bus. The port expander translates the serial information from the SPI bus to its parallel bus representation. The parallel bus drives the inputs to a Digital-to-Analog Converter (DAC), which generates an analog representation of the digital values.

The block diagram for the circuit is shown below:

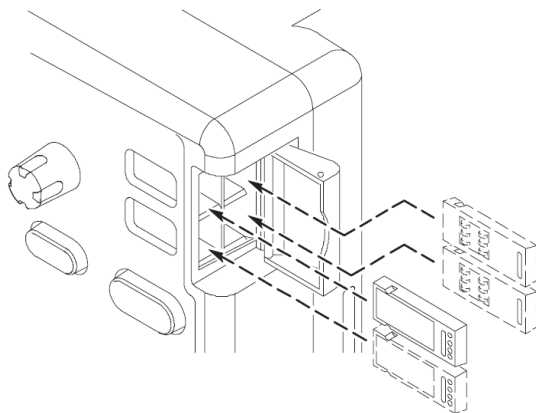


By using a Mixed-Signal Oscilloscope, you can trace the signal path from start to finish to verify the circuit operation and, if necessary, debug the circuit.

## MSO4000B Series Lab Setup

### Key Take Away Points

- Parallel and serial buses are often combined with analog circuitry in many mixed-signal, embedded designs. An MSO provides unique insight into the operation of these systems.
- With the DPO4EMBD application module installed, the MSO4000B Series oscilloscope can trigger on, decode, and search SPI bus traffic. It can be installed in any of the four application module slots on the front panel of the instrument.

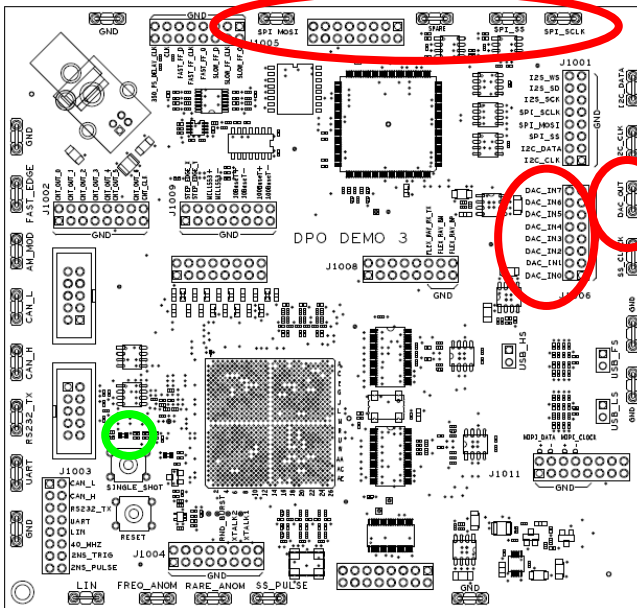


### MSO4000B Series Procedure:

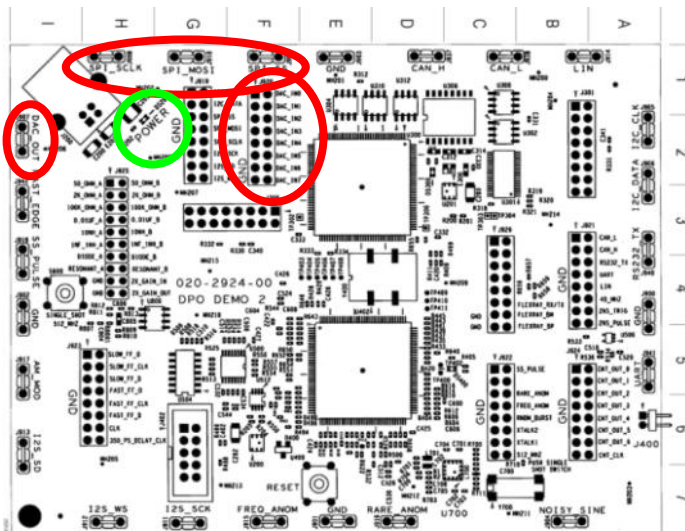
- With the oscilloscope power off, install the **DPO4EMBD** one of the application module slots on the front panel of the instrument.
- Power up the oscilloscope.
- Press the front panel **Utility** button.
- If necessary, press the **About** bottom bezel button to display the status screen.
- Verify that the **DPO4EMBD Embedded Serial Triggering and Analysis** application module is detected.
- Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a complete mixed-signal application circuit which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has a complete mixed-signal application circuit which we can use for this lab.

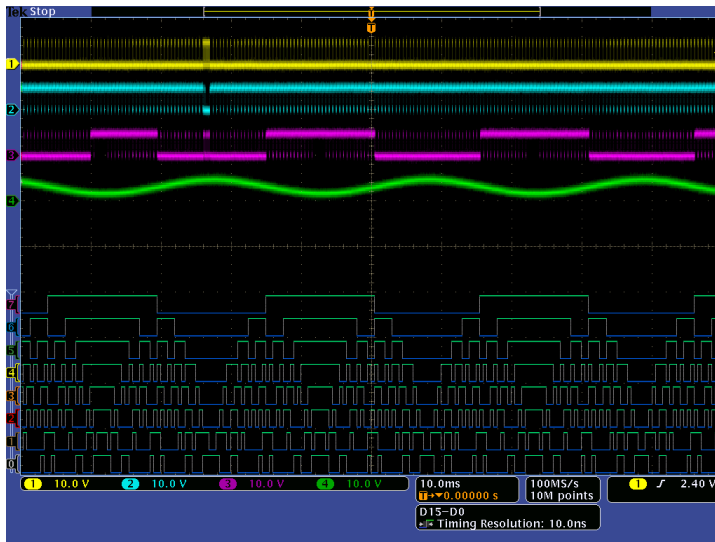


## DPO Demo Board Procedure:

- Power up the demo board.
- Verify the power LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **SPI\_SCLK** test point on the demo board.
- Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **SPI\_SS** test point on the demo board.
- Attach a TPP0500 or TPP1000 probe to the Channel 3 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **SPI\_MOSI** test point on the demo board.
- Attach a TPP0500 or TPP1000 probe to the Channel 4 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **DAC\_OUT** test point on the demo board.
- Attach a P6616 MSO probe to the front of the MSO. Set aside probe Group 2.
- Connect probe Bit 0 to **DAC\_IN0**, probe Bit 1 to **DAC\_IN1**, and so on, up to Bit 7 to **DAC\_IN7**.
- If the probe inputs have the ground extenders attached, make sure that the probe ground pins are all connected to the connector's GND pins on the left side of the connector. If the probe inputs do not have ground extenders attached, connect a ground wire from the automotive spade on the side of the probe to a GND test point on the board.

## Key Take Away Points

- The display should look about like this:



- Here you can see many SPI serial signals (channels 1-3), and analog sine wave (channel 4), and some digital signals (D7-D0). However, it is difficult to interpret the meaning of the digital data, especially the serial data, from this display.
- Let's look at an easy way to interpret the serial data.

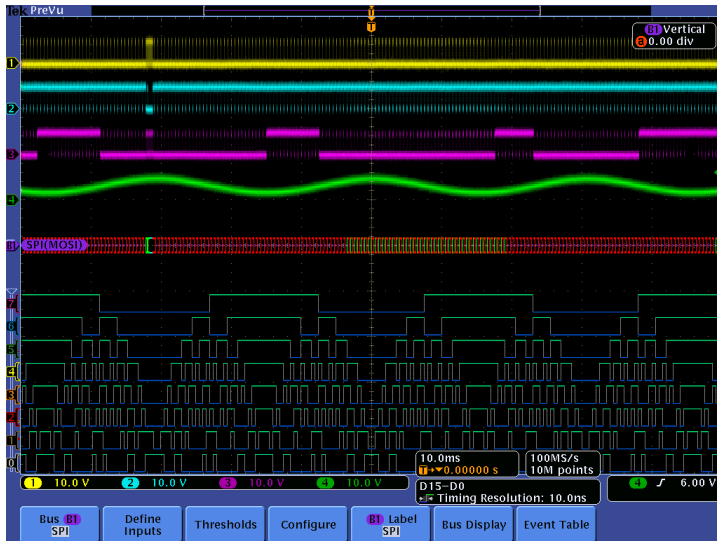
## MSO4000B Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Turn on all of the analog channels by pressing the front panel **2**, **3**, and **4** buttons.
- ❑ Press the blue front panel **D15-D0** button.
- ❑ Press the **D15-D0 On/Off** bottom bezel button.
- ❑ Press the **Turn On D7-D0** side bezel button.
- ❑ Press the front panel **Autoset** button.
- ❑ Set the Horizontal **Scale** to display a couple of cycles of the sine wave on channel 4. This value will be about **10 ms/div**.
- ❑ Press the front panel **D15-D0** button.
- ❑ Press the **Thresholds** bottom bezel button. Notice that Autoset has adjusted each of the digital channel thresholds.
- ❑ Turn the Multipurpose **a** control fully counter-clockwise to group all of the digital channels.
- ❑ Press the **Choose Preset** side bezel button and select **TTL** using the Multipurpose **a** control.
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **10M**.
- ❑ Press the front panel **Menu Off** button twice.
- ❑ Press the front panel **Single** button.

## MSO4000B Series SPI Bus Decoding

### Key Take Away Points

- The MSO4000B Series can automatically decode SPI bus data. Setting up a basic SPI bus waveform display takes only a few simple steps. After turning on a bus with a front panel button, the menus guide you through the setup in the left-to-right order across the bottom bezel buttons.
- The decoded serial bus (B1) is shown at the center of the display:



- When you use Wave Inspector to zoom in on the serial bus details, you can see the individual decoded data bytes:

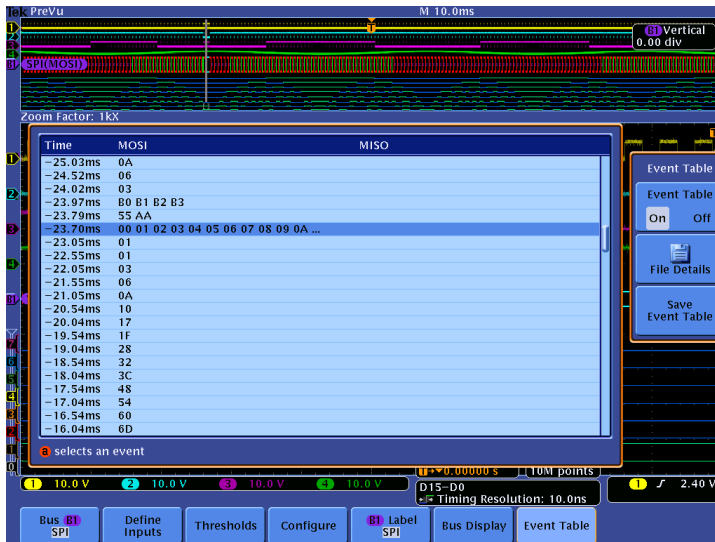


### MSO4000B Series Procedure:

- ❑ Press the front panel Bus **B1** button.
- ❑ Press the **Bus B1** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **SPI** Bus Type.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ Verify that **SS** Framing is selected, the SCLK Input is on channel **1**, the SS Input is on channel **2**, and the MOSI Input is on channel **3**.
- ❑ Press the **Thresholds** bottom bezel button.
- ❑ Using the Multipurpose **a** and **b** controls, set the Threshold values for channels 1, 2, and 3 to about **2.4 V**. Note that, when the analog signals are less than about 1 division high, this setting is very critical. You may need to adjust the thresholds or the vertical scale settings slightly to get consistent decoding.
- ❑ Press the **Configure** bottom bezel button.
- ❑ Verify that SCLK is a **rising-edge** clock, SS is **Active Low**, and MOSI is **Active High**.
- ❑ Press the **-more- 1 of 2** side bezel button.
- ❑ Verify that the Word Size is **8 bits** and that the Bit Order is **MS First**.
- ❑ Press the **Bus Display** bottom bezel button.
- ❑ Notice that the data can be displayed in **Hex** or **Binary**.
- ❑ Press **Menu Off** once to remove the side menu.
- ❑ Using the **Wave Inspector** pan and zoom controls, zoom in on one word of the decoded serial signal.

## Key Take Away Points

- Although the bus waveform display is very familiar to most hardware engineers, there are another display formats that other engineers, such as software engineers, may find more useful.
- For large quantities of data, and for those who are not comfortable with waveform displays, you can also use the Event Table to display the SPI data (in the selected format) along with the time stamps. The display should now look something like this:



- Notice that, from the Event Table menu, you can also save the Event Table data in .CSV format with a single button press.

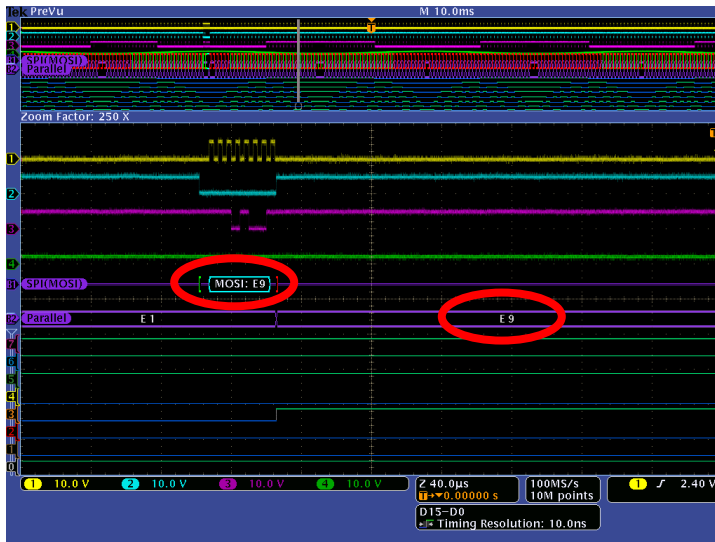
## MSO4000B Series Procedure:

- ❑ Press the **Event Table** bottom bezel button.
- ❑ Repeatedly press the **Event Table** side bezel button until it is set to **On**.
- ❑ Using the Multipurpose **a** control, slowly scroll through Event Table messages. Notice that the zoom indicators in the overview window indicate the message position in the acquired waveform.
- ❑ You can press the **Save Event Table** side bezel button to save the Event Table in CSV format to the pre-selected mass storage device.
- ❑ When you are done using the Event Table display, press the **Event Table** side bezel button to select **Off**.

## MSO4000B Series Parallel Bus Decoding

### Key Take Away Points

- The MSO4000B Series can automatically decode parallel buses, too. Setting up a basic parallel bus waveform display takes only a few simple steps. After turning on a bus with a front panel button, the menus guide you through the setup in the left-to-right order across the bottom bezel buttons.
- The decoded parallel bus (B2) is shown just below the center of the display. When you use Wave Inspector to zoom in on the decoded values on the serial and parallel buses, you can see the individual decoded data bytes:



### MSO4000B Series Procedure:

- ❑ Press the front panel Bus **B2** button.
- ❑ Press the **Bus B2** bottom bezel button. Verify that **Parallel** is selected.
- ❑ Using the Multipurpose **a** control, position bus B2 just below B1.
- ❑ Press the **Define Inputs** bottom bezel button.
- ❑ Verify that Clocked Data is set to **No**.
- ❑ Using the Multipurpose **a** control, set the Number of Data Bits to **8**.
- ❑ Press the **Bus Display** bottom bezel button.
- ❑ Notice that the data can be displayed in **Hex** or **Binary**.
- ❑ Press **Menu Off** once to remove the side menu.
- ❑ Using the **Wave Inspector** pan and zoom controls, zoom in on one word of the decoded serial signal and notice the relationship to the decoded values on the parallel bus.
- ❑ When you are done with zoom, press the Wave Inspector zoom button or turn the inner zoom control fully counter-clockwise to turn off zoom.

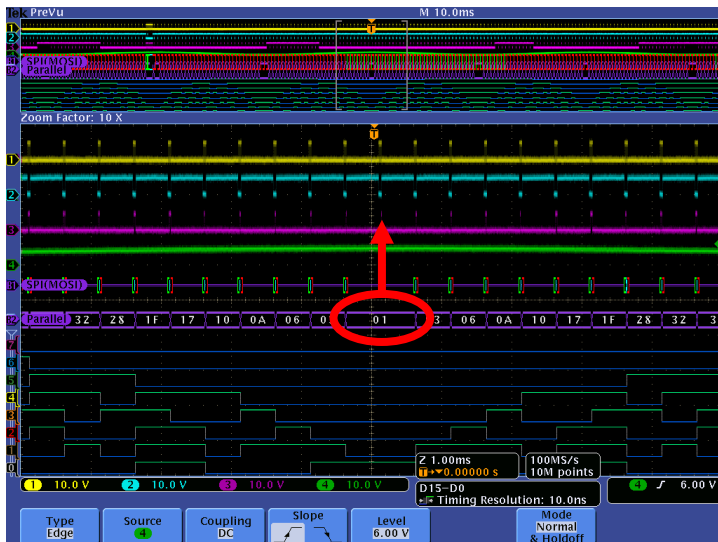
## MSO4000B Series Mixed-Signal Triggering

### Key Take Away Points

- What serial or parallel data values relate to the positive peak on the analog waveform? You can easily find out by triggering on the analog waveform and examining the decoded bus data, as shown below:



- Zooming in, we see that the digital value of 01 hex corresponds to the positive peak of the DAC output voltage:

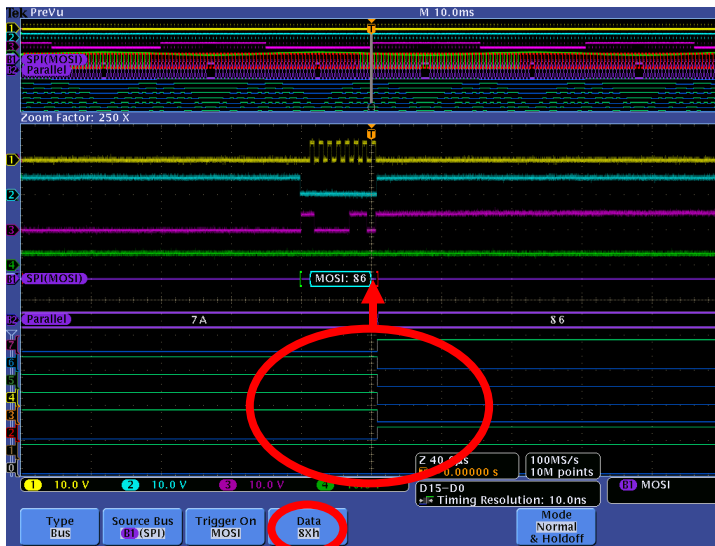


### MSO4000B Series Procedure:

- Turn off zoom.
- Press the front panel **Trigger Menu** button.
- Press the **Source** bottom bezel button.
- Using the Multipurpose **a** control, select channel **4** as the trigger source.
- Press **Menu Off**.
- Using the front panel **Trigger Level** control, set the trigger level at the top edge of the green channel 4 waveform.
- Press the front panel **Single** button.
  
- Adjust the Wave Inspector pan and zoom controls as needed to view the decoded data values at the time of the trigger event.

## Key Take Away Points

- What does the analog waveform look like when many of the digital inputs to the DAC are transitioning simultaneously?
- Many DACs generate glitches on their analog outputs when multiple digital inputs change at the same time. This is especially critical at mid-scale, where the 8-bit digital data values might be transitioning from 7F hex (0111 1111 binary) to 80 hex (1000 0000) binary.
- You can easily find out by triggering on the decoded digital values (in this case, either on the serial or parallel bus) and examining the analog waveform, as shown below:



- In this case, the DAC circuit is well-designed and there is no large mid-scale glitch on the analog output.

## MSO4000B Series Procedure:

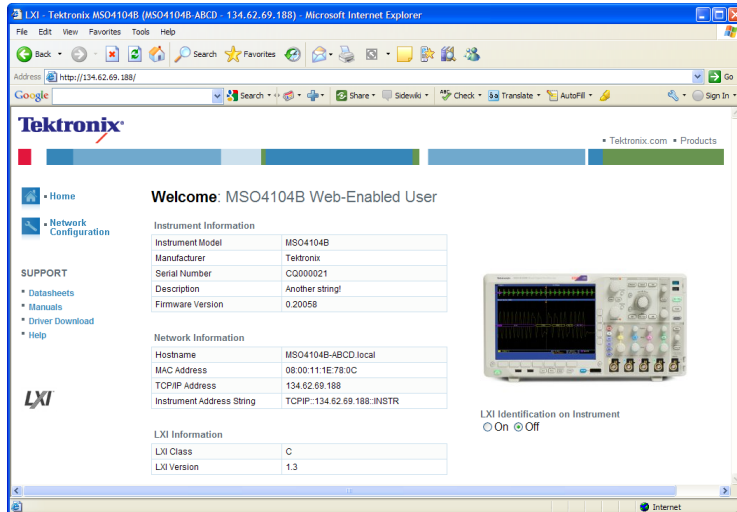
- ❑ Press the front panel Trigger **Menu** button.
- ❑ Press the **Type** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **Bus** Trigger Type.
- ❑ Verify that the Source Bus is set to **B1 (SPI)**.
- ❑ Press the **Trigger On** bottom bezel button.
- ❑ Press the **MOSI** side bezel button to trigger on a specific SPI data value.
- ❑ Press the **Data** bottom bezel button.
- ❑ Press the **MOSI** side bezel button.
- ❑ Using the Multipurpose **a** and **b** controls, set the trigger data value to **8X** hex. (It turns out that the exact values of 7F and 80 hex do not occur in this design.)
- ❑ Press **Menu Off**.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the Wave Inspector pan and zoom controls as needed to view the decoded bus values and the corresponding analog waveform.



# MSO4000B/DPO4000B Series

## LXI Class C Compliant

### Web Interface Lab



### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
- One TPP0500 or TPP1000 passive probe
- One PC with Internet browser installed
- One standard or cross-over Ethernet cable to connect the oscilloscope directly to the PC,  
or two standard Ethernet cables to connect both PC and oscilloscope to LAN

## Overview of MSO/DPO4000B Web Interface

Increasingly, companies are finding that distributed design teams are an efficient way to bring the right resources together for a design project. Engineers around the world need to share design details at the outset, and evaluation and measurement results as the project progresses.

The MSO/DPO4000B Series can be connected to the Internet via the LAN port and a standard web browser. An available LXI Class-C-compliant web interface enables control of network configuration, control of the oscilloscope using a graphical user interface including a regularly updated screen display (e\*Scope), and saving screen images and data to a remote location.

With the e\*Scope™ web based remote control feature, a common network browser, and Internet connection, engineers around the world can all see the oscilloscope display – at the same time. In addition, they can adjust the oscilloscope settings remotely to get a closer look at suspected problem areas in the waveform. And e\*Scope also provides tools to download the oscilloscope's stored waveform data and screen shots to the PCs anywhere in the world.

## Overview of LXI Class C Compliance

LXI (which stands for LAN eXtensions for Instrumentation) defines the communications protocols for instrumentation and data acquisition systems using Ethernet. LXI is a standard developed by the LXI Consortium, who maintain the LXI specification, promote the use of LXI, and ensure interoperability.

LXI-compliant devices can also interoperate with devices that are not LXI-compliant, as well as instruments that employ other remote interfaces such as GPIB, VXI, and PXI. To simplify communication with non-LXI instruments, every LXI instrument must have an Interchangeable Virtual Instrument (IVI) driver. The IVI Foundation defines a standard driver Application Programming Interface (API). There are two IVI driver formats in use in the industry: IVI-COM for working with COM-based (usually Windows) development environments and IVI-C for working in traditional programming languages and many industry-standard analysis tools.

LXI Class C is the baseline standard which provides LAN capabilities, a web interface, and IVI drivers. (Class B adds expanded triggering and communication capabilities. Class A devices build upon Class B devices by adding a wired trigger bus for precision triggering.) The MSO/DPO4000B Series interface is LXI Class C compliant.

## Objectives

- Obtain an overview of LXI Class C compliance
- Learn how to connect an oscilloscope to a PC via Ethernet.
- Obtain a basic understanding of the web interface (e\*Scope) connectivity.
- Learn how to remotely control an oscilloscope using e\*Scope.
- Learn how to transfer oscilloscope screen shots and data to a PC using e\*Scope.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- You can connect to the MSO/DPO4000B Series via Ethernet connection through a standard PC web browser by simply entering the oscilloscope's IP address in the address bar of the browser. The web interface enables viewing of instrument status and configuration, status and modification of network settings, and instrument control (e\*Scope).
- There are two ways to physically connect the oscilloscope and PC via Ethernet: through an existing IP network or directly ("peer-to-peer").
- The next step in connecting an oscilloscope to a PC via Ethernet is to assign an Internet Protocol (IP) address to the oscilloscope. This can be done in a couple of different ways. But it must be done carefully to prevent disruption on the network.
- NOTE: You should always discuss plans for network connections with the network administrator. If Dynamic Host Configuration Protocol (DHCP) is available to automatically supply the IP address, the network administrator can tell you. If you need a static IP address, you should get it from the network administrator.

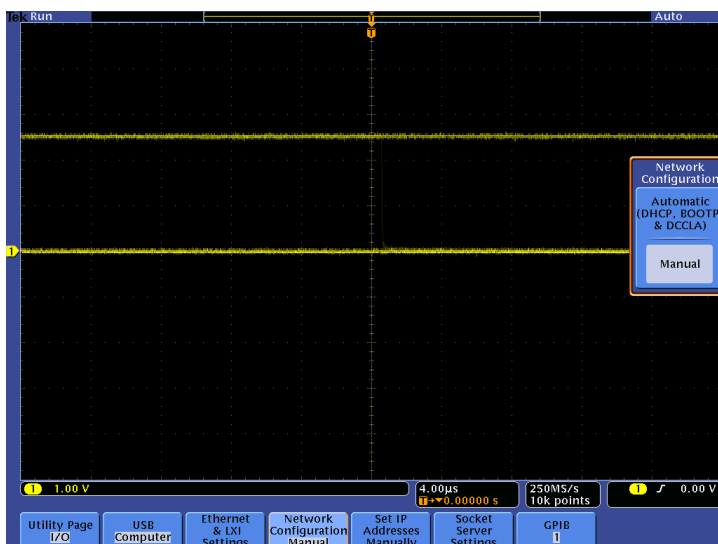
### MSO/DPO4000B Series Procedure:

- ❑ Connect the TPP0500 or TPP1000 probe to channel 1.
- ❑ Connect the probe tip to the PROBE COMP signal on the lower right corner of the oscilloscope.
- ❑ Connect the probe ground to the ground connection just above the PROBE COMP signal.
- ❑ For an IP network connection:
  - ❑ Connect a standard Ethernet cable between the network connection and the Ethernet connector on the oscilloscope's rear panel.
- ❑ For direct connection to your PC:
  - ❑ Connect a standard or cross-over Ethernet cable between the PC's Ethernet connector and the Ethernet connector on the oscilloscope's rear panel.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state. Note that this operation does not affect the Ethernet connection settings.
- ❑ Press the front panel **Autoset** button to get a stable display.
- ❑ Press the front panel **Utility** button.
- ❑ Press the **Utility Page** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **I/O** to control the Input/Output settings.

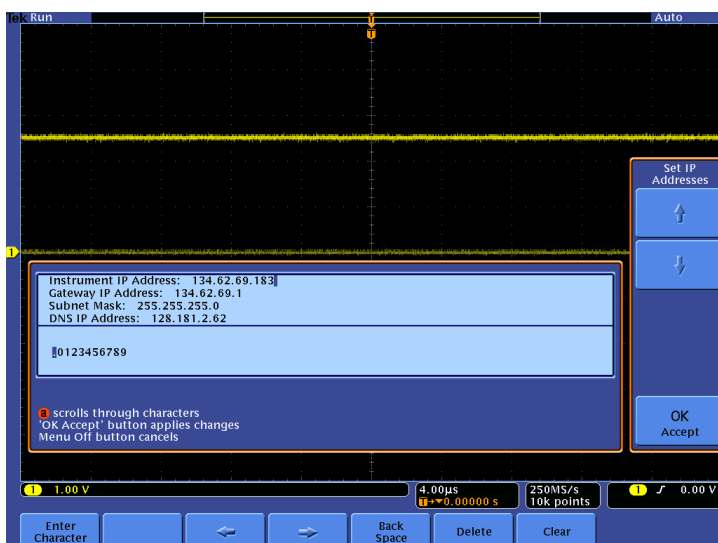
## Static IP Address Setup

### Key Take Away Points

- If using a static IP address, obtain a valid static IP address from your network administrator.
- If you are connecting to the PC via a network, you should also get the IP address for the network gateway. If you are connecting directly to your PC (a “peer-to-peer” connection), figure out the IP address of your PC, as the PC is the gateway for this kind of connection.
- To manually set up the IP address, you need to select Manual Network Configuration:



- The static IP address setup should look about like this:



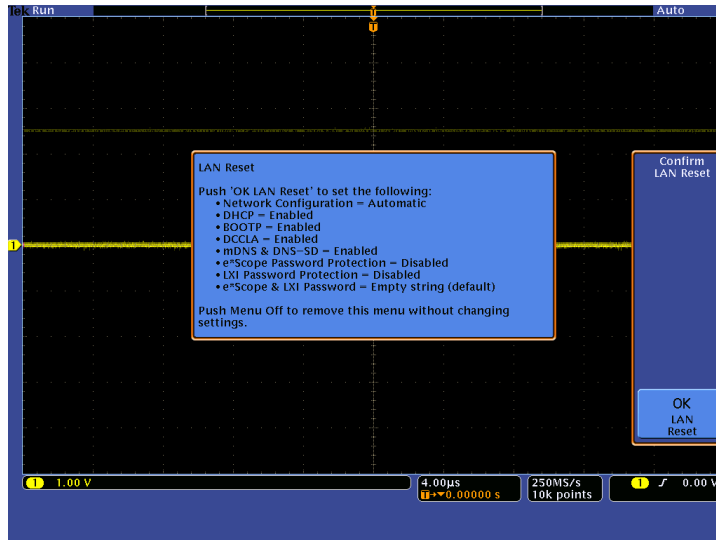
### MSO/DPO4000B Series Procedure:

- ❑ Press the **Network Configuration** bottom bezel button.
- ❑ Press the **Manual** side bezel button.
- ❑ Using the arrow side bezel buttons, move the cursor down to the **Instrument IP Address:** line.
- ❑ Using an attached USB keyboard or the Multipurpose a control and the bottom bezel buttons, enter the static IP address you received from the network administrator.
- ❑ Using the arrow side bezel buttons, move the cursor down to the **Gateway IP Address:** line.
- ❑ If you are connecting to a network, enter the network gateway IP address you received from the network administrator. If you are connecting directly to a PC, enter the PC's IP address. This gateway IP address field must be filled in for the Test Connection feature to work.
- ❑ Press the **OK Accept** side bezel button.
- ❑ Turn off the oscilloscope.
- ❑ Turn on the oscilloscope again to use the new IP addresses during the power-up configuration process.
- ❑ Press the front panel **Utility** button.
- ❑ Press the **Utility Page** bottom bezel button.
- ❑ Using the Multipurpose a control, select **I/O** to control the Input/Output settings.
- ❑ Press the **Test Connection** side bezel button to verify communication with the PC.

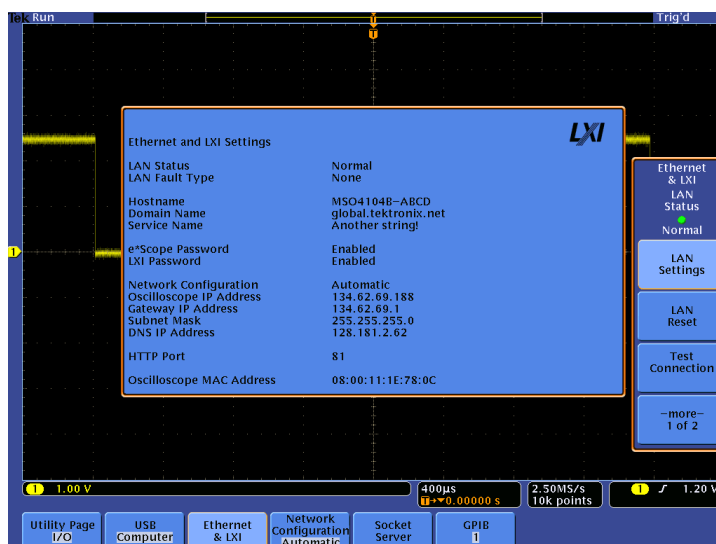
## Dynamic IP Address Setup

### Key Take Away Points

- If, instead, you want to use dynamic IP address setup, verify with the network administrator that it is available and follow this procedure.
- Start by resetting the LAN configuration:



- If you connected your oscilloscope to the network and are using DHCP, you should see a popup message displaying the assigned IP address. If instead, you receive an error message, you did not get an IP address assigned.
- You can press the Test Connection side bezel button to “ping” the gateway. This information could help troubleshoot the network connection.
- The LAN Settings page shows the Ethernet and LXI settings:



### PC Procedure:

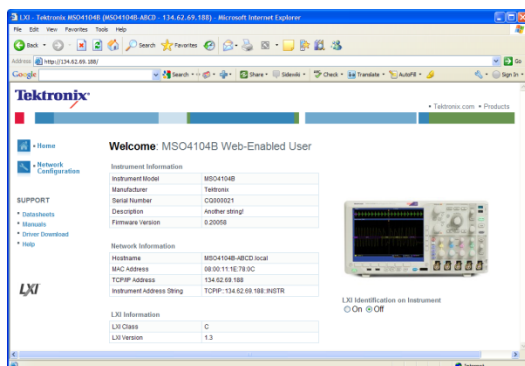
- ❑ Press the **Ethernet & LXI Settings** bottom bezel button.
- ❑ Press the **LAN Reset** side bezel button and the **OK LAN Reset** side bezel button. This operation takes a few seconds to complete.

- ❑ Press the **Test Connection** side bezel button to verify communication with the gateway.
- ❑ Press the **LAN Settings** side bezel button.

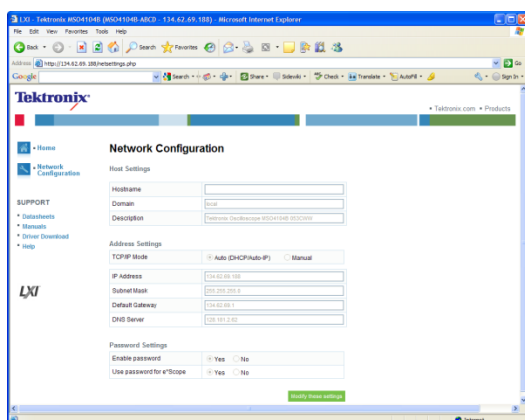
## LXI-enabled Instrument Control

### Key Take Away Points

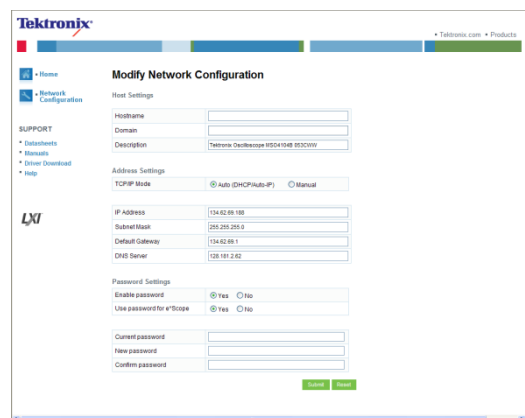
- When you enter the oscilloscope's IP address into the browser's address box, you should see the Instrument Welcome Page for the oscilloscope:



- The LXI Network Configuration page should look about like this:



- Pressing the Modify these settings button brings you to this web page:



### PC Procedure:

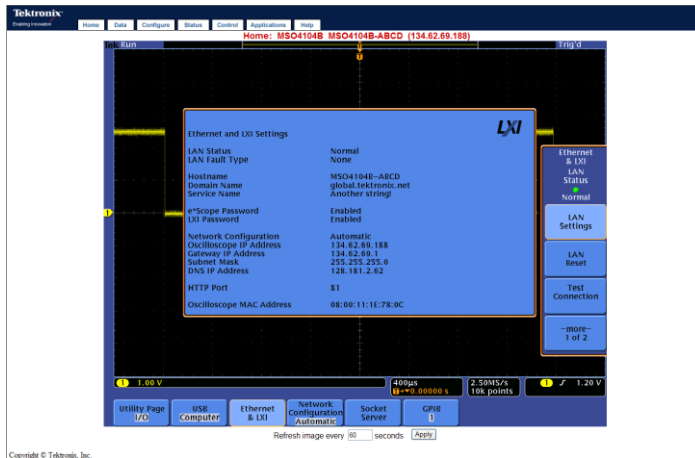
- Launch your Internet browser (e.g. Microsoft Internet Explorer) program on the PC.
- Type the oscilloscope's IP address into the web address box. You can use the default port address (80) or you can explicitly set the port address by appending ":80" to the end of the oscilloscope's IP address. For example:

**http://134.62.69.188:80**

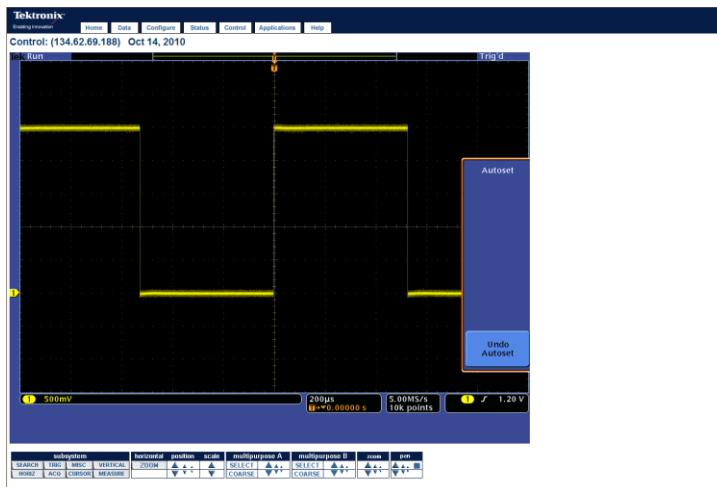
- The oscilloscope's LXI web page is displayed in your browser.
- Click on the **Network Configuration** link at the left side of the web page.

## Key Take Away Points

- When you select Instrument Control – e\*Scope, you will launch a separate window with the familiar e\*Scope display, showing the same display as on the oscilloscope:



- As shown above, you can easily capture the image of the entire browser window. You can also press the right mouse button while pointing to the screen image and select Save Picture As... to save the screen shot in .BMP format.
- Notice the oscilloscope display is now updated in the browser. By default, the display in the Home tab will be updated every 60 seconds.
- You can control the oscilloscope via the Control tab. Notice that the display in the Control tab is updated about once per second:



## PC Procedure:

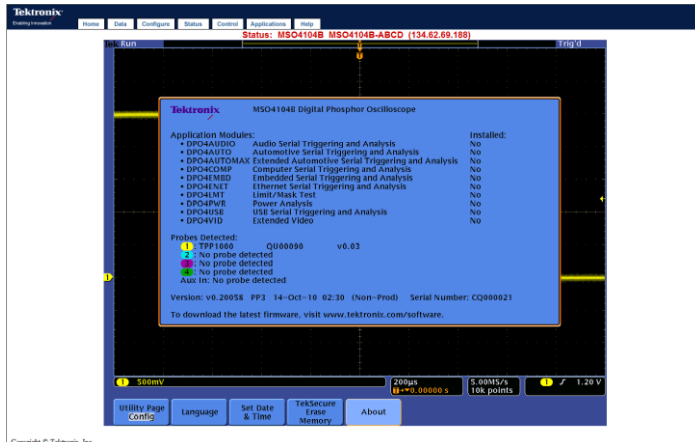
- Just as the LXI page is located on port 80 of the instrument's IP address, the e\*Scope instrument control pages for the oscilloscope are located on port 81.
- Type the oscilloscope's IP address into the web address box and append ":81" to the end of the oscilloscope's IP address. For example:

**http://134.62.69.188:81**

- Using your mouse, click on the **Control** tab at the top of the display.
- Click on the **ACQ** button in the subsystem menu at the bottom of the screen.
- Click on the **AUTOSET** button in the acquire menu to get a stable display.
- Click on the **MISC** button in the subsystem menu.
- Click on the **MENU OFF** button in the miscellaneous menu.
- Click on the **VERTICAL** button in the subsystem menu.
- Click on the large arrow keys in the vertical pos scale menu to scale and position the waveform in the center of the screen.
- Click on the **HORIZ** button in the subsystem menu.
- Click on the large arrow keys in the horizontal pos scale menu to scale and position the waveform in the center of the screen.

## Key Take Away Points

- When menus are displayed, you can click directly on the display to emulate pressing the corresponding side or bottom bezel button.
- You can display the oscilloscope's Utility->About information via the Status tab.



- You can also view instrument application information via the Applications tab, and Frequently Asked Question information via the Help tab. By default, these tabs point to the appropriate locations on tek.com, but this can be changed via the Configure tab.

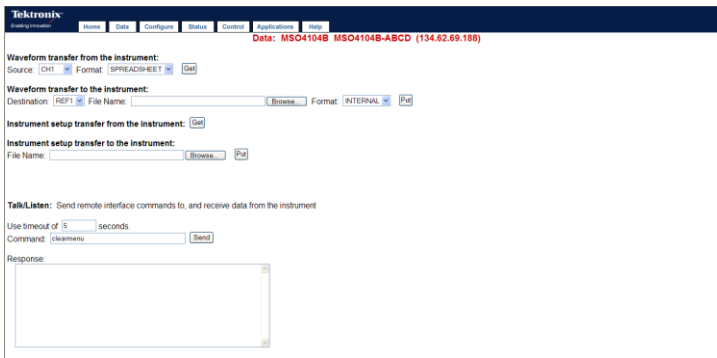
## PC Procedure:

- ❑ Click on the **Status** tab at the top of the screen.



## Key Take Away Points

- There are five features on the Data tab:
  - Waveform data transfer from the oscilloscope to the PC, in either binary (“INTERNAL” or .ISF) and text (“SPREADSHEET” or .CSV) format. The source waveform can be an analog channel, a math channel, a reference, or an MSO’s digital channel.
  - Binary waveform data can be transferred from the PC to one of the references.
  - The instrument setup file can be downloaded to the PC. This is a text file which contains all of the oscilloscope’s current settings.
  - An oscilloscope setup file can also be uploaded from the PC to the oscilloscope.
  - Commands can be sent to the oscilloscope through the Talk/Listen interface on the Data tab. This is a way to remotely control the instrument use the programmable interface. See the Programmer Manual for further information.
- The Data tab looks like this:

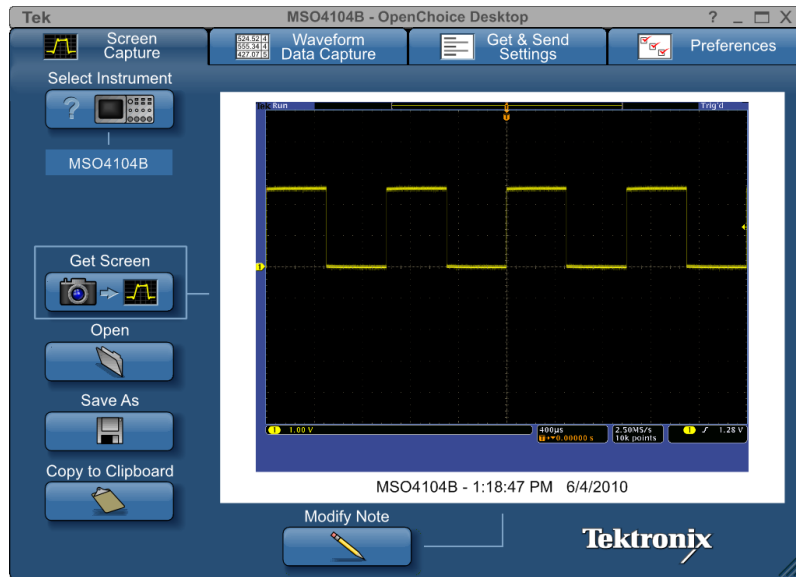


## PC Procedure:

- Click on the **Data** tab at the top of the screen.
- Under **Waveform transfer from the instrument:**, set the Source to **CH1** and the Format to **SPREADSHEET**.
- Press the **Get** button.
- Press the **Save** button in the Windows File Download popup message and specify the filename to save the data file to your PC.
- Under **Instrument setup transfer from the instrument:**, press the **Get** button.
- Press the **Save** button in the Windows File Download popup message and specify the filename to save the setup file to your PC.
- Notice that “clearmenu” is the default command. Press the **Send** button in the Talk/Listen: section. Notice that this command has the same effect as pressing Menu Off on the oscilloscope.
- Type **\*IDN?** into the Command: text box and press **Send**.
- Notice that a text string of instrument identification information is returned in the Response: text box.
- Type **Curve?** Into the Command: text box and press **Send**.
- Notice that a long list of waveform data information is returned in the Response: text box. Notice that you can scroll up and down through the data values.
- Type **Set?** Into the Command: text box and press **Send**.
- Notice that the instrument setup information is returned in the Response: text box.

# MSO4000B/DPO4000B Series

## OpenChoice Desktop Connectivity Lab



### Equipment List

One MSO/DPO4000B Series oscilloscope with the latest firmware version installed

One TPP0500 or TPP1000 passive probe

One PC with OpenChoice Desktop and TekVISA installed

(software comes on CD with each instrument and is available for free download from [www.tek.com](http://www.tek.com))

One USB cable (174-4401-00)

## Overview of OpenChoice Desktop Connectivity

For simple oscilloscope / PC connectivity, the OpenChoice Desktop program provides most of the features that most users are looking for, with USB plug-n-play ease of use. With just a few clicks of a mouse, the free OpenChoice Desktop program easily transfers screen shots, waveform data, and setup files to the PC. The program also provides tools for remotely controlling the instrument from the PC and debugging control programs.

