Instruction Manual

Embedded Protocols:
I2C, SPI, UART/RS-232
Serial Trigger and Decode

Embedded Protocols Serial Trigger and Decode Instruction Manual

Contents

About This Manual

Teledyne LeCroy offers an array of toolsets for decoding and debugging serial data streams. These toolsets may be purchased as optional software packages, or are provided standard with some oscilloscopes.

This manual explains how to use the following software:

- I^2C Serial Trigger and Decoder

- SPI Serial Trigger and Decoder

- UART Serial Trigger and Decoder

- RS-232 Serial Trigger and Decoder

Assumptions

This manual is presented with the assumption that:

- You have a basic understanding of the serial data standard physical and protocol layer specifications, and know how these standards are used in embedded controllers.

- You have a basic understanding of how to use an oscilloscope, and specifically the Teledyne LeCroy oscilloscope on which the option is installed. Only features directly related to serial data trigger and decode are explained in this manual; please see the oscilloscope online Help file, Operator's Manual or Getting Started Manual for other instructions.

- You have purchased and installed one of the serial data products described in this manual.

Compatibility

Teledyne LeCroy is constantly expanding coverage of serial data standards and updating software. Some capabilities covered in this documentation may only be available with the latest version of our firmware. You can download the free firmware update from teledynelecroy.com.

While some of the screen images in this manual may not exactly match what is on your oscilloscope display—or show an example taken from another standard—be assured that the functionality is nearly identical, as much functionality is shared.

About the Embedded Options

The Embedded Protocols options include I^{2}C, SPI, and UART/RS-232 serial triggers and decoders, sold separately or as a package.

Decode

Teledyne LeCroy decoders apply software algorithms to extract Embedded-encoded serial data information from physical layer waveforms measured on your oscilloscope. The extracted information is displayed over the actual physical layer waveforms, color-coded to provide fast, intuitive understanding of the relationship between message frames and other, time synchronous events.

Trigger

Trigger the oscillosocpe upon finding specific message frames, data patterns, or errors in serial data streams. Conditional filtering at different levels enables you to target the trigger to a single message or a range of matching data.

Measure

The PROTObus MAG option adds a protocol-specific set of measurements to the oscilloscope's standard measurement capabilities and enables you to quickly plot the measurement results.

Graph Measurements

Measurement data can be viewed as a Histogram, Track, or Trend plot of the digitally encoded data values for a specific input versus time. These plots effectively perform a digital-to-analog conversion that can be viewed right next to the decoded waveform.

Filter and Gate Measurements

Measurements can be filtered to include only the specified frame types, IDs, or data patterns. As with all traces, you can set a gate to restrict measurements to a horizontal range of the grid corresponding to a specific time segment of the acquisition.

About the I^{2}C Option

I^{2}C is a standardized protocol created by Philips with a documented technical specification. NXP (formerly Philips Semiconductors) provides a full description of the standard at:

www.nxp.com/documents

The I^{2}Cbus conditional data trigger allows triggering on a range of data bytes corresponding with reads or writes to specific sub-address memory blocks in the EEPROM. It can also aid in monitoring data outputs from I^{2}C- based sensors, such as analog-to-digital converters, and triggering when data is outside a safe operating range. Other features include:

- Address conditions in binary and data conditions in hexadecimal to trigger on a range of addresses using "Don't Care" bits

- Frame length triggering

- EEPROM triggering on up to 96 bits (12 bytes) of data at any location within an I^{2}C frame or at a user-defined location in a 2048 byte window

- All permutations of Read, Write, or R/W Don't Care trigger conditions for 7 and 10-bit addresses

- ACK response triggering

About the SPI Option

SPI was popularized by Motorola but is not a standard, per se. There are variants with differences characterized by how data is clocked, whether data is MSB or LSB format, and whether it is multislave or single-slave.

While SPI has no formal standard, information is often included in the technical documentation for the microprocessor supporting the protocol.

"Simplified" SPI (SIOP, SSPI, and SPI-Custom) decoders do not require use of a Chip Select line. In its place is the ability to set a minimum Interframe Time. By eliminating the Chip Select line presence requirement, an additional oscilloscope channel is preserved for use with other analog signals.

The SPIbus option allows triggering on SPI messages, targeted to a specific data pattern or a range of data. As with the decoder, the serial data trigger can be configured for any of the many variants of SPI.

About the UART/RS-232 Option

UART is a generic backbone for many proprietary serial data protocols, each with different physical layers. UART has no formal standard. The protocol evolved from mechanical rotating teletypewriter devices. Formats were formalized with the advent of the first electronic computers.

RS-232 is a special case of UART, with a more defined protocol and specific physical layer. The physical layer is defined in Electronic Industries Association (EIA) EIA-RS-232-C and Telecommunications Industry Association (TIA) TIA-232-F. Its protocol layer is not specified; however, UART is commonly implemented. Resources can be found at www.eia.org and www.tiaonline.org.

The decoder features:

- Ability to define the UART byte with 9-bit data, with the 9th data bit functioning as an alert bit with a value setable to 0, 1, or X.