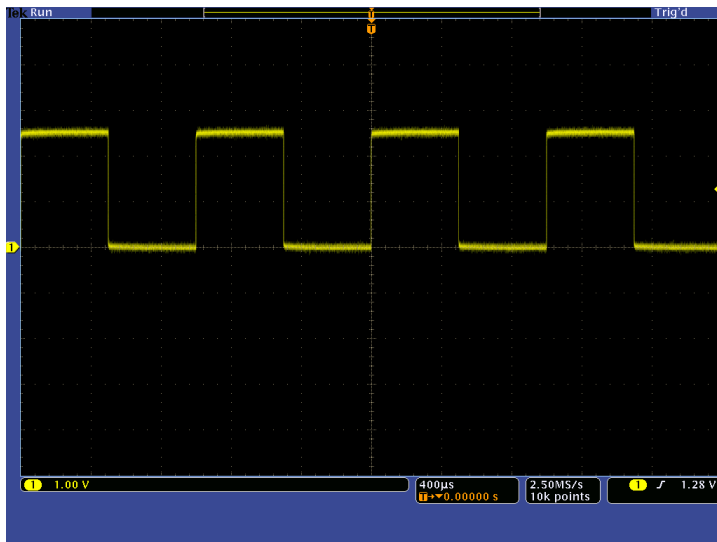
### Objectives

- Obtain a basic understanding of OpenChoice Desktop connectivity.
- Learn how to use USB plug-n-play to connect an oscilloscope to a PC.
- Learn how to transfer oscilloscope screen shots, waveform data, and oscilloscope setup files to a PC using OpenChoice Desktop.
- Learn how to remotely control an oscilloscope using Talker/Listener scripts.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- For this lab, set up a simple display, such as the PROBE COMP signal:



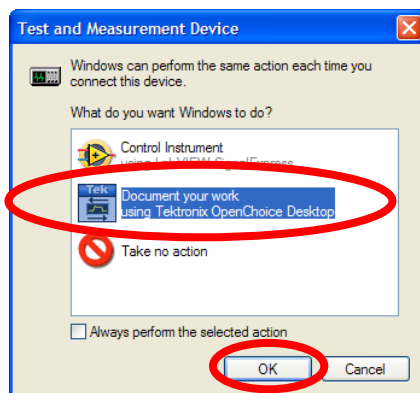
### MSO/DPO4000B Series Procedure:

- Power up the oscilloscope.
- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Connect the TPP0500 or TPP1000 probe to channel 1.
- Connect the probe tip to the PROBE COMP signal on the lower right corner of the oscilloscope.
- Connect the probe ground to the ground connection just above the PROBE COMP signal.
- Press the front panel **Autoset** button.
- Repeatedly press the **Menu Off** button until all menus are removed.

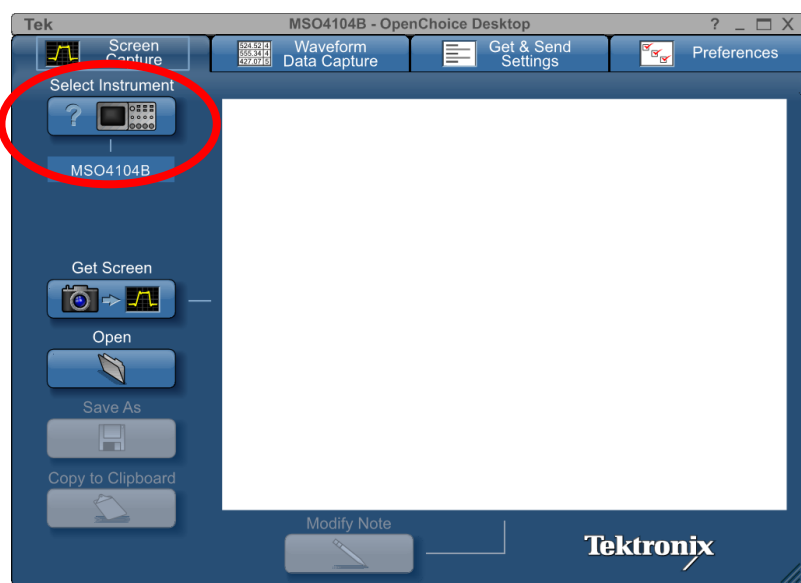
## Basic OpenChoice Desktop Lab

### Key Take Away Points

- After you connect the USB cable between the oscilloscope and the PC, the USB plug-n-play driver should launch a Test and Measurement Device window like this:



- When you select the OpenChoice Desktop icon, the program will launch and automatically select the instrument which you connected, as shown in the upper left corner:



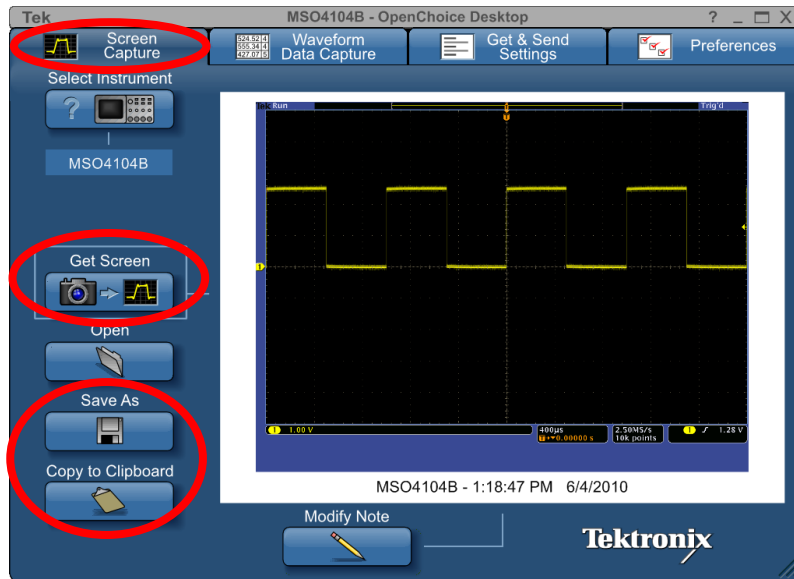
- Although the connected oscilloscope was automatically selected, you can manually select a different instrument by pressing the Select Instrument button.
- Notice that tabs at the top of the display. The three most basic capabilities of OpenChoice Desktop are found on the first three tabs:
  - Capture a screen image for archival or insertion into documentation or a presentation.
  - Capture waveform data for off-line analysis or archival.
  - Get and send instrument setup files.

### PC Procedure:

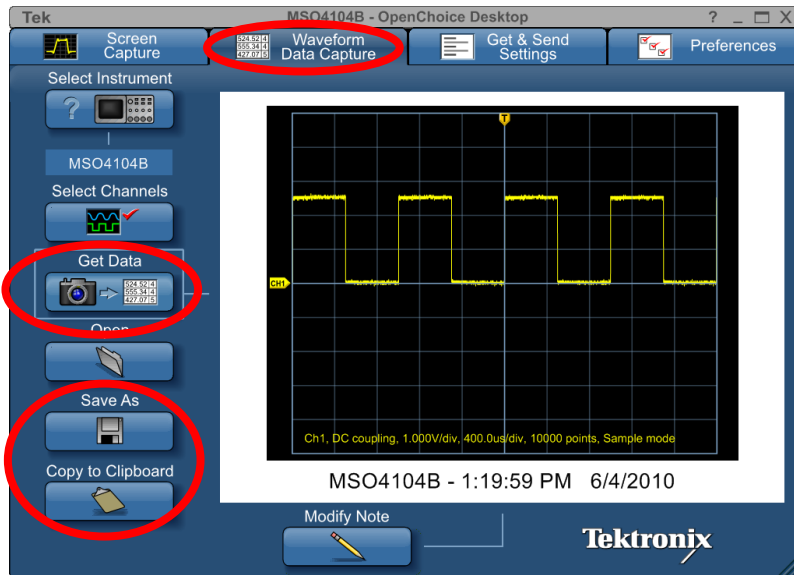
- Connect the rectangular end of the USB cable to a USB Host port on the PC and connect the 'D' shaped connector to the USB Device port on the back of the oscilloscope.
- Highlight the **Document your work using Tektronix OpenChoice Desktop** selection.
- Click on the **OK** button.

## Key Take Away Points

- With a single mouse click, you can download the oscilloscope's screen image, and with one more mouse click you can save the image to the PC or copy it to the Windows Clipboard:



- The image file is automatically annotated with the instrument name and time and date of the image capture. You can press the **Modify Note** button and change the text to add your own note.
- Just as easily, you can download, graph, and save the acquired waveform data with two mouse clicks:



- The displayed channels are selected by default, but you can manually select which channels of waveform data to download by pressing the Select Channels button.

## PC Procedure:

- ❑ Notice that the **Screen Capture** tab at the top of the OpenChoice Desktop screen has been selected.
- ❑ Click on the **Get Screen** button on the left side of the screen.
- ❑ Click on the **Save As** button on the left side of the screen to specify a file path and save the image on your PC.

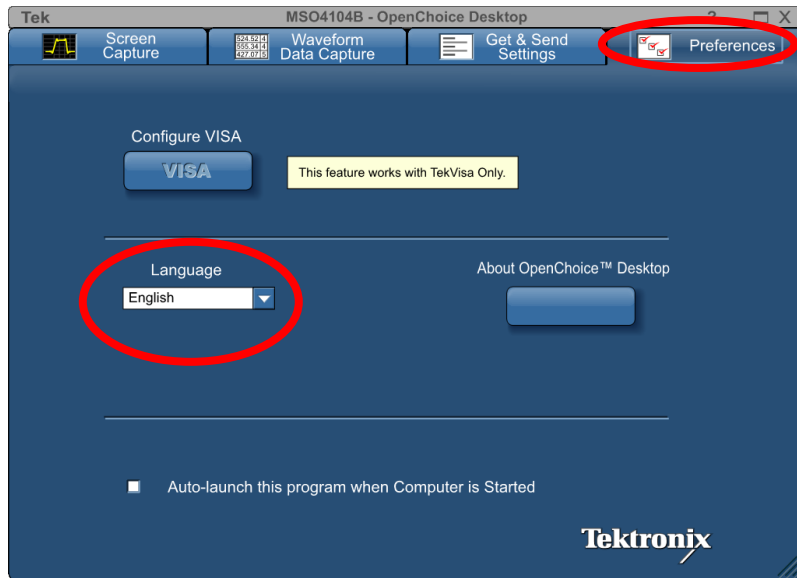
- ❑ Click on the **Waveform Data Capture** tab at the top of the OpenChoice Desktop screen.
- ❑ Click on the **Get Data** button on the left side of the screen.
- ❑ Click on the **Save As** button on the left side of the screen to specify a file path and save the data file on your PC.

## Key Take Away Points

- With a single mouse click, you can download the oscilloscope's current setup information, as shown in the text window below. The scroll bar at the right side of the text window allows you to examine each of the many settings:



- If you want to upload a setup file from the PC to the oscilloscope, press the **Send Settings** button, or press the **Send to Multiple** button to send the setup file to multiple instruments.
- The final Preferences tab provides a number of useful capabilities and tools.



## PC Procedure:

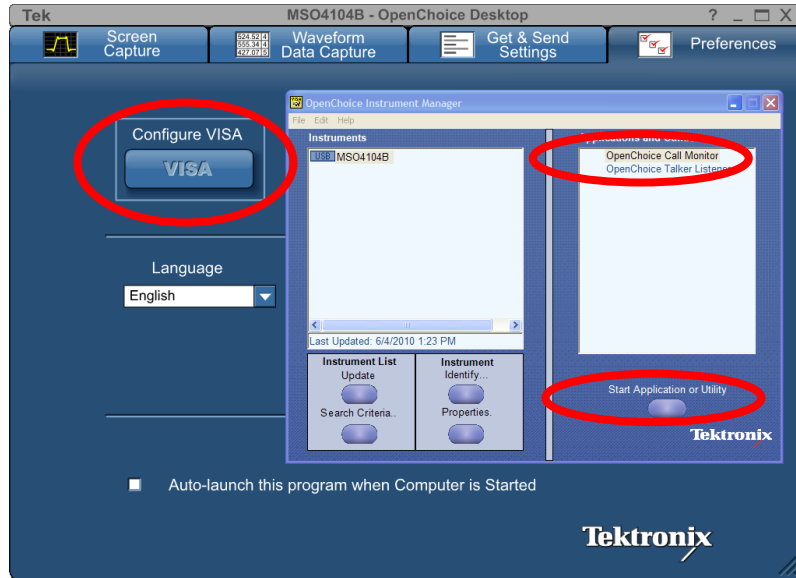
- ❑ Click on the **Get & Send Settings** tab at the top of the OpenChoice Desktop screen.
- ❑ Click on the **Get Settings** button on the left side of the screen.
- ❑ Click on the **Save As** button on the left side of the screen to specify a file path and save the setup file on your PC.
- ❑ Click on the **Send Settings** button on the left side of the screen to send the file back to the oscilloscope.

- ❑ Click on the **Preferences** tab at the top of the OpenChoice Desktop screen.
- ❑ Click on the **Language** drop-down menu and select one of the available languages for the OpenChoice Desktop user interface.
- ❑ Click on the **About OpenChoice Desktop** button to display version information.
- ❑ Click on the popup screen to clear it.

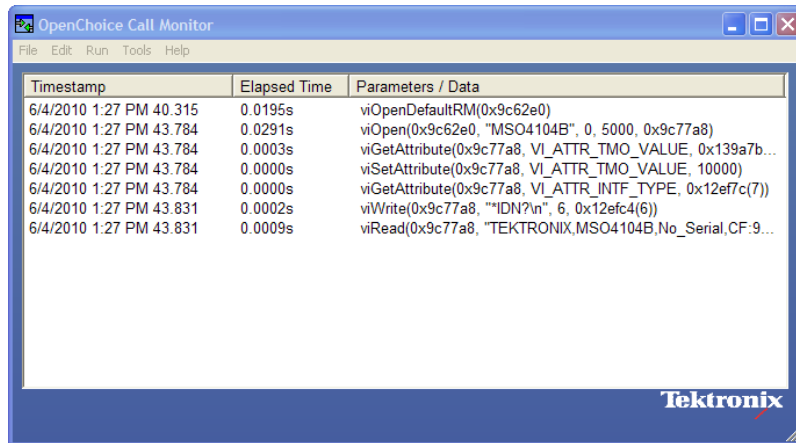
## Call Monitor and Talker / Listener Lab

### Key Take Away Points

- The OpenChoice Instrument Manager program provides two applications by default.



- The first application is the OpenChoice Call Monitor. This program monitors the communications between the oscilloscope and the PC:



- The call monitor can be used to capture, time, and log the low-level communications. For example, the screen shot above captures all of the steps when the "\*IDN?" query is sent to the oscilloscope.

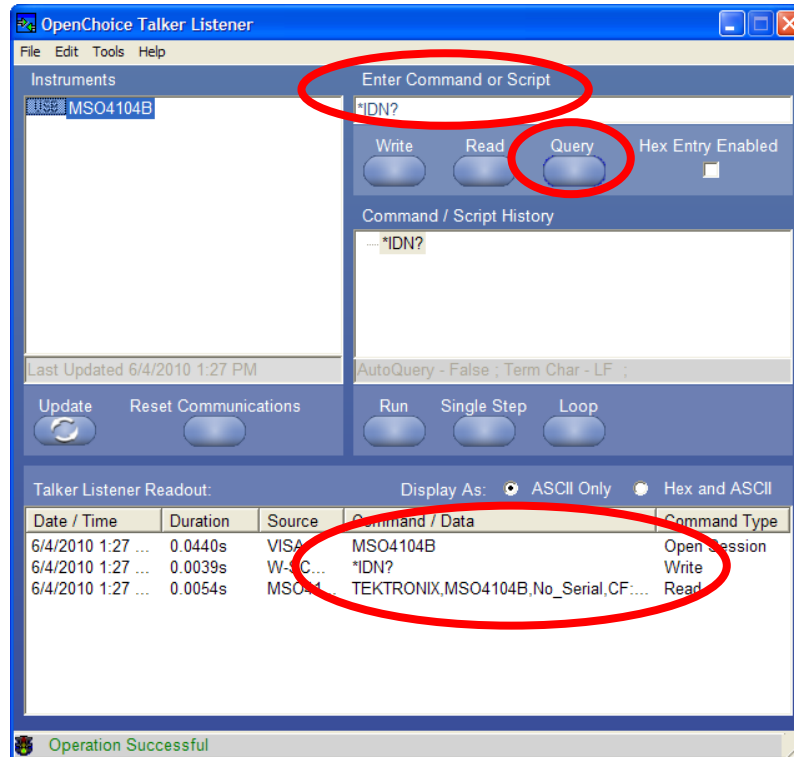
### PC Procedure:

- Click on the **Configure VISA** button to launch the OpenChoice Instrument Manager program.
- In the Instrument Manager program, click on the **OpenChoice Call Monitor** entry to highlight it and click on the **Start Application of Utility** button.

- In the Instrument Manager program, click on the **OpenChoice Talker Listener** entry to highlight it and click on the **Start Application of Utility** button.

## Key Take Away Points

- The second application is the OpenChoice Talker Listener which allows you to interact with the oscilloscope using the programmable interface. For details, see the MSO/DPO4000B Programmer's Manual.
- By default, the “\*IDN?” query is loaded into the text box at the top of the screen.



- As shown in the bottom section of the display, the query opens a VISA session (first line), sends the command to the oscilloscope (second line), and reads back the oscilloscope's response (third line).
- You can type other commands and queries into the text box at the top. Click on the **Write** button if it is a command or the **Query** button if it is a query.
- The commands are logged in the Command / Script History window. To repeat any of those commands, simply click on them to copy them into the text box at the top and then click on the **Write** or **Query** button.

## PC Procedure:

- ❑ Click on the **Query** button to send the “\*IDN?” query to the oscilloscope.
- ❑ Click on the **Tools** menu at the top of the screen, select **Options...**, check the **AutoQuery** box, and click **OK**.

- ❑ Type “**FACTory**” into the text box at the top of the screen and click on the **Write** button.
- ❑ Type “**SET?**” into the text box at the top of the screen and click on the **Query** button.
- ❑ Click on “**FACTory**” in the Command / Script History window in the center of the screen and click on the **Write** button.

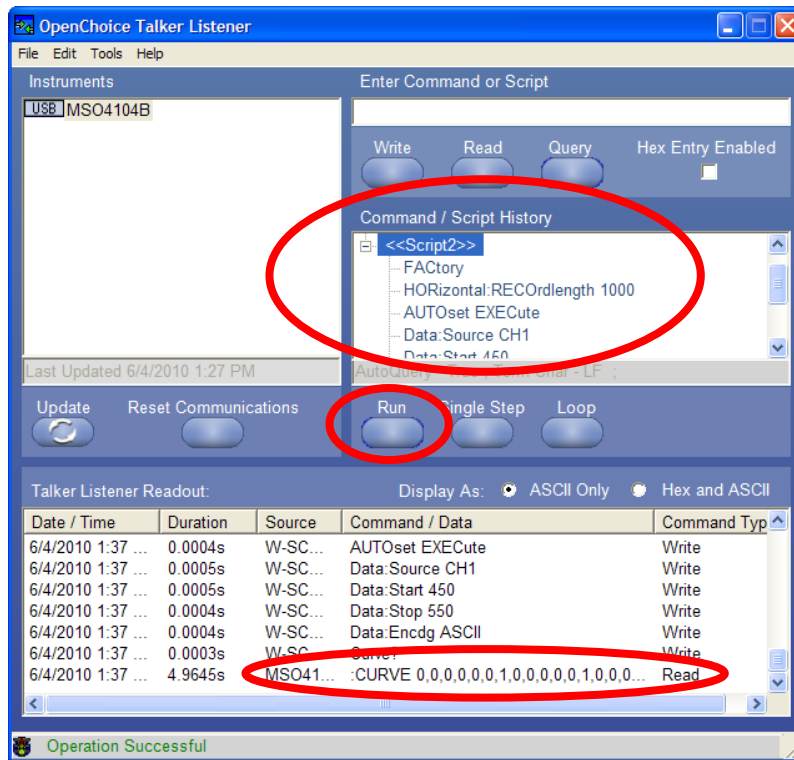


## Key Take Away Points

- If you have repetitive or complex tasks, you may find it easier to save the commands into a script file and reload them from the file.
- Here is a simple example program which extracts the middle 101 samples out of a 1000 point acquisition:

```
Talker Listener Script: <<Script2>>
FACTory
HORizontal:RECOrdlength 1000
AUTOset EXECute
Data:Source CH1
Data:Start 450
Data:Stop 550
Data:Encdg ASCII
Curve?
```

- You can read and execute a command script with just a few clicks of the mouse:



## PC Procedure:

- ❑ Using a simple text editor like Windows Notepad, create a text file called “**StartStop.txt**” with the following contents:

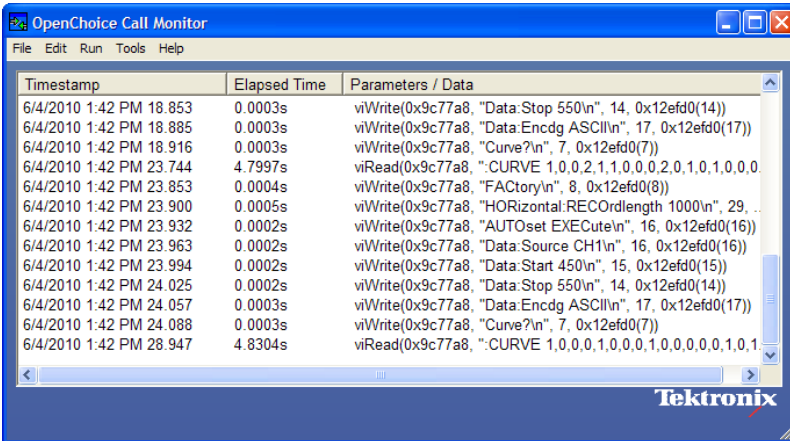
### Talker Listener Script:

```
<<Script2>>
FACTory
HORizontal:RECOrdlength 1000
AUTOset EXECute
Data:Source CH1
Data:Start 450
Data:Stop 550
Data:Encdg ASCII
Curve?
```

- ❑ Click on the **File** menu at the top of the screen, click on **Open Script...**, navigate to and select the file you just created, and click on the **Open** button.
- ❑ Notice that the script file text has been loaded into the center Command / Script History window on the display.
- ❑ Press the **Run** button to run the script.

## Key Take Away Points

- Now, go back and look at the OpenChoice Call Monitor. Notice it has logged all of the communications between the oscilloscope and the PC:

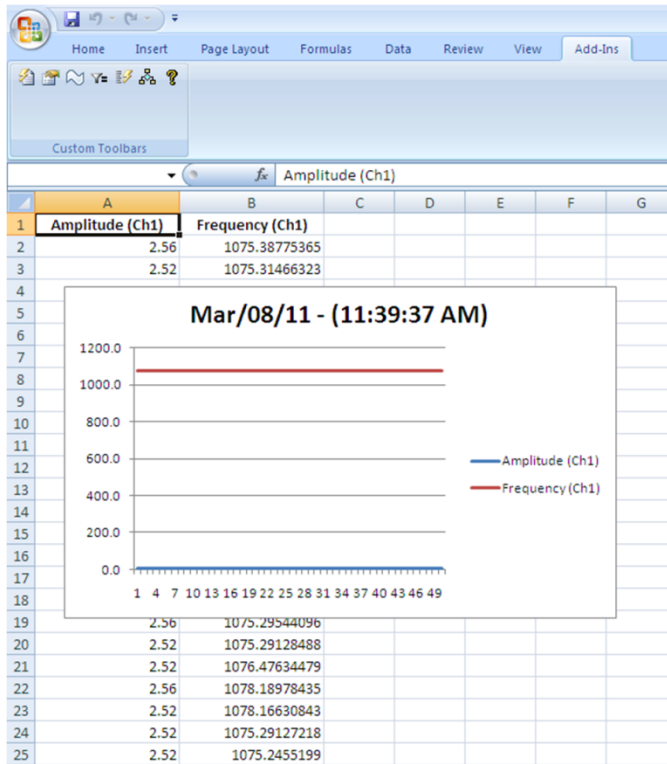


## PC Procedure:

- In the OpenChoice Call Monitor program, click on **File**, click on **Save...**, type in a file path and file name, and click **Save** to save the log file.

# MSO4000B/DPO4000B Series

## TekXL and TekW Toolbars Lab



### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
- One TPP0500 or TPP1000 passive probe
- One PC with Microsoft Office, TekXL and TekW toolbars, and TekVISA installed  
(This Tektronix software is available for free download from [www.tek.com](http://www.tek.com))
- One USB cable (174-4401-00)

## Overview of PC Connectivity with TekXL and TekW Toolbars

For simple connectivity between an oscilloscope and Microsoft Word and Excel applications on the PC, the TekW and TekXL toolbars provide most of the features that most users are looking for. With just a few clicks of a mouse, the free toolbars easily transfer screen shots, waveform data, measurements, and setup files to the PC and insert them directly into Word documents and Excel spreadsheets.

The TekW Word toolbar allows you to:

- Connect the oscilloscope to the PC over USB.
- Get oscilloscope settings from the oscilloscope, save them to a file, and send them back to the oscilloscope, all from within Word.
- Capture an acquired waveform, graph the data values, and insert the graph into the document.
- Capture automatic measurement values at regular time intervals and insert a table of values into the document.
- Capture triggered waveforms, graph the data, and insert the graph into the document.
- Capture triggered automatic measurement data and insert a table of values into the document.
- Capture the oscilloscope's screen image and insert it into the document.

The TekXL Excel toolbar allows you to:

- Connect the oscilloscope to the PC over USB.
- Get oscilloscope settings from the oscilloscope, save them to a file or workbook, and send them back to the oscilloscope, all from within Excel.
- Capture an acquired waveform, insert the data values into the spreadsheet, and optionally graph the data.
- Capture automatic measurement values at regular time intervals, insert a table of values into the spreadsheet, and optionally graph the measurement data.
- Capture triggered waveforms and insert the data values into columns in the spreadsheet.
- Capture triggered automatic measurements and insert the data values into the spreadsheet.
- Capture the oscilloscope's screen image and insert it into the spreadsheet.

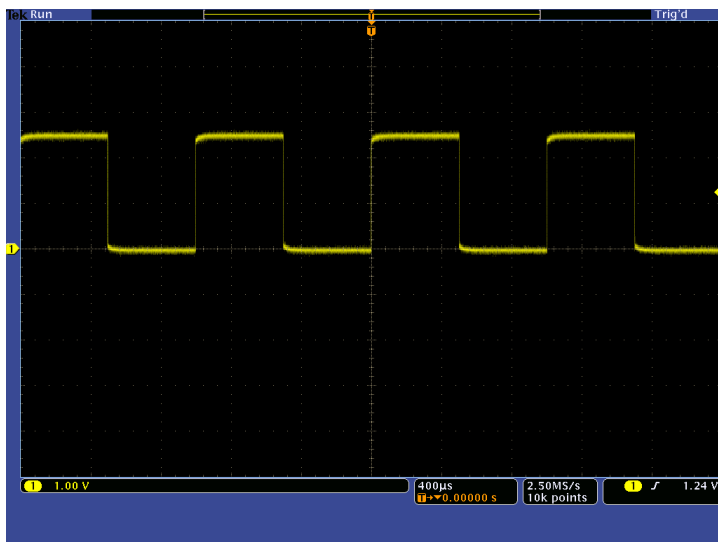
### Objectives

- Learn how to install the Tek toolbars into the Microsoft Office applications and connect the oscilloscope to the PC via USB.
- Learn how to transfer oscilloscope screen shots, waveform data, and automatic measurement results directly into a Word document on a PC.
- Learn how to transfer oscilloscope waveform data, timed measurements, triggered waveform captures, and screen shots directly into an Excel spreadsheet on a PC.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- For this lab, set up a simple display, such as the PROBE COMP signal:

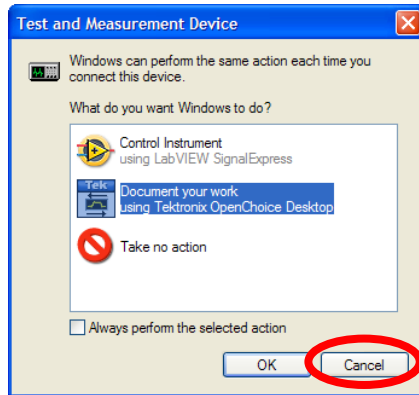


### MSO/DPO4000B Series Procedure:

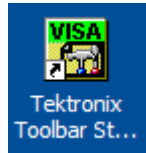
- Power up the oscilloscope.
- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Connect the TPP1000 or TPP0500 probe to channel 1.
- Connect the probe tip to the PROBE COMP signal on the front of the oscilloscope.
- Connect the probe ground to the ground connection next to the PROBE COMP signal.
- Press the front panel **Autoset** button.

## Key Take Away Points

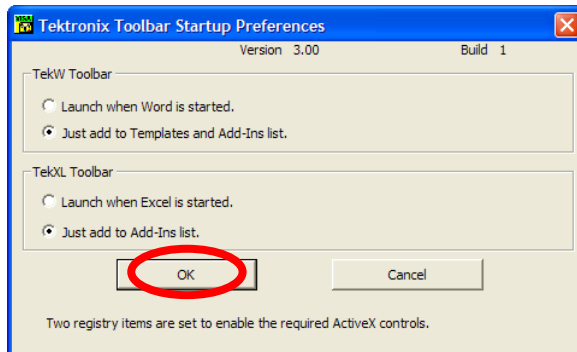
- After you connect the USB cable between the oscilloscope and the PC, the USB plug-n-play driver may launch a Test and Measurement Device window like this on the PC display:



- When you installed the toolbars on your PC, the following icon was probably installed on your PC desktop:



- From this configuration window you can specify whether or not the toolbars will be launched automatically or manually (through the Tools->Templates and Add-ins list in Excel 2007 or File->Options->Add\_Ins in Excel 2010):



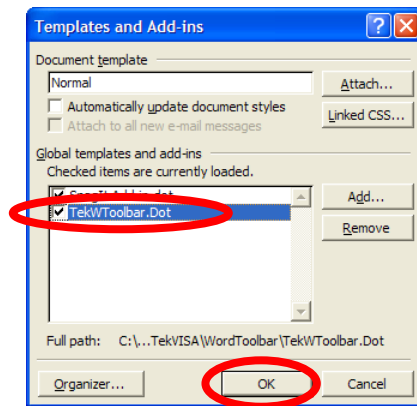
## PC Procedure:

- Connect the rectangular end of the USB cable to a USB Host port on the PC and connect the 'D' shaped connector to the USB Device port on the back of the oscilloscope.
- If the Test and Measurement Device popup appears, click on the **Cancel** button.
- Double-click on the **Tektronix Toolbar Startup** icon.
- When you are done, click on the **OK** button.

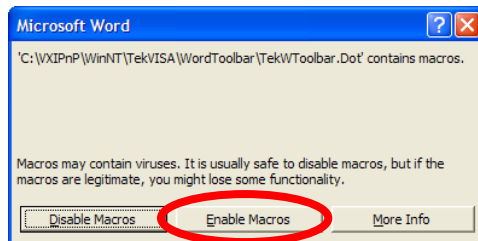
## TekW Toolbar Lab

### Key Take Away Points

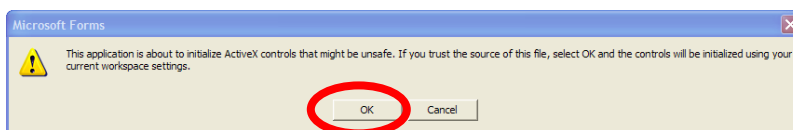
- If you need to add the TekWToolbar template add-in, you should see the following popup:



- Then you may see a security warning that macros have been disabled. If this happens, click on the Enable button:



- Finally, you may see this popup:



- When the TekWToolbar is properly installed, you should see it appear at the top of the display:

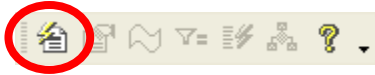


### PC Procedure:

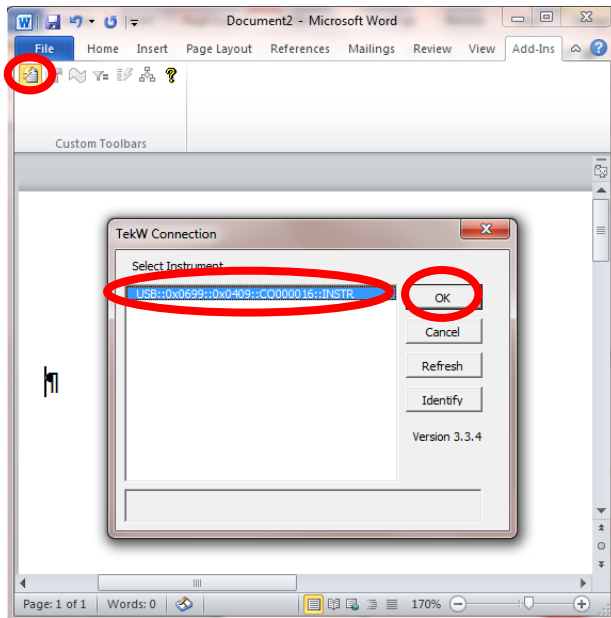
- ❑ Launch Microsoft Word.
- ❑ If the TekW toolbar does not appear near the top of the Word window:
  - ❑ The interface varies between versions of Word, but for Word 2002:
    - ❑ Click on **Tools** and then click on **Templates and Add-ins...**
    - ❑ Check the box next to **TekWToolbar.Dot**.
    - ❑ Click on **OK**.
    - ❑ Right click in the menu area at the top of the Word window and click on **TekWToolbar** to display the toolbar.
  - ❑ For Word 2007:
    - ❑ Click on the **Office Button** and **Word Options**.
    - ❑ Select **Add-Ins**.
    - ❑ Select **Templates** in the **Manage** text box and press **Go...**
    - ❑ Check the box next to **TekWToolbar.Dot**.
    - ❑ Click on **OK**.
    - ❑ Click on the new **Add-Ins** tab at the top of the screen.
  - ❑ For Word 2010:
    - ❑ Select **File-> Options-> Add-Ins**.
    - ❑ Select **Word Add-ins** in the **Manage** text box and press **Go...**
    - ❑ Check the box next to **TekWToolbar.Dot**.
    - ❑ Click on **OK**.
    - ❑ Click on the new **Add-Ins** tab at the top of the screen.
- ❑ If you see a warning popup about macros, click on the **Enable Macros** button.
- ❑ If you see a warning popup about initializing ActiveX controls, click on the **OK** button.

## Key Take Away Points

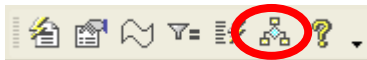
- Work from left to right across the TekWToolbar to set up and use the toolbar features:



- The first step is to connect to the oscilloscope. Simply select it from the list of connected devices:



- For documentation tasks in Word, the most useful feature will likely be the TekW Screen Capture button:



- When you click on the TekW Screen Capture button, the oscilloscope screen image will be inserted into the Word document at the cursor, much more easily than saving the image to a flash drive and copying it into the document.

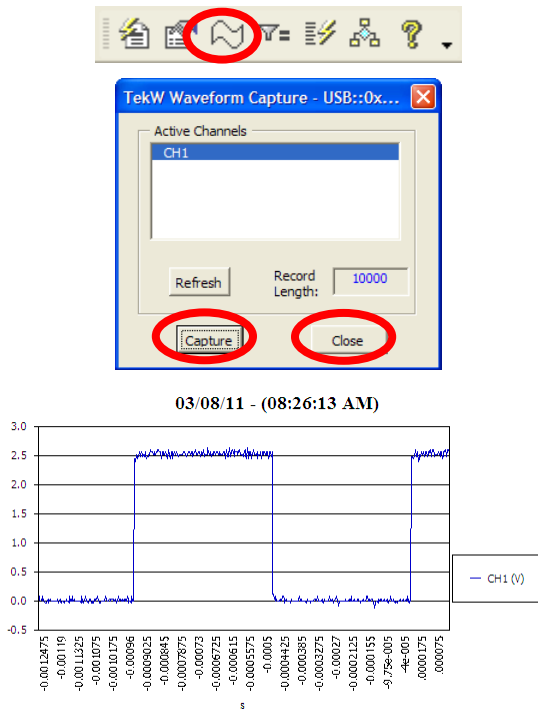
## PC Procedure:

- ❑ Mouse over each of the buttons in the TekWToolbar to discover their functions.
- ❑ Click on the left-most button in the TekWToolbar. A mouse-over will identify it as **TekW Connection**.
- ❑ Highlight the oscilloscope in the list and click on the **OK** button.
- ❑ Place your cursor in your Word document at the location where you would like to insert an oscilloscope screen image.
- ❑ Click on the sixth button from the left in the TekWToolbar. A mouse-over will identify it as **TekW Screen Capture**.



## Key Take Away Points

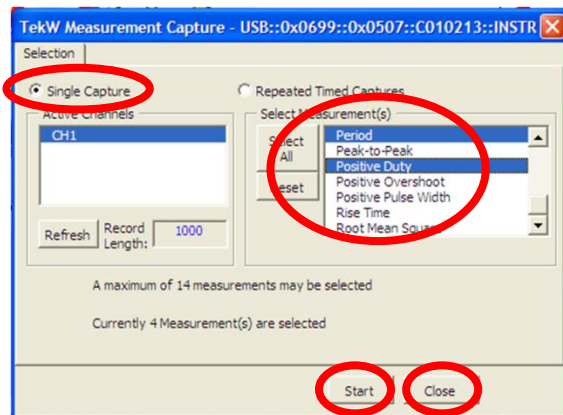
- You can also graph the waveform data with the TekW Waveforms feature:



- The other very useful TekW feature for most documentation tasks is to quickly and remotely capture waveform measurements using the TekW Measurements button:



- Select up to 14 automatic measurements from the list:



- When you click Start, you will automatically insert a table of measurement values at the cursor:

CH1	CH1 Frequency	CH1 Period	CH1 Positive Duty
Amplitude 2.52	1075.37722217	0.00092990625	49.99474235935

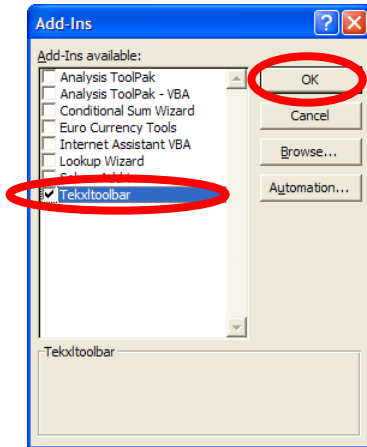
## PC Procedure:

- Click on the third button from the left in the TekWToolbar. A mouse-over will identify it as **TekW Waveforms**.
- Click on the **Capture** button to capture the selected waveform data, graph it, and insert it into the document at the cursor.
  
- When you are done, click on the **Close** button.
  
- Click on the fourth button from the left in the TekWToolbar. A mouse-over will identify it as **TekW Measurements**.
  
- Click on the **Single Capture** radio button at the top of the window.
- You select and deselect measurements from the list by clicking on them. **Amplitude** is already highlighted. Click on the **Frequency**, **Period**, and **Positive Duty** measurements in the list at the right side of the screen.
- Click on the **Start** button to insert the measurement table.
  
- Click on the **Close** button when you are done.

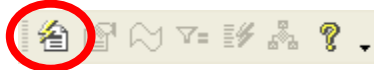
## TekXL Toolbar Lab

### Key Take Away Points

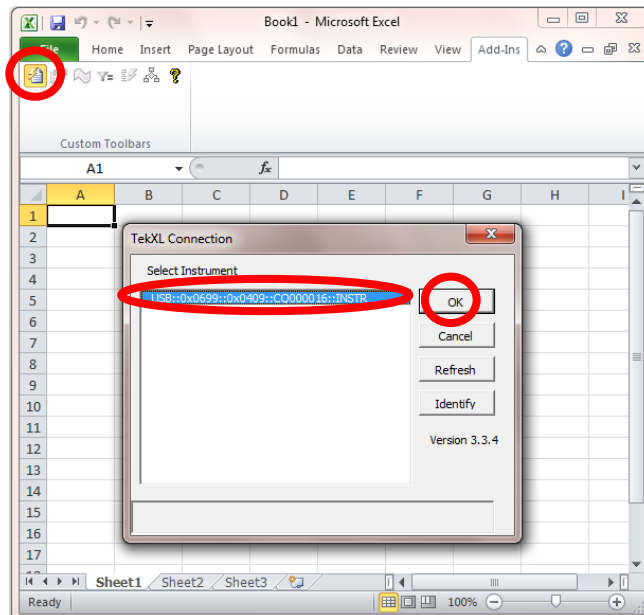
- If you need to add the TekXLToolbar add-in, you should see the following popup:



- When the TekXLToolbar is properly installed, you should see it appear at the top of the display. Work from left to right across the TekXLToolbar to set up and use the toolbar features:



- The first step is to connect to the oscilloscope. Simply select it from the list of connected devices:

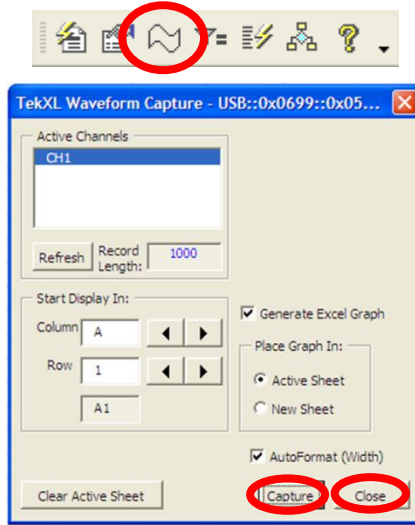


### PC Procedure:

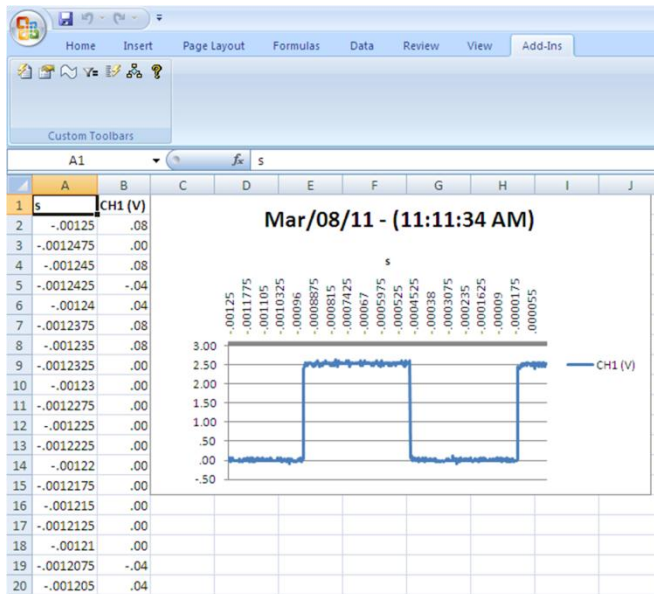
- Launch Microsoft Excel.
- If the TekXL toolbar does not appear near the top of the Word window:
  - The interface varies between versions of Excel, but for Excel 2002:
    - Click on **Tools** and then click on **Add-ins....**
    - Check the box next to **Tekxltoolbar**.
    - Click on **OK**.
  - For Excel 2007:
    - Click on the **Office Button** and **Excel Options**.
    - Select **Add-Ins**.
    - Select **Excel Add-ins** in the **Manage** text box and press **Go....**
    - Check the box next to **Tekxltoolbar**.
    - Click on **OK**.
    - Click on the new **Add-Ins** tab at the top of the screen.
  - For Excel 2010:
    - Select **File-> Options-> Add-Ins**.
    - Select **Excel Add-ins** in the **Manage** text box and press **Go....**
    - Check the box next to **Tekxltoolbar**.
    - Click on **OK**.
    - Click on the new **Add-Ins** tab at the top of the screen.
- Mouse over each of the buttons in the TekXLToolbar to discover their functions.
- Click on the left-most button in the TekXLToolbar. A mouse-over will identify it as **TekXL Connection**.
- Highlight the oscilloscope in the list and click on the **OK** button.

## Key Take Away Points

- For analysis tasks in Excel, one of the most useful features will be the TekXL Waveforms button:



- By default, the TekXL Waveforms feature will insert the data values in the active Excel tab and automatically generate a graph of the data values, starting at the specified column and row coordinates:



## PC Procedure:

- Click on the third button from the left in the TekXLToolbar. A mouse-over will identify it as **TekXL Waveforms**.
- Click on the **Capture** button to capture the selected waveform data, graph it, and insert it into the document at the cursor.

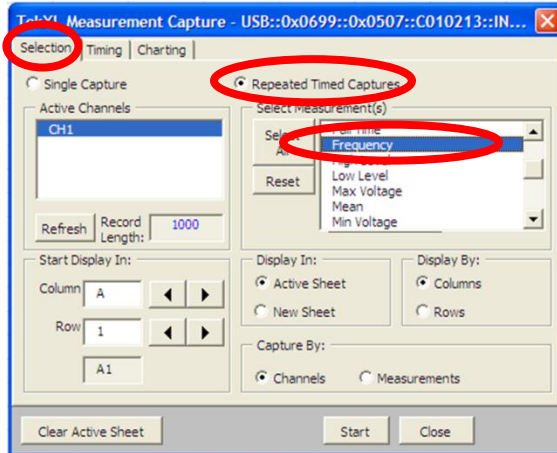
- When you are done, click on the **Close** button.

## Key Take Away Points

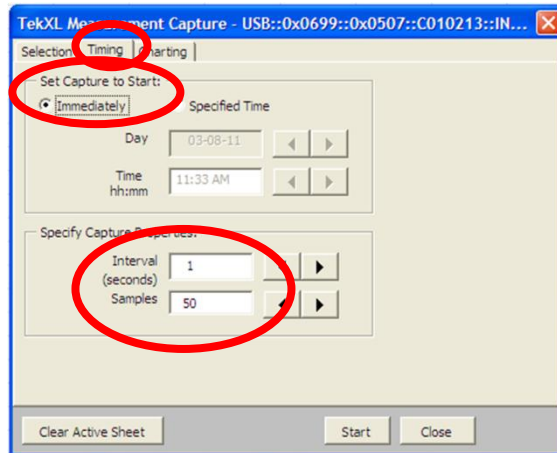
- Another very useful TekXL feature for analysis tasks is to automatically log regularly-scheduled waveform measurements using the TekXL Measurements button:



- Select up to 14 automatic measurements from the list:



- On the Timing tab, you can select how many measurements to make, how often, and when to start the measurements. By default, you will get 50 measurements, taken once a second, starting as soon as you click on the Start button:

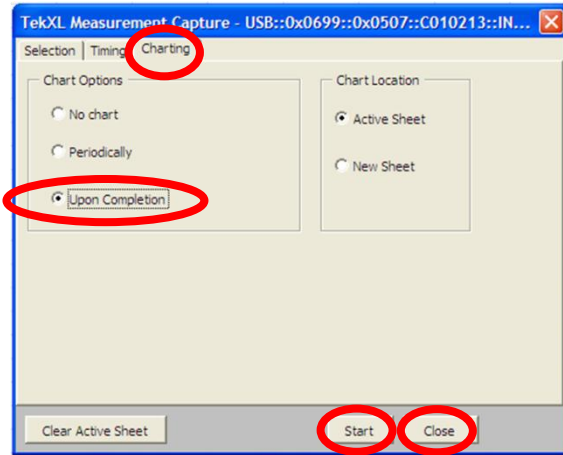


## PC Procedure:

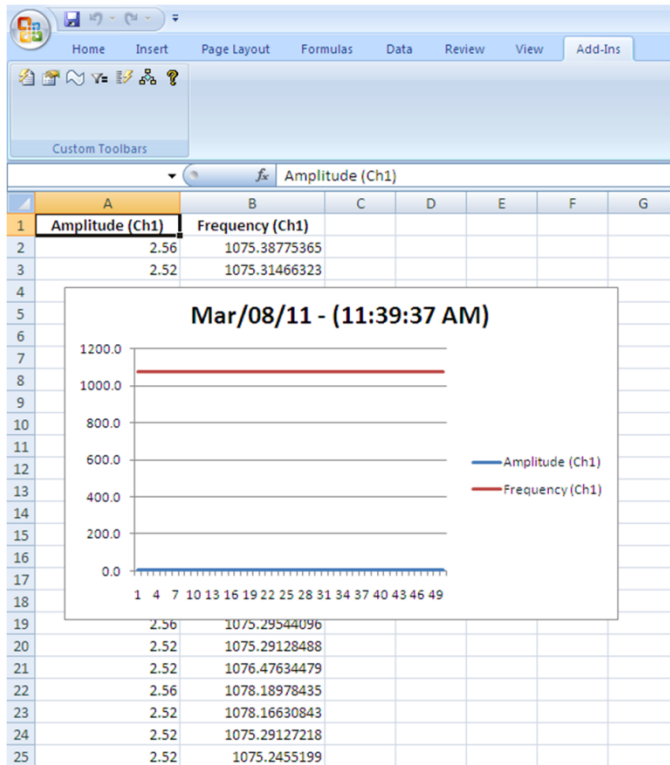
- ❑ Click on the fourth button from the left in the TekXLToolbar. A mouse-over will identify it as **TekXL Measurements**.
- ❑ On the **Selection** tab, click on the **Repeated Timed Captures** radio button at the top of the window.
- ❑ You select and deselect measurements from the list by clicking on them. **Amplitude** is already highlighted. Click on the **Frequency** measurement in the list at the right side of the screen.
- ❑ Click on the **Timing** tab at the top of the window.

## Key Take Away Points

- On the Charting tab, you can select whether or not you automatically generate a graph of the measurement values:



- By default, the TekXL Measurements feature will insert the measurement values in the active Excel tab and automatically generate a graph of the values, starting at the specified column and row coordinates (specified on the Selection tab):



## PC Procedure:

- Click on the **Charting** tab at the top of the window.
- Click on the **Upon Completion** radio button to specify that the graph will be generated after all of the measurement values are acquired.
- Click on the **Start** button to insert the measurement table.

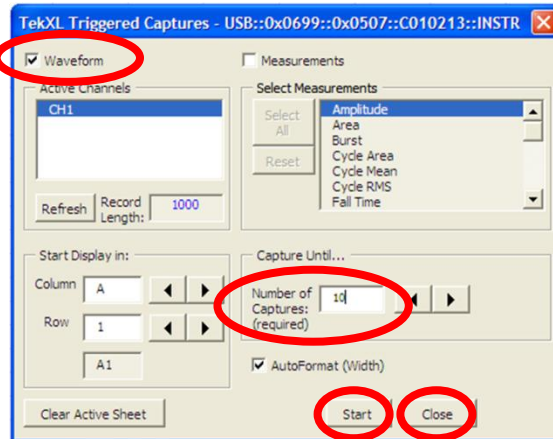
- Click on the **Close** button when you are done.

## Key Take Away Points

- If you want to intermittently capture waveform or measurement data only when the oscilloscope triggers, you will find the TekXL Triggered Captures feature to be useful:

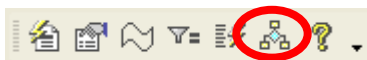


- The TekXL Triggered Captures feature allows you to select among the active waveforms or among the list of automatic measurements. You can specify how many triggered sets of data you want to log:



- By default, the TekXL Triggered Captures feature will insert the measurement values in the active Excel tab and automatically generate a graph of the values, starting at the specified column and row coordinates.

- Finally, just like with TekW toolbars, you can insert an oscilloscope screen shot into the document with the TekXL Screen Capture button:

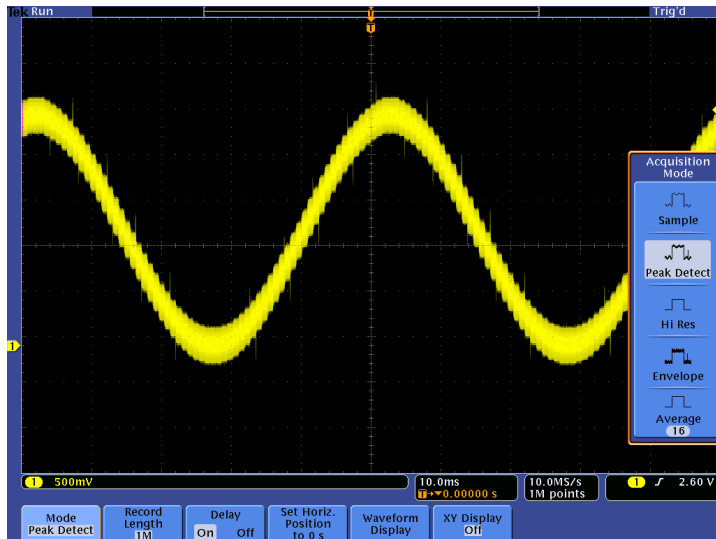


## PC Procedure:

- ❑ Click on the fifth button from the left in the TekXLToolbar. A mouse-over will identify it as **TekXL Triggered Captures**.
- ❑ Click on the **Waveform** radio button at the top of the window.
- ❑ Set the **Number of Captures** to **10**.
- ❑ Click on the **Start** button to insert the triggered waveform data table.
- ❑ Click on the **Close** button when you are done.
- ❑ Click on the sixth button from the left in the TekXLToolbar. A mouse-over will identify it as **TekXL Screen Capture**.

# MSO4000B/DPO4000B Series

## Acquisition Lab



### Equipment List

One MSO/DPO4000B Series oscilloscope with the latest firmware version installed  
Two TPP0500 or TPP1000 passive probes  
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)  
[Note: screen shots in this document were made with 020-2924-XX demo board]

## Understanding the MSO/DPO4000B Series Acquisition Modes

You are probably familiar with the analog (hardware) bandwidth-limit filters on the inputs of most oscilloscopes. The MSO/DPO4000B Series has such bandwidth filters in the analog channel menu (250 MHz and 20 MHz low-pass filters) which can be used to remove high-frequency noise from a signal. For example, the 20 MHz filter can be very useful to eliminate stray RF signals from low-frequency circuits like power supplies.

However, the MSO/DPO4000B Series also provides several more powerful acquisition tools that enable you to control the acquisition of a complex signal. This lab goes through some of these features step-by-step to allow you to see the capabilities.

### Lab Objectives

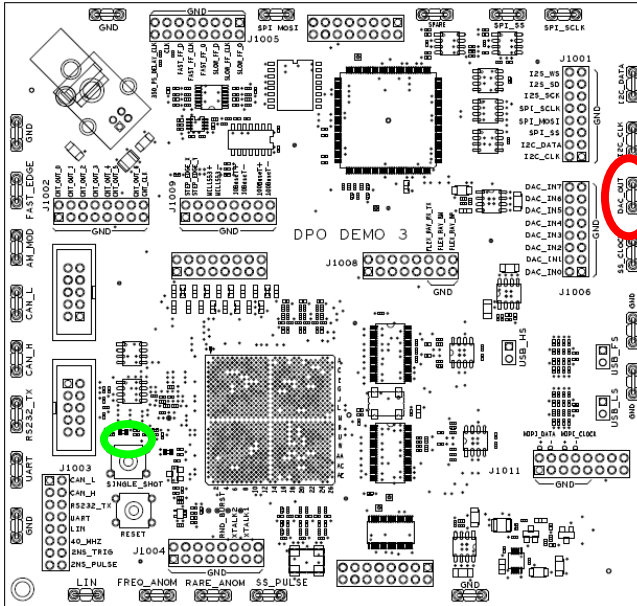
- Obtain a basic understanding of MSO/DPO4000B Series acquisition mode controls.
- Learn how to apply peak detect to reliably capture signal spikes.
- Learn how to apply averaging techniques to remove noise from signals.



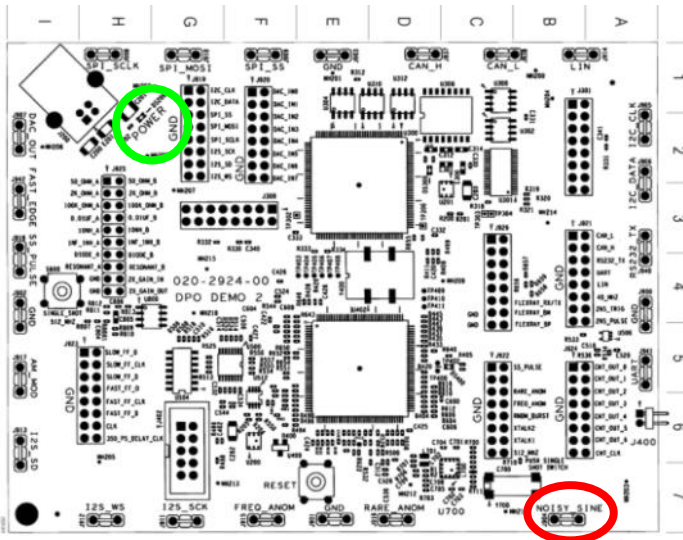
## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a DAC\_OUT signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) has a Noisy Sine signal which we will use for this lab.

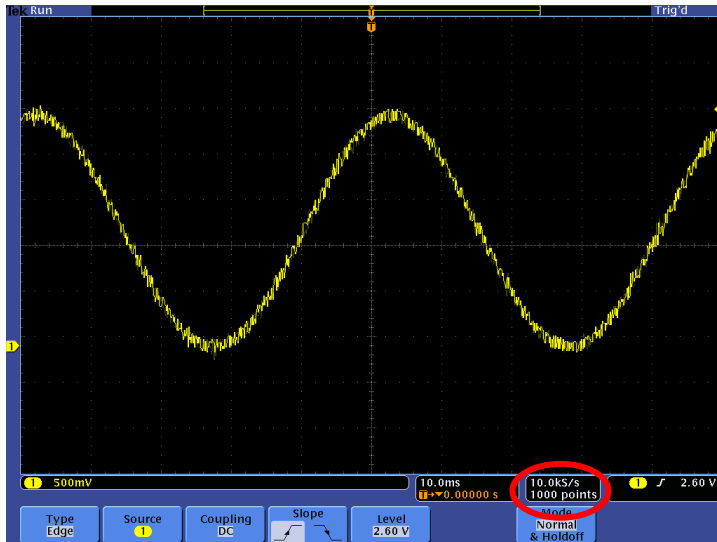


### DPO Demo Board Procedure:

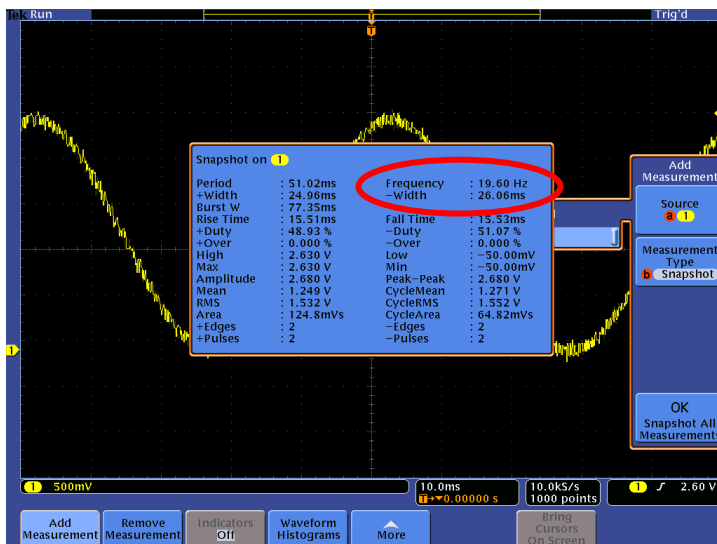
- Power up the demo board.
- Verify the power LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.
- Attach the probe ground to the **GND** test point on the demo board.
- Connect the probe tip to the **Noisy Sine** or **DAC\_OUT** test point on the demo board.

## Key Take Away Points

- Notice the readouts of sample rate and record length at the bottom of the display. The signal should look about like this:



- Let's take a quick look at the signals parameters. From the Measurement Snapshot, we can see that the signal is a ~20 Hz sine wave.



- At first glance, this may look like a reasonable setup. We are sampling the 20Hz sine wave at 10 kS/s, which is plenty fast to represent the sine wave accurately.
- However, if you watch the display carefully, you will occasionally see relatively large, fast spikes at various locations on the waveform.

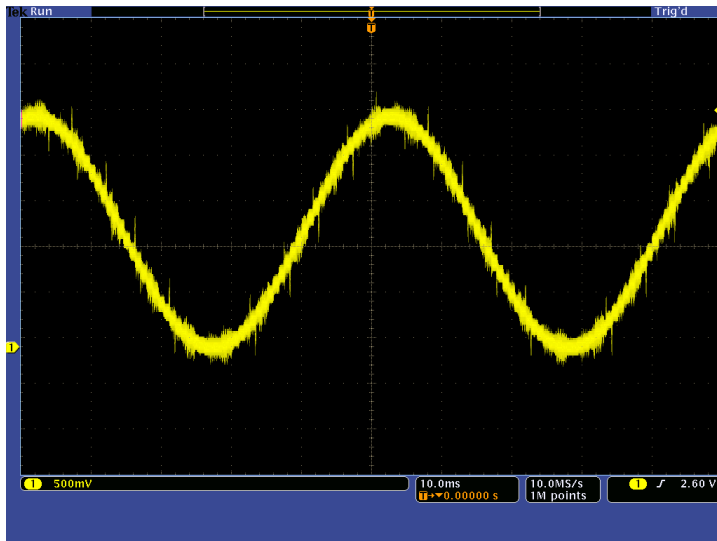
## MSO/DPO4000B Series Procedure:

- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Set the channel 1 vertical scale to **500 mV/div**.
- Set the horizontal scale to **10 ms/div**.
- With the channel 1 Vertical **Position** control, center the waveform on the display.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **1000**.
- Press the **Trigger Menu** button.
- Press the **Mode** bottom bezel button and the **Normal** side bezel button.
- Using the Trigger **Level** control, adjust the trigger level to the top of the waveform, about **2.6V**.
- Press the front panel **Measure** button.
- Press the **Add Measurement** bottom bezel button.
- With the Multipurpose **b** control, select **Snapshot** and press the **OK Snapshot All Measurements** side bezel button.
- When finished, press the **Menu Off** button twice.

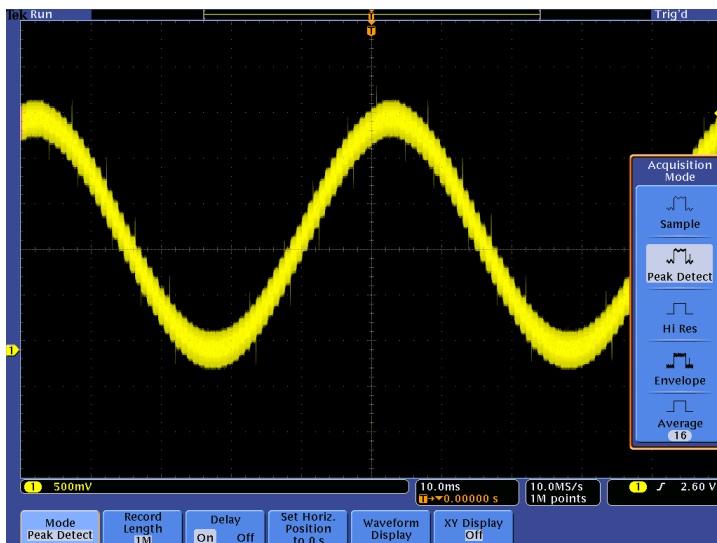
## MSO/DPO4000B Series Peak Detect

### Key Take Away Points

- One way to see more horizontal detail is to increase the record length. This also has the effect of raising the sample rate, which in turn raises the single-shot bandwidth. By selecting 1M record length, notice that we have also increased the sample rate to 10 MS/s. With the increased record length, you can now see a more realistic view of the noisy signal:



- You can see that the displayed trace is now quite thick, and there are some stationary spikes on it. To investigate these spikes more closely, we can use Peak Detect, which assures that we capture and display all of the peaks of the signal. With Peak Detect, the display should now look about like this:



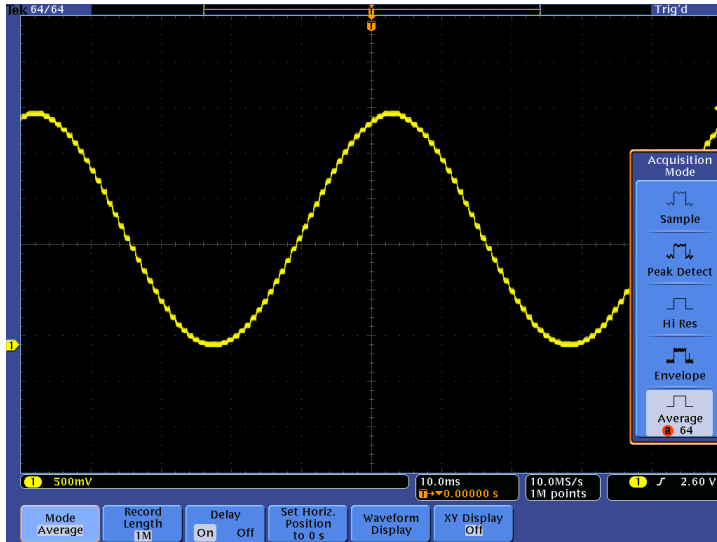
### MSO/DPO4000B Series Procedure:

- Press the front panel **Intensity** button.
  - With the Multipurpose **a** control, set the Waveform Intensity to **90%**.
  - Press the front panel **Intensity** button.
  - Press the front panel **Acquire** button.
  - Press the **Record Length** bottom bezel button.
  - Using the Multipurpose **a** control, select **1M**.
  - Press the **Menu Off** button twice.
- 
- Press the front panel **Acquire** button.
  - Press the **Mode** bottom bezel button.
  - Press the **Peak Detect** side bezel button.
  - This digital peak detect captures and displays peaks at the maximum sample rate of the product, capturing pulses as narrow as  $1/(\text{sample rate})$ .
- 
- You can also try **Envelope** mode, which provides a similar display, but accumulates the peaks between acquisitions, as if infinite persistence were turned on.

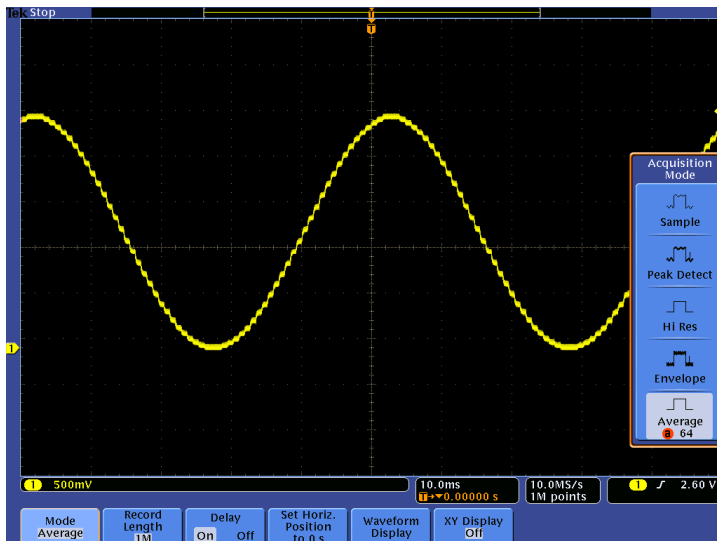
## MSO/DPO4000B Series Averaging

### Key Take Away Points

- Because this signal appears to be repetitive, we can use averaging (which averages successive acquisitions together, point by point, and displays the result).



- Notice how averaging removes random variations between acquired waveforms and preserves the stationary events such as the sine wave and the spikes. In this display, we can see the discrete voltage steps on the output of the circuit.
- If you want to see the result of exactly 64 averages, you can use Single sequence to acquire only that many waveforms. This takes a few seconds to complete.



### MSO/DPO4000B Series Procedure:

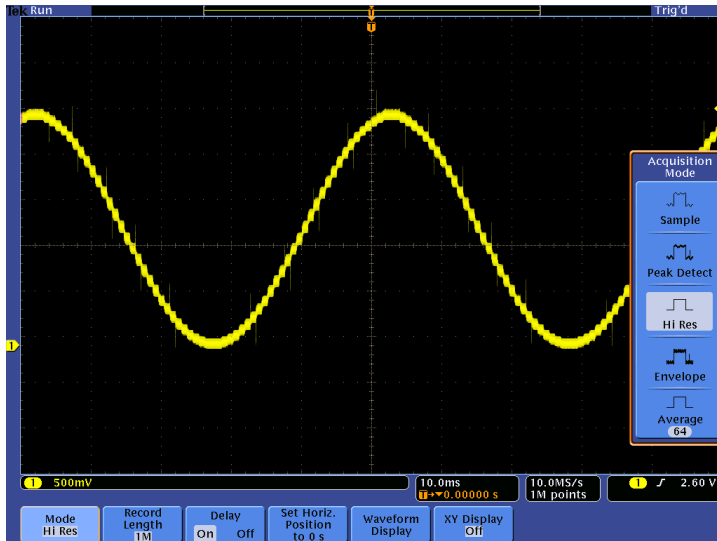
- ❑ Press the **Average** side bezel button.
- ❑ Using the Multipurpose a control, set the number of averages to **64**.

- ❑ Press the front panel **Single** button.

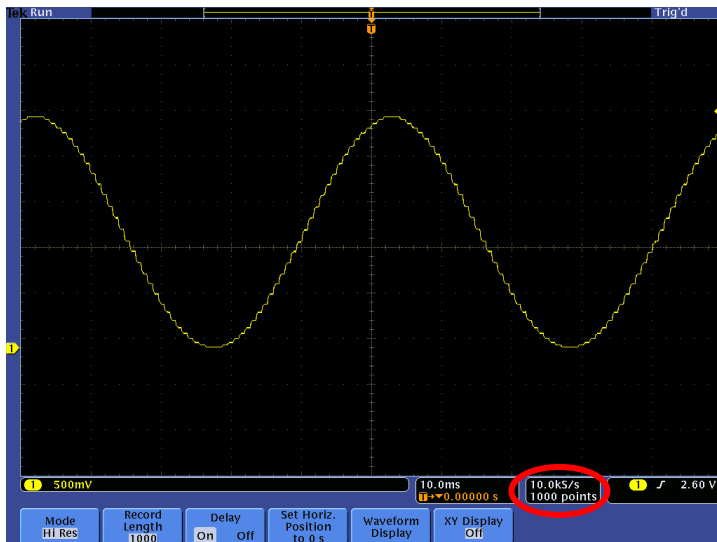
## MSO/DPO4000B Series Hi Res Acquisition

### Key Take Away Points

- Because averaging mode averages samples between acquisitions, a repetitive signal is required. However, it does retain the full bandwidth of the signal.
- Another type of averaging, called Hi Res or “box-car averaging” averages groups of samples within a single acquisition and replaces them with the higher-vertical-resolution mean value. The tradeoff is that the bandwidth of the signal is reduced. However, this method does work on single-shot acquisitions.



- We can control the bandwidth of Hi Res by adjusting the sample rate and record length. Here, the bandwidth has been limited to about 4.4 kHz:



### MSO/DPO4000B Series Procedure:

- ❑ Press the **Hi Res** side bezel button.
- ❑ Press the front panel **Run / Stop** button.

- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1000**.

- ❑ Notice that the resulting sample rate is 10 kS/s. From the equation on the next page, we can calculate the Hi Res bandwidth as  $0.44 * 10\text{kS/s} = 4.400 \text{ kHz}$ .

The bandwidth limiting and the increase in vertical resolution due to Hi Res varies with the maximum sample rate and the actual sample rate of the instrument. The actual sample rate is controlled by the Record Length and Horizontal Scale controls, and the sample rate is displayed near the bottom of the screen.

The resulting 3 dB bandwidth is  $0.44 \times \text{sample rate}$  and the increase in bits of vertical resolution is  $0.5 \log_2 (\text{maximum sample rate} / \text{actual sample rate})$ .

For the DPO4104B and MSO4104B, which have a maximum sample rate of 5 GS/s, Hi Res provides the following performance:

Sample Rate	Bits of Vertical Resolution	3 dB Bandwidth Limit (0.44 x Sample Rate)
2.5 GS/s	8.5 bits	1.1 GHz *
1 GS/s	9 bits	440 MHz
250 MS/s	10 bits	110 MHz
50 MS/s	11 bits	22 MHz
10 MS/s	12 bits	4.4 MHz
2.5 MS/s	13 bits	1.1 MHz
1 MS/s	14 bits	440 KHz
250 KS/s	15 bits	110 KHz
25 KS/s	>15 bits	11 KHz
250 S/s	>15 bits	110 Hz
25 S/s	>15 bits	11 Hz
2.5 S/s	>15 bits	1.1 Hz

For the DPO4054B, DPO4034B, MSO4054B, and MSO4034B, which have a maximum sample rate of 2.5 GS/s, Hi Res provides the following performance:

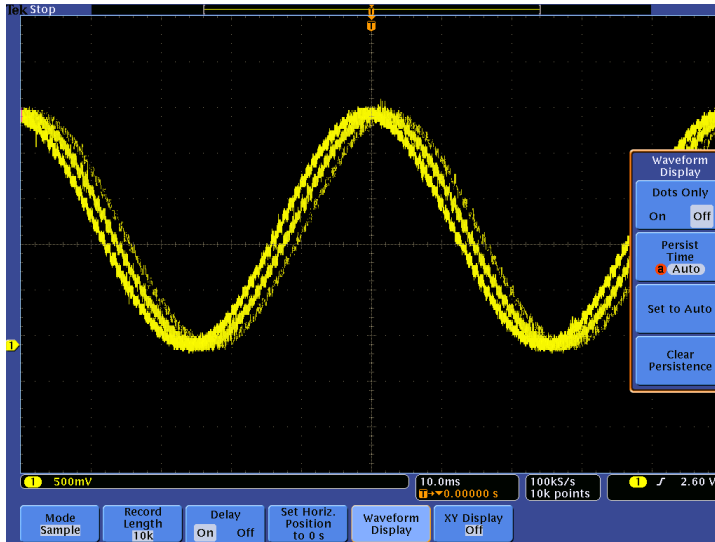
Sample Rate	Bits of Vertical Resolution	3 dB Bandwidth Limit (0.44 x Sample Rate)
1.25 GS/s	8.5 bits	550 MHz*
500 MS/s	9 bits	220 MHz*
100 MS/s	10 bits	44 MHz
25 MS/s	11 bits	11 MHz
5 MS/s	12 bits	2.2 MHz
1 MS/s	13 bits	440 KHz
500 KS/s	14 bits	220 KHz
100 KS/s	15 bits	44 KHz
25 KS/s	>15 bits	11 KHz
250 S/s	>15 bits	110 Hz
25 S/s	>15 bits	11 Hz
2.5 S/s	>15 bits	1.1 Hz

\* The maximum Hi Res bandwidth is further limited by the analog bandwidth.

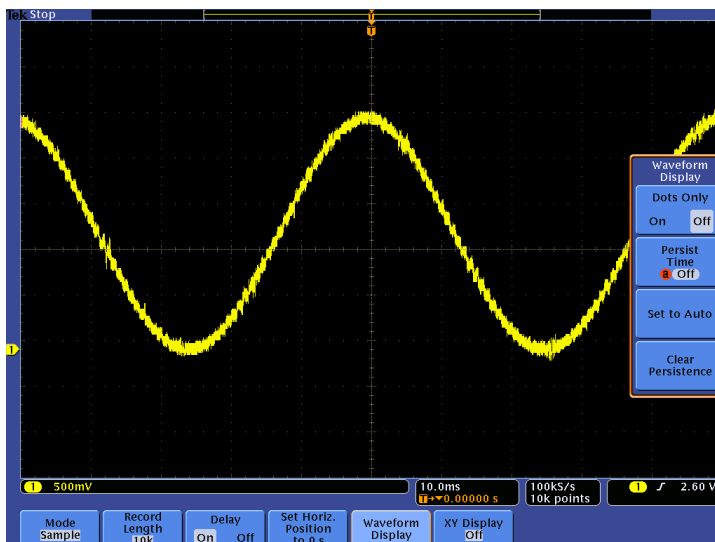
## MSO/DPO4000B Series DPO Off Display

### Key Take Away Points

- Because there was some persistence selected by Auto mode, you may see multiple waveforms on the display when you hit Stop:



- If you want to see only the last acquired waveform, there are three alternatives. The first is to force the product into Preview mode, for example by slightly adjusting one of the controls. The second is to use Single instead of Run/Stop. However, some customers do not like either of these work-arounds and have been requesting "DPO Off".
- With Persist Time set to Off, the high waveform capture rate of the DPO has been turned off, and stopping the acquisitions now results in the display of only a single waveform:



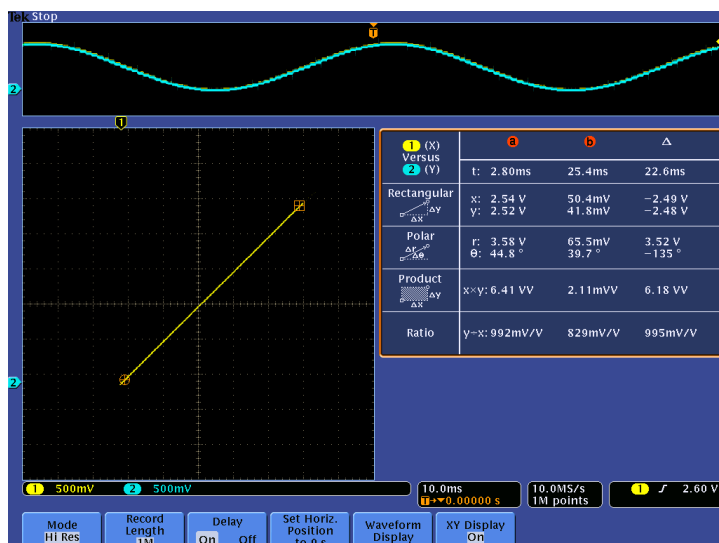
### MSO/DPO4000B Series Procedure:

- ❑ Press the **Mode** bottom bezel button.
- ❑ Press the **Sample** side bezel button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **10k**.
- ❑ Press the **Waveform Display** bottom bezel button.
- ❑ Notice that the **Persist Time** is set to **Auto** by default, as shown in the side bezel readout.
- ❑ Press the front panel **Run / Stop** button.
- ❑ Adjust the channel 1 vertical position control slightly. Notice the readout in the upper left corner of the display changes from **Stop** to **PreVu**.
- ❑ Press the front panel **Single** button. Notice that only a single waveform is acquired.
- ❑ Turn the Multipurpose **a** control one position clockwise, until Off is selected.
- ❑ Press the front panel **Run / Stop** button to start acquisitions.
- ❑ First, notice that the waveform capture rate has slowed considerably. This is the way traditional DSOs acquire waveforms.
- ❑ Press the front panel **Run / Stop** button to stop acquisitions.
- ❑ Notice that only a single waveform was acquired and displayed.

## MSO/DPO4000B Series XY Display

### Key Take Away Points

- Most oscilloscope displays show voltages on the vertical (“Y”) axis and time on the horizontal (“X”) axis, since the user is most often interested in signal behavior over time. This type of display is often called a “YT” display.
- However, sometimes the relative behavior of two signals is more critical. Examples are measuring relative frequency or phase between two signals. The XY display allows the user to plot one signal on the vertical axis and the second on the horizontal axis.
- In this first setup, the same signal is plotted on the X and Y axes, so the resulting display is a straight line at 45 degrees.
- The XY display provides a unique set of cursor measurements, including readouts in both rectangular and polar coordinates on the XY display, as well as matching cursor indications on the YT waveforms at the top of the screen:



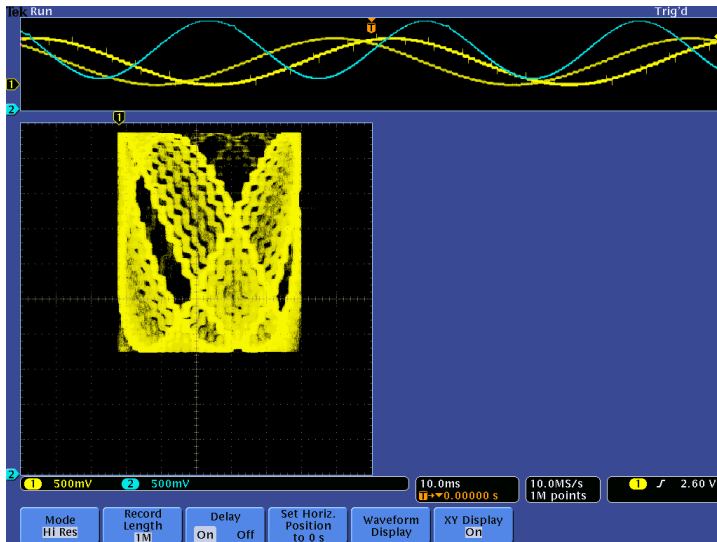
### MSO/DPO4000B Series Procedure:

- ❑ Attach a TPP500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **Noisy Sine** or **DAC\_OUT** test point on the demo board.
- ❑ Press the front panel **2** button to turn on channel 2.
- ❑ Set the channel 2 vertical scale to **500 mV/div**.
- ❑ With the channel 1 and 2 Vertical **Position** controls, center the waveforms on the display.
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1M**.
- ❑ Press the **Waveform Display** bottom bezel button.
- ❑ Press the **Set to Auto** side bezel button.
- ❑ Press the **XY Display** bottom bezel button and the **Triggered XY** side bezel button.
- ❑ Press the front panel **Single** button.
- ❑ Press the front panel **Menu Off** button to remove the side menu.
- ❑ Press the front panel **Cursors** button.
- ❑ Using the Multipurpose controls, notice how the cursors move around on the XY display.
- ❑ When you are done, press the **Cursors** button to turn off the cursor display.

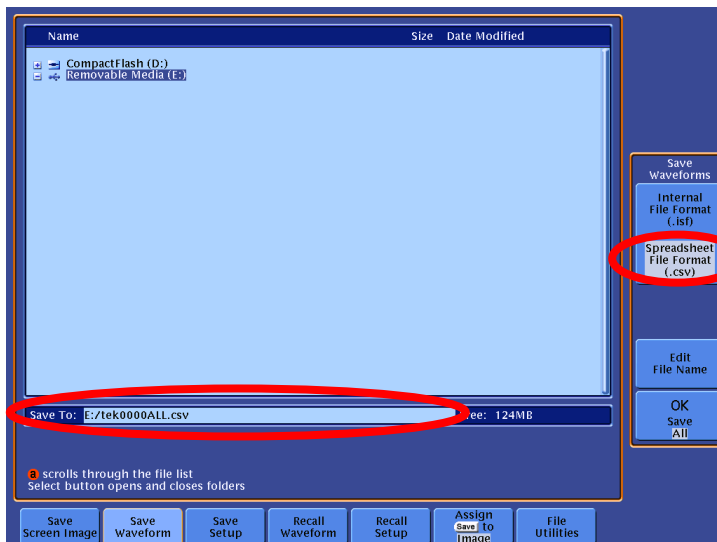


## Key Take Away Points

- If we display two different signals, we get a more interesting XY display. In this example, we are displaying two sinusoidal signals with different fundamental frequencies. Because the frequencies are not integer multiples of one another, the relative phases of the signals are constantly moving, and the XY display is also moving:



- Because the XY display is simply a different way of displaying pairs of waveforms, the underlying data values are still available for measurements, as well as for saving for off-line analysis. Waveforms can be saved individually in binary or spreadsheet (CSV) format, or all active waveforms can be saved in a single CSV file:



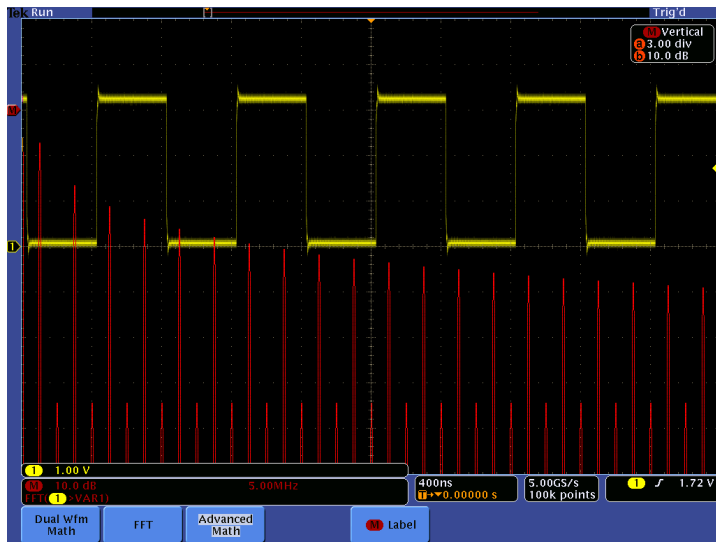
## MSO/DPO4000B Series Procedure:

- ❑ Move the Channel 2 probe tip to the **DAC Out** or other low-frequency signal test point on the demo board.
- ❑ Press the front panel **2** button to display the channel 2 vertical menu.
- ❑ Adjust the channel 2 vertical position to get the waveform on-screen.
- ❑ Press the front panel **Run/Stop** button.

- ❑ Press the **Save/Recall Menu** button below the display.
- ❑ Press the **Save Waveform** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **All Displayed Waveforms** as the Source.
- ❑ Using the Multipurpose **b** control, select **File** as the Destination.
- ❑ Press the **File Details** side bezel button.
- ❑ Press the **Spreadsheet File Format (.csv)** side bezel button. Notice that a default file name such as tek0000ALL.csv has been created for you.
- ❑ Press the **OK Save** side bezel button.

# MSO4000B/DPO4000B Series

## Math Application Lab



### Equipment List

- One 4-channel MSO/DPO4000B Series oscilloscope with the latest firmware version installed
- Four TPP0500 or TPP1000 probes
- One TDP0500 or TDP1000 high-voltage differential probe
- One TCP0030 current probe
- DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or DPO Demo 2 board and USB host-to-device cable (020-2924-XX and 174-4401-00)
- One 878-0544-XX or 3PQS power demo board and 12VAC power adapter
- One video generator, 75 Ohm cable, and 75 Ohm feed-through terminator

## Introduction

This lab contains a few waveform analysis applications of the MSO4000B / DPO4000B Series highlighting the capabilities of the math system. Step-by-step instructions and a few application hints are provided. Although the setup information for each application is fairly complete, the labs do build on previous setups, so reading through the document may help. Some screen shots are provided to help you if you are unable to get the equipment to actually complete a lab experiment.

The math system has three separate sections, Dual Wfm Math, FFT, and Advanced Math. Each has different capabilities, and these labs will cover some highlights from each.

## Dual Wfm Math in the MSO/DPO4000B Series

Many basic waveform math requirements can be addressed with the basic math capabilities found under the Dual Wfm (Waveform) Math bottom bezel button in the Math menu. Basically, these capabilities include addition, subtraction, multiplication, and division of any two analog channel or internal reference waveforms.

In this section, we will look at some of the most common applications for dual waveform math: pseudo-floating and instantaneous power measurements, and dynamic on-resistance measurements.

## Pseudo-Floating Measurements

All voltage measurements are differential measurements. That is, the measurements are always comparing the voltage of one point to another (reference) point. Often, the reference point is ground, and most oscilloscope probes connect their reference or ground lead to the power line ground through the oscilloscope.

However, in some applications, you need to measure the voltage difference between two points where neither point is at ground. This is sometimes called a “floating” measurement. The highest performance solution is to use an active differential probe, especially for high-speed and high-voltage signals. These probe inputs are carefully matched for high-frequency response and loading, and may be capable of safely measuring much higher voltages than passive probes. But active differential probes are more expensive than the standard passive probes, and you may not have any available.

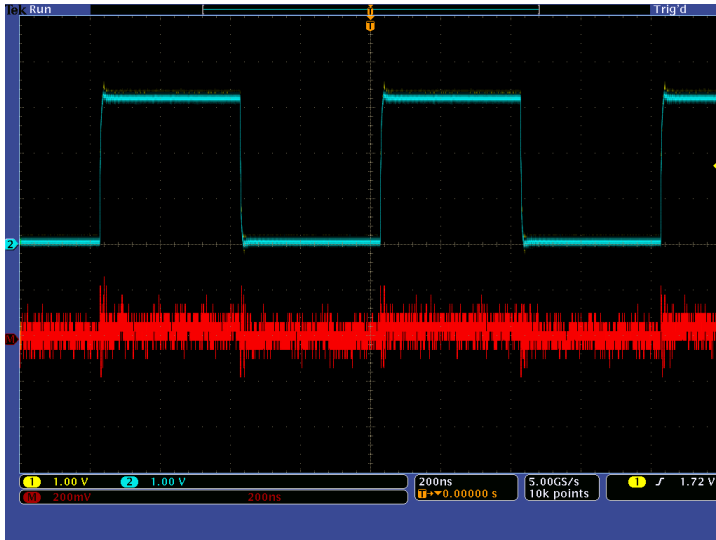
Within certain limits, such as low frequencies (less than a few MHz) and small ratios between common-mode and differential signal amplitudes (less than 10 or so), you can make good differential voltage measurements with two passive probes and math subtraction. By calculating the difference between two ground-referenced signals, the oscilloscope can calculate the floating voltage difference.

### MSO/DPO4000B Series Setup Procedure:

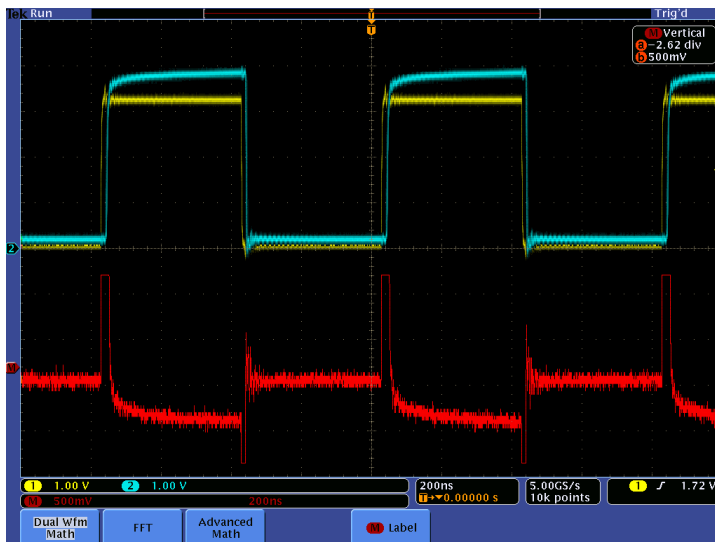
- Verify the USB cable is plugged into the MSO/DPO4000B Series oscilloscope and the demo board.
- Verify the power LED is lit.
- Connect TPP0500 or TPP100010x passive probes to channels 1 and 2 on the front of the MSO/DPO4000B Series oscilloscope.
- Connect the probe grounds to **GND**.
- Connect the channel 1 probe to the **CNT\_CLK** test point.
- Connect the channel 2 probe to the **CNT\_CLK** test point.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Press the front panel **2** button to turn on channel 2.
- In this case, the signals on channel 1 and channel 2 are very similar. Using the front panel vertical scale and position controls, scale the signals so they occupy about half of the screen vertically, and position them so they overlap.
- Press the Trigger Level control to automatically set the trigger level to 50%.
- Set the Horizontal **Scale** to **200 ns/div**.
- Press the front panel **Acquire** button.
- Press the **Mode** bottom bezel button and the **Hi Res** side bezel button. This enables a “box-car averaging” filter which reduces noise on the signal.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **100k**.

## Key Take Away Points

- The MSO/DPO4000B Series' Dual Wfm Math provides simple waveform math capabilities with just a few controls in this one simple menu. As you can see, there are eight choices of inputs (4 analog channels and 4 internal reference waveforms) and four math operators. The display should look something like this:



- When you are done, the display should look something like this:



- Notice that the math waveform represents only the voltage difference between the two input signals.

## MSO/DPO4000B Series Procedure:

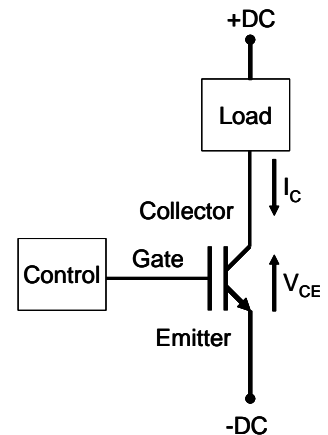
- Press the red front panel **M** button.
- Press the **Dual Wfm Math** bottom bezel button.
- Press the **Operator** side bezel button until **-** (minus) is selected.
- Press **Menu Off** once to clear the side menu.
- Notice that the difference between the two probes is nearly zero when the probes are connected to the same signal, as expected.
- However, notice that the mathematical difference waveform provides a very sensitive measure of the voltage differences between these two logic signals.
- Use the Multipurpose **a** control to select adjust the math waveform vertical position and the Multipurpose **b** control to adjust the vertical scale.
- If you want to display the math equation in the lower left corner in the Dual Wfm Math mode, press the **Advanced Math** bottom bezel button, press **Display Expression** in the side menu to select **On**, and press the **Dual Wfm Math** bottom bezel button to select Dual Wfm Math mode again.
- Move the channel 2 probe to the **FAST\_FF\_CLK** test point.
- Notice that the math difference waveform makes even small amplitude and/or timing differences very apparent.

## Instantaneous Power Measurements

Another common oscilloscope measurement which requires simple math is measurement of instantaneous power. One specific measurement is the power dissipation in the switching device in a switch-mode power supply.

In this lab, you will measure the power dissipated in an Insulated Gate Bipolar Transistor (IGBT) or MOSFET switching device. The instantaneous power is the product of the current flowing through the device (the Collector or Drain current,  $I_C$  or  $I_D$ ) and the voltage across the device (the Collector voltage relative to the Emitter,  $V_{CE}$ , or the Drain voltage relative to the Source,  $V_{DS}$ ).

When the switching device is turned on, the voltage across the device is very small and the current is large. When the device is turned off, the voltage across the device is large and the current is very small.

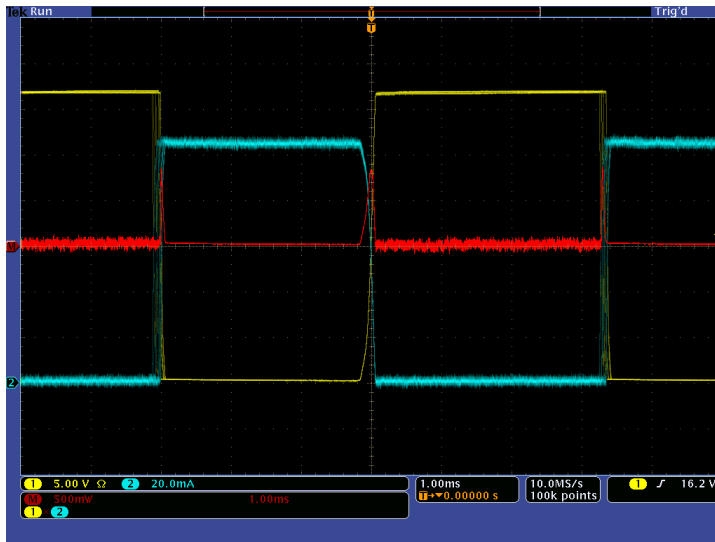


## MSO/DPO4000B Series Setup Procedure:

- For this lab, use the power demo board. Connect 12VAC power adapter to demo board and plug in to AC power.
- Connect a TDP0500 or TDP1000 differential probe to channel 1 on the front of the MSO/DPO4000B Series oscilloscope.
- Connect the + and - inputs together. Make sure that the **Range** is set to **42.0 V**.
- Press the **Menu** button on the probe's comp box, and press the **AutoZero** side bezel button.
- Connect the + input of the differential probe to the **Collector** test point.
- Connect the - input of the differential probe to the **Emitter** test point.
- Connect a TCP0030 current probe to channel 2 on the front of the oscilloscope.
- Make sure that the current probe's jaw is closed. Press the **Degauss AutoZero** button on the probe.
- Connect the current probe around the **Collector Current** loop and close the jaws.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Press the front panel **2** button to turn on channel 2.
- In this case, the voltage and current waveforms are square waves, 180 degrees out of phase. If the channel 2 signal is in phase with the channel 1 signal, remove the current probe, turn it over, and reconnect it.
- Using the front panel vertical scale and position controls, scale the signals so they occupy about half of the screen vertically, and position them so they overlap.
- Press the front panel **Acquire** button.
- Press the **Mode** bottom bezel button and the **Hi Res** side bezel button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **100k**.

## Key Take Away Points

- The instantaneous power waveform should look something like this:



- Notice that, because the voltage and current are out of phase (one waveform has a value of zero, so the product of waveforms is zero), the instantaneous power is very small except during the turn-on and turn-off transitions.

## MSO/DPO4000B Series Procedure:

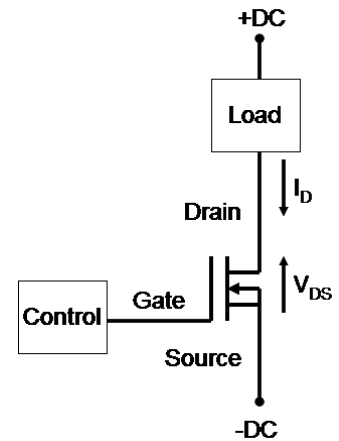
- ❑ Press the red front panel **M** button.
- ❑ Press the **Dual Wfm Math** bottom bezel button.
- ❑ Press the **Operator** side bezel button until **X** (multiply) is selected.
- ❑ Press **Menu Off** once to clear the side menu.
- ❑ Use the Multipurpose **a** control to select adjust the math waveform vertical position and the Multipurpose **b** control to adjust the vertical scale.

## Dynamic On-Resistance Measurements

Another common power measurement which requires simple oscilloscope math is measurement of the dynamic on-resistance of a power switching device. This measurement characterizes the impedance of the switching device during the conduction cycle when the device is “on” and conducting current.

Remember Ohm’s law which states that “ $V = I * R$ ” or “ $R = V / I$ ”? In this lab, you will measure the voltage across and the current flowing through an MOSFET switching device. The dynamic on-resistance is ratio of the voltage across the device when it is turned on (the Drain voltage relative to the Source,  $V_{DS}$ ) to the current flowing through the device (the Drain current,  $I_D$ ).

When the switching device is turned “on”, the voltage across the device is very small and the current is large. Therefore, we would expect that the dynamic on-resistance of a good switching device will be small, a few Ohms or less.



### MSO/DPO4000B Series Setup Procedure:

- For this lab, use the power demo board. Connect 12VAC power adapter to demo board and plug in to AC power.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Connect a TDP0500 or TDP1000 differential probe to channel 1 on the front of the oscilloscope.
- Connect the + and – inputs together. Make sure that the **Range** is set to **42.0 V**. It is very important that the probe and oscilloscope do not clip the signal, or distortion from signal overdrive can result.
- Press the **Menu** button on the probe’s comp box, and press the **AutoZero** side bezel button. Because we are measuring small voltages, this is a very important step!
- Connect the + input of the differential probe to the **Collector** test point.
- Connect the - input of the differential probe to the **Emitter** test point.
- Set the channel 1 positive edge trigger level to about **15V**.
- Connect a TCP0030 current probe to channel 2 on the front of the oscilloscope.
- Press the **Range** button on the current probe’s comp box until the **5A** range is selected.
- Make sure that the current probe’s jaw is closed. Press the **Degauss AutoZero** button on the probe.
- Connect the current probe around the **Collector Current** loop and close the jaws.
- Press the front panel **2** button to turn on channel 2.
- In this case, the voltage and current waveforms are square waves, 180 degrees out of phase. If the channel 2 signal is in phase with the channel 1 signal, remove the current probe, turn it over, and reconnect it.
- Using the front panel vertical scale and position controls, scale the signals so they occupy about half of the screen vertically, and position them so they overlap.
- Press the front panel **Acquire** button.
- Press the **Mode** bottom bezel button and the **Hi Res** side bezel button to maximize the vertical resolution. For the following oscilloscope setup, the vertical resolution is increased to about 10 bits and the real-time bandwidth is reduced to around 100 MHz, which helps increase the resolution of the measurement and limit the noise in the measurement.

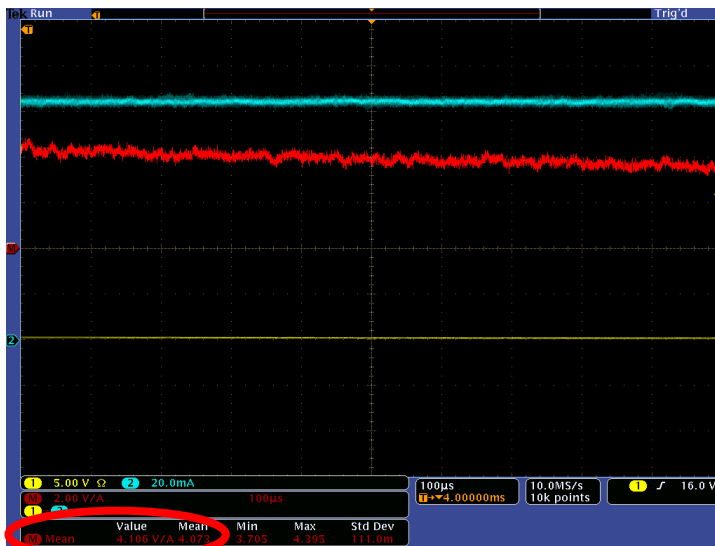


## Key Take Away Points

- The waveform display should look something like this:



- Notice that, to the left of the trigger point, the voltage across the device is very small when the switching device is “on”. This is the region where we will make the dynamic on-resistance measurement. To optimize the math and measurement dynamic range, we adjust the acquisition window to include and display only the saturation region of the waveform. This is one way to manually force screen gating for measurements.
- The math and measurement display should look something like this:



## MSO/DPO4000B Series Procedure:

- Using the horizontal **Position** control, position the trigger (orange indicator) well to the left of the display (in the screen shot on the left, a horizontal position of about 5 ms).
- Press the red front panel **M** button.
- Press the **Dual Wfm Math** bottom bezel button.
- Press the **Operator** side bezel button until  $\div$  (divide) is selected.
- Press **Menu Off** once to clear the side menu.
- Use the Multipurpose **a** control to select adjust the math waveform vertical position and the Multipurpose **b** control to adjust the vertical scale.
- Press the front panel **Measure** button.
- Press the **Add Measurement** bottom bezel button.
- Using the Multipurpose **b** control, select the **Mean** measurement and press the **OK Add Measurement** side bezel button.
- Press **Menu Off** twice.
- The measurement readout, in units of **V/A** (which is equivalent to Ohms), indicates the desired dynamic on-resistance measurement.

## FFT in the MSO/DPO4000B Series

### Introduction

The MSO/DPO4000B Series provides a frequency domain display of any analog channel or internal reference waveform. This FFT analysis is found under the FFT bottom bezel button in the Math menu.

The FFT function also provides four windows. Here is a general guideline for choosing the appropriate window:

- **Rectangular:** This is the best type of window for resolving frequencies that are very close to the same value but worst for accurately measuring the amplitude of those frequencies. It is the best type for measuring the frequency spectrum of non-repetitive signals and measuring frequency components near DC. Use Rectangular for measuring transients or bursts where the signal levels before and after the event are nearly equal. Also, use this window for equal-amplitude sine waves with frequencies that are very close and for broadband random noise with a relatively slow varying spectrum.
- **Hamming:** This is a very good window for resolving frequencies that are very close to the same value with somewhat improved amplitude accuracy over the rectangular window. It has a slightly better frequency resolution than the Hanning. Use Hamming for measuring sine, periodic, and narrow band random noise. This window works on transients or bursts where the signal levels before and after the event are significantly different.
- **Hanning:** This is a very good window for measuring amplitude accuracy but less so for resolving frequencies. Use Hanning for measuring sine, periodic, and narrow band random noise. This window works on transients or bursts where the signal levels before and after the event are significantly different.
- **Blackman-Harris:** This is the best window for measuring the amplitude of frequencies but worst at resolving frequencies. Use Blackman-Harris for measuring predominantly single frequency waveforms to look for higher order harmonics.

### Simple FFT of a Square Wave

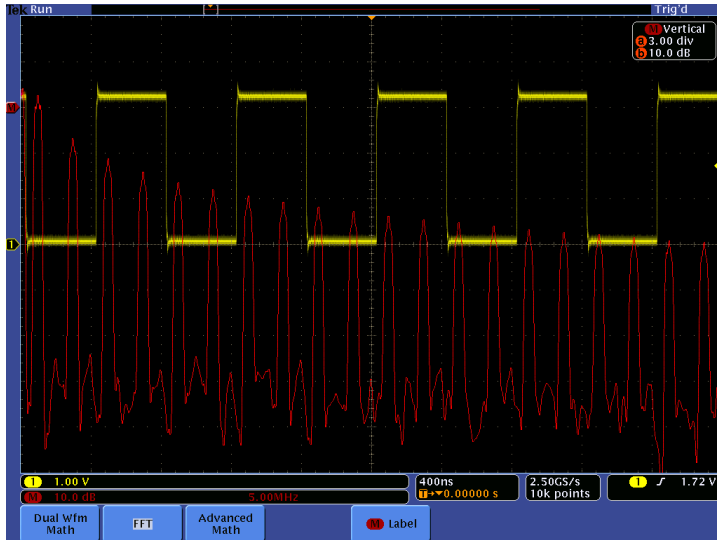
If you want to display the frequency domain representation of a square wave, the FFT function can calculate and display the spectrum. This display will include a representation of all of the signal components, including the desired square wave as well as the noise and amplitude modulation of the signal.

### MSO/DPO4000B Series Setup Procedure:

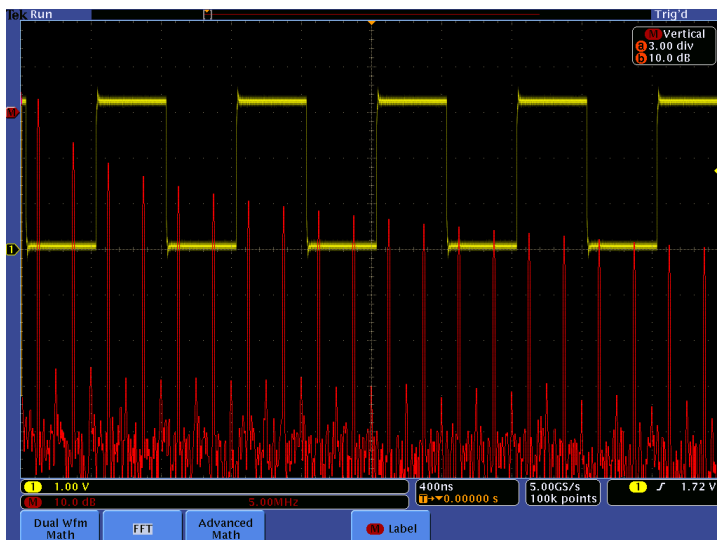
- For this lab, use the DPO demo 3 board (679-6506-XX) or DPO Demo 2 board (020-2924-XX). Power up the demo board.
- Verify the power LED is lit.
- Connect a TPP0500 or TPP100010x passive probe to channel 1 on the front of the MSO/DPO4000B Series oscilloscope.
- Connect the probe ground to **GND** on the demo board.
- Connect the channel 1 probe to the **CNT\_CLK** signal on the demo board.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Press the front panel **Autoset** button to automatically set up a stable display.

## Key Take Away Points

- The peak at the left side of the display represents the DC (0 Hz) content of the signal. The next FFT peak, about 1 division from the left side of the display, is the “fundamental” frequency of the input square wave signal is about 5 MHz. Since the remaining major peaks are at odd integer multiples of this frequency (“odd harmonics”), from Fourier analysis theory we know that this input signal is indeed a square wave.



- The FFT’s frequency resolution can be dramatically improved by increasing the amount of input data. This is done by increasing the record length. With a 10X increase in record length, notice that the FFT peaks are much sharper and better defined:

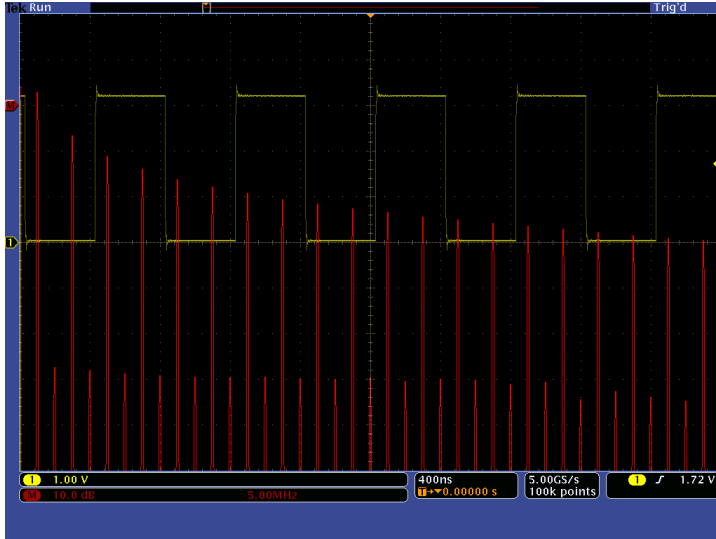


## MSO/DPO4000B Series Procedure:

- Press the red front panel **M** button.
- Press the **FFT** bottom bezel button.
- Press the **Horizontal** side bezel button to attach the Multipurpose controls to the FFT’s horizontal controls.
- Rotate the Multipurpose **a** control fully clockwise to set the zero-frequency point in the middle of the display.
- With the Multipurpose **b** control, set the horizontal resolution to **5 MHz/div**.
- With the Multipurpose **a** control, set the center frequency to **25 MHz**. This will place the zero-frequency point at the left side of the display.
- Press **Menu Off** once.
- The Multipurpose controls are now able to control the FFT’s vertical position and scale.
- With the Multipurpose **b** control, set the FFT Vertical Scale to **10.0 dB/div**.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **100k**.
- Press the red front panel **M** button.
- Press the **FFT** bottom bezel button.
- Rotate the Multipurpose **a** control fully clockwise.
- With the Multipurpose **b** control, set the horizontal resolution to **5 MHz/div**.
- With the Multipurpose **a** control, set the center frequency to **25 MHz**.

## Key Take Away Points

- The increased FFT frequency resolution helps identify the exact harmonic frequencies, but it also accentuates the appearance of some of the noise. Although the vertical scale is logarithmic (10 dB/div), it is possible to reduce the random noise in the FFT display. One way is to average the input signal. With 512 averages, the noise is much less noticeable.



- Cursors can be used to measure the amplitudes and frequencies of the harmonics in the FFT display:



## MSO/DPO4000B Series Procedure:

- Press the front panel **Acquire** button.
- Press the **Mode** bottom bezel button.
- Press the **Average** side bezel button and select **512** averages with the Multipurpose **a** control.
- Press the front panel **Cursors** button once.
- Using the Multipurpose controls, position the cursors on the fundamental and third harmonics, as shown at the left. Notice the readouts in the upper right corner of the display, showing the absolute and relative frequencies and amplitudes.

### FFT of a Complex Waveform

The MSO/DPO4000B Series FFT calculates the frequency domain representation of the entire input signal. If you want to display the frequency domain representation of a portion of a very complex waveform, you need to first adjust the acquisition to capture only that portion of the signal.

For this lab, you need to verify the spectrum of the positive  $\sin(x)/x$  video test signal. This  $\sin(x)/x$  pulse occurs on only half of a video line, and you do not want to include the rest of the video signal, such as the video's horizontal and vertical intervals, in the FFT analysis.

### MSO/DPO4000B Series Setup Procedure:

- ❑ For this lab, use a standard analog video generator that can provide a frequency response signal. For this example, a  $\sin(x)/x$  pulse was used, but a multiburst signal could be used instead. To demonstrate the math, connect the video generator directly to the MSO/DPO4000B Series oscilloscope through a 75 Ohm cable and 75 Ohm feed-through terminator on channel 1 on the front of the MSO/DPO4000B Series oscilloscope.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Press the front panel **Autoset** button to do a video autoset to automatically get a stable display.
- ❑ In the experiment shown below, the video autoset determined that the signal was a 525i/NTSC signal and set up the video trigger to trigger on all lines, scaled the signal appropriately, and turned on the video IRE graticule.

## Key Take Away Points

- Because the MSO/DPO4000B Series FFT calculates the frequency domain representation of the entire acquired waveform, you can gate the waveform using the acquisition controls. In this case, the FFT analysis is run on only the positive  $\sin(x)/x$  video signal. As theory would predict, a  $\sin(x)/x$  time-domain pulse has a flat frequency response across the entire baseband video bandwidth, as shown below:



## MSO/DPO4000B Series Procedure:

- ❑ Press the front panel Trigger **Menu** button.
- ❑ Press the **Trigger On** bottom bezel button.
- ❑ Press the **Line Number** side bezel button and select an active line, such as **22**, with the Multipurpose **a** control.
- ❑ Using the front panel channel 1 horizontal scale and position controls, set the acquisition window to capture only the positive  $\sin(x)/x$  pulse, as shown at the left.
- ❑ Press the red front panel **M** button.
- ❑ Press the **FFT** bottom bezel button.
- ❑ Press the **Horizontal** side bezel button to attach the Multipurpose controls to the FFT's horizontal controls.
- ❑ Rotate the Multipurpose **a** control fully clockwise to set the zero-frequency point in the middle of the display.
- ❑ With the Multipurpose **b** control, set the horizontal resolution to **1.25 MHz/div**.
- ❑ With the Multipurpose **a** control, set the center frequency to **12.5 MHz**. This will place the zero-frequency point at the left side of the display.
- ❑ Press **Menu Off** once.
- ❑ The Multipurpose controls are now able to control the FFT's vertical position and scale.

## Advanced Math in the MSO/DPO4000B Series

### Introduction

In addition to the basic waveform math and FFT capabilities, the MSO/DPO4000B Series provides Advanced Math, which allows the user much more flexibility in specifying the mathematical function. This Advanced Math analysis is found under the Advanced Math bottom bezel button in the Math menu.

In this section, we will look at several common applications for advanced waveform math:

- comparison of a signal to a reference
- scaling and offsetting transducer signals
- instantaneous power measurements using pseudo-floating voltage measurements
- video linearity testing
- integration and inductor flux density measurements
- logarithms
- creating digital signals
- FFTs of idealized digital signals
- binary math with digital signals
- off-line editing of advanced math equations
- measurement trends

## Hints for Using Math with Reference Waveforms

Reference waveforms and live channel waveforms act a little differently in math. Here are a few hints for applying math with references:

- Math is always calculated point-by-point, starting at the left of the waveforms. Even if the reference waveform is displayed with a different horizontal scale and/or position (which can be adjusted in the Reference waveform menu), the math is calculated point-by-point.
- Because math always starts at the left side of the waveform, trigger points are ignored.
- Because math is done on points only, time/div and sample rate differences are ignored.
- Because math is done point-by-point, if the input waveform record lengths are different, the math system will point-replicate to interpolate values so it can operate on equal-length waveforms. (For example, if you are adding a 1k record to a 10k record, each sample in the 1k record will be repeated 10 times.)
- So, to minimize confusion, it is recommended that you acquire reference waveforms exactly the way you plan to acquire the live waveforms, with the same record length, time/div, and trigger setup and position.

If you are going to save or post-process the math waveform, there are a few other details which could be important. Each waveform has a "header" which contains information about the way the waveform was acquired and how it should be displayed (such as vertical and horizontal scales, record length, trigger position, and acquisition mode). Since the math waveform header must contain "something reasonable" under all circumstances, a simple algorithm to select the "main source" is performed by the MSO/DPO4000B Series oscilloscope before each math calculation that goes like this:

- If all source waveforms are live, set main source to the lowest numerical channel,
- else, if one source is live, set main source to that channel,
- else, set main source to the non-live source with the fastest timebase.

Then the math waveform header is formed using information from the main source waveform header, as well as the math parameters.

This header information is visible over the programmable interface with the "DATA:SOURce MATH" and "WFMOutpre?" commands.



## Comparison of a Signal to a Reference

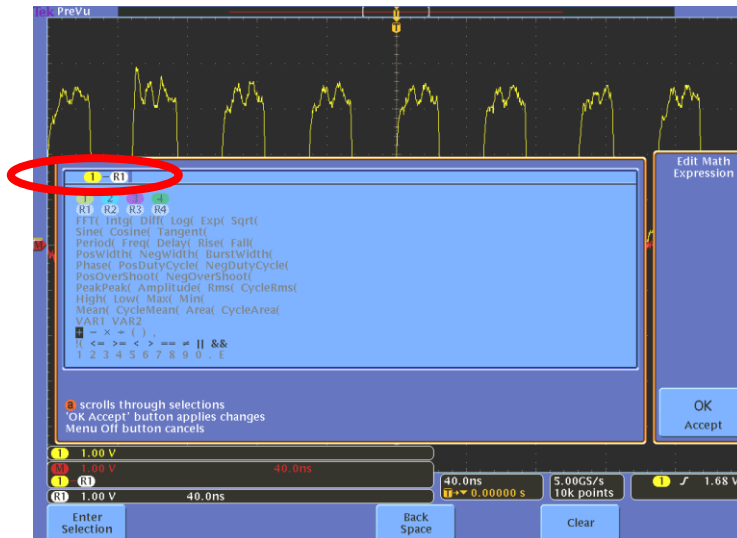
Another common use of waveform math is to compare a live waveform to a stored reference. Although a simple comparison can be done with Dual Wfm Math, this lab shows how a comparison can be done with Advanced Math. As well as a simple introduction to the use of Advanced Math, this technique also opens up possibilities such as comparing pseudo-floating voltage measurements to references.

### MSO/DPO4000B Series Setup Procedure:

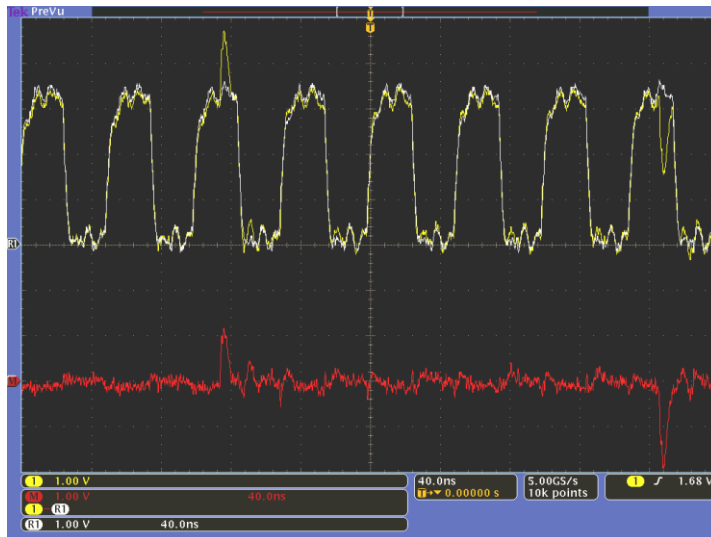
- For this lab, use the DPO Demo 3 board (679-6506-XX) or DPO Demo 2board (020-2924-XX). Power up the demo board.
- Verify the power LED is lit.
- Connect a TPP0500 or TPP1000 10x passive probe to channel 1 on the front of the MSO/DPO4000B Series oscilloscope.
- Connect the probe ground to **GND** on the demo board.
- Connect the channel 1 probe to the **XTALK1** signal on the demo board.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Press the front panel **Autoset** button to automatically get a stable display.
- Press the front panel Save/Recall **Menu** button and the **Save Waveform** bottom bezel button.
- Use the Multipurpose **a** control if necessary to select channel **1** as the **Waveform Source**.
- Press the **To R1** side bezel button to save a reference waveform. Notice that a white reference waveform is automatically displayed.

## Key Take Away Points

- The MSO/DPO4000B Series' Advanced Math editor allows you to build the math expression out of simple operators and waveforms with the Multipurpose control and bezel button interface. The display should look about like this:



- Notice how the math comparison of the live waveform to a reference highlights the positive and negative glitches on the waveform, as shown below:



## MSO/DPO4000B Series Procedure:

- Press the red front panel **M** button.
- Press the **Advanced Math** bottom bezel button.
- Press the **Edit Expression** side bezel button.
- Enter the math expression:
  - Press the **Clear** bottom bezel button.
  - Highlight the yellow channel 1 icon with the Multipurpose **a** control and press the **Enter Selection** bottom bezel button.
  - Highlight the minus sign with the Multipurpose **a** control and press the **Enter Selection** bottom bezel button.
  - Highlight the white **R1** icon with the Multipurpose **a** control and press the **Enter Selection** bottom bezel button.
  - Press the **OK Accept** side bezel button to complete the equation and calculate the result.
- Press the **Display Expression** side bezel button to select **On**. Notice that the equation is now displayed in lower left corner of the display, just below the math scale factor readout.
- Press the **Menu Off** button.

## Scaling and Offsetting Transducer Signals

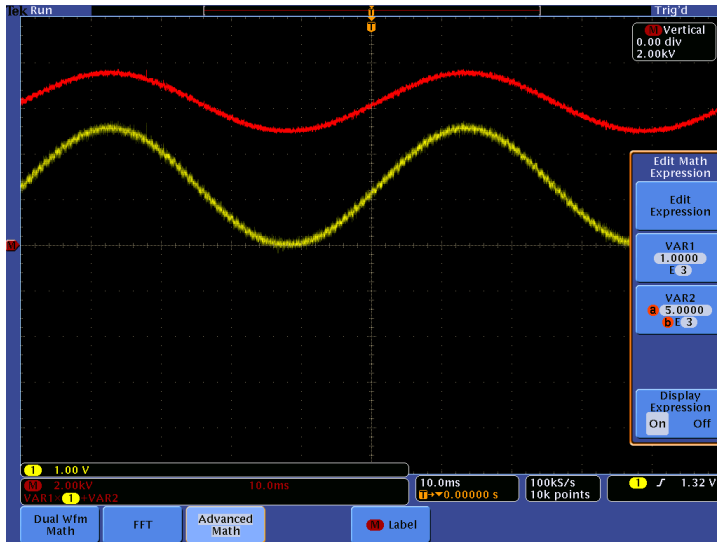
Transducers are electronic devices which output a voltage that represents some physical quantity. Examples include thermocouples, pressure sensors, tachometers, and accelerometers. The output voltages of these devices are often at vertical scale factors or DC offsets which do not provide the desired display on the oscilloscope. Advanced Math provides a simple way to correct the vertical scale and/or offset, often more practical than adjusting the oscilloscope controls or external signal conditioning accessories.

### MSO/DPO4000B Series Setup Procedure:

- For this lab, use the DPO Demo 3 board (679-6506-XX) or DPO Demo 2 board (020-2924-XX). Power up the demo board.
- Verify the power LED is lit.
- Connect a TPP0500 or TPP100010x passive probe to channel 1 on the front of the MSO/DPO4000B Series oscilloscope.
- Connect the probe ground to **GND** on the demo board.
- Connect the channel 1 probe to the **NOISY SINE** or **DAC\_OUT** signal on the demo board.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.

## Key Take Away Points

- The MSO/DPO4000B Series' Advanced Math editor allows you to easily scale and offset a channel waveform. The display should look about like this:



- Notice how the VAR1 and VAR2 controls can be used to provide simple control of numeric factors at high resolution, over a very wide dynamic range.

## MSO/DPO4000B Series Procedure:

- Press the front panel **Autoset** button.
- Set the Horizontal **Scale** to **10 ms/div**.
- Press the red front panel **M** button.
- Press the **Advanced Math** bottom bezel button.
- Press the **Edit Expression** side bezel button.
- Enter the math expression "**VAR1 X ch1 + VAR2**":
  - Press the **Clear** bottom bezel button.
  - Highlight **VAR1** with the Multipurpose **a** control and press the **Enter Selection** bottom bezel button.
  - Highlight the **X** (multiply) sign with the Multipurpose **a** control and press the **Enter Selection** button.
  - Highlight the yellow channel **1** icon with the Multipurpose **a** control and press the **Enter Selection** button.
  - Highlight the **+** sign with the Multipurpose **a** control and press the **Enter Selection** bottom bezel button.
  - Highlight **VAR2** with the Multipurpose **a** control and press the **Enter Selection** bottom bezel button.
  - Press the **OK Accept** side bezel button.
  - Repeatedly press the **Display Expression** side bezel button until **On** is selected.
- Press the front panel **Fine** button to turn off fine control resolution.
- With the Multipurpose controls, set VAR1 to 1000 (**1.0000 E3**).
- Press the **VAR2** side bezel button. With the Multipurpose controls, set VAR2 to 5000 (**5.0000 E3**).

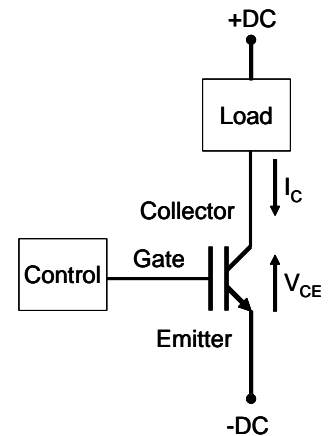
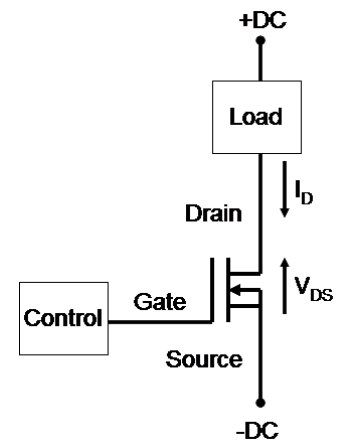
## Instantaneous Power Measurements Using Pseudo-floating Voltage Measurements

Another common oscilloscope measurement which requires simple math is measurement of instantaneous power. One specific measurement is the power dissipation in the switching device in a switch-mode power supply, in this case, an Insulated Gate Bipolar Transistor (IGBT) or Metal Oxide Semiconductor Field Effect Transistor (MOSFET).

As with many other power supply signals, the signals you are looking at are not referenced to ground. In fact, there is no ground reference on this power demo board. Therefore, you will be making "floating" measurements. But because you will be using math to measure these floating voltages, the measurements are sometimes called "pseudo-floating" or "A-B" measurements.

Although the voltage drop across the switching device is usually best measured with an active differential probe and the current flowing through the device is usually best measured with a current probe, you don't always have these probes available. Advanced Math provides another way to make this instantaneous power measurement with standard passive voltage probes, using the Pseudo-floating technique described in an earlier lab.

Depending upon the type of switching device used, the names of the connections change, but the basic concept is the same.

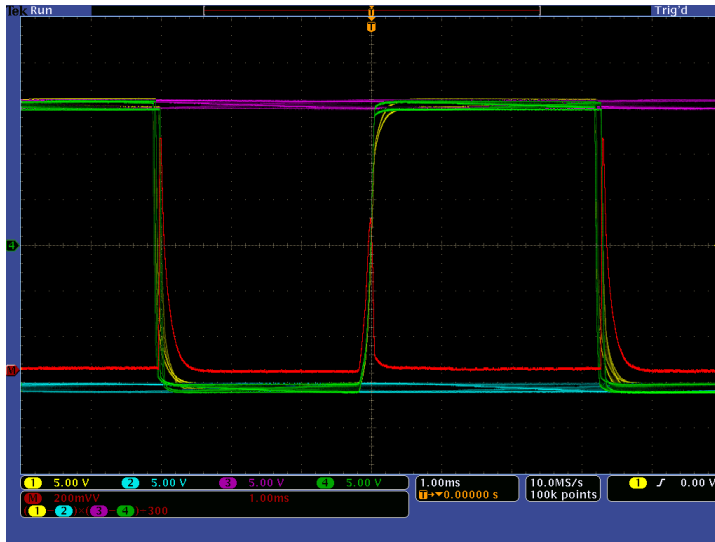


### MSO/DPO4000B Series Setup Procedure:

- ❑ For this lab, use the power demo board. Connect 12VAC power adapter to demo board and plug in to AC power.
- ❑ Connect a TPP0500 or TPP1000 passive probe to each of the four analog channel inputs on the front of the MSO/DPO4000B Series oscilloscope.
- ❑ To measure the floating voltage across the switching device, you will subtract channel 2 from channel 1 to calculate the voltage:
  - ❑ Connect the channel 1 probe to the **Collector** or **Drain** test point.
  - ❑ Connect the channel 2 probe to the **Emitter** or **Source** test point.
  - ❑ Connect each of the probe grounds to the **Neutral** or **GND** test points.
- ❑ To measure the current flowing through the switching device (which equals the current flowing through the 300 Ohm load), you will measure the voltage across the load (again, a floating measurement) and divide by the load resistance (according to Ohm's Law).
  - ❑ Connect the channel 3 probe to the high side of the load (**+DC** test point).
  - ❑ Connect the channel 4 probe to the low side of the load (**Collector** or **Drain** test point).
  - ❑ Connect each of the probe grounds to the **Neutral** or **GND** test points.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Press the front panel **2**, **3**, and **4** buttons to turn on channels 2, 3, and 4.
- ❑ Using the front panel vertical **Position** controls, place the ground references for all four analog channels near the center of the display.
- ❑ Using the front panel vertical scale controls, scale the signals so they occupy at least half of the screen vertically, and position them so they overlap.
- ❑ Using the front panel vertical scale and position controls, scale the signals so they occupy about half of the screen vertically, keeping all of the scale factors set to the same values.
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Mode** bottom bezel button and the **Hi Res** side bezel button.
- ❑ Press the **Record Length** bottom bezel button. Using the Multipurpose **a** control, select **100k**.

## Key Take Away Points

- Advanced math allows simple instantaneous power measurements to be made, using only passive probes, as shown below:



- In this case, the differential voltage across the switching device is multiplied by the current flowing through it. The current is measured by dividing the differential voltage across the load by the 300Ω load resistance.
- As previously noted, the performance of the pseudo-floating measurements is limited, but for many debug applications it is adequate and convenient.)

## MSO/DPO4000B Series Procedure:

- Press the red front panel **M** button.
- Press the **Advanced Math** bottom bezel button.
- Press the **Edit Expression** side bezel button.
- Enter the math expression **“(ch1 – ch2) X ((ch3 - ch4) / 300)”**.
- Press the **OK Accept** side bezel button to complete the equation and calculate the result.
- Press the **Display Expression** side bezel button to select **On**.
- Press the **Menu Off** button.

## Video Linearity Testing

A common video test is to drive a piece of video equipment with a staircase or linear ramp test signal and differentiate the output signal to identify any linearity distortion in the equipment. These distortions might be analog in nature, such as clipping in an amplifier, or quantization errors or calculation errors in digital video processing equipment.

### MSO/DPO4000B Series Setup Procedure:

- For this lab, use a standard analog video generator that can provide a linearity signal. For this example, a 5-step linearity staircase signal was used, but a 10-step staircase or luminance ramp signal could be used instead. To demonstrate the math, connect the video generator directly to the MSO/DPO4000B Series oscilloscope through a 75 Ohm cable and 75 Ohm feed-through terminator on channel 1 on the front of the MSO/DPO4000B Series oscilloscope.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Press the front panel **Autoset** button to do a video autoset to automatically get a stable display.
- Because differentiation is done by subtracting adjacent samples ( $\text{output}[n] = \text{input}[n-1] - \text{input}[n]$ ), it is usually best to lower the number of samples so the differences stand out above the noise. In this case, we set the record length to 1000 points and average the signal to minimize random noise so the signal characteristics will be more visible.
  - Press the front panel **Acquire** button.
  - Press the **Mode** bottom bezel button
  - Press the **Average** side bezel button and turn the Multipurpose **a** control to select the desired number of averages.
  - Press the **Record Length** bottom bezel button.
  - Using the Multipurpose **a** control, select **1000**.

### Key Take Away Points

- Notice how the math waveform allows you to see very minor differences in the heights of each step, often caused by non-linearities in video equipment:



### MSO/DPO4000B Series Procedure:

- Press the red front panel **M** button.
- Press the **Advanced Math** bottom bezel button.
- Press the **Edit Expression** side bezel button.
- Enter the math expression **"Diff(ch1)"**.
- Press the **OK Accept** side bezel button to complete the equation and calculate the result.
- Press the **Display Expression** side bezel button to select **On**.
- Press the **Menu Off** button.



## Logarithmic Displays

An oscilloscope typically displays signals on a linear Voltage vertical axis. However, it is sometimes desirable to display large-dynamic-range signals, especially power waveforms, on a logarithmic axis. The Advanced Math system provides a simple way to display simple or complex waveforms on a logarithmic vertical axis.

If the input signal is a voltage across a load resistance, the instantaneous power delivered to the load is the square of the signal divided by the load resistance. ( $P = V^2 / R$  with the units of Watts)

For logarithmic displays, a common unit is the dBm (deciBel referenced to a milliWatt), measured with a 50 Ohm load. The resulting math expression is  $10 * \log_{10}(\text{Power, in mW}) = 10 * \text{Log}(\text{ch1} \times \text{ch1} / 50 \times 1000)$ .

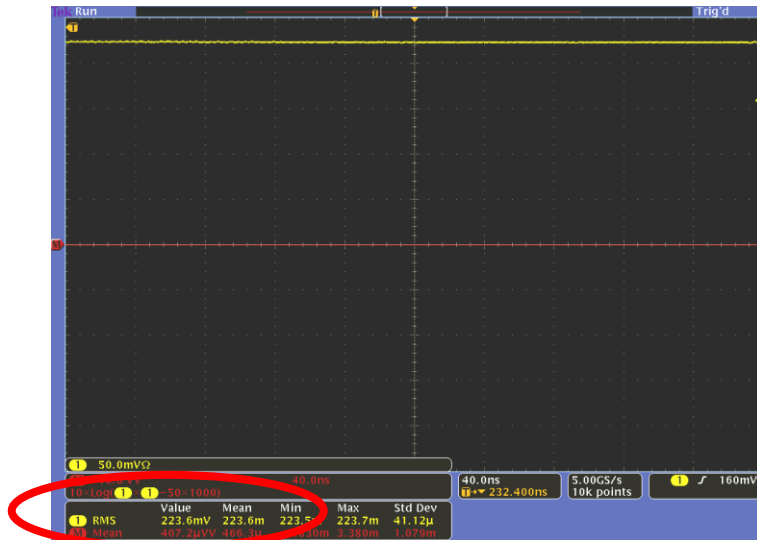
The reference point for this logarithmic display is 0 dBm, which corresponds to a signal with an amplitude of  $0.2235 V_{\text{RMS}}$ . Note that the Log function requires a positive input; the output is NULL if the input is  $\leq 0$ .

### MSO/DPO4000B Series Setup Procedure:

- For this lab, use any signal generator.
- Connect the signal to channel 1 with a 50 Ohm BNC cable.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Press the front panel yellow channel **1** button to bring up the channel 1 menu.
- Press the **Impedance** bottom bezel button until **50Ω** is selected.
- Press the front panel **Autoset** button to automatically get a stable display.

## Key Take Away Points

- After entering the math expression, you can verify that the equation is correct by measuring the RMS value of the signal with automatic measurements. When the RMS value of the signal is 0.2235 V, the logarithmic display should be at 0dBm, as shown in the measurement readouts in the lower left corner of the display:



- Here is a logarithmic display of instantaneous power, with positive peaks at 0dBm and negative peaks near the noise floor (theoretically zero power or  $-\infty$  dBm). When looking at small signals, it may be helpful to filter the signal to minimize noise. In this example, Averaging was enabled:



## MSO/DPO4000B Series Procedure:

- Press the front panel **Acquire** button.
- Press the **Mode** bottom bezel button and the **HiRes** side bezel button.
- Press the red front panel **M** button.
- Press the **Advanced Math** bottom bezel button.
- Press the **Edit Expression** side bezel button.
- Enter the math expression “**10 X Log(ch1 X ch1 / 50 X 1000)**”.
- Press the **OK Accept** side bezel button to complete the equation and calculate the result.
- Press the **Display Expression** side bezel button to select **On**.
- While the Math menu is displayed, you can use the Multipurpose controls to adjust the math vertical scale and position. In the screen shots at the left, the vertical position (**0** dBm point) is at the center of the screen, and the vertical scale is set to **10 dBm/div**.
- Press the **Menu Off** button.

### Integration without Accumulating Offsets

Integration is a mathematical technique to find the area under a curve. The integration function always starts at a zero value, and calculates the integral by adding new input data points to the current value of the integral ( $\text{output}[n] = \text{output}[n-1] + \text{input}[n]$ ).

One common application is to calculate energy delivered by a signal by integrating the instantaneous power waveform over time. However, over time, any offsets in the signal are accumulated. In some cases, the user would like to be able to ignore these offsets.

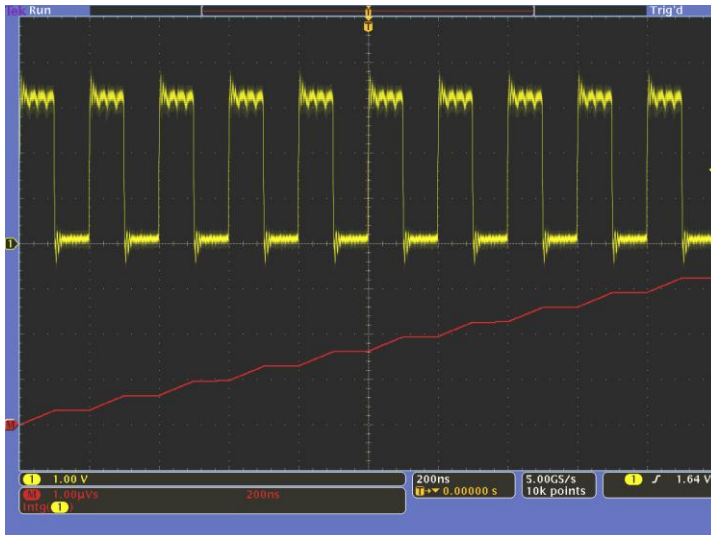
The Advanced Math system allows the use of waveform measurements to be used as scalar arguments. One such use is with integration, where you can use an equation like  $\text{Integral}(\text{ch1} - \text{mean}(\text{ch1}))$ .

### MSO/DPO4000B Series Setup Procedure:

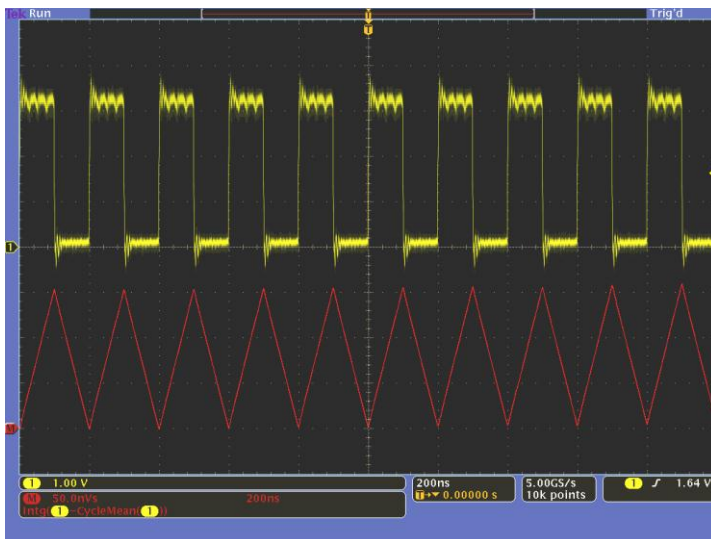
- For this lab, use the DPO Demo 3 board (679-6506-XX) or DPO Demo 2 board (020-2924-XX). Power up the demo board.
- Verify the power LED is lit.
- Connect a TPP0500 or TPP100010x passive probe to channel 1 on the front of the MSO/DPO4000B Series oscilloscope.
- Connect the probe ground to **GND** on the demo board.
- Connect the channel 1 probe to the **CNT\_OUT0** signal on the demo board.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Press the front panel **Autoset** button to automatically get a stable display.

## Key Take Away Points

- Notice how the integral continues to accumulate the offsets in the input signal across the display (because the input signal has a DC offset):



- Although there are other ways to remove the offset, advanced math can use the automatic measurement system to calculate the value for each waveform and subtract it out:



## MSO/DPO4000B Series Procedure:

- ❑ Press the red front panel **M** button.
- ❑ Press the **Advanced Math** bottom bezel button.
- ❑ Press the **Edit Expression** side bezel button.
- ❑ Enter the math expression "**Intg(ch1 - CycleMean(ch1))**".
- ❑ Press the **OK Accept** side bezel button to complete the equation and calculate the result.
- ❑ Press the **Display Expression** side bezel button to select **On**.
- ❑ Press the **Menu Off** button.

## Inductor Flux Density Measurements

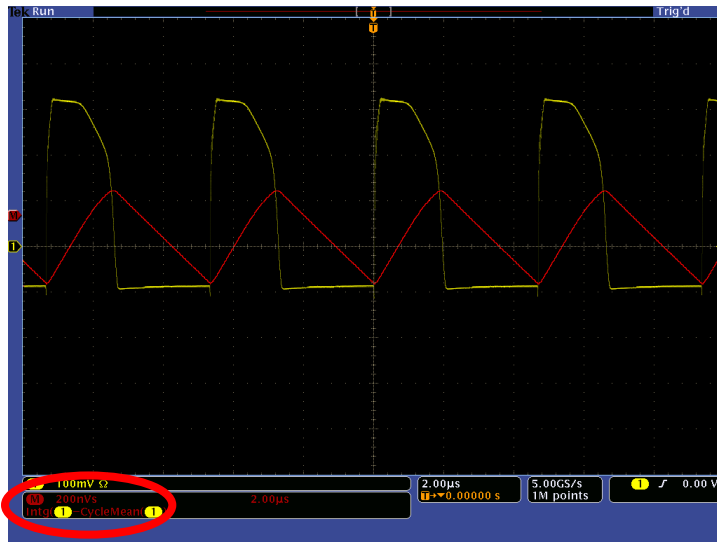
Faraday's Law relates the flux density in an inductor or coil to the integral of the voltage applied across a winding. Therefore, we can measure the flux density  $B(t)$  by acquiring and integrating the voltage waveform using the technique just explained.

### MSO/DPO4000B Series Setup Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Connect a TDP0500 or TDP1000 differential probe to channel 1 on the front of the oscilloscope.
- ❑ Connect the **+** and **-** inputs together. Make sure that the **Range** is set to **42.0 V**.
- ❑ Press the **Menu** button on the probe's comp box, and press the **AutoZero** side bezel button.
- ❑ Connect the differential probe across the inductor under test. For example, you can use the **±Vcore** test points on the power demo board.
- ❑ Set the channel 1 positive edge trigger level to the center of the waveform. If the trigger is unstable due to noise, press the front panel Trigger **Menu** button, the **Coupling** bottom bezel button, and the **HF Reject** side bezel button.
- ❑ Press the front panel **Autoset** button to scale and position the waveform on the display. If you wish, you can further optimize the display with the front panel controls.
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1M**.
- ❑ If the signal is noisy, press the **Mode** bottom bezel button and the **Average** side bezel button.

## Key Take Away Points

- The flux density measurement display should look something like this:



## MSO/DPO4000B Series Procedure:

- Press the red front panel **M** button.
- Press the **Advanced Math** bottom bezel button.
- Press the **Edit Expression** side bezel button.
- Press the **Clear** bottom bezel button.
- Using the Multipurpose **a** control, select **Intg(** and press the **Enter Selection** bottom bezel button.
- Using the Multipurpose **a** control, select the yellow **1** and press the **Enter Selection** bottom bezel button.
- Using the Multipurpose **a** control, select the minus sign **-** and press the **Enter Selection** bottom bezel button.
- Using the Multipurpose **a** control, select **CycleMean(** and press the **Enter Selection** bottom bezel button.
- Using the Multipurpose **a** control, select the yellow **1** and press the **Enter Selection** bottom bezel button.
- Using the Multipurpose **a** control, select the closing parenthesis **)** and press the **Enter Selection** bottom bezel button twice.
- Press the **OK Accept** side bezel button.
- Repeatedly press the **Display Expression** side bezel button until **On** is selected.
- Press **Menu Off** once to clear the side menu.
- Use the Multipurpose **a** control to select adjust the math waveform vertical position and the Multipurpose **b** control to adjust the vertical scale.

## Creating Digital Signals – The Logic of Greater Than (or Less Than)

When working with digital signals, you sometimes want to see all of the analog characteristics. But when you don't, Advanced Math allows you to transform them into ideal binary waveforms for further analysis.

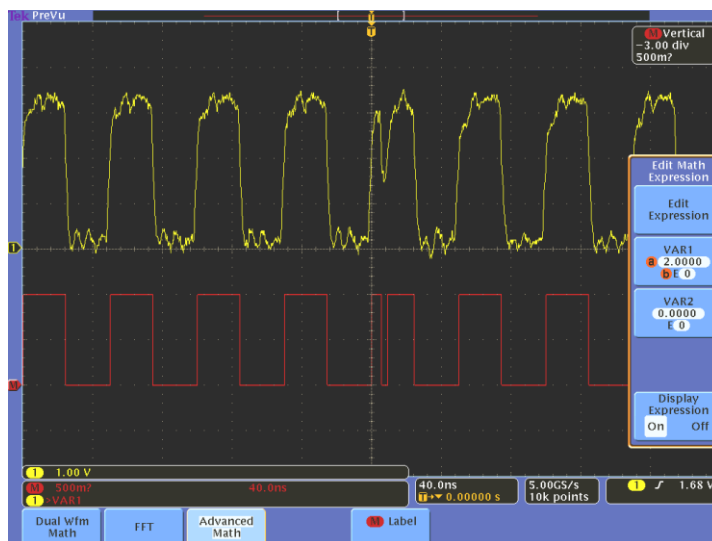
The Advanced Math system relational operators are  $>$ ,  $<$ ,  $>=$ , and  $<=$ . These operators compare a waveform to a scalar value (a fixed number, a variable value you specify, or a measurement value) and output a digital signal which is a digital high when the equation is true and a digital low when the equation is false. The simplest is a digital comparator such as "ch1 > 2" which creates a digital high signal whenever channel 1 exceeds 2.0 V.

### MSO/DPO4000B Series Setup Procedure:

- For this lab, use the DPO Demo 3 board (679-6506-XX) or DPO Demo 2 board (020-2924-XX). Power up the demo board.
- Verify the power LED is lit.
- Connect a TPP0500 or TPP1000 10x passive probe to channel 1 on the front of the MSO/DPO4000B Series oscilloscope.
- Connect the probe ground to **GND** on the demo board.
- Connect the channel 1 probe to the **XTALK1** signal on the demo board.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.

### Key Take Away Points

- Notice that the math waveform is the digital representation of the analog channel 1 signal. In this example, the glitch crosses through the threshold value and is interpreted as a transition in the digital signal, as it would in the hardware receiver in the circuit:



### MSO/DPO4000B Series Procedure:

- Press the red front panel **M** button.
- Press the **Advanced Math** bottom bezel button.
- Press the **Edit Expression** side bezel button.
- Enter the math expression "ch1 > VAR1".
- Press the **OK Accept** side bezel button to complete the equation and calculate the result.
- Press the **Display Expression** side bezel button to select **On**.
- Press the front panel **Fine** button to turn off fine control resolution.
- Press the **VAR1** side bezel button.
- With the Multipurpose controls, set **VAR1** to the desired digital threshold value, such as 2V (**2.0000 E0**).
- Press the **Menu Off** button.

## FFTs of Idealized Digital Signals

FFTs provide the frequency domain representation of the input signal. In the case of a real square wave, the FFT display includes the spectral representation of all of the signal components, both the desired square wave as well as the noise and amplitude modulation of the signal. In some cases, this is desirable, but in others you are really most interested in the spectrum of the idealized square wave.

The standard math FFT allows you to display the spectral representation of any of the analog channels or reference waveforms. The FFT function in advanced math allows an arbitrarily complex argument. (However, the FFT function itself cannot be part of an argument, so it must be the outer-most function in a complex math equation.)

As seen in the last lab, the Advanced Math system allows the creation of idealized digital waveforms. These waveforms can also be analyzed by the FFT function.

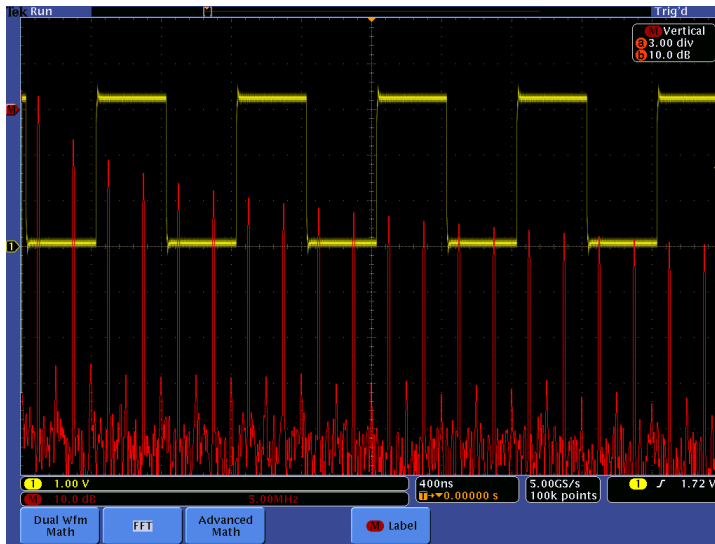
### MSO/DPO4000B Series Setup Procedure:

- For this lab, use the DPO Demo 3 board (679-6506-XX) or DPO Demo 2 board (020-2924-XX). Power up the demo board.
- Verify the power LED is lit.
- Connect a TPP0500 or TPP1000 10x passive probe to channel 1 on the front of the MSO/DPO4000B Series oscilloscope.
- Connect the probe ground to **GND** on the demo board.
- Connect the channel 1 probe to the **CNT\_CLK** signal on the demo board.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Press the front panel **Autoset** button to automatically get a stable display.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **100k**.

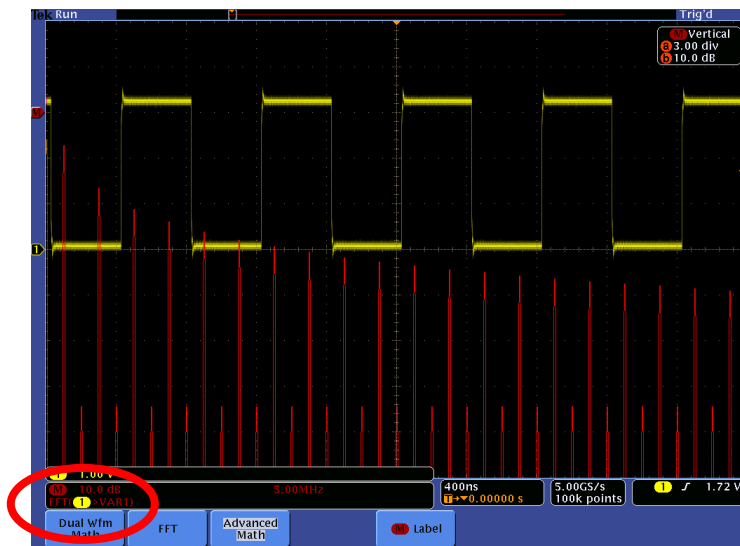


## Key Take Away Points

- This is the FFT of the real square wave, as set up earlier in this lab:



- Notice how much “cleaner” the FFT display of the idealized square wave is:



## MSO/DPO4000B Series Procedure:

- Press the red front panel **M** button.
- Press the **Advanced Math** bottom bezel button.
- Press the **Edit Expression** side bezel button.
- Enter the math expression “**FFT(ch1 > VAR1)**”.
- Press the **OK Accept** side bezel button to complete the equation and calculate the result.
- Press the **Display Expression** side bezel button to select **On**.
- Press the front panel **Fine** button to turn off fine control resolution.
- Press the **VAR1** side bezel button.
- With the Multipurpose controls, set **VAR1** to the desired digital threshold value, such as 2V (**2.0000 E0**).
- Press the **Horizontal** side bezel button.
- Rotate the Multipurpose **a** control fully clockwise to set the zero-frequency point in the middle of the display.
- With the Multipurpose **b** control, set the horizontal resolution to **5 MHz/div**.
- With the Multipurpose **a** control, set the center frequency to **25 MHz**.
- Press **Menu Off** once.
- With the Multipurpose **b** control, set the FFT Vertical Scale to **10.0 dB/div**.
- Press the **Menu Off** button.

## Binary Math with Digital Signals

Advanced Math provides other operators that work with idealized digital waveforms, allowing you to do other analysis. The Advanced Math system binary operators are !, ==, ≠, ||, and &&.

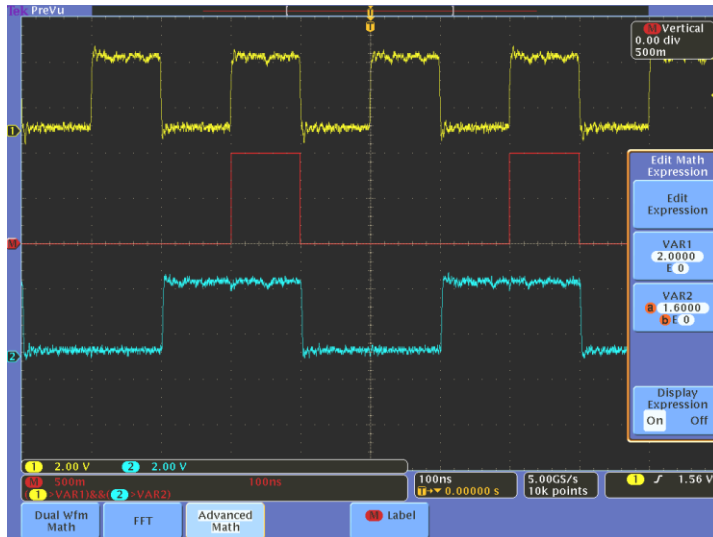
- The **!()** operator inverts the logic of the expression in the parentheses. For example,  $!(ch1 > 1.6)$  inverts the idealized digital waveform with a 1.6V digital threshold.
- The **==** operator provides the logical XNOR function on the preceding and following arguments. For example,  $(ch1 > 2.4) == (ch2 > 2.4)$  provides a high output whenever the idealized digital representations of channel 1 and channel 2 are at the same logic level, using a 2.4V digital threshold.
- The **≠** operator provides the logical XOR function on the preceding and following arguments. For example,  $(ch1 > 2.4) \neq (ch2 > 2.4)$  provides a high output whenever the idealized digital representations of channel 1 and channel 2 are at the opposite logic level, using a 2.4V digital threshold.
- The **||** operator provides the logical OR function on the preceding and following arguments. For example,  $(ch1 < 0) || (ch1 > 5)$  provides a high output whenever the channel 1 signal is outside the range of 0V to 5V.
- The **&&** operator provides the logical AND function on the preceding and following arguments. For example,  $(ch1 \geq 1) \&\& (ch1 \leq 2)$  provides a high output whenever the channel 1 signal is between 1.0V and 2.0V.

### MSO/DPO4000B Series Setup Procedure:

- For this lab, use the DPO Demo 3 board (679-6506-XX) or DPO Demo 2 board (020-2924-XX). Power up the demo board.
- Verify the power LED is lit.
- Connect TPP0500 or TPP1000 10x passive probes to channels 1 and 2 on the front of the MSO/DPO4000B Series oscilloscope.
- Connect the channel 1 probe to the **CNT\_OUT0** signal on the demo board.
- Connect the probe ground to **GND** on the demo board.
- Connect the channel 2 probe to the **CNT\_OUT1** signal on the demo board.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.

## Key Take Away Points

- Notice that the math waveform is the logical AND of the digital representations of the analog channel 1 and 2 signals:



- Now that you have a math waveform, you can make measurements on it. For example, you can measure the resulting duty cycle:



## MSO/DPO4000B Series Procedure:

- Press the red front panel **M** button.
- Press the **Advanced Math** bottom bezel button.
- Press the **Edit Expression** side bezel button.
- Enter the math expression “(ch1 > VAR1) && (ch2 > VAR2)”.
- Press the **OK Accept** side bezel button to complete the equation and calculate the result.
- Press the **Display Expression** side bezel button to select **On**.
- Press the front panel **Fine** button to turn off fine control resolution.
- Press the **VAR1** side bezel button.
- With the Multipurpose controls, set **VAR1** to the desired digital threshold value, such as 2V (**2.0000 E0**).
- Press the **VAR2** side bezel button.
- With the Multipurpose controls, set **VAR2** to the desired digital threshold value, such as 1.6V (**1.6000 E0**).
- To provide a stable display, we enable logic triggering, acquiring signals whenever both channels 1 and two are high.
- Then, press the front panel **Measure** button.
- Press the **Select Measurement M** bottom bezel button.
- Select the desired measurement from the list in the side menu. For example, the **Positive Duty Cycle** measurement is found on page 2 of this menu.
- Press the **Menu Off** button.

## Off-line Editing of Advanced Math Equations

Advanced Math equations are stored as text strings in the ASCII setup files saved and recalled by the oscilloscope. These files can be edited with a text editor, for example to modify a complex equation, or to generate multiple setup files with slightly different values. A few of the specific commands relating to the math system look like this:

```
:MATH:TYPE ADVANCED
:MATH:DEFINE "((CH1<VAR1)&&(CH2>VAR2))"
:MATH:VERTICAL:SCALE 100.0000E-6
:MATH:VERTICAL:POSITION 0.0000
```

## MSO/DPO4000B Series Setup Procedure:

- For this lab, connect a mass storage device such as a USB Flash drive to the MSO/DPO4000B Series.
- Turn on Advanced Math and enter an equation.
- Press the front panel Save/Recall **Menu** button.
- Press the **Save Setup** bottom bezel button and the **To File** side bezel button.
- Using the Multipurpose **a** control, navigate to the desired file system location and press the **Save To Selected File** side bezel button.
- Connect the mass storage device to your computer and open the setup file (default name is "tek00000.set") with a text editor. Use the editor's find feature to locate the text you want to edit.
- For example, you could replace the variables with specific complex numeric constants, perhaps more easily with a text editor than with the on-screen editor:

```
:MATH:DEFINE "((CH1<3.14159265358979)&&(CH2>0.707106781186547))"
```

or inserting math functions that are not available through the user interface, such as trig functions:

```
:MATH:DEFINE "(CH1*CH2)*Cos(Phase(CH1,CH2)*0.017453)"
to measure the mean true power in an instantaneous power waveform.
```

- Then, save the file and exit the editor.
- Connect the mass storage device to the oscilloscope again.
- Press the front panel Save/Recall **Menu** button.
- Press the **Recall Setup** bottom bezel button and the **From File** side bezel button.
- Using the Multipurpose **a** control, navigate to the desired file system location and press the **Recall From Selected File** side bezel button.
  
- The Advanced Math equation is a quoted text string in the setup file. The string can be up to 127 characters in length, but it must conform to the choices available in the on-screen math editor menu. If there is an error, such as:

```
:MATH:DEFINE "((CH1<VAR3)&&(CH2>VAR2))"
```

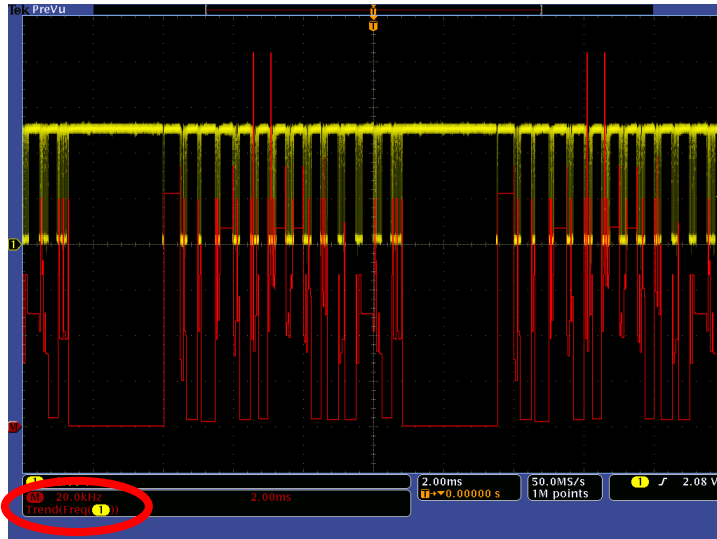
the oscilloscope will pop up an error message and ignore the part of the setup file that is incorrect.

## Measurement Trends

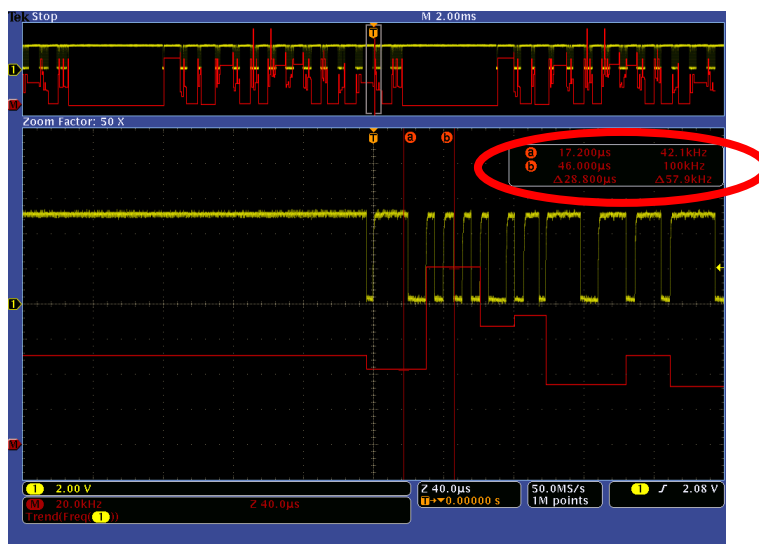
Most Advanced Math equations contain mathematical operators and functions which use channel or reference waveforms as arguments. There is an advanced math function which can form a math waveform out of a series of waveform timing measurements, the trend() function. Specifically, trend() works with  $\pm$ PulseWidth,  $\pm$ Duty Cycle, Frequency, and Period. A measurement trend plot provides a convenient way to monitor changes in signal parameters over time.

### Key Take Away Points

- With the trend() function, you can plot the variations of automatic timing measurements over time:



- Now that you have a math waveform, you can make cursor measurements on it. For example, you can measure the frequency values at various times along the math waveform:

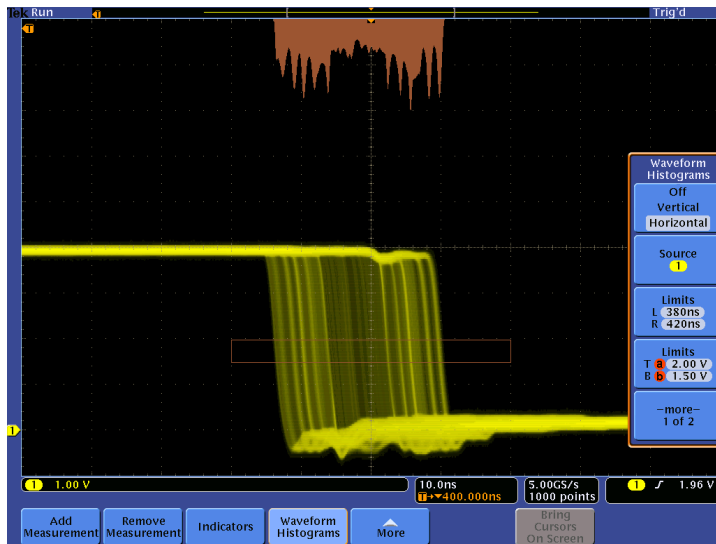


### MSO/DPO4000B Series Procedure:

- Press the front panel **Default Setup** button.
- Connect a probe to channel 1. Connect the probe ground to GND and the probe tip to a digital signal such as an I<sup>2</sup>C data signal.
- Press the front panel **Acquire** button and the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **1M**.
- Press the front panel **Autoset** and **Single** buttons.
- Press the front panel **M** button.
- Press the **Advanced Math** bottom bezel button.
- Press the **Edit Expression** side bezel button.
- Press the **Clear** bottom bezel button.
- Using the Multipurpose **a** control and the bottom bezel buttons, enter the equation "**Trend(Freq(ch1))**".
- Press the **OK Accept** side menu button.
- Repeatedly press the **Display Expression** side bezel button until **On** is selected.
- Press the **Menu Off** button once to remove the side menu.
- Using the Multipurpose controls, scale and position the math waveform.
- Press the **Menu Off** button once.
- Press the **Cursors** button.
- Notice the cursor measurements of the measurement trend plot.

# MSO4000B/DPO4000B Series

## Waveform Histograms Lab



### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
  - One TPP0500 or TPP1000 Passive Probe
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]

## Overview of Waveform Histograms

A histogram is a graphical display which shows the density or relative proportions of cases of a varying quantity falling into each of several bins or categories. For example, in a Digital Phosphor Oscilloscope, the waveform intensity at each picture element (or pixel) on the display represents the relative frequency-of-occurrence. In this way, the brightness of the pixels is a statistical representation of a time-varying signal.

Waveform histograms show the density of the waveform samples in a row or column of pixels ("hits") in a specified area on the oscilloscope display. The user specifies the portion of the displayed waveform to be analyzed by positioning a rectangle or box on the display.

A vertical histogram shows the number of waveform samples which occur at each of the 250 digitizer levels on the display. The box specifies the waveform samples that are analyzed.

A horizontal histogram shows the number of waveform samples which occur in each of the 1000 pixel columns on the display. The box specifies the waveform samples that are analyzed.

In either case, the waveform histogram data is normalized such that the display of the bin with the highest number of hits is scaled to 2 divisions tall. The default display format scales the histogram data linearly, but a logarithmic display format is also available which can improve visibility of details of bins with few hits.

In addition to the waveform histogram display, automatic measurements on the histogram data are available:

**Waveform Count:** Displays the number of waveforms that contributed to the histogram.

**Hits in Box:** The number of samples within the histogram box or on its boundaries.

**Peak Hits:** The number of samples in the bin that contains the most hits.

**Median:** The middle histogram data value, where half of all histogram data points are less than this value and half are greater than this value.

**Peak-to-peak:** Vertical histograms display the voltage of the highest nonzero bin minus the voltage of the lowest nonzero bin. Horizontal histograms display the time of the right-most nonzero bin minus the time of the left-most nonzero bin.

**Histogram Max:** The voltage of the highest nonzero bin in vertical histograms or the time of the right-most nonzero bin in horizontal histograms.

**Histogram Min:** The voltage of the lowest nonzero bin in vertical histograms or the time of the left-most nonzero bin in horizontal histograms.

**Histogram Mean:** The average of all histogram data points within or on the histogram box.

**Standard Deviation:** The standard deviation (Root Mean Square deviation) of all histogram data points within or on the histogram box.

**Sigma1:** The percentage of the hits in the histogram that are within one standard deviation of the histogram mean.

**Sigma2:** The percentage of the hits in the histogram that are within two standard deviations of the histogram mean.

**Sigma3:** The percentage of the hits in the histogram that are within three standard deviations of the histogram mean.

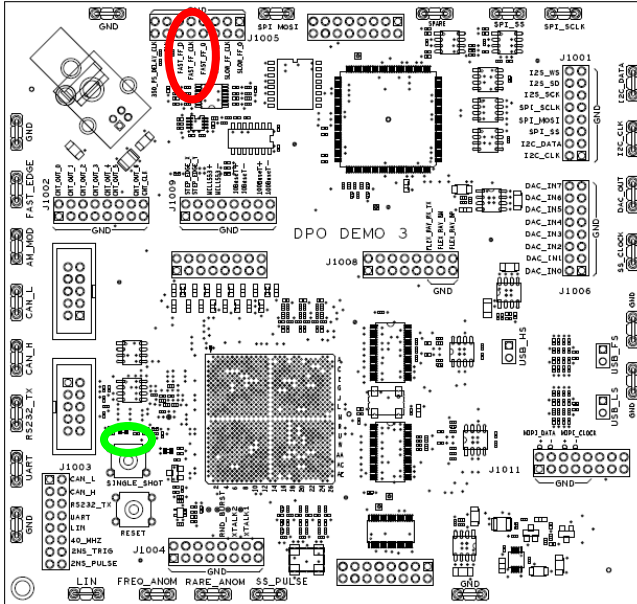
### Objectives

- Obtain a basic understanding of waveform histogram displays and automatic measurements on histogram data.
- Learn how to set up and demonstrate waveform histograms with a MSO/DPO4000B Series oscilloscope.

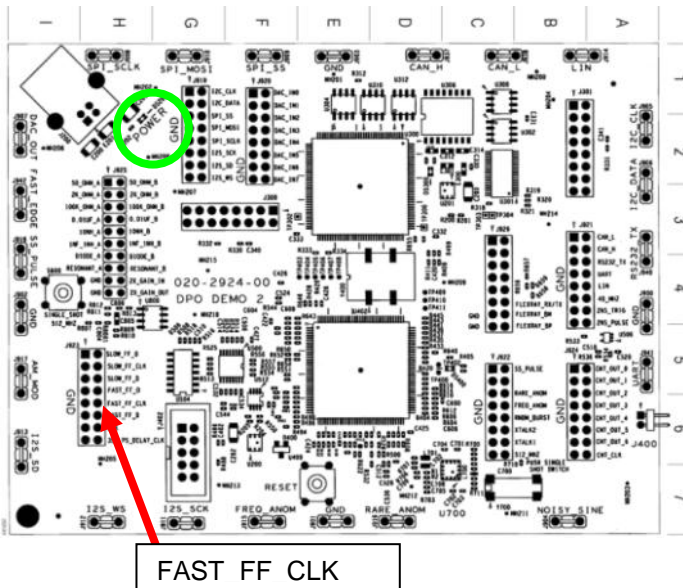
## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a FAST\_FF\_CLK signal which we will use for this lab. This is a 1.25 MHz signal with a slow variation in duty cycle. (The timing of the falling edges vary at about a 1 Hz rate.):



- The DPO Demo 2 board (020-2924-XX) has a FAST\_FF\_CLK signal which we will use for this lab. This is a 1.25 MHz signal with a slow variation in duty cycle. (The timing of the falling edges vary at about a 1 Hz rate.)



### DPO Demo Board Procedure:

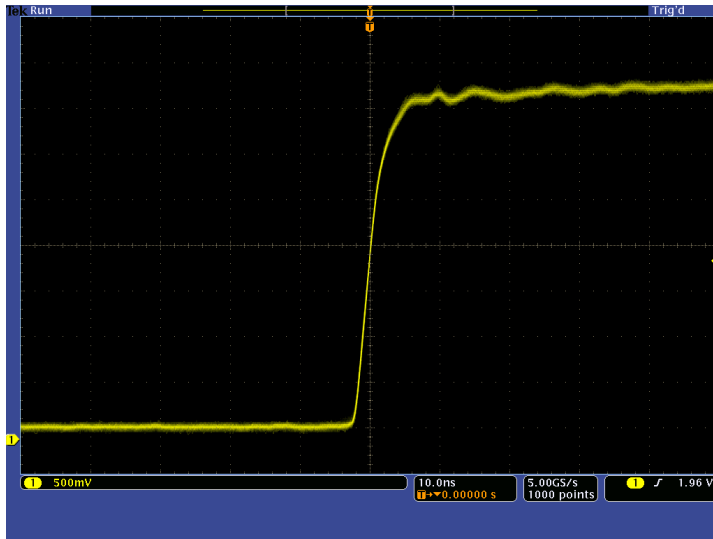
- Power up the demo board.
- Verify the power LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.
- Attach the probe ground to the **GND** test point on the demo board.
- Connect the probe tip to the **FAST\_FF\_CLK** test point on the demo board.



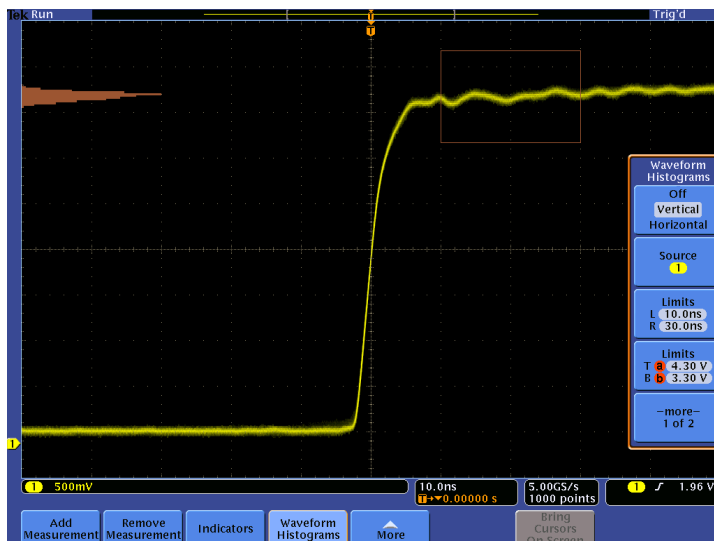
## Vertical Waveform Histograms

### Key Take Away Points

- Vertical waveform histograms allow you to evaluate the distribution of voltage values on a signal over time. For example, on this digital signal, the “high” voltage is approximately 4V, but there is some noise superimposed on the signal, as shown below:



- The vertical histogram display provides a way to measure and characterize this noise over a region on the waveform, specified by the graphical box. The noise can be displayed as a linear or logarithmic histogram, shown at the left side of the display, aligned with the box. Notice that the noise histogram appears to be a fairly bell-shaped curve:



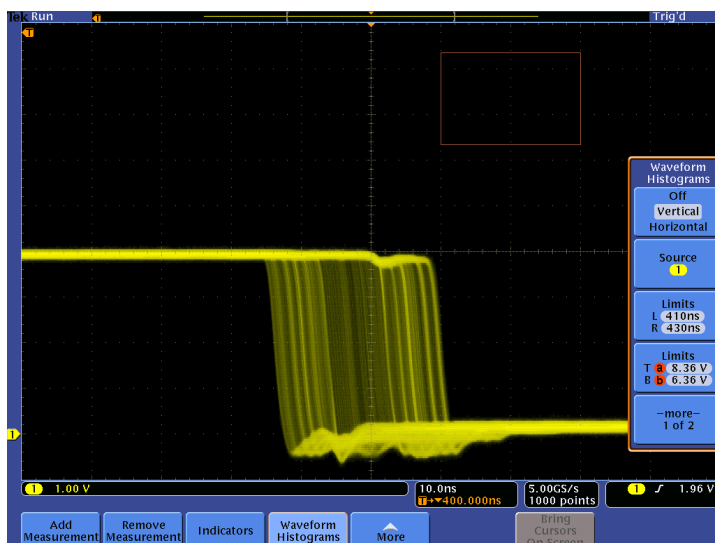
### MSO/DPO4000B Series Procedure:

- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Set the Vertical **Scale** to **500mV/div** and center the position of the waveform vertically on the display.
- Press the front panel **Level** control labeled **Push to Set to 50%** button to automatically set the trigger level.
- Set the Horizontal **Scale** to **10ns/div**.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **1000**.
- Press the front panel **Measure** button.
- Press the **Waveform Histograms** bottom bezel button.
- Press the first side bezel button once to select **Vertical** histograms.
- Press the third side bezel button to attach the controls to the horizontal box limit controls.
- Using the Multipurpose **a** control, set the **Left** side of the box to **10 ns**.
- Using the Multipurpose **b** control, set the **Right** side of the box to **30 ns**.
- Press the fourth side bezel button to attach the controls to the vertical box limit controls.
- Using the Multipurpose **a** control, set the **Top** of the box to about **4.3 V**.
- Using the Multipurpose **b** control, set the **Bottom** of the box to about **3.3 V**.

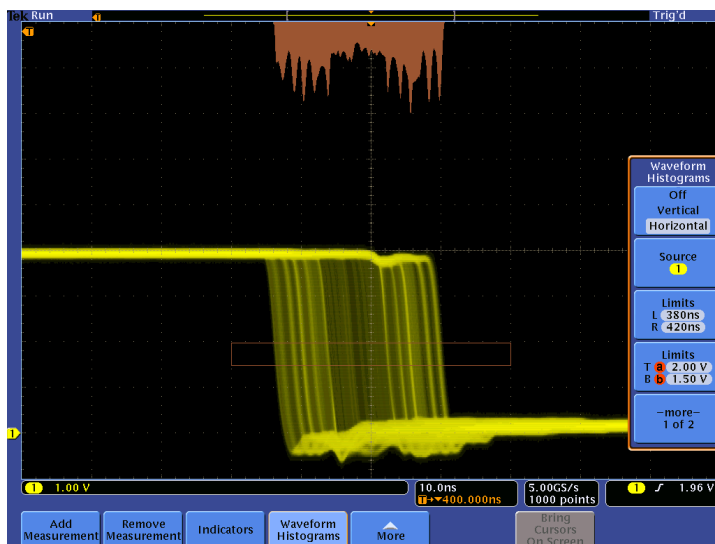
## Horizontal Waveform Histograms

### Key Take Away Points

- Horizontal waveform histograms allow you to evaluate the changes in position of a signal over time. In many cases, this is referred to as “jitter”. For example, on this digital signal, the falling edge is varying back and forth by over 20 ns:



- The horizontal histogram display below shows the jitter on the falling edge of the FAST\_FF\_CLK signal. The histogram is positioned at the top of the display and is aligned with the box. The histogram is always scaled such that the peak value is 2 divisions high.



- Notice that the histogram is not at all bell-shaped, suggesting that the edge jitter is not due to random noise.

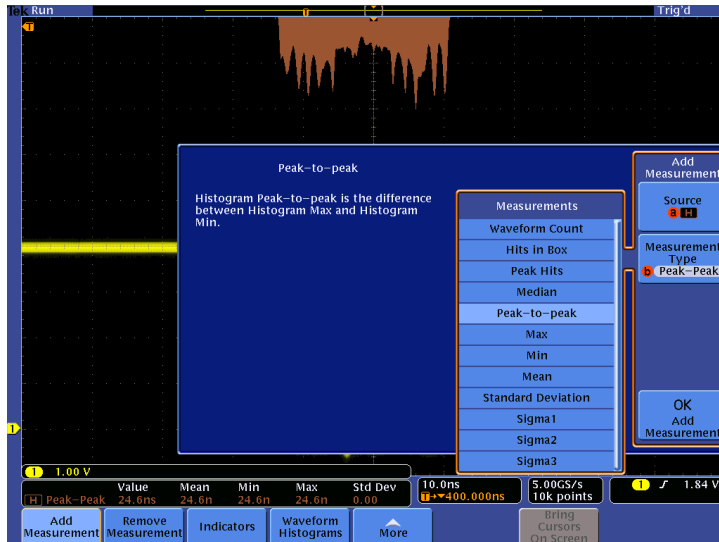
### MSO/DPO4000B Series Procedure:

- NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- Turn the horizontal **Position** control counter-clockwise until the falling edge of the signal is centered on the display. The trigger delay readout should indicate about 400 ns, shown at the bottom of the display.
- Set the Vertical **Scale** to 1 V/div.
- Press the front panel **Acquire** button.
- Press the **Waveform Display** bottom bezel button.
- Turn the Multipurpose **a** control fully clockwise to enable infinite persistence.
- Press the front panel **Measure** button.
- Press the **Waveform Histograms** bottom bezel button.
- Press the first side bezel button once to select **Horizontal** histograms.
- Press the third side bezel button to attach the controls to the horizontal box limit controls.
- Using the Multipurpose **a** control, set the **Left** side of the box to **380 ns**.
- Using the Multipurpose **b** control, set the **Right** side of the box to **420 ns**.
- Press the fourth side bezel button to attach the controls to the vertical box limit controls.
- Using the Multipurpose **a** control, set the **Top** of the box to about **2.0 V**.
- Using the Multipurpose **b** control, set the **Bottom** of the box to about **1.5 V**.

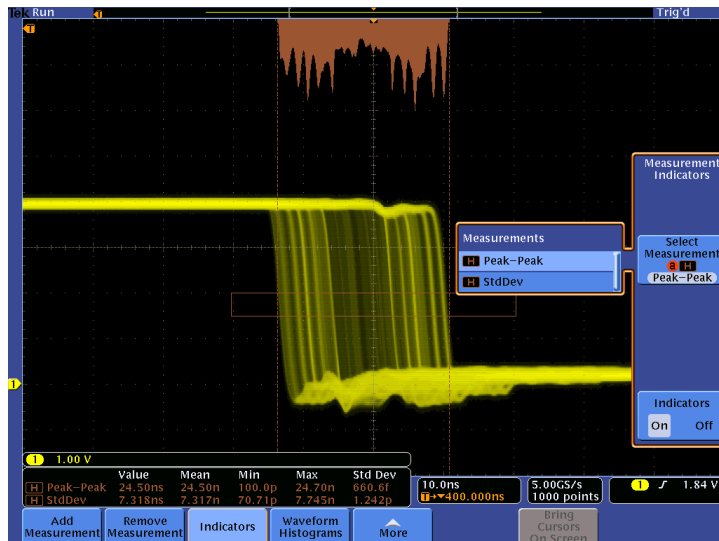
## Automatic Measurements on Histogram Data

### Key Take Away Points

- In addition to graphing the waveform histogram data, the oscilloscope can make automatic measurements on the data.
- When the histogram data is selected as the source for the measurements, the list of appropriate measurement types appears:



- The measurements on the histogram data appear at the bottom of the screen, in the same color as the histogram display:



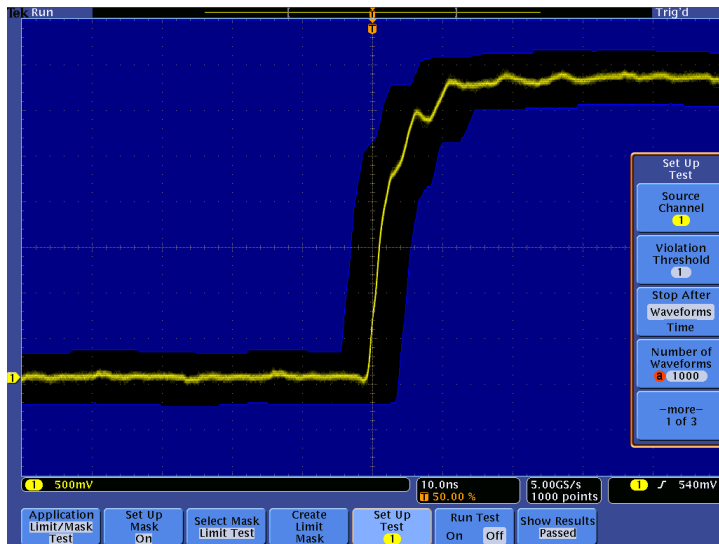
- In this case, the peak-to-peak and RMS jitter measurements on the edge are made automatically.

### MSO/DPO4000B Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the **Add Measurement** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **H** as the measurement source.
- ❑ Using the Multipurpose **b** control, select the **Peak-to-peak** measurement and press the **OK Add Measurement** side bezel button.
- ❑ Using the Multipurpose **b** control, select the **Standard Deviation** measurement and press the **OK Add Measurement** side bezel button.
- ❑ Press the front panel **Menu Off** button once to clear the side menu.
- ❑ To indicate where a measurement is made on the histogram and the waveform, press the **Indicators** bottom bezel button.
- ❑ Press the **Indicators** side bezel button to turn on the indicators.
- ❑ Using the multipurpose **a** control, select the **Peak-Peak** measurement.
- ❑ Press the front panel **Menu Off** button twice to clear the menus.

# MSO4000B/DPO4000B Series

## Limit and Mask Testing Lab



### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
  - One DPO4LMT application module
  - One TPP0500 or TPP1000 passive Probe
  - DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or  
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
- [Note: screen shots in this document were made with 020-2924-XX demo board]

## Overview of Limit and Mask Testing

This lab contains simple demos of the optional limit testing and mask testing applications of the MSO/DPO4000B Series. Both of these applications are enabled by the DPO4LMT application module.

In the cases of both limit testing and mask testing, the tests actually are remarkably complex. The graphical comparison of a live waveform to a template or mask requires the signal be triggered, and that the amplitude, rise-time, fall-time, delay, and the jitter measurements all be made simultaneously and that the results fall within the specified tolerances.

Limit Testing compares a live waveform to a “template” waveform, where the template is specified by a single Y-T waveform and horizontal and vertical tolerances around the waveform. Limit testing is commonly used in manufacturing and engineering for unattended monitoring circuit behavior over variations of time (like over the weekend) and temperature (as you vary the circuit’s ambient temperature from 0 to 50 Celsius). Although Limit Testing is simple to set up, it is limited to working with single-valued Y-T waveforms, so it does not work with eye diagrams.

Mask Testing is generally used to verify compliance to industry standards, most commonly used with communication signals. As you will see, many industry-standard masks are provided, but you can also specify your own to match your application.

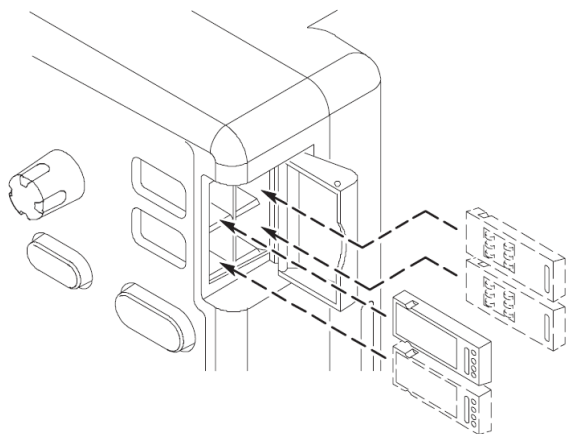
### Objectives

- Obtain a basic understanding of limit testing and mask testing applications.
- Learn how to set up and demonstrate limit testing and mask testing with a MSO/DPO4000B Series oscilloscope.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- With the DPO4LMT application module installed, the MSO/DPO4000B Series oscilloscope can perform limit testing and mask testing on signals. It can be installed in any of the four application module slots on the front panel of the instrument.

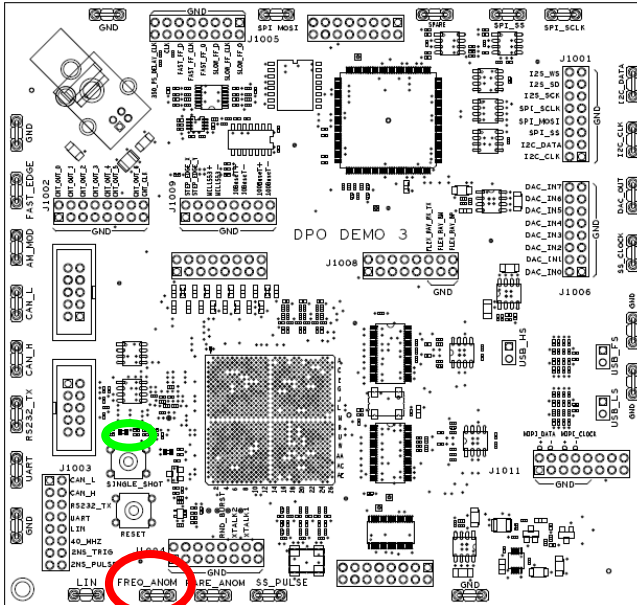


### MSO/DPO4000B Series Procedure:

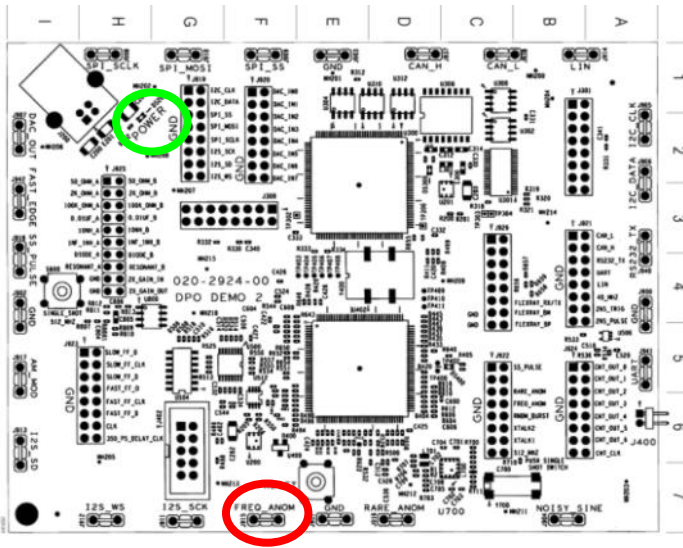
- ❑ With the oscilloscope power off, install the **DPO4LMT** application module into one of the slots on the front panel of the instrument.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4LMT Limit / Mask Test** application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a FREQ\_ANOM signal which we can use for this lab.



- The DPO Demo 2 board (020-2924-XX) also has a FREQ\_ANOM signal which we can use for this lab.



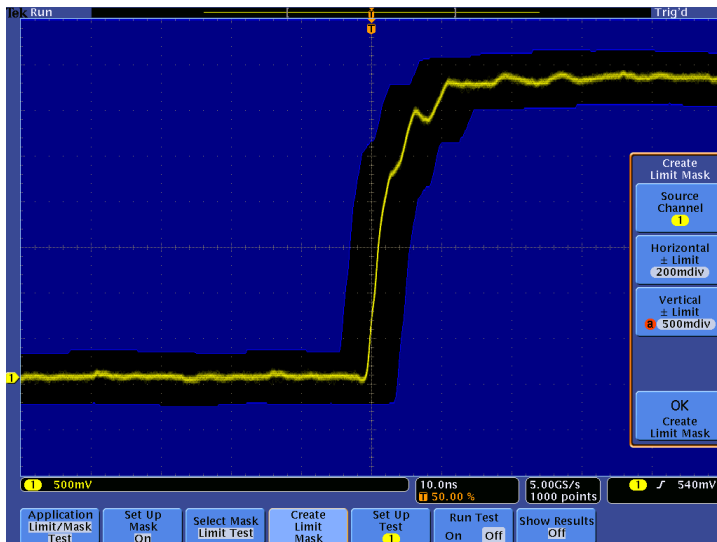
## DPO Demo Board Procedure:

- Power up the demo board.
- Verify the power LED is lit.
- Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.
- Attach the probe ground to the **GND** test point on the demo board.
- Connect the probe tip to the **FREQ\_ANOM** test point on the demo board.

## Limit Testing

### Key Take Away Points

- The MSO/DPO4000B Series' Limit Test provides automated monitoring and capture of signals which vary outside a predetermined tolerance from a standard or "template" waveform. The signal under test is typically one of the analog channels, although math and reference signals can be used. The template waveform is typically stored in a reference, but it can also be stored in a file.
- For simplicity, this lab uses a template based on a single waveform acquired in sample mode. For a smoother template, you might want to base the template on an averaged waveform. However, if you want to build a template that accommodates some noise on a signal with overshoots, you might want to base the template on an envelope or peak detect waveform.
- After creating a limit test template, the display should look about like this:



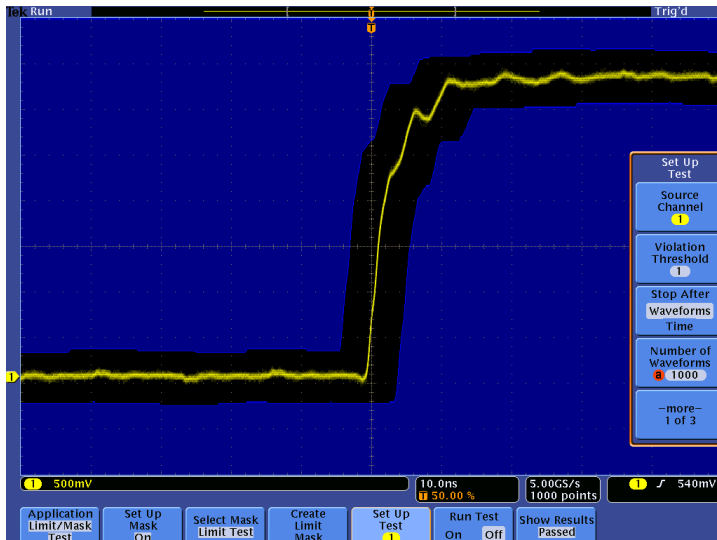
- Note: Selecting Limit Test will force Horizontal Delay to Off, as you can see in the bottom bezel in the Acquire menu.

### MSO/DPO4000B Series Procedure:

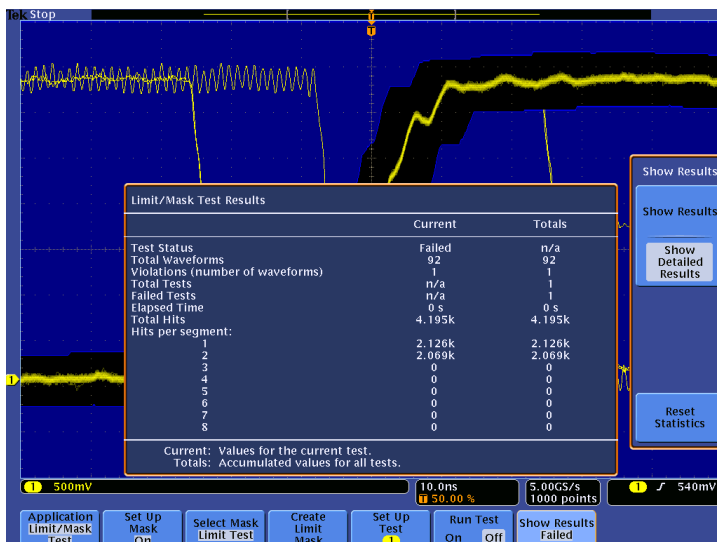
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Set the Vertical **Scale** to **500mV/div** and center the position of the waveform vertically on the display.
- ❑ Press the front panel **Level** control labeled **Push to Set to 50%** button to automatically set the trigger level.
- ❑ Set the Horizontal **Scale** to **10ns/div**.
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1000**.
- ❑ Press the front panel **Test** button.
- ❑ Press the **Application** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **Limit/Mask Test**.
- ❑ Press the **Select Mask** bottom bezel button.
- ❑ Press the **Limit Test** side bezel button.
- ❑ Press the **Create Limit Mask** bottom bezel button.
- ❑ Press the **Horizontal ± Limit** side bezel button.
- ❑ Using the Multipurpose **a** control, set the horizontal margin to **200 mdiv**.
- ❑ Press the **Vertical ± Limit** side bezel button.
- ❑ Using the Multipurpose **a** control, set the vertical margin to **500 mdiv**.
- ❑ Press the **OK Create Limit Mask** side bezel button.

## Key Take Away Points

- Limit Testing can drive a number of actions based on the outcome of the testing. For simplicity in this demo, we will simply test 1000 waveforms and stop acquisitions if an error is detected.



- After a few tests, a limit test failure occurred. The results display looks about like this:



## MSO/DPO4000B Series Procedure:

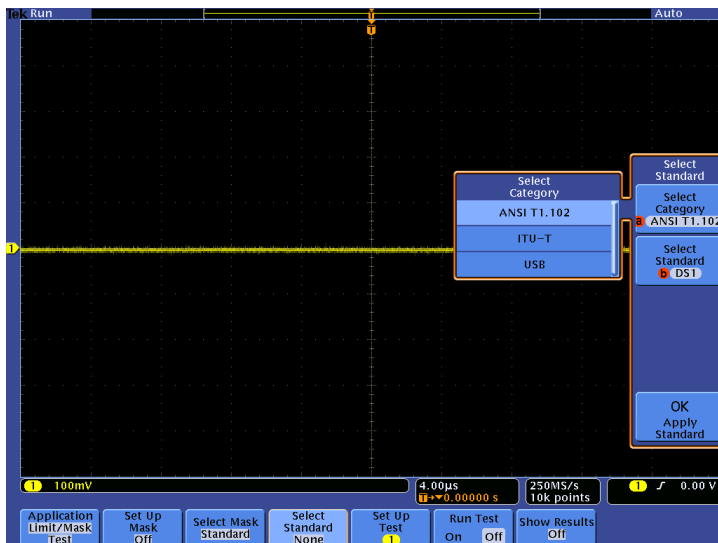
- Press the **Set Up Test** bottom bezel button.
- Verify the **Violation Threshold** value is set to 1. This means that a single limit test violation is considered a test failure.
- Verify that **Stop After Waveforms** is selected in the side menu.
- Press the front panel **Fine** button until Fine is turned off.
- Using the Multipurpose a control, set the **Number of Waveforms** to test to **1000**.
- Press the **-more- 1 of 3** side bezel button.
- Press the **Select Action** side bezel button to view the choices of action if a test failure occurs. Select **Stop Acquisition**.
- Repeatedly press the **Action on Failure** side bezel button until **On** is selected.
- Press the **-more- 2 of 3** side bezel button.
- Verify that **Pre-Test Delay** is set to **0** and **Repeat on Completion** is set to **Off**.
- Press the **Run Test** bottom bezel button until **On** is selected.
- Press the **Show Results** bottom bezel button.



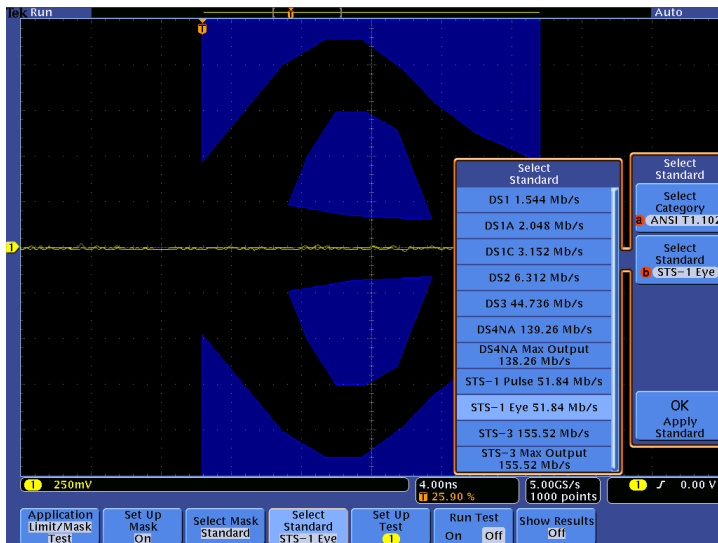
## Mask Testing

### Key Take Away Points

- There are not any standard communication signals available on the commonly-available demo boards, so this section of the lab will be limited to stepping through the user interface.
- The selection of a standard mask looks like this:



- When a standard mask has been selected, the display looks like this:



### MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **Test** button.
- ❑ Press the **Application** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **Limit/Mask Test**.
- ❑ Press the **Select Mask** bottom bezel button.
- ❑ Press the **Standard** side bezel button.
- ❑ Press the **Select Standard** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select the **ANSI T1.102** mask category. Other selections include ITU-T and USB High-Speed masks.
- ❑ Press the **Select Standard** side bezel button. Notice the available ANSI T1.102 masks.
- ❑ Using the Multipurpose **b** control, select the one of the masks and press the **OK Apply Standard** side bezel button.
- ❑ The remainder of the mask test setup and operation is similar to the Limit Test shown in the last section of this lab.

# TEK-DPG

Deskew Pulse Generator

Application Lab

Minimizing Skew in Power Measurements



## Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
- One TEK-DPG Deskew Pulse Generator
- One 067-1686-00 Power Measurement Deskew and Calibration Fixture
- One TDP0500 or TDP1000 Differential Probe
- One TCP0030 Current Probe

## The Importance of Probe Deskew for Power Measurements

### Introduction

When engineers are making critical high-speed timing measurements between channels, they usually recognize the need to carefully match the delays through their probes. This may be simplified by using the same kind of probes whenever possible. The actual skew can be verified by connecting all of the probes to a common signal source, even the PROBE COMP signal on the front of the oscilloscope and verifying that the timing of all of the waveforms is matched.

But why is probe skew a concern for low-speed applications such as power measurements? First, even if the power supply's switching frequency is below 1 MHz, the rise-times of the switching waveforms may be on the order of 1 ns. Second, the phase relationships between voltages and currents in a switching device are very critical in determining the amount of power instantaneously dissipated in the switching device.

### The 067-1686-00 Power Measurement Deskew and Calibration Fixture

The 067-1686-00 fixture converts a pulse signal into a set of test point connections. These connections provide you with a convenient way to compensate for timing differences between voltage and current probes and the signal paths within the oscilloscope.

This fixture can be used with a variety of passive, active, differential, and current probes. In this lab, we will concentrate on some of the most common power probes used with the DPO4000B and MSO4000B Series products. Please refer to the 067-1686-00 Instructions on [www.tek.com](http://www.tek.com) for more information about other supported probes.



### The TEK-DPG Deskew Pulse Generator

The TEK-DPG Deskew Pulse Generator is a signal-generating accessory for select Tektronix oscilloscopes that feature the TekVPI interface.



- In this lab, we will use the TEK-DPG and the 067-1686-00 to manually optimize power probe deskew. We will also demonstrate the measurement errors that can occur because of probe skew.

## Manual Deskew Procedure for Power Probes with the MSO/DPO4000B Series

### Oscilloscope Setup Procedure:

- Plug in and turn on the oscilloscope.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- Connect the TDP1000 or TDP0500 differential probe to channel 1.
- Connect the TCP0030 current probe to channel 2. (Notice that the vertical readout automatically shows the correct units of Amperes.)
- Press the front panel **2** button to display channel 2.
- Connect the TEK-DPG to channel 3. (The TEK-DPG is not fully supported by the Aux In input. There is no probe setup menu or 50Ω termination for the Aux In input.)
- Press the front panel **3** button to display the trigger signal on channel 3.
- Connect the TEK-DPG's BNC connector to Port A on the deskew fixture.
- NOTE: For best results, warm up the equipment for 20 minutes before making critical adjustments.

### Key Take Away Points

- TDP0500 / TDP1000 and TCP0030 connections:

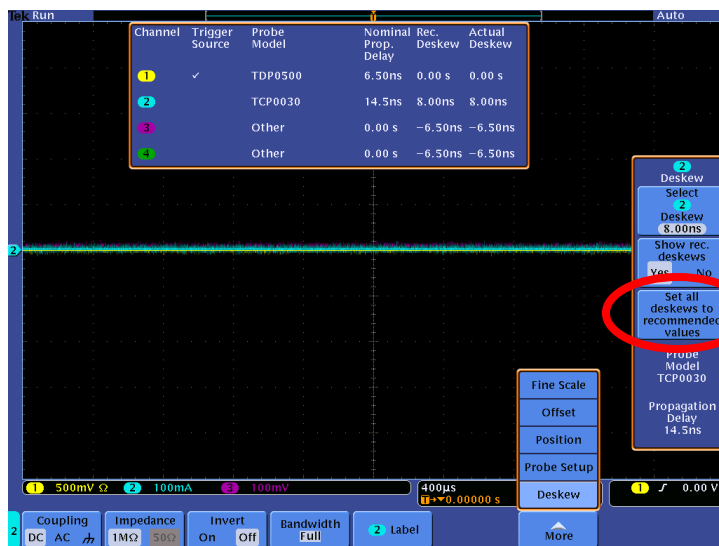


### Test Procedure:

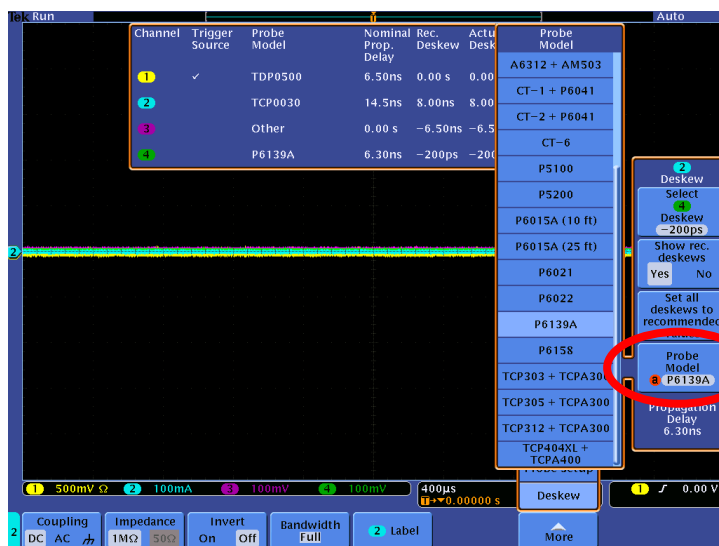
- Short the TDP0500 or TDP1000 probe tips together.
- Press the **Menu** button on the TDP probe.
- Make sure that the **Range** is set to **4.25 V**.
- Press the **AutoZero** side bezel button to remove any DC offsets from the probe and channel input.
- Connect the TDP probe to the long square pins on the deskew fixture as shown at the left.
- Press the **Menu** button on the TCP0030 current probe.
- Select the **5A** range, either by pressing the **Range** button on the probe or the side bezel button on the oscilloscope until the **5A range** is selected.
- Make sure that the current probe's jaw is closed.
- Press the **Degauss AutoZero** button on the probe.
- Connect the TCP0030 probe to the deskew fixture as shown at the left.

## Key Take Away Points

- For some applications, adequate deskew performance can be achieved simply by accounting for the differences in nominal propagation delay for the probes.
- The vertical channel deskew menu simplifies the calculations of recommended deskew values for each of the input channels relative to the trigger source.
- Nominal propagation delays are automatically read from VPI probes and entered into the deskew table. Propagation delays for a list of standard probes can be easily selected from a list. Finally, propagation delays can be manually entered for any probe or cable.
- Setting the deskew values to the recommended values, the display should look about like this:



- Manually identifying a common probe can also easily add nominal propagation delay and deskew values:

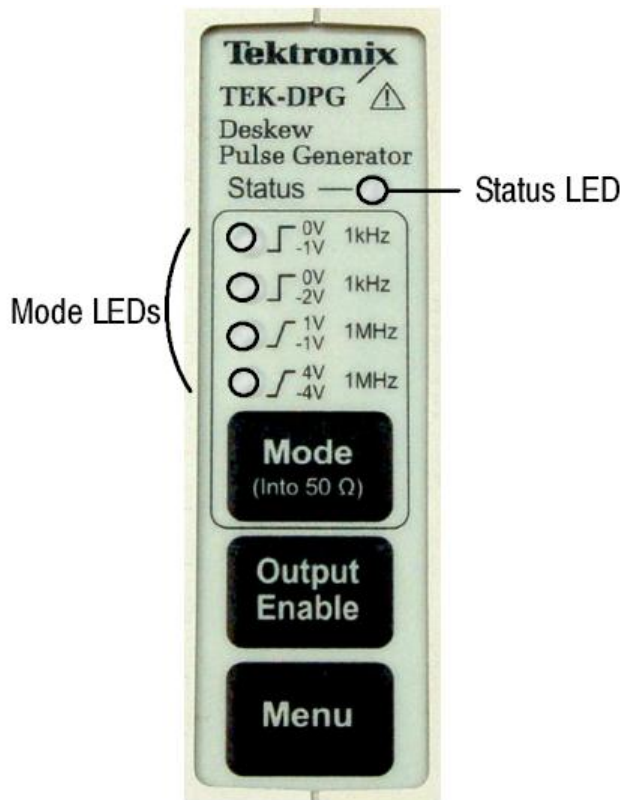


## MSO/DPO4000B Series Procedure:

- With the channel 2 vertical menu displayed, repeatedly press the **More** bottom bezel button until **Deskew** is selected.
- Notice that the nominal propagation delays for the VPI probes on channels 1 and 2 are automatically entered into the table.
- Press the **Set all deskews to recommended values** side bezel button.
- Notice that the Actual Deskew for the trigger source (channel 1) is set to 0 and the values for the remaining channels are set with respect to the deskew of the trigger source with the push of a button.
- Imagine that you have a TPP0500 or TPP1000 passive probe connected to channel 4.
  - Press the **Select** side bezel button.
  - With the Multipurpose **a** control, select channel 4.
  - Press the **Probe Model** side bezel button.
  - With the Multipurpose **a** control, select **TPP0500** or **TPP1000**.
  - Notice that the nominal propagation delay is automatically provided.
  - Press the **Set all deskews to recommended values** side bezel button.
- If, instead, you want to manually set the propagation delay:
  - With the Multipurpose **a** control, select **Other**.
  - Press the **Propagation Delay** side bezel button.
  - With the Multipurpose **a** control, select the propagation delay.
  - Press the **Set all deskews to recommended values** side bezel button.

## Key Take Away Points

- To more precisely set the propagation delays, let's see how to use the TEK-DPG and deskew fixture with these probes.
- Controls and readouts on the TEK-DPG:

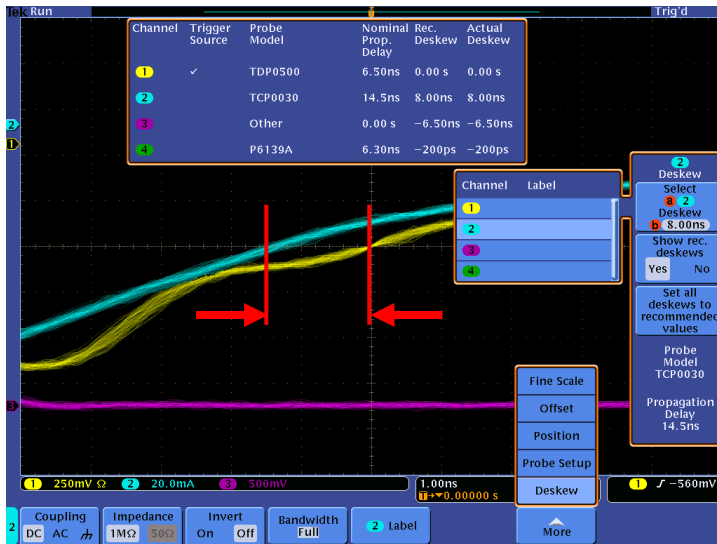


## Test Procedure:

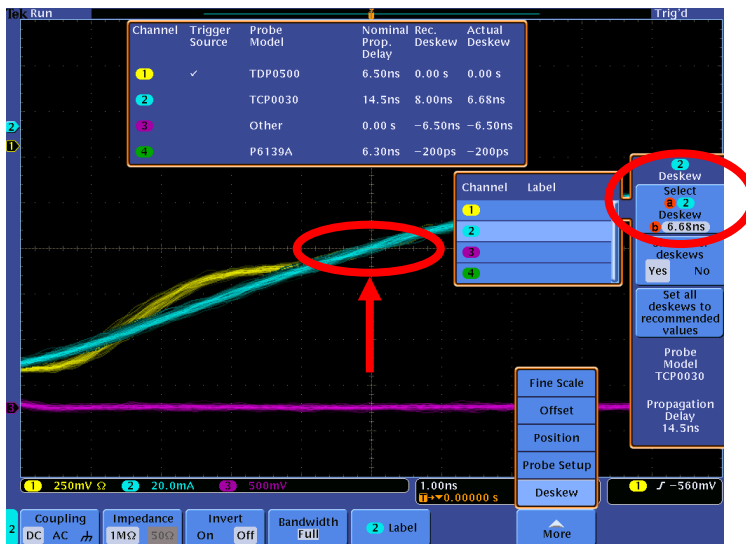
- Notice the interface of the TEK-DPG.
- The Status LED glows amber at power-on to indicate the generator is on and the output at the BNC cable is not enabled.
- Press the **Mode** button until the 1<sup>st</sup> green Mode LED ( $\pm 1V_{pk-pk}$  1 kHz signal with  $<1$  ns risetime) is lit.
- Press the **Output Enable** button and notice that the Status LED is now green. If the LED glows red, disconnect and reconnect the generator to clear the fault that may have occurred.
- Like other TekVPI probes, the TEK-DPG can also be controlled through the oscilloscope's user interface.
- Press the TEK-DPG's **Menu** button (or select the channel **3** vertical menu and select **Probe Setup** in the **More** sub-menu) and notice the control menu.

## Key Take Away Points

- The display should look something like this:



- We want to adjust the timing of the differential probe to match the timing of the current probe. When the deskew adjustment has been made, the display should look something like this:

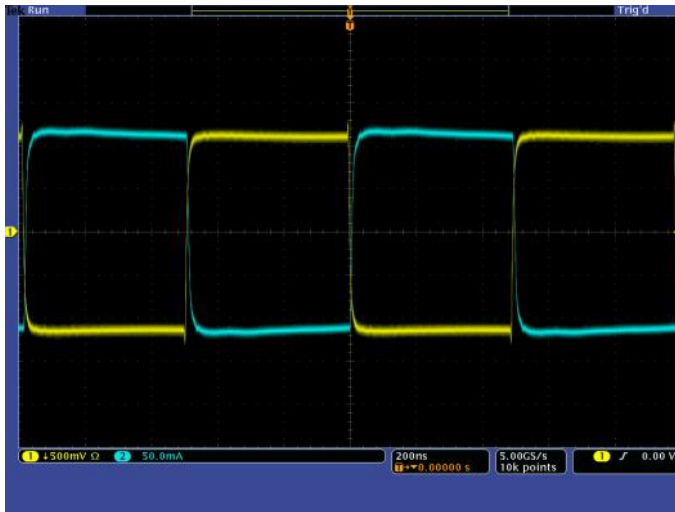


## Test Procedure:

- Press the front panel **Autoset** button to get a stable display.
- Set the vertical scale of channels 1-3 so each channel occupies at least half of the display. (You can use vertical **Fine Scale** if you want to maximize the vertical resolution.)
- Adjust the vertical position so the waveforms are centered in the display.
- Set the **Horizontal Scale** to 1 ns/div.
- Notice the delay difference between channels 1 and 2.
- Press the front panel **2** button to display the channel 2 setup menu.
- Repeatedly press the **More** bottom bezel button until **Deskew** is selected.
- Using the Multipurpose **b** control, adjust the channel 2 **Deskew** until the channel 2 waveform timing matches the channel 1 waveform timing at the center of the display.

### Key Take Away Points

- So why is proper deskew important for low-frequency power measurements?
- Consider that a typical power measurement is made by measuring the voltage across a power switching device (like with the differential probe on channel 1) and the current flowing through the switching device (like with the current probe on channel 2) and multiplying the waveforms together to get the instantaneous power, as shown below.
- The voltage across and the current flowing through a typical switching device are square waves that are 180 degrees out of phase. To simulate this, we will use a higher-frequency deskew pulse signal and invert the channel 1 signal.



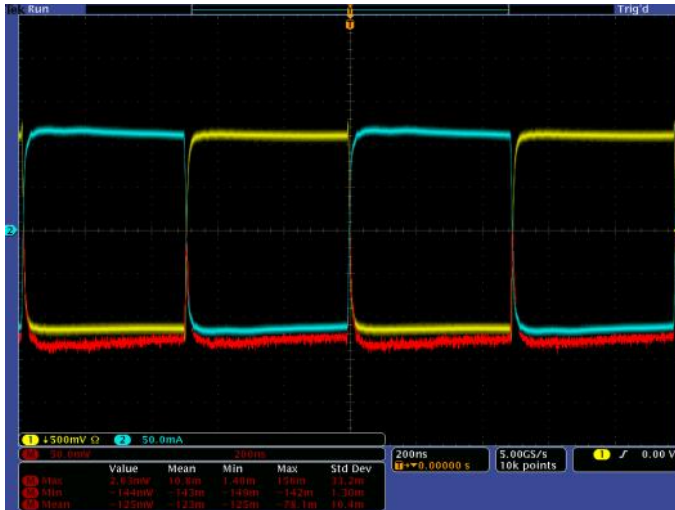
### Test Procedure:

- ❑ Press the **Mode** button on the TEK-DPG until mode **3** ( $\pm 1V$ , 1 MHz) is selected.
- ❑ Press the front panel **3** button to turn off the display of channel 3.
- ❑ Press the **Autoset** button.
- ❑ Press the front panel **1** button to display the channel 1 vertical control menu.
- ❑ Repeatedly press the **Invert** bottom bezel button until **On** is selected.
- ❑ Set the vertical scales of channels 1 and 2 so each channel occupies at least half of the display.
- ❑ Adjust the vertical position so the waveforms are centered in the display.
- ❑ Adjust the horizontal scale to display at least 1 cycle.



## Key Take Away Points

- With properly deskewed probes, when the math multiply waveform is calculated, we would expect that a positive signal times a negative signal would result in a negative product, which it does in the display below. Also, note that during the signal transitions through zero, the product becomes approximately zero.



## Test Procedure:

- ❑ Press the red front panel **M** button to turn on the math waveform and display the menu.
- ❑ Press the **Dual Wfm Math** bottom bezel button.
- ❑ Press the **Operator** side bezel button until **X** (multiply) is selected.
- ❑ Press the front panel **Measure** button.
- ❑ Press the **Add Measurement** bottom bezel button.
- ❑ Using the Multipurpose **b** control, select the **Max** measurement and press the **OK Add Measurement** side bezel button.
- ❑ Using the Multipurpose **b** control, select the **Min** measurement and press the **OK Add Measurement** side bezel button.
- ❑ Using the Multipurpose **b** control, select the **Mean** measurement and press the **OK Add Measurement** side bezel button.
- ❑ Press **Menu Off** twice.

## Key Take Away Points

- Again, with properly deskewed probes, notice that the product is negative, except during the signal transitions through zero, when the product becomes approximately zero.



- When probe skew is extreme, the math multiply waveform shows a large positive signal during the probe skew interval, which is a large measurement error due only to probe skew:

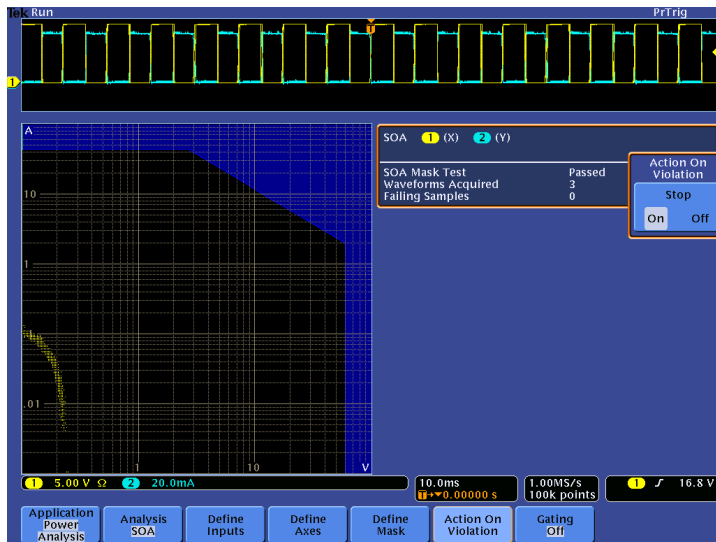


## Test Procedure:

- ❑ Press the front panel **2** button to display the channel 2 vertical control menu.
- ❑ Repeatedly press the **More** button until the **Deskew** side menu is displayed.
- ❑ Using the Multipurpose **b** control, adjust the deskew to the end of the range, such as either  $\pm 100$  ns.
- ❑ Notice the substantial change in shape and amplitude of the math waveform. Proper probe deskew adjustments are necessary to prevent these large measurement errors.
- ❑ Also, remember that timing errors in YT displays correspond to phase errors in XY displays. For example, when looking at a 10 MHz signal, a deskew error of 1 ns results in a 3.6 degree error.

# MSO4000B/DPO4000B Series

## Power Measurements Lab



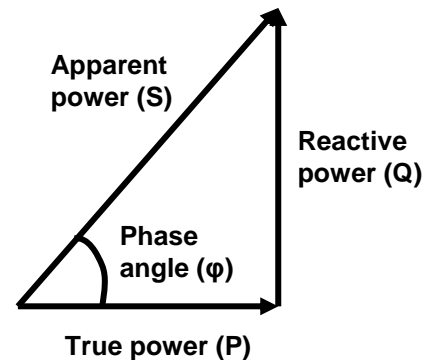
### Equipment List

- One MSO/DPO4000B Series oscilloscope with the latest firmware version installed
- One DPO4PWR application module
- One TDP0500 or TDP1000 Differential Probe
- One TCP0030 Current Probe
- One 878-0544-XX or 3PQS power demo board and 12VAC power adapter

## Overview of Automatic Power Measurements

The DPO4PWR application module enables consistent, automatic measurements of most common power supply measurements, including:

- Power Quality, which provides a single table of measurements and measurement statistics for the AC input section of a power conversion circuit, including:
  - the RMS voltage and current
  - voltage and current crest factors, which are the peak-to-RMS ratios for the signals
  - frequency
  - true power (P), the actual power delivered to the resistive part of the load, measured in Watts. It is also  $V_{RMS} * I_{RMS} * \cos(\phi)$
  - reactive power (Q), the power delivered to and temporarily stored in the reactive (inductive or capacitive) elements of the load, measured in Volt-Amperes Reactive or VAR
  - apparent power (S), the product of the RMS voltage and current (mathematically, the absolute value of the vector sum of the true and reactive power), measured in Volt-Amperes or VA
  - power factor, the ratio of true power to apparent power. (If the signals are pure sine waves, the power factor is the cosine of the phase angle between the current and voltage waveforms.)
  - phase angle ( $\phi$ ), which is the angle between the real and apparent power vectors, equal to the impedance phase angle
- Harmonics, which provide a frequency-domain view of the AC input (generally, the current), with :
  - magnitude and phase measurements of each harmonic
  - Total Harmonic Distortion as a percentage of the fundamental (THD-F)
  - Total Harmonic Distortion as a percentage of the RMS measurement (THD-R)
  - RMS measurement of the waveform
- dV/dt and dI/dt Cursors,
  - a slew rate measurement, added to the cursor readout, between the cursors on the selected waveform
- Switching Loss, which provides a table of measurements and measurement statistics for the losses across each acquired waveform, including:
  - Turn-on, Turn-off, Conduction, and Total Power Loss
  - Turn-on, Turn-off, Conduction, and Total Energy Loss
- Safe Operating Area, which includes:
  - an X-Y display of the switching device voltage and current
  - mask testing of the signals relative to a graphical description of the device specification limits
- Ripple, which provides a table of measurements and measurement statistics for the AC components of the signals
- Modulation Analysis, which generates a graphical display of the specified measurement values across the acquired waveform, showing the variations in the modulated switching signal



In this lab, we will go through each of these measurement areas. This lab is based on the power demo board. However, similar steps can be used to make these measurements on another power demo board or a customer's power supply circuit. (Be sure to use probes with appropriate maximum ratings.)

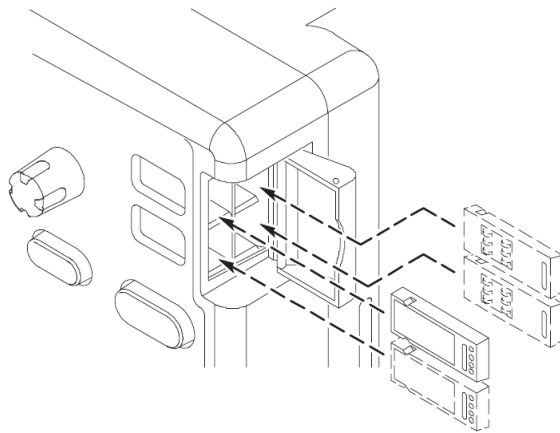
## Objectives

- Obtain a basic understanding of power measurements.
- Learn how customers use oscilloscopes to measure power supply parameters.
- Learn how to set up and demonstrate power supply measurements with a MSO/DPO4000B Series oscilloscope.

## MSO/DPO4000B Series Lab Setup

### Key Take Away Points

- With the DPO4PWR application module installed, the MSO/DPO4000B Series oscilloscope can make a variety of automatic power measurements. The application module can be installed in any of the four application module slots on the front panel of the instrument.

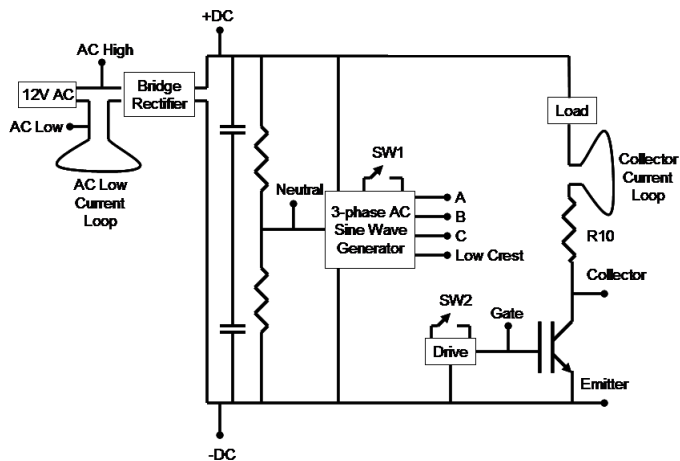


### MSO/DPO4000B Series Procedure:

- ❑ With the oscilloscope power off, install the **DPO4PWR** application module into one of the slots on the front panel of the instrument.
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.
- ❑ Verify that the **DPO4PWR** Power Analysis application module is detected.
- ❑ Verify that the instrument has the latest firmware version installed.

## Key Take Away Points

- The 3PQS Power Demo board has a variety of power signals which we can use for this lab. However, this demo board does not support some measurements such as the magnetics measurements.



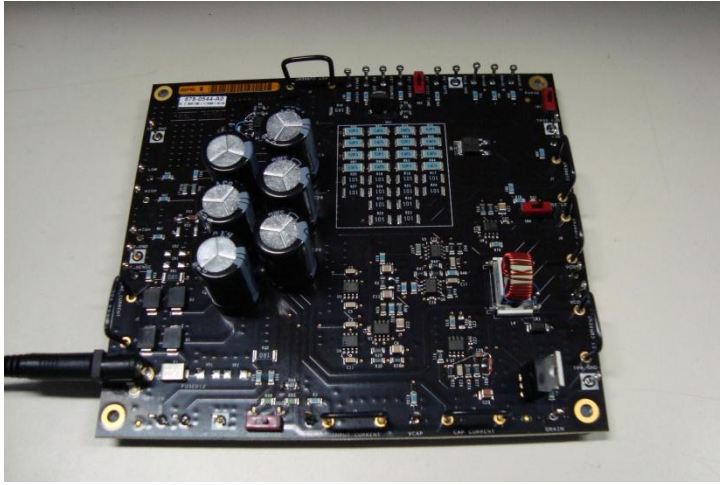
- The switching device on the 3PQS Power Demo board is an Insulated Gate Bipolar Transistor (IGBT) and has a  $V_{CEsat}$  of about 1.8V.

## 3PQS Power Demo Board Procedure:

- ❑ Connect the 12VAC power adapter to the demo board and plug it in. NOTE: This must be an AC-output adapter. A normal DC-output adapter will not work.
- ❑ NOTE: Most voltages on this power demo board are not referenced to ground. Do not use standard passive probes and do not connect probe grounds on this board. Instead, use the recommended differential and current probes.
- ❑ NOTE: No voltage potential on the board exceeds 30 Volts. However, some of the components on this board do get very warm.

### Key Take Away Points

- The 878-0544-XX Power Demo board is the preferred demo tool and has a variety of power signals which we can use for this lab:

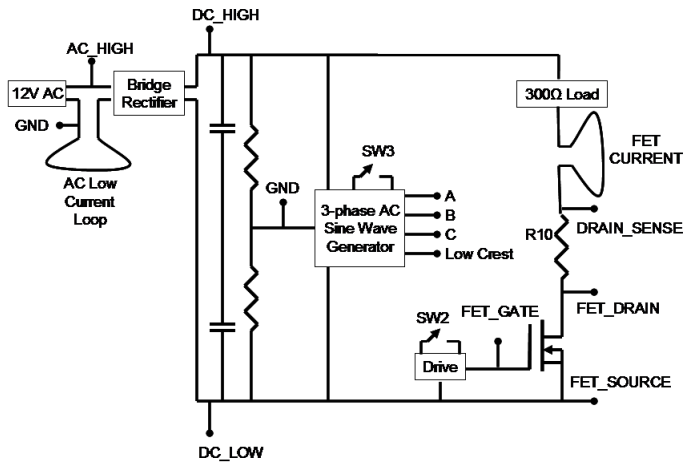


### 878-0544-XX Power Demo Board Procedure:

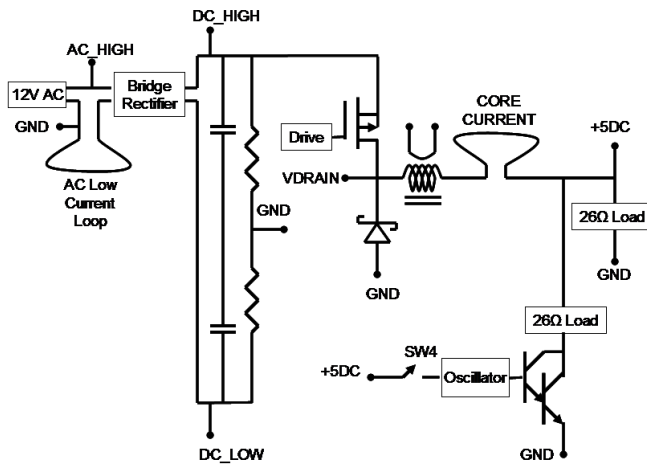
- ❑ Connect the 12VAC power adapter to the demo board and plug it in. NOTE: This must be an AC-output adapter. A normal DC-output adapter will not work.
- ❑ NOTE: Most voltages on this power demo board are not referenced to ground. Do not use standard passive probes and do not connect probe grounds on this board. Instead, use the recommended differential and current probes.
- ❑ NOTE: No voltage potential on the board exceeds 30 Volts. However, some of the components on this board do get very warm.

## Key Take Away Points

- The 878-0544-XX Power Demo board combines most of the features of two previous power demo boards, the 3PQS board (which was introduced with the TPS2000 Series oscilloscopes) and the PQS board (which was introduced with the TDSPWR power measurement application).
- When SW1 is in the left position, the board functions much like the 3PQS board. The simplified schematic looks like this:



- The switching device on the 878-0544-XX Power Demo board is a MOSFET and has an  $R_{DS(on)}$  of about  $26m\Omega$ .
- When SW1 is in the right position, the board functions much like the PQS board. The simplified schematic looks like this:



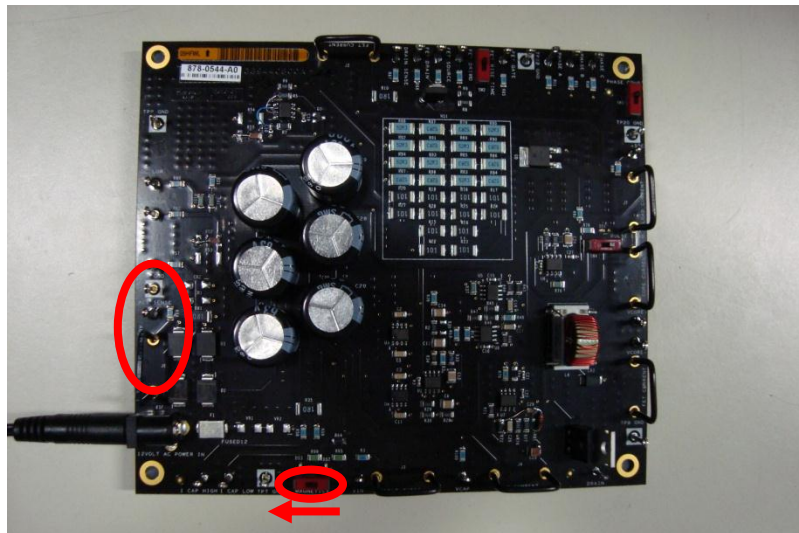
## 878-0544-XX Power Demo Board Procedure:



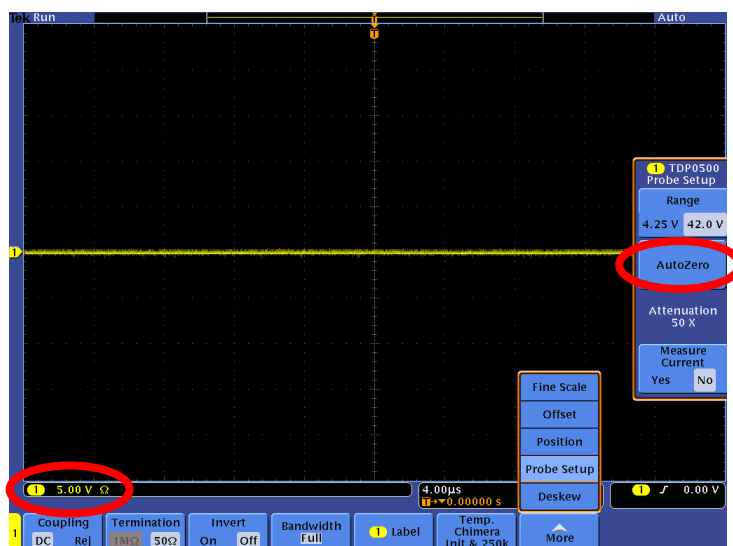
## Power Quality Measurements

### Key Take Away Points

- To demonstrate power quality measurements, this section of the lab measures the input voltage and current to the demo board.



- The display should look like this after AutoZeroing the differential probe:

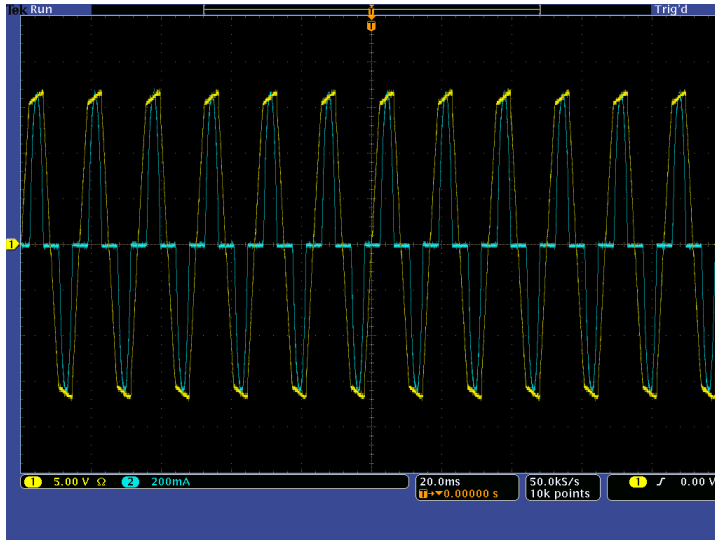


### MSO/DPO4000B Series Procedure:

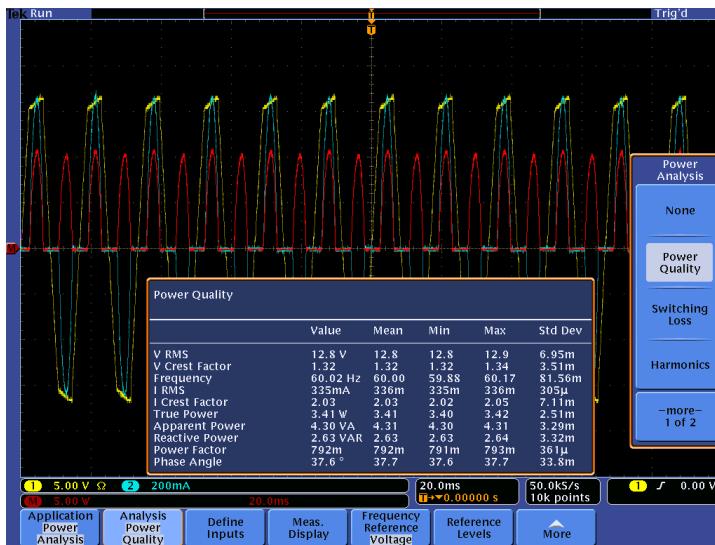
- Press the front panel **Default Setup** button.
- Connect a TDP0500 or TDP1000 differential probe to channel 1 of the oscilloscope.
- Connect the + and - inputs together. Make sure that the **Range** is set to **42.0 V**.
- Press the **Menu** button on the probe's comp box. Press the **AutoZero** side bezel button.
- Connect the - input of the differential probe to the **AC Low** test point.
- Connect the + input of the differential probe to the **AC High** test point.
- Set the Horizontal **Scale** to **20ms/div**. This setting should allow a few cycles to be displayed on screen.
- Press the front panel **2** button to turn on channel 2.
- Connect a TCP0030 current probe to channel 2 on the oscilloscope. Make sure that the **Range** is set to **5 A**.
- Make sure that the current probe's jaw is closed. Press the **Degauss AutoZero** button on the probe.
- Connect the current probe around the **AC Low** current loop and close the jaws.
- Scale the signals so they occupy at least half of the screen vertically and position them so they overlap.
- In this case, the voltage and current waveforms are in phase. If the phase of channel 2 signal is opposite of the channel 1 signal, remove the current probe, turn it over, and reconnect it.

## Key Take Away Points

- The display should look about like this:



- With the Power Quality measurements enabled, the display should look about like this:



- Notice that the power quality measurement values are average measurements made on all complete cycles within the selected region of the acquisition (the entire waveform, by default) and the statistics of those average measurements are accumulated across all acquisitions.

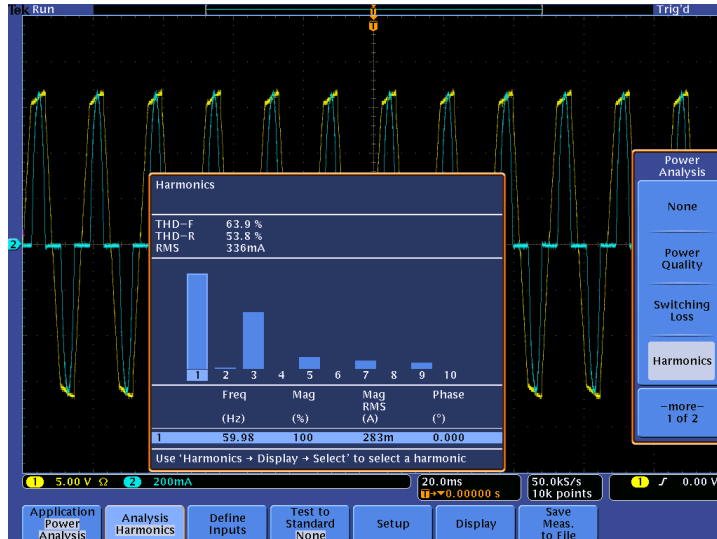
## MSO/DPO4000B Series Procedure:

- Set the Horizontal **Scale** to **20 ms/div**.
- Press the front panel **Test** button.
- Press the **Analysis** bottom bezel button.
- Press the **Power Quality** side bezel button.
- Press the **Define Inputs** bottom bezel button.
- Verify that the **Voltage** is on channel **1** and the **Current** is on Channel **2**.
- Press the **Frequency Reference** bottom bezel button.
- Verify that the **Voltage** is selected as the frequency reference, since the current is a distorted sine wave, especially around the zero crossing where frequency measurements would be made.
- Press the **Reference Level** bottom bezel button.
- Notice the side menu selections, including the **Hysteresis** control, which can be used to reduce the sensitivity to noise on noisy power signals.
- Press the front panel **Menu Off** button once to remove the side menu.

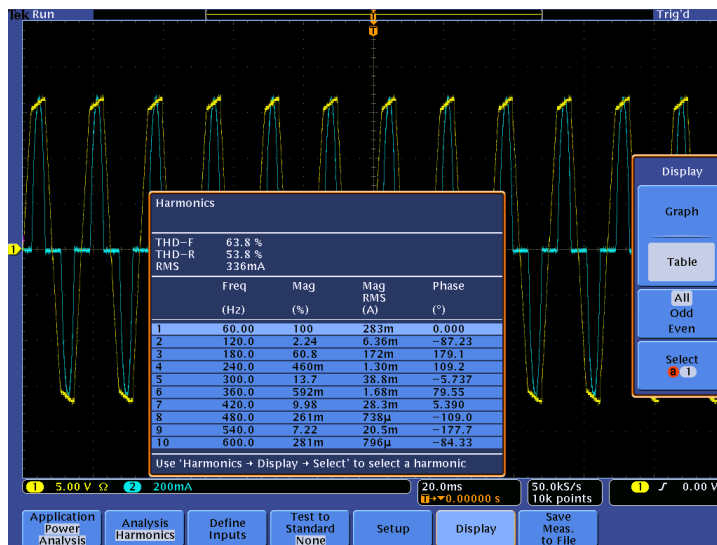
## Harmonics Measurements

### Key Take Away Points

- To demonstrate harmonics measurements, this section of the lab measures the input voltage and current to the demo board, as with the power quality measurements.
- With the Harmonics measurements enabled, the display should look about like this:



- The harmonics can also be displayed in table format:



### MSO/DPO4000B Series Procedure:

- NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- If necessary, press the front panel **Test** button to display the power application bottom menu.
- Press the **Analysis** bottom bezel button.
- Press the **Harmonics** side bezel button.
- Press the **Setup** bottom bezel button.
- Press the **Frequency Reference** side bezel button.
- Using the Multipurpose **a** control, select **V** as the frequency reference, since the current waveform is a very distorted sine wave around the zero crossing.
- Notice the **Hysteresis** side menu selection which can be used to reduce the sensitivity to noise on noisy power signals.
- Press the **Display** bottom bezel button.
- Using the Multipurpose **a** control, select the **5<sup>th</sup>** harmonic.
- Press the **Table** side bezel button to display the harmonics table view.
- In this display, you can also use the Multipurpose **a** control to pan through the list.
- You can press the **Save Meas. to File** bottom bezel button to save the table results in .CSV format to the USB or CompactFlash drive.

## IEC-61000-3-2 Pre-compliance

IEC 61000-3-2 is a standard that defines permitted harmonic-current limits. It categorizes equipment into four classes (A, B, C and D) and imposes different harmonic-current limits on each class. It also defines cases where no limits apply. The standard was initially released in 1995, and then substantially revised in 2000, and again in 2006.

Equipment Examples:

Class A:

- Balanced 3-phase equipment
- Household appliances (not in Class D)
- Non-portable tools
- Dimmers
- Audio equipment

Class B:

- Portable Tools
- Arc Welding

Class C:

- Lighting
  - Incandescent lighting with dimmers (Power > 25 W) use Table1
  - Lighting equipment (Power > 25 W) use Table2
  - Lighting ≤ 25 W use Table3

Class D: (Input power  $P \leq 600$  W)

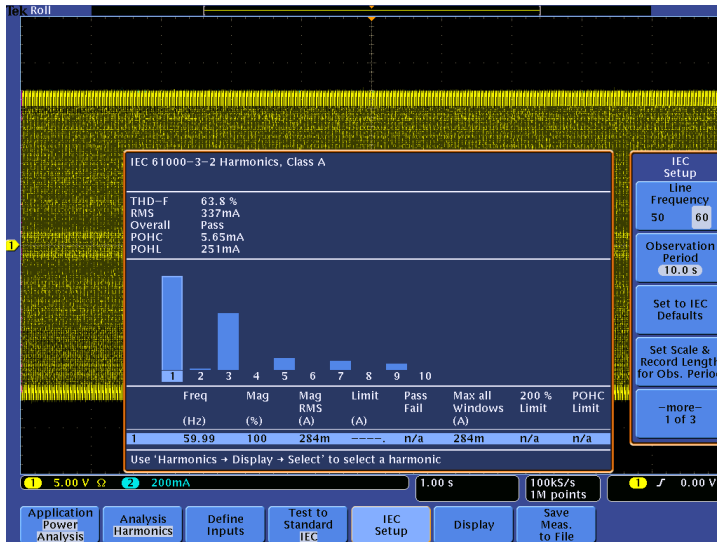
- PC
- Monitors
- TV Receivers

Input current harmonic levels are checked using both the average and maximum values over the whole test interval. Any harmonic is allowed to fluctuate up to a maximum of 150% of its limit, provided that its average value is below 100% of the limit.

In addition, some trade-off between harmonics is allowed for odd harmonics ranging from 21 to 39, based on a value called the Partial Odd Harmonic Current (POHC), which is the RMS sum of all the odd harmonics between 21 and 39. This RMS sum is compared to the Partial Odd Harmonic Limit (POHL), which is the RMS sum of the limits for the same set of harmonics. If the actual POHC is less than the POHL, then the average value of any individual harmonic in this group may exceed 100% of its limit, again provided that no individual measurement exceeds 150% of the limit throughout the test. Obviously one or more of the other harmonics must be correspondingly less than 100% of its limit - otherwise the POHC will not be less than 100% of the POHL.

## Key Take Away Points

- For example, with the IEC 61000-3-2 harmonics pre-compliance measurements enabled, the display should look about like this:



- The harmonics measurements can also be displayed in table format:



- In this example, the horizontal scale selection forces the oscilloscope into roll mode by default. If you prefer to work with full acquisitions, you need to set the trigger mode to Normal.

## MSO/DPO4000B Series Procedure:

- NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- Press the **Test to Standard** bottom bezel button.
- Press the **IEC 61000-3-2** side bezel button.
- Press the **IEC Setup** bottom bezel button.
- Press the **Set Scale & Record Length for Obs. Period** side bezel button to automatically set the conditions for observing the signal. (If you make any control changes, it would be wise to press this button again to assure that the configuration is optimized.)
- Press the **-more- 1 of 3** side bezel button and notice that this menu allows you to select the A, B, C, or D device class.
- Press the **-more- 2 of 3** side bezel button and notice the additional controls, including **Hysteresis** which can be used to reduce the sensitivity to noise on noisy power signals.
- The **Grouping** control determines whether or not the harmonic value at any integer harmonic includes the sum of a specified number of its neighboring non-integer spectral lines.
- Press the **Display** bottom bezel button and use the Multipurpose **a** control, select the 5<sup>th</sup> harmonic.
- Press the **Table** side bezel button to display the harmonics table view. In this display, you can also use the Multipurpose **a** control to pan through the list.
- You can press the **Save Meas. to File** bottom bezel button to save the table results in .CSV format to the USB or CompactFlash drive.

### **MIL-STD-1399 Pre-compliance**

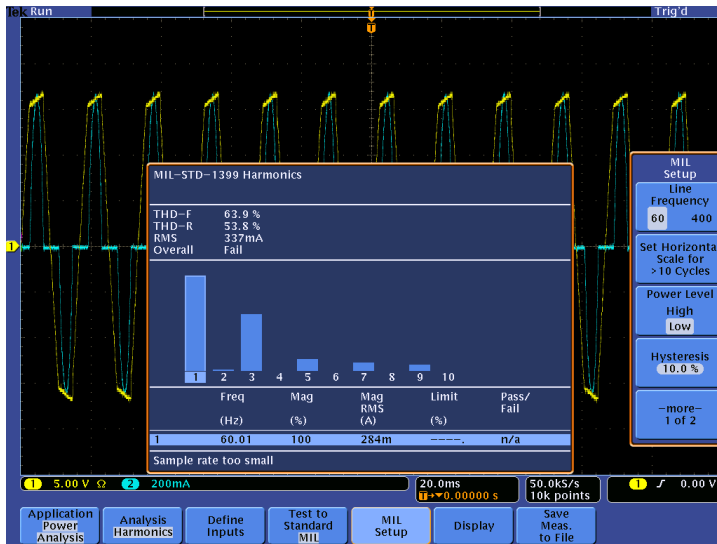
MIL-STD-1399 establishes electrical interface characteristics for shipboard equipment utilizing AC electric power to ensure compatibility between user equipment and the electric power system. The main types of shipboard electric power to be supplied from the electric power system are as follows:

- Type I – 440V or 115V, 60 Hz ungrounded (the standard shipboard electric power source).
- Type II – 440V or 115V, 400 Hz ungrounded (limited application).
- Type III – 440V or 115V, 400 Hz ungrounded, with tighter tolerances than types I and II (restricted use).

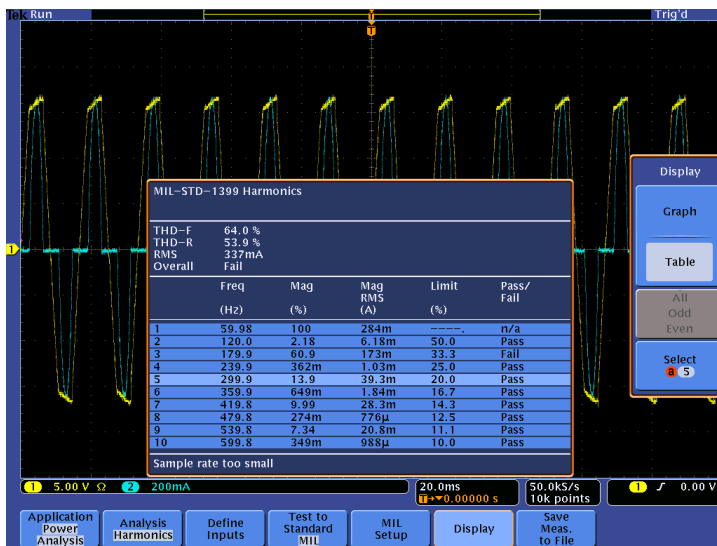
The input current waveform for all types must not cause single harmonic line currents to be generated that are greater than 3% of the unit's full rated load fundamental current between the 2<sup>nd</sup> and 32<sup>nd</sup> harmonic.

## Key Take Away Points

- The MIL-STD-1399 harmonics measurements enabled, the display should look about like this:



- The harmonics measurements can also be displayed in table format:



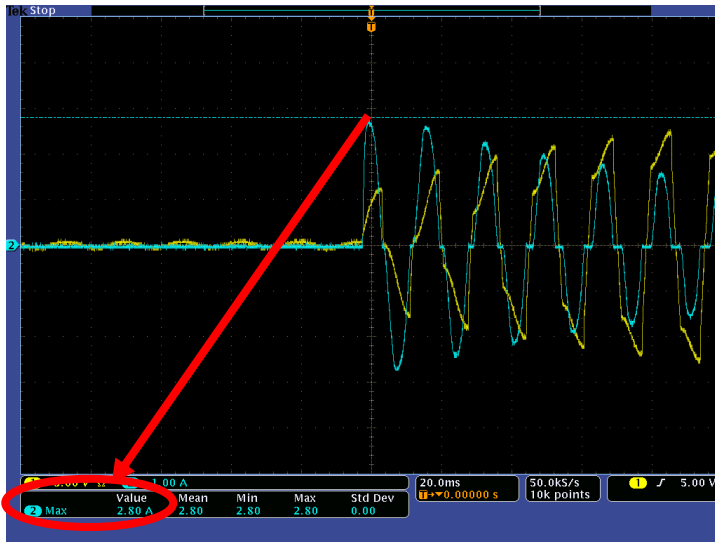
## MSO/DPO4000B Series Procedure:

- NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- Press the **Test to Standard** bottom bezel button.
- Press the **MIL-STD-1399** side bezel button.
- Press the **MIL Setup** bottom bezel button.
- Repeatedly press the **Line Frequency** side bezel button until **60** is selected.
- Press the **Set Horizontal Scale for >10 Cycles** side bezel button to automatically set the conditions for observing the signal.
- Press the **Display** bottom bezel button.
- Using the Multipurpose **a** control, select the **5<sup>th</sup>** harmonic.
- Press the **Table** side bezel button to display the harmonics table view.
- In this display, you can also use the Multipurpose **a** control to pan through the list.
- You can press the **Save Meas. to File** bottom bezel button to save the table results in .CSV format to the USB or CompactFlash drive.

## Inrush Current Measurements

### Key Take Away Points

- Before leaving the topic of power measurements on the input section of a power supply, we should mention inrush current measurements. Although these measurements are not made with new features of the power application, some customers will want to make the measurements.
- The instantaneous peak inrush current can be easily measured with the standard automatic measurements such as Max, as shown at the lower left side of the display:



- The instantaneous inrush current is often measured to verify that the power supply's input capacitor's charging current does not exceed the maximum current rating for the capacitor or any other components in the input path. This high initial current is the result of the capacitor appearing as a short circuit when the power is first applied. This current is often much greater than the steady-state current drawn by the power supply.

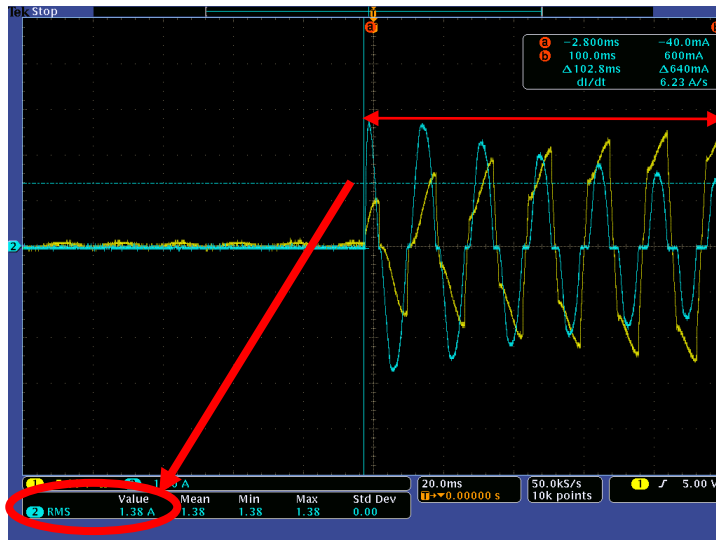
### MSO/DPO4000B Series Procedure:

- NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- Press the front panel **Test** button to remove the power application display.
- Reduce the channel 2 vertical sensitivity to **1 A/div**.
- Set the horizontal scale to **20 ms/div**.
- Move the Trigger **Level** to about **5V**.
- Press the front panel Trigger **Menu** button, the **Mode** bottom bezel button, and the **Normal** side bezel button.
- Remove the power from the demo board.
- Press the front panel **Single** button.
- Apply power to the demo board.
- Press the front panel **Measure** button.
- Press the **Add Measurement** bottom bezel button.
- Using the Multipurpose **a** control, select channel **2** as the Source.
- Using the Multipurpose **b** control, select the **Max** Measurement Type.
- Press the **OK Add Measurement** side bezel button.
- Press the **Indicators** bottom bezel button.
- Using the Multipurpose **a** control. Select the **2 Max** measurement.



## Key Take Away Points

- For other applications, such as determining whether or not the inrush current will open the line fuse or circuit breaker, the peak inrush current may be defined as the RMS current over a specified time period, such as the first 100 ms after power is applied. For example, this time period may be chosen to model the thermal time-constant of the critical device. Such a device will not respond to very short pulses, but rather the  $I_{RMS}^2 \cdot R$  heating.
- This measurement is most easily measured with gated automatic measurements, as shown at the lower left side of the display:



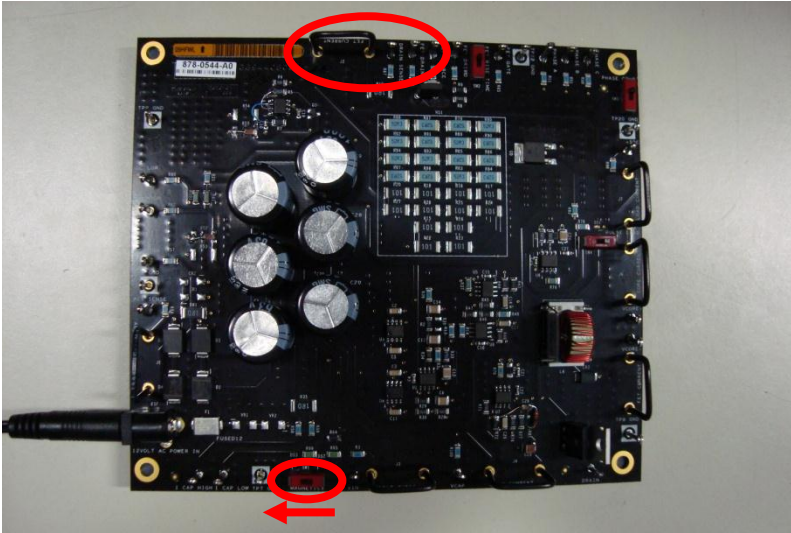
## MSO/DPO4000B Series Procedure:

- Press the **Remove Measurement** bottom bezel button.
- Press the **OK Remove Measurement** side bezel button.
- Press the **Add Measurement** bottom bezel button.
- Using the Multipurpose **b** control, select the **RMS** measurement and press the **OK Add Measurement** side bezel button.
- Press the **Indicators** bottom bezel button.
- Using the Multipurpose **a** control. Select the **2 RMS** measurement.
- Repeatedly press the **More** bottom bezel button until **Gating** is selected.
- Press the **Between Cursors** side bezel button.
- Using the Multipurpose **a** control, place the **a cursor** just to the left of the first cycle of current.
- Using the Multipurpose **b** control, place the **b cursor** near the right edge of the display where the cursor delta time readout indicates a time delta of **100 ms**.
  
- When you are done, press the **Remove Measurement** bottom bezel button.
- Press the **Remove All Measurements** side bezel button.
- Press the front panel **Cursors** button to remove the cursors.

## dV/dt and dI/dt Cursors

### Key Take Away Points

- To demonstrate dV/dt and dI/dt cursors and switching loss measurements, this section of the lab measures the power dissipated in the Insulated Gate Bipolar Transistor (IGBT) on the demo board.



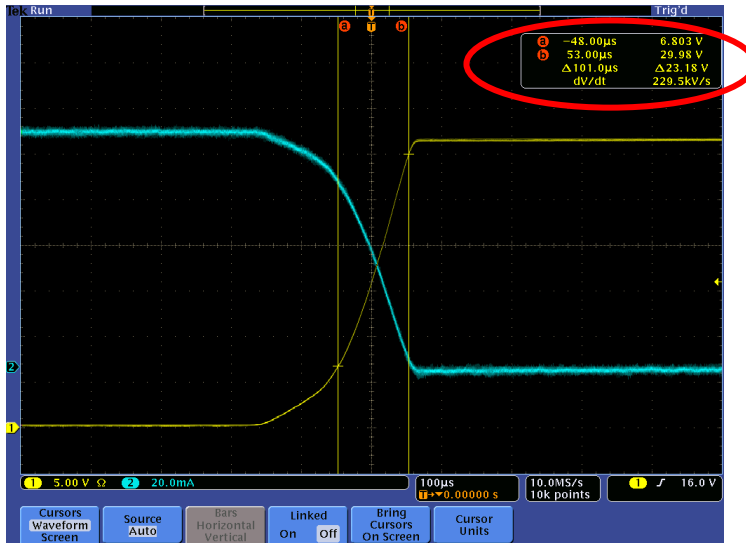
- Measurements like these can only be done with an oscilloscope, typically using waveform math to create the instantaneous power waveform. In this lab, the power dissipated in the MOSFET switching device is the product of the Drain current ( $I_D$ ) and the Drain voltage relative to the Source ( $V_{DS}$ ). When the switching device is turned on, the voltage across the device is very small and the current is large. When the device is turned off, the voltage across the device is large and the current is very small.

### MSO/DPO4000B Series Procedure:

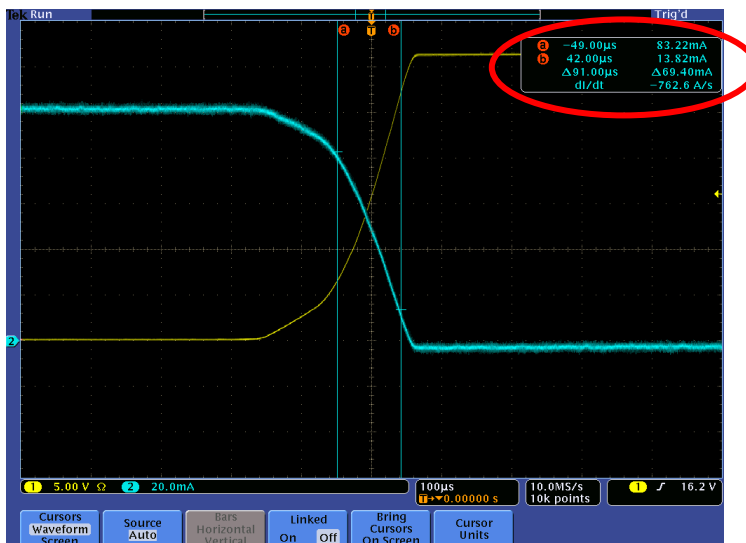
- NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- Press the front panel **Test** button to display the power application bottom menu.
- Press the **Analysis** bottom bezel button and the **None** side bezel button to turn off the display of the power application.
- Connect the - input of the differential probe to the **Source** test point.
- Connect + input of the TDP0500 or TDP1000 differential probe on channel 1 to the **Drain** test point.
- Connect the TCP0030 current probe on channel 2 around the **Drain Current** current loop and close the jaws.
- Set the Horizontal **Scale** to approximately **100 $\mu$ s/div**. This setting should allow a few cycles to be displayed on screen.
- Using the front panel vertical scale and position controls, scale the signals so they occupy about half of the screen vertically, and position them so they overlap.
- Use the **Trigger Level** control to adjust the trigger level to the center of the waveform, about **15V**.
- At this point in the circuit, the voltage and current waveforms are square waves, 180 degrees out of phase. If the channel 2 signal is in phase with the channel 1 signal, remove the current probe, turn it over, and reconnect it.
- Press the front panel **Menu Off** button twice to remove the menus.

## Key Take Away Points

- Whenever you press the front-panel Cursors button, a pop-up message appears in the cursor readout box advising that you “Push and hold Cursors for menu”. When you push and hold the Cursors button, you will see the cursor control menu at the bottom of the screen.
- The display with the dV/dt cursor readout should look about like this:



- Notice that the units of the dV/dT cursor readout are in Volts/time. In this case, they are in kV/s, which is the same as V/ms.
- The display with the dI/dt cursor readout should look about like this:



## MSO/DPO4000B Series Procedure:

- ❑ Press the front panel **1** button to make channel 1 the selected channel.
- ❑ Press and hold the front panel **Cursors** button.
- ❑ Using the Multipurpose controls, position the cursors on the edge of the (yellow) voltage waveform.
- ❑ Notice that there is an additional cursor readout which shows the slope or slew rate of the waveform (mathematically, the derivative of voltage with respect to time, or dV/dt).
- ❑ Press the front panel **2** button to make channel 2 the selected channel.
- ❑ If necessary, use the Multipurpose controls to position the cursors on the edge of the (cyan) current waveform.

## Optimum Cursor Measurement Resolution

### Key Take Away Points

- Cursors always move in single-pixel increments. For the MSO/DPO4000B Series with its XGA display, the graticule is 1000 pixels wide (10 divisions), so the increments are 1/100 of the time/div setting.
- If zoom is off and both cursors are shown on the display, the resolution is limited to a single pixel, about like this:



- With the display fully zoomed, the cursor resolution is still a single pixel, but the readout should look about like this:



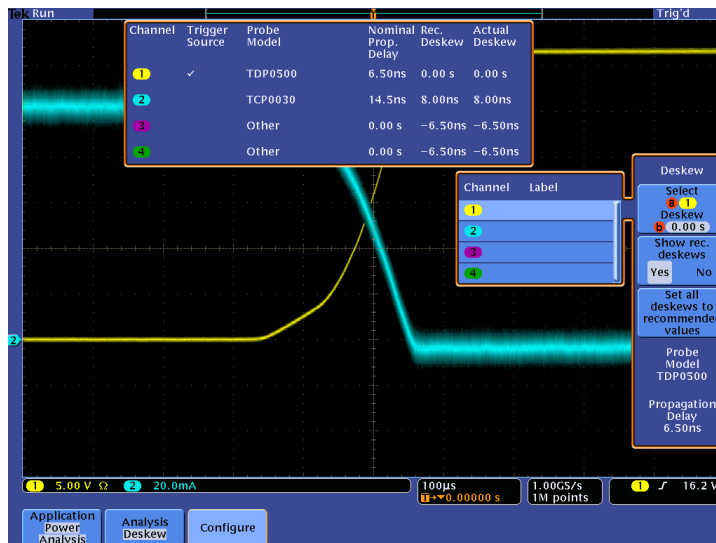
### MSO/DPO4000B Series Procedure:

- Using the Multipurpose controls, position the cursors on exactly the same point on the rising edge of the (yellow) voltage waveform, where the cursor positions so that the delta time readout is zero.
- Notice the differences in cursor readout time values as you adjust the Multipurpose **b** control a single click away. With these oscilloscope settings, the cursor resolution is **1µs**.
- Although this method may provide adequate cursor placement and adequate cursor readout resolution, you can get better results by using zoom.
- Press the front panel **Acquire** button.
- Press the **Record Length** bottom bezel button.
- Using the Multipurpose **a** control, select **1M** record length.
- Using the Wave Inspector controls, zoom all the way into the second rising edge on the waveform.
- Press the **Bring Cursors On Screen** bottom bezel button.
- At this zoom factor, align the cursors and then notice the differences in cursor readout values as you adjust the Multipurpose **b** control by a single click. With these oscilloscope settings, the cursor resolution is **0.0001µs** or 100 ps! In other words, the horizontal cursor resolution is increased by the zoom factor, or 10,000 in this case.
- When you are done, press the front panel **Cursors** button to remove the cursors.
- Turn off **Zoom**.

## Probe Deskew

### Key Take Away Points

- Switching Loss measurements are especially sensitive to timing skew between channels. So, before proceeding, this section of the lab guides you through the quick setup of probe deskew.
- For this demonstration, we will be using the probes' propagation delays to calculate the correct deskew values. (For more exacting applications, you could use the manual deskew procedure, using the TEK-DPG and deskew fixture, provided in the previous lab.)
- The display should look about like this:



- Notice that the nominal propagation delays for each of the attached probes are listed in the table. When you press the **Set all deskews to recommended values** side bezel button, the deskew value for the trigger source channel is set to zero and the other channels are set to the differences in propagation delays.

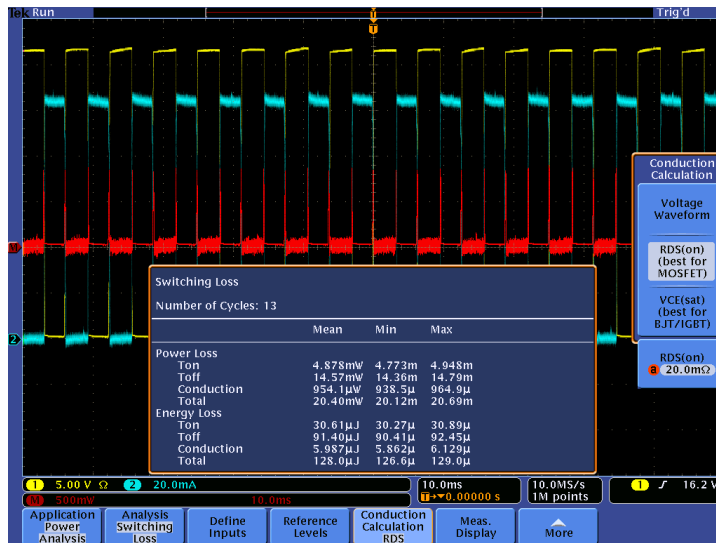
### MSO/DPO4000B Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the front panel **Test** button.
- ❑ Press the **Analysis** bottom bezel button.
- ❑ If necessary, press the **-more-** side bezel button to go to page 2 of the Power Analysis menu.
- ❑ Press the **Deskew** side bezel button.
- ❑ Press the **Configure** bottom bezel button.
- ❑ Press the **Set all deskews to recommended values** side bezel button.
- ❑ Notice that all of the deskew values are now updated in the right column of the table.

## Switching Loss Measurements

### Key Take Away Points

- One of the critical parameters for accurate switching loss measurements is the calculation of the switching device's behavior during conduction. There are three ways to determine the correct values:
  - Provide the  $R_{DS(on)}$  value (best model for MOSFETs) based on the device data sheet. This value is the expected on-resistance between the drain and source of the device when it is conducting.
  - Provide the  $V_{CE(sat)}$  value (best model for BJTs and IGBTs) based on the device data sheet. This is the expected saturation voltage from the collector to the emitter of the device when it is saturated.
  - Measure the voltage drop across the switching device during conduction. Because this voltage is typically very small compared with the voltage across the switching device when it not conducting, you generally cannot measure both voltages at the same vertical setting on the oscilloscope.
- With the Switching Loss measurements enabled, the display should look about like this:



- Notice that the switching loss measurements are made on each individual complete cycle within the selected region of the acquisition (the entire waveform, by default) and the statistics of those measurements are accumulated across the acquisition, but not between acquisitions.

### MSO/DPO4000B Series Procedure:

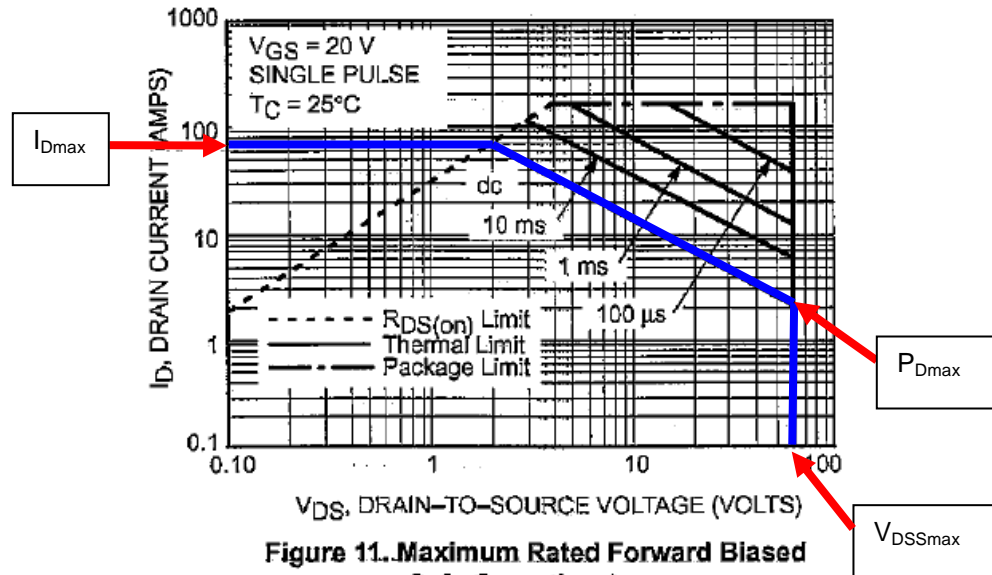
- NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- Press the **Analysis** bottom bezel button to display the side menu.
- Press the **–more–** side bezel button to go to page 1 of the Power Analysis menu.
- Press the **Switching Loss** side bezel button.
- Press the **Define Inputs** bottom bezel button.
- Verify that the **Voltage** is on channel 1, the **Current** is on Channel 2, and **Gate Voltage** is set to **None**.
- Press the **Conduction Calculation** bottom bezel button.
- Press the **RDS(on)** side bezel button.
- For simplicity in this demo, you may leave the default **RDS(on)** value of **20mΩ**. Or to use the  $R_{DSon}$  value from the data sheet, set the value to **26mΩ** using the Multipurpose **a** control. (Or you can also measure this actual value and enter the measured value.)
- Press the front panel **Single** button.
- Press the front panel **Menu Off** button once to remove the side menu.

## Safe Operating Area Analysis

The Safe Operating Area (SOA) display provides a very simple graphical method for monitoring the interactions between voltage and current. If you exceed the maximum limits (defined by maximum instantaneous current, maximum instantaneous voltage, and maximum instantaneous power) for the device, it will fail. Typically these specifications are provided in the component's data sheet. For example, the key maximum specifications for the MOSFET on the 878-0544-XX power demo board are:

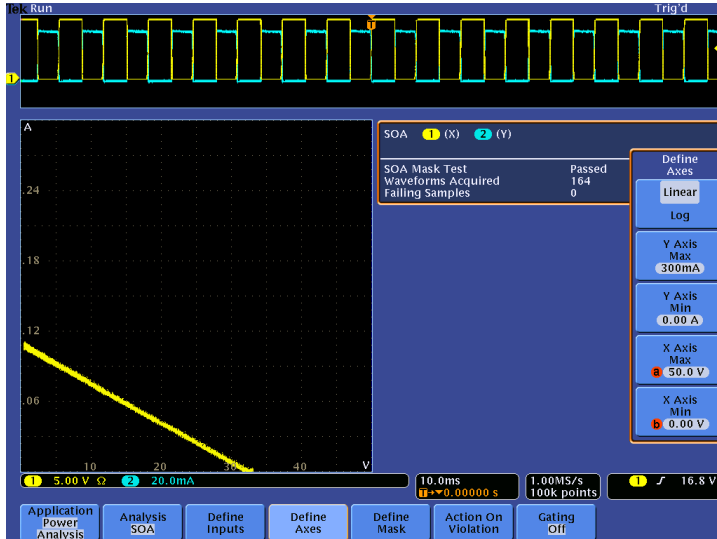
- $V_{DSSmax} = 60\text{ V}$
- $I_{Dmax} = 45\text{ A}$ , with peaks to 150A
- $P_{Dmax} = 125\text{ W}$

The resulting SOA graph from the MOSFET's data sheet is:

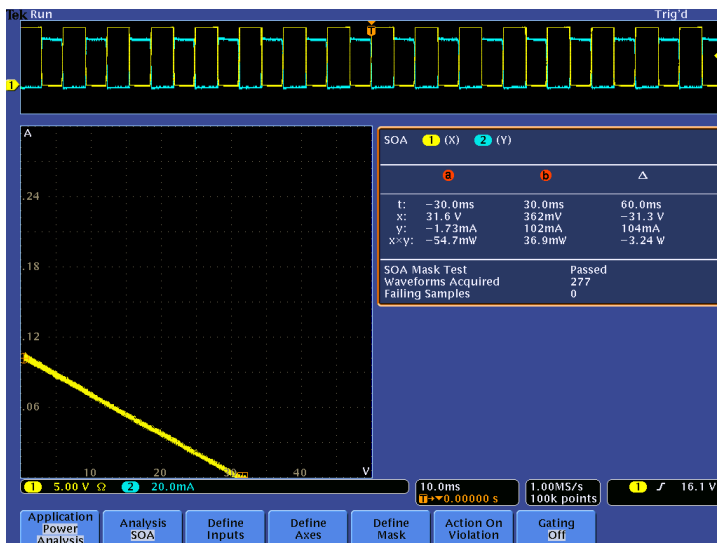


## Key Take Away Points

- To demonstrate Safe Operating Area (SOA) measurements, this section of the lab displays the voltage across the MOSFET versus the current flowing through the MOSFET.
- The SOA display should look about like this:



- NOTE: Especially for this complex display, the demo may be more effective if you increase the waveform intensity.
- X-Y cursors can be used to identify specific points in the waveform, such as those that violate the SOA mask. The display with cursors looks like this:



- Although these display modes for SOA can be useful for visual analysis, the real power in the SOA XY display is with mask testing.

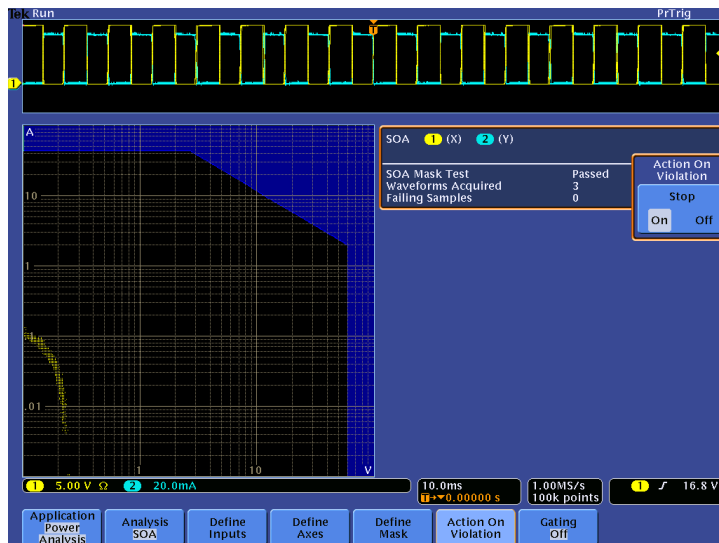
## MSO/DPO4000B Series Procedure:

- NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- Press the front panel **Run/Stop** button to restart acquisitions.
- Press the **Analysis** bottom bezel button.
- Press the **-more-** side bezel button to go to page 2 of the Power Analysis menu.
- Press the **Safe Operating Area** side bezel button.
- NOTE: The current firmware changes the record length to a maximum of **100k points**.
- Press the front panel **Menu Off** button once to remove the side menu.
- Press the front panel **Intensity** button, adjust the waveform **Intensity** with the Multipurpose **a** control, and press the **Intensity** button again.
- Press the **Define Axes** bottom bezel button.
- Use this menu to select log or linear graphs, and to set the minimum and maximum values for the SOA graph appropriately. For the example at the left, select **Linear**, **Y Axis Max** of **300mA**, and **X Axis Max** of **50.0V**.
- Press the front panel **Menu Off** button once.
- Press the front panel **Cursors** button once to enable cursors on the SOA and waveform displays.
- Using the Multipurpose controls, notice that you can identify the position of any point on the SOA plot and the waveform display at the top of the display.
- When you are done, press the front panel **Cursors** button to turn off the cursors.



## Key Take Away Points

- In this section of the lab, enter the custom mask limit values, based on the component specifications.
- The vertical side of the SOA mask is set at the  $V_{DSmax}$  value of 60 V, from 1 mA to about 2A (where the power hits the  $P_{Dmax}$  value of 125 W).
- The horizontal top of the SOA mask is set at the  $I_{Dmax}$  value of 45 A, from 10 mV to about 3V (where the power hits the  $P_{Dmax}$  value of 125 W).
- The angled side of the SOA mask is drawn where the power equals the  $P_{Dmax}$  value of 125 W.
- The SOA mask test log display should look about like this:



- Clearly in this case, as in many cases in embedded system power applications, the design is not pushing the limits of the device. As long as the maximum voltage and current do not exceed half of the maximum values, a careful analysis of the SOA display is probably not necessary.
- NOTE: When more than 50,000 waveforms have been acquired, the Waveforms Acquired readout will indicate ">50,000". Similarly, when more than 50,000 waveform samples have failed the mask test, the Failing Samples readout will indicate ">50,000".

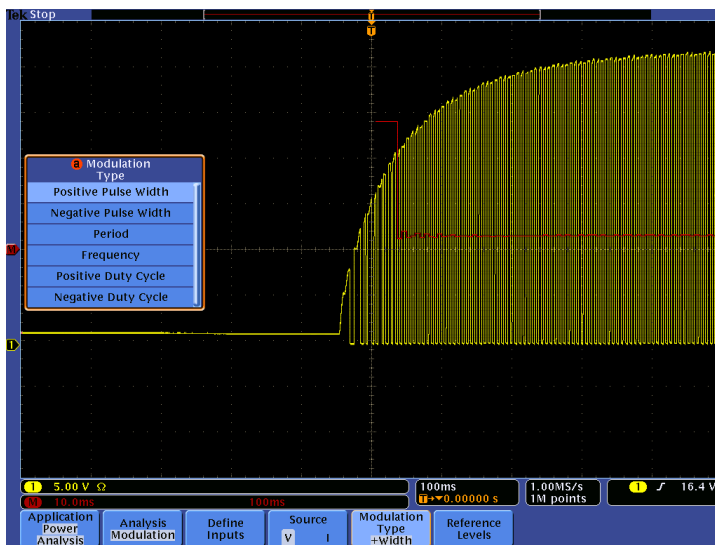
## MSO/DPO4000B Series Procedure:

- ❑ Press the **Define Axes** bottom bezel button.
- ❑ In the side menu, select **Log** axes.
- ❑ Verify that the **Y Axis Max** is set to **100A**.
- ❑ Using the Multipurpose **b** control, set **Y Axis Min** to **1mA**.
- ❑ Press the **X Axis Max** side bezel button.
- ❑ Using the Multipurpose **a** control, set **X Axis Max** to **100V**.
- ❑ Verify that the **X Axis Min** is set to **100 mV**.
- ❑ Press the **Define Mask** bottom bezel button.
- ❑ Notice that this menu allows you to turn mask testing off, to define a mask based on limit values, or to generate a custom SOA mask of 4 to 10 points. Repeatedly press the top side bezel button until **Set Limits** is selected.
- ❑ Press the **Maximum Voltage** side bezel button.
- ❑ Using the Multipurpose **a** control, enter the  $V_{DSmax}$  value of **60 V**.
- ❑ Press the **Maximum Current** side bezel button.
- ❑ Using the Multipurpose **a** control, enter the  $I_{Cmax}$  value of **45 A**.
- ❑ Press the **Maximum Power** side bezel button.
- ❑ Using the Multipurpose **a** control, enter the  $P_{Cmax}$  value of **120 W**.
- ❑ Press the **Action On Violation** bottom bezel button.
- ❑ Repeatedly press the **Stop** side bezel button until **On** is selected.

## Modulation Analysis with Measurement Trends

### Key Take Away Points

- To demonstrate modulation measurements, this section of the lab characterizes the control signal on the gate of the MOSFET.
- The display should look about like this:



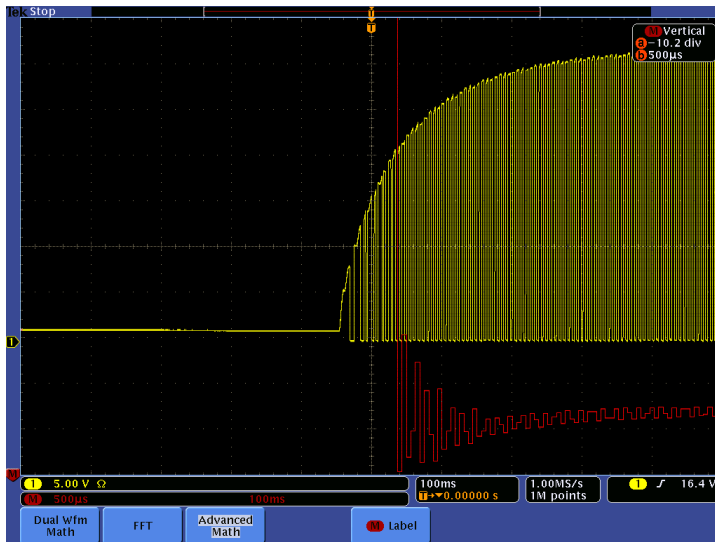
- The math waveform is showing the trend in cycle-to-cycle pulse width measurements made on the MOSFET gate drive signal as the power supply's oscillator starts up. However, at this math vertical scale setting, it is difficult to see the variations in the pulse width measurements.

### MSO/DPO4000B Series Procedure:

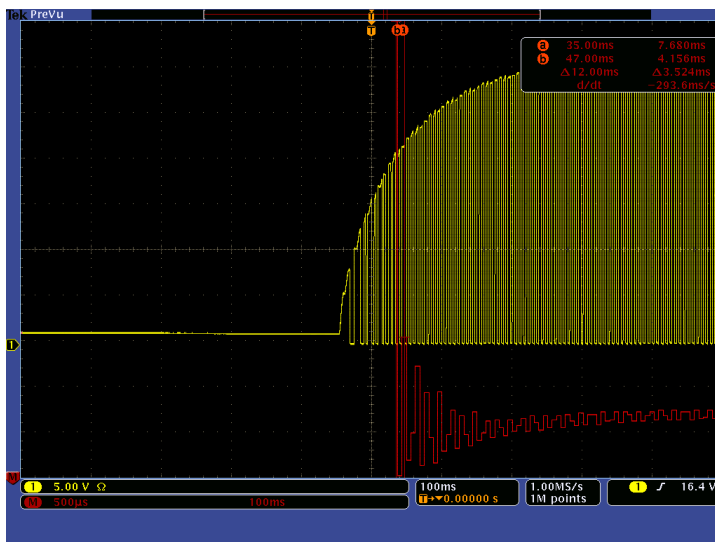
- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the front panel **2** button twice to turn off channel **2**.
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Record Length** bottom bezel button.
- ❑ Using the Multipurpose **a** control, select **1M**.
- ❑ Set the Horizontal **Scale** to **100 ms/div**.
- ❑ Press the front panel Trigger **Menu** button.
- ❑ Press the **Mode** bottom bezel button and the **Normal** side bezel button.
- ❑ Remove the power from the demo board.
- ❑ Press the front panel **Single** button.
- ❑ Re-connect the power to the demo board.
- ❑ Press the front panel **Test** button.
- ❑ Press the **Analysis** bottom bezel button.
- ❑ If necessary, press the **-more-** side bezel button to go to page 2 of the Power Analysis menu.
- ❑ Press the **Modulation** side bezel button.
- ❑ Press the **Modulation Type** bottom bezel button.
- ❑ Verify that the **Positive Pulse Width Modulation Type** is selected.

## Key Take Away Points

- To view the variations in the pulse width measurement, we adjust the vertical scale and position of the math waveform:



- Since the math waveform represents pulse width measurement values (with units of time), it should be possible to measure the variations in pulse widths with the cursors. The display should look about like this:



- Notice that the math values represent the trends in the selected modulation measurement across the acquired waveform. In this case, it represents the response of the oscillator's control loop during startup.
- This modulation analysis could also be used to measure the response of the power supply's control loop to a change in input voltage ("line regulation") or a change in load ("load regulation").

## MSO/DPO4000B Series Procedure:

- Press the red front panel **M** button to attach the Multipurpose controls to the math scale and position controls.
- Using the Multipurpose controls, change the math vertical scale and position to view the variations in the math waveform.

- Press the front panel **Cursors** button.
- Using the Multipurpose controls, measure the peak-to-peak variation in pulse widths as the oscillator starts up.

- When you are done, press the front panel **Cursors** button.
- Press the **Analysis** bottom bezel button, the **-more-** side bezel button, and the **None** side bezel button.
- Press the front panel **Run/Stop**

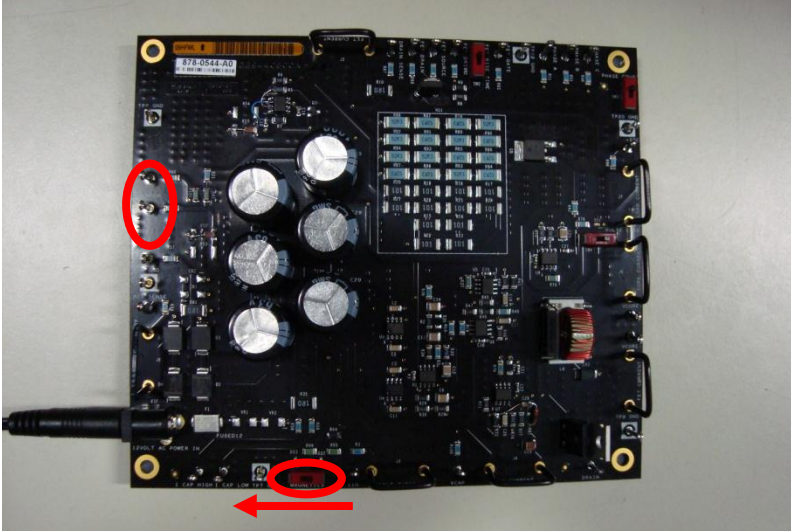
	button.
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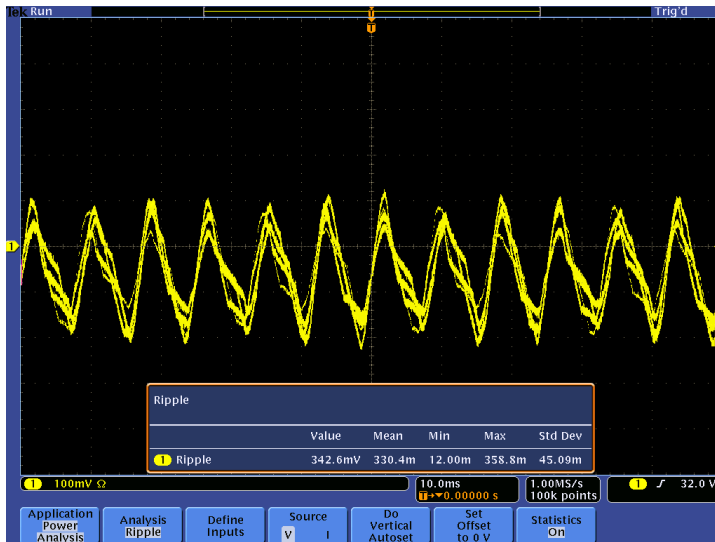
## Ripple Measurements

### Key Take Away Points

- To demonstrate ripple measurements, this section of the lab measures the voltage across the DC output section of the demo board.



- The display should look about like this:



- Notice that the ripple measurement values are amplitude measurements made on the entire acquired waveform and the statistics of those average measurements are accumulated across all acquisitions.

### MSO/DPO4000B Series Procedure:

- NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- Press the **Analysis** bottom bezel button and press the **Ripple** side bezel button.
- Connect the - input of the differential probe to the **DC LOW** test point.
- Connect + input of the differential probe on channel 1 to the **DC HIGH** test point.
- Press the front panel **Test** button.
- Press the **Define Inputs** bottom bezel button.
- Verify that the **Voltage** is on channel 1.
- Press the **Do Vertical Autoset** bottom bezel button to add vertical offset to remove the DC component from the signal and autoscale the AC component for optimal measurement accuracy.
- When you are done, press the **Set Offset to 0 V** bottom bezel button to remove the vertical offset added by the Do Vertical Offset operation above.

## Understanding the TekVPI Interface

### Introduction

The **TekVPI (Tektronix Versatile Probe Interface)** architecture is the new-generation probe interface architecture for the MSO/DPO4000B Series oscilloscopes. TekVPI probes combine excellent electrical probe performance with advanced, bidirectional serial interface communications with the oscilloscope. The design architecture of TekVPI provides users improved ease-of-use in probe setup, easy selection of displayed probe status and setup information, as well as accurate probe measurement performance results all intended to simplify and improve the performance of the user's test and measurement experience.

In 1969, Tektronix introduced a probe interface which used a BNC type connector for passing the acquired analog signal and added an analog-encoded scale factor detection pin, which enabled the compatible oscilloscope to automatically detect and scale the displayed vertical attenuation range appropriately. Today, we refer to this interface as TekProbe™ Level 1. A P6139A or P6139B passive probe is a common example.

In 1986, probe usability was further enhanced with the introduction of the TekProbe-BNC Level 2 probe interface architecture which supports the required operating power requirements for "active" probe types which contained transistors, IC's, or other active components as part of the probe's signal conditioning network design. TekProbe-BNC Level 2 further extended the capabilities of Level 1 designs by adding probe communications with the oscilloscope to improve the usability of increasingly sophisticated probe types and to accomplish calibrated offset at the probe tip.

In early 2006, Tektronix introduced the next generation of probe interface, the TekVPI architecture. Each TekVPI probe features controls and indicators right on the probe for quick and easy access to the probe's most commonly required setup controls and operating status. TekVPI probes also have a Menu button that enables users to quickly and easily access a probe setup menu on the oscilloscope. The instrument provides comprehensive probe information including: probe model type, probe serial number, probe operating status and warnings. Additionally, all probe setup controls can be changed and monitored from the instrument display. Because of the probe communications, the oscilloscope can save the probe setup and provide remote control of the probes through the programmable interfaces (USB, GPIB, and Ethernet).

Traditionally, the precisely-regulated power resources for the active probes were provided by the host oscilloscope. Therefore, every oscilloscope was burdened with the cost and weight of the power conditioning circuits. Sometimes, instrument constraints limited the number or type of probes which were supported. The TekVPI architecture moves the complexity of the power conditioning into the probe itself, where the design can be optimized for that specific probe. The TekVPI host oscilloscope distributes a +12 V<sub>DC</sub> bulk power supply which each probe or adapter regulates to meet its own needs, providing more flexibility in probe support. An example of this benefit is found with the TCP0030, 30 Ampere AC/DC current probe. Previous current probes of this measurement range required external power supplies to provide the necessary resources required for "bucking currents" and to perform degaussing operations necessary to maintain accurate measurement capability. The TCP0030 and TCP0150 TekVPI current probes now eliminate this need for an external power supply when used with the MSO/DPO4000B series.

The TekVPI design also simplifies the attachment of the probe or adapter, allowing the user to simply insert the probe connector into the oscilloscope's TekVPI input channel connector. The probe is locked in place until the user presses the push-button lock release. To assure electrical signal integrity of the probe interface connections gold-plated spring contacts are used. In addition to TekVPI probes, the interface is directly compatible with BNC cables and TekProbe level 1 probes such as the P6139A and P6139B.



Note: On the MSO/DPO4000B Series, the Aux In connector provides full power and communication capabilities, but only offers 1 M $\Omega$  termination. Therefore, when probes which expect 50 $\Omega$  termination are connected, you will see an error message pop up. The probe will still work, but since the termination is 1 M $\Omega$  instead of 50 $\Omega$ , the voltage delivered to the Aux In input amplifier will be about twice the expected size and may have some ringing on fast edges.

#### Incompatible probe

The probe attached to Aux In is not compatible with that oscilloscope input.

Push Menu Off to remove this message.

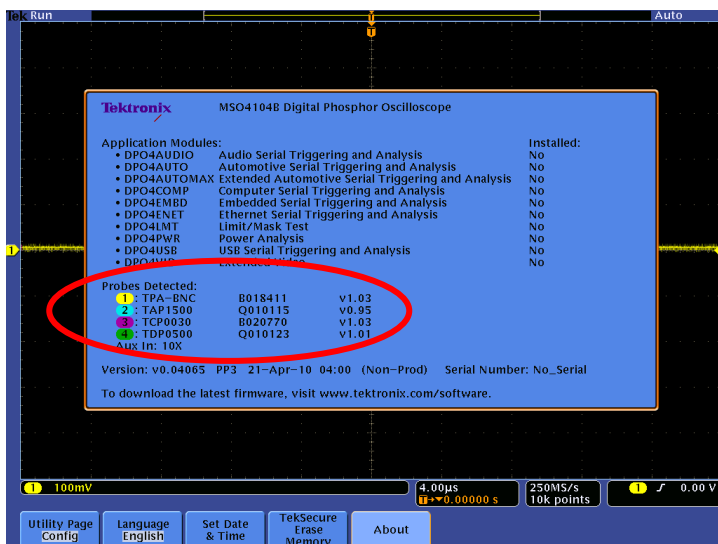
### Lab Objectives

For this lab, if you have the optional probes and the time, go through the procedure on the right side of each page. If not, simply follow the pictures and text on the left side of each page.

- Obtain a basic understanding of the TekVPI interconnect.
- Learn how to control the TekVPI probes with the MSO/DPO4000B Series oscilloscope.
- Learn about some basic applications of the new TekVPI probes.

### Key Take Away Points

- When all of these probes are connected to the oscilloscope, the About menu should look something like this:



- Make sure that the LED on each probe's comp box is lit after each probe is connected.
- Notice that, where applicable, the probe type, probe serial number, and probe software version are displayed for each channel.

### MSO/DPO4000B Series Procedure:

- Power up the oscilloscope.
- Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- Press the front panel **Utility** button.
- If necessary, press the **About** bottom bezel button to display the status screen.
- Connect a TPA-BNC to channel 1 input.
- Connect a TAP1500 to channel 2 input.
- Connect a TCP0030 to channel 3 input.
- Connect a TDP0500 or TDP1000 to channel 4 input.
- Connect a TPP0500 or TPP100010X passive probe to the Aux In input.

## Coaxial Cable

### Key Take Away Points

- Coaxial cables with BNC connections are directly compatible with the TekVPI interface on the MSO/DPO4000B Series oscilloscope.
- When a coax cable is connected to an analog channel on a MSO/DPO4000B Series oscilloscope, the relevant readout and controls for the probe appear in that channel's Probe Setup menu.
- The Probe Type control allows you to specify if the signal is a Voltage or Current. Notice that the units on the channel 1 readout match this selection.
- The Attenuation control allows you to specify the amount of external attenuation that has been applied to the signal. Notice that the units/div value on the channel 1 readout reflect this selection.



### MSO/DPO4000B Series Procedure:

- ❑ Connect a coax cable to the Channel 1 input. (Since there is no communication from the cable, it doesn't really matter if you do this step or not.)
- ❑ Press the front panel channel 1 button.
- ❑ Repeatedly press the **More** bottom bezel button until **Probe Setup** is selected and the Probe Setup side menu is displayed.
- ❑ Press the **Probe Type** side bezel button and notice that the units on the channel 1 readout in the lower left corner of the display change as you toggle the Probe Type.
- ❑ Using the Multipurpose **a** control, adjust the **Attenuation** and notice that the units/div value on the channel 1 readout in the lower left corner of the display changes as you adjust the Attenuation.



## P6139A and P6139B Passive Probes

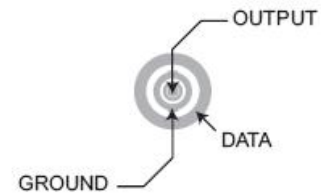
### Key Take Away Points

- The P6139A and P6139B are examples of TekProbe level 1 probes. It uses a BNC connector to transmit the analog signal, and transmits the probe's voltage scale factor data via a spring-loaded pin. (See picture at right.)
- The P6139A and P6139B 10X passive voltage probes are directly compatible with the TekVPI interface on the MSO/DPO4000B Series oscilloscope.
- When a probe is connected to an analog channel on a MSO/DPO4000B Series oscilloscope, the relevant readout and controls for the probe appear in that channel's Probe Setup menu.
- In the case of a P6139A and P6139B, there are no controls, and the menu displays that the probe is a 10X voltage probe.
- Notice that the units on the channel 1 readout are Volts.



- Full controls are offered on the bottom bezel buttons. However, if the Impedance has been set to 50Ω, the Impedance is reset to the expected default value of 1MΩ when the P6139A or P6139B probe is attached.

### MSO/DPO4000B Series Procedure:



### TekProbe level 1 probe (P6139A)

- ❑ Connect the P6139A or P6139B 10X passive voltage probe to the Channel 1 input.
- ❑ Press the front panel channel 1 button.
- ❑ Repeatedly press the **More** bottom bezel button until **Probe Setup** is selected and the Probe Setup side menu is displayed.
- ❑ This is the P6139B probe:



## TPA-BNC Adapter

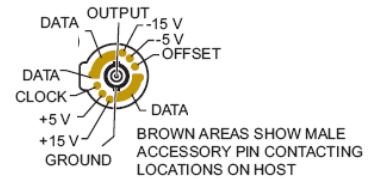
### Key Take Away Points

- TekProbe level 2 probes include power connections for active probes and increased data communications with the scope. However, they are not mechanically compatible with the TekVPI connector.
- The data and clock signals are I<sup>2</sup>C serial bus connections.
- The TPA-BNC adapter is designed to allow the user to connect legacy TekProbe level 2 probes, such as the P624X series active and differential probes and the TCP202 current probes, to the MSO/DPO4000B Series.
- When the TPA-BNC by itself is attached to channel 1 and the channel's Probe Setup menu is selected, the display should look about like this:



- When a TekProbe level 1 probe (such as the P6139A or P6139B) or a TekProbe BNC level 2 probe (such as the P6243) is attached to the TPA-BNC, the probe information is displayed in the About menu and the appropriate information is displayed in the channel 1 Probe Setup menu.

### MSO/DPO4000B Series Procedure:



### TekProbe level 2 probe

- ❑ Connect the TPA-BNC adapter to the Channel 1 input.
- ❑ Press the front panel channel 1 button.
- ❑ Repeatedly press the **More** bottom bezel button until **Probe Setup** is selected and the Probe Setup side menu is displayed.
- ❑ Connect the P6139A or P6139B to the input of the TPA-BNC.
- ❑ Press the front panel **Utility** button.
- ❑ If necessary, press the **About** bottom bezel button to display the status screen.

## TPA-BNC – Just A Mechanical Adapter?



There is more under the cover than meets the eye! Although described as an adapter, the TPA-BNC is *much more* than a passive signal path, mechanical adapter. It contains sophisticated circuit boards, ICs, connectors and shielding.

It is a mechanical adapter (TEKPROBE BNC to TekVPI), but it also is a power converter and a TEKPROBE Level 2 to TekVPI control signal converter allowing the use of existing TEKPROBE Level 2 interface active voltage probes, high and low voltage differential probes, micro-volt pre-amplifier probe, and current probes to name a few with the Tektronix oscilloscope products that use the TekVPI probe interface.

- Power Conversion – requires circuitry to convert the TekVPI voltage levels (12V, 5V) and provide the voltage levels (+15V, -15V, +5V, -5V) required for TEKPROBE interface probing solutions to function.
- Control Signal Conversion – requires circuitry to convert TEKPROBE control signaling; such as attenuation factor, range, product serial number, and product type into TekVPI control signaling formats.
- Backward Compatibility – allows moving into the next generation of test and measurement tools while maintaining compatibility to use existing TEKPROBE interface tools without losing your present DUT test fixtures and testing setups.

## TPA-BNC – NOT JUST ANOTHER ADAPTER!

## TPP0500 and TPP1000 Passive Probes

### Key Take Away Points

- For high-fidelity acquisition of high-speed ground-referenced voltage signals, the TPP0500 / TPP1000 is an excellent choice:
  - 500 MHz / 1 GHz probe bandwidth provides wide-bandwidth general-purpose probing for any of the MSO/DPO4000B Series scopes.
  - $\leq 4$  pF input capacitance minimizes probe AC loading on the circuit.
  - 10 M $\Omega$  input resistance at the probe tip minimizes probe DC loading on the circuit.
  - 300 V CAT II Maximum Input Voltage provides wide dynamic range while minimizing AC (capacitive) loading.
- The MSO/DPO4000B Series Probe Setup menu for the TPP0500 / TPP1000 probes should look about like this:



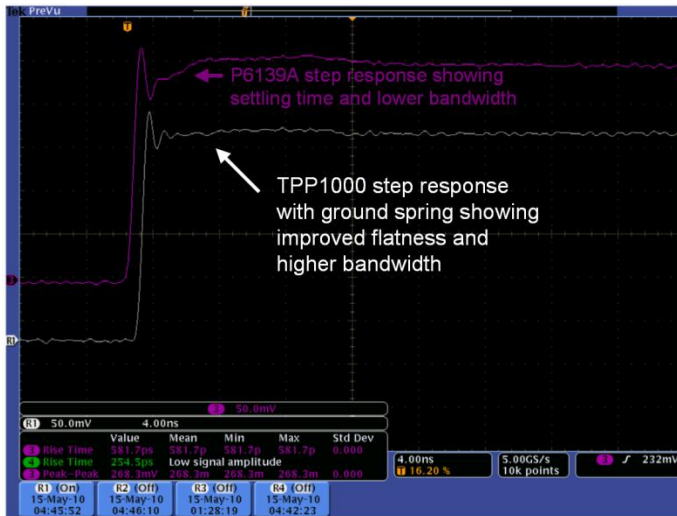
### MSO/DPO4000B Series Procedure:



- Connect a TPP0500 or TPP1000 probe to channel 1.
- Press the front panel channel 1 button to display the vertical menu.
- Repeatedly press the **More** button until **Probe Setup** is selected.
- The TPP probes have an automated AC calibration capability.
- Connect the probe tip to the PROBE COMP signal on the lower right corner of the oscilloscope.
- Connect the probe ground to the ground connection just above the PROBE COMP signal.
- Press the **Compensate Probe for 1** side bezel button.

## Key Take Away Points

- The step response performance of the TPP0500 / TPP1000 passive probes is significantly better than that of other industry-standard passive probes:



- The TekVPI connector on the TPP0500 / TPP1000 has a mechanical key which corresponds to the TekVPI connector on the front of the MSO/DPO4000B Series. This mechanical lockout prevent attachment of the probe to oscilloscopes which do not support these probes:



## MSO/DPO4000B Series Procedure:

## TAP1500 Active Probe

### Key Take Away Points

- For high-fidelity acquisition of high-speed ground-referenced voltage signals, the TAP1500 is an excellent choice:
  - $\geq 1.5$  GHz probe bandwidth provides full system bandwidth for any of the MSO/DPO4000B Series scopes.
  - $\leq 1$  pF input capacitance minimizes probe AC loading on the circuit.
  - $1\text{ M}\Omega$  input resistance minimizes probe DC loading on the circuit.
  - $-8\text{ V}$  to  $+8\text{ V}$  probe input dynamic range for high-speed signals, as indicated in the menu readout.
  - $-10\text{ V}$  to  $+10\text{ V}$  DC input offset range to optimize the measurement system's dynamic range when signals are offset from ground.
  - Higher bandwidth versions (TAP2500 and TAP3500) are also available.
- Notice that when you attach the probe, if the channel's termination is not already set to  $50\Omega$ , it will be set to  $50\Omega$ .
- Notice that you can call up the MSO/DPO4000B Series Probe Setup menu simply by pressing the Menu button on the probe. The display should look about like this:



### MSO/DPO4000B Series Procedure:

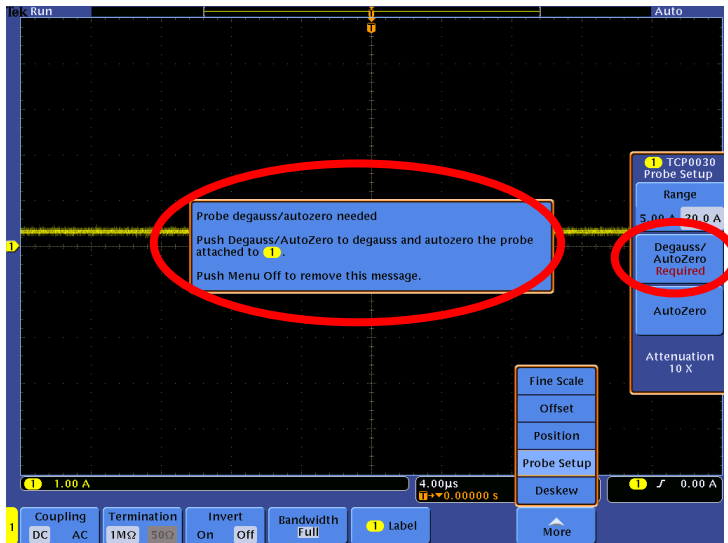


- ❑ Connect the TAP1500 probe to channel 1.
- ❑ On the probe, press the **Menu** button.
- ❑ To offset the input signal in the probe, use the Multipurpose **a** control.
- ❑ To minimize any DC offsets in the probe, after the probe and oscilloscope have warmed up for at least 20 minutes, short the probe input to ground and press the **AutoZero** side bezel button on the oscilloscope.

## TCP0030 Current Probe

### Key Take Away Points

- For high-fidelity acquisition of high-speed current signals, the TCP0030 is an excellent choice:
  - DC to >120 MHz bandwidth.
  - Provides automatic units scaling and readout on the oscilloscope display.
  - 30 A<sub>RMS</sub> / 50 A<sub>peak</sub> pulse current capability.
- When you first connect the current probe, you will see a pop-up notifier in the middle of the display if the probe needs to be degaussed and the offsets zeroed out. Also, notice the red error message which appears when the probe jaws are open:



- You can call up the MSO/DPO4000B Series Probe Setup menu simply by pressing the Menu button on the probe. The display should look about like this:



### MSO/DPO4000B Series Procedure:

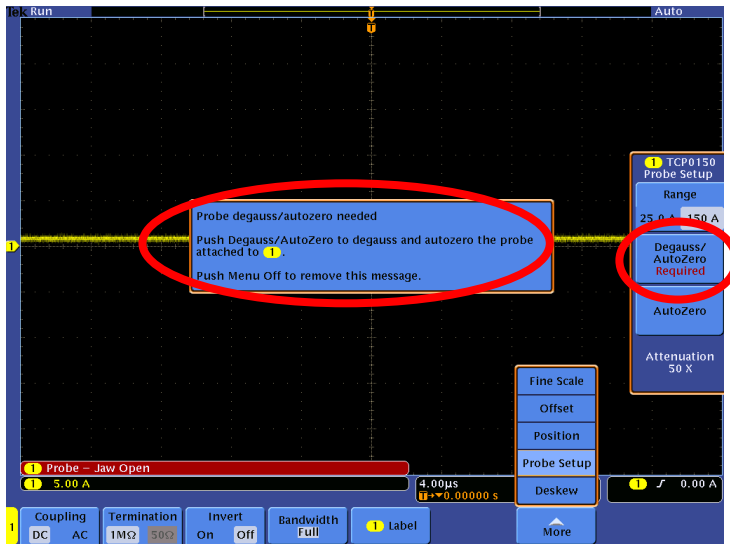


- Connect the TCP0030 probe to channel 1.
- To remove any residual magnetic fields and DC offsets in the current probe, press the **Degauss / AutoZero** button, either on the probe or on the side bezel menu on the oscilloscope.
- On the probe, press the **Menu** button.
- To match the vertical sensitivity of the probe to the signal, press the **Range** button, either on the probe or on the side bezel menu on the oscilloscope.
- Notice that the units on the vertical and trigger readouts change to units of current (mA and A).

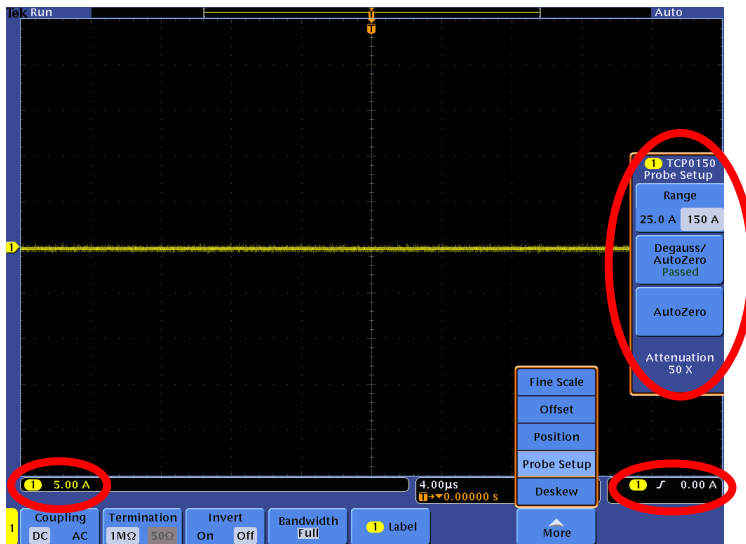
## TCP0150 Current Probe

### Key Take Away Points

- For high-fidelity acquisition of large current signals, the TCP0150 is an excellent choice:
  - DC to 20 MHz bandwidth.
  - Provides automatic units scaling and readout on the oscilloscope display.
  - 150 A<sub>RMS</sub> / 500 A<sub>peak</sub> pulse current capability.
- You can call up the MSO/DPO4000B Series Probe Setup menu simply by pressing the Menu button on the probe. The display should look about like this:



- After Degauss/Autozero, the display should look about like this:



### MSO/DPO4000B Series Procedure:



- Connect the TCP0150 probe to channel 1.
- To remove any residual magnetic fields and DC offsets in the current probe, press the **Degauss / AutoZero** button, either on the probe or on the side bezel menu on the oscilloscope.
- On the probe, press the **Menu** button.
- To match the vertical sensitivity of the probe to the signal, press the **Range** button, either on the probe or on the side bezel menu on the oscilloscope.
- Notice that the units on the vertical and trigger readouts change to units of current (mA and A).



## TDP0500 and TDP1000 Differential Probes

### Key Take Away Points

- For high-fidelity acquisition of high-speed differential voltage signals, the TDP1000 and TDP0500 are excellent choices:
  - 1 GHz and 500 MHz probe bandwidths.
  - <1 pF differential input capacitance minimizes probe AC loading on the circuit.
  - 1 M $\Omega$  differential input resistance minimizes probe DC loading on the circuit.
  - $\pm 42$  V (DC + pk AC) differential input voltage range to address a variety of automotive, power supply, and serial communications applications.
  - 100 Hz, 10 kHz, and 1 MHz bandwidth limiting filters to reduce unwanted noise.
  - Higher bandwidth, lower dynamic-range versions (TDP1500 and TDP3500) are also available.
- Notice that when you attach the probe, if the channel's termination is not already set to 50 $\Omega$ , it will be set to 50 $\Omega$ .
- Notice that you can call up the MSO/DPO4000B Series Probe Setup menu simply by pressing the Menu button on the probe. The display should look about like this:

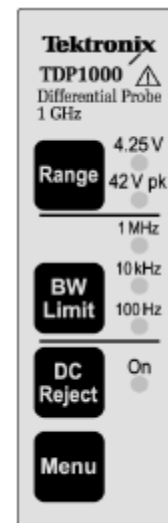


- As you work with the probe, you will find that the probe controls are integrated into the oscilloscope's user interface. For example, when you adjust Vertical Offset in the channel menu's More->Offset menu, you're actually adjusting the offset in the probe.

### MSO/DPO4000B Series Procedure:



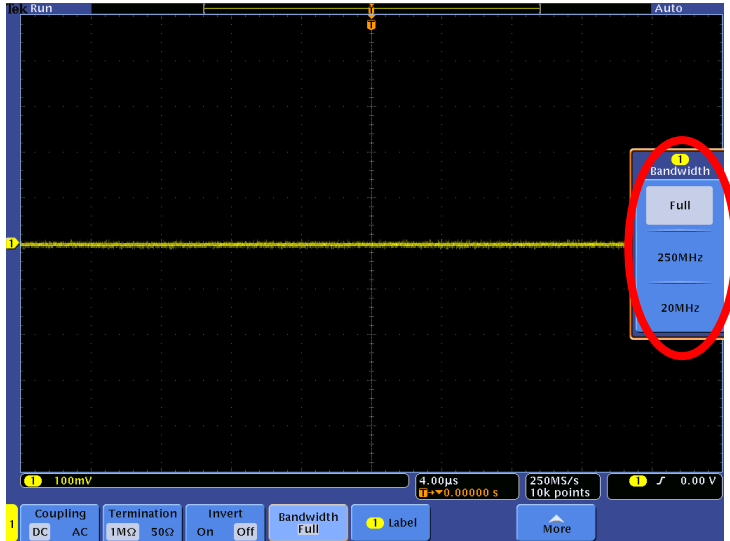
- Connect the TDP0500 or TDP1000 probe to channel 1.
- On the probe, press the **Menu** button.



- To match the vertical sensitivity of the probe to the signal, press the **Range** button.
- On the probe, press the **Menu** button.
- Repeatedly press the **More** bottom bezel button until the Offset side menu is displayed.
- To offset the input signal in the probe, use the Multipurpose a control.

## Key Take Away Points

- The TDP probe adds new bandwidth and coupling capabilities. Before you connect the probe, the channel's menu looks something like this:



- After connecting the TDP probe, the menu changes to look something like this:



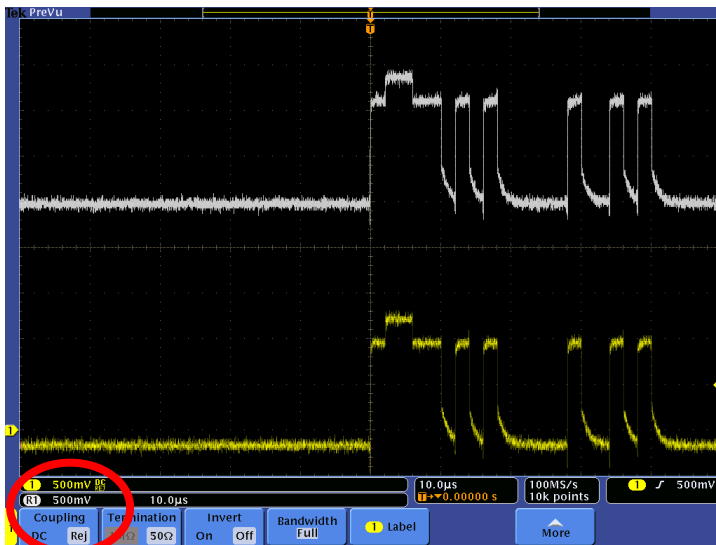
- Notice that additional bandwidth selections have been added to the Bandwidth side menu.

## MSO/DPO4000B Series Procedure:

- ❑ To minimize any DC offsets in the probe, after the probe and oscilloscope have warmed up for at least 20 minutes, set the range to the desired setting, short both probe inputs to ground and press the **AutoZero** side bezel button on the oscilloscope.
- ❑ Remove the probe from channel 1.
- ❑ Press the front panel channel 1 button.
- ❑ Press the **Bandwidth** bottom bezel button.
- ❑ Connect the TDP0500 or TDP1000 probe to channel 1.
- ❑ Notice that additional bandwidth selections have been added to the Bandwidth side menu.
- ❑ To minimize noise on the display, select the lowest bandwidth setting that does not distort the signal.

## Key Take Away Points

- Notice that the DC Reject (“Rej”) capability of the probe has replaced the channel’s AC coupling selection in the bottom bezel menu.
- DC Reject is useful when you are measuring small amplitude signals superimposed on a large differential offset component. DC Reject generates an internal offset that cancels the DC component of the signal.
- Because the input is always directly coupled, the DC reject mode does not increase the common and differential mode dynamic ranges for DC components. The DC reject mode also disables any capability of external offset adjustment.
- In the screen shot below, the probe is connected between the CAN\_H and GND signals. With the probe and oscilloscope DC-coupled, the signal appears as a 1Vpp AC signal riding on a 2.5V DC baseline, as shown in the white reference trace below. (The CAN\_H signal is positive relative to the baseline, and the CAN\_L signal is negative relative to the baseline.) When the probe’s DC Reject enabled, you’ll notice that most of the DC offset has been removed, similar to AC coupling.



- Finally, notice the variety of probing accessories for the TDP series for versatile connectivity to the device under test: point probing, variable spacing, square pin connection, KlipChip connection, and a new solder-down connection that incorporates damping networks for improved signal fidelity.

## MSO/DPO4000B Series Procedure:

- Connect the probe to a signal with significant DC offset, such as **CAN\_H**.
- Press the **DC Reject** button on the TDP0500 or TDP1000 probe and notice the effect on the display.
- Look at the box of probing accessories provided with the TDP Series of probes.

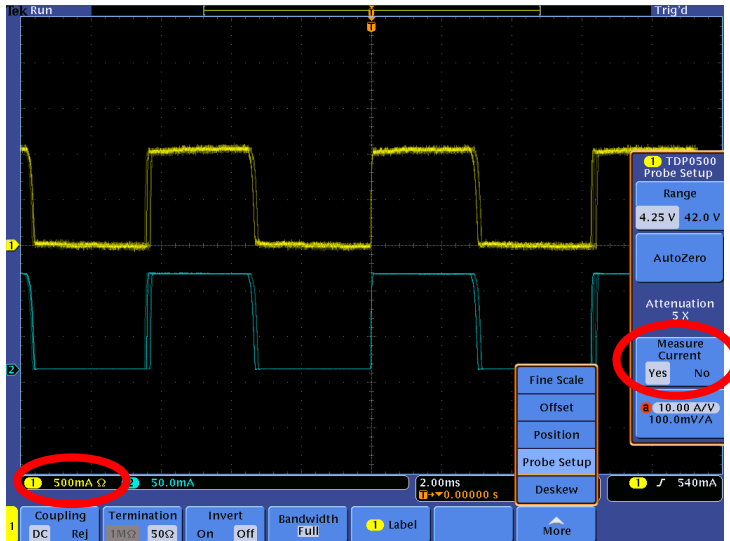
## Key Take Away Points

### (optional) Measuring Current with Differential Probes

- Differential probes can also provide wideband current measurements by measuring the voltage drop across a known impedance. For example, the 3PQS power demo board has a  $1\Omega$  resistor in series with the load, as shown below:



- For comparison purposes, the screen shot below shows the TCP0030 current measurement on channel 2. The display of the current waveform should look about like this:



### MSO/DPO4000B Series Procedure:

- Connect the 12VAC power adapter to the demo board and plug it in.
- On the 878-0544-XX demo board, connect the differential probe to the DRAIN\_SENSE and FET\_DRAIN test points.
- On the 3PQS board, connect the differential probe across the large  $1\Omega$  resistor which is in series with the load.
- Press the **Menu** button on the probe.
- Press the **Range** side bezel button until the **4.25 V** range is selected.
- Repeatedly press the **Measure Current** side bezel button until **Yes** is selected.
- Since you are measuring the current through a  $1\Omega$  resistor, and Ohm's Law says that  $R = V / I$ , the appropriate current scale factor is  $1 \text{ A/V}$  or  $1 \text{ V/A}$ . Using the Multipurpose **a** control, set the scale factor to **1.000 A/V**.
- Press the front panel **Autoset** button.
- If the signal looks too noisy, you can filter the display with HiRes. Press the front panel **Acquire** button, the **Mode** bottom bezel button, and the **Hi Res** side bezel button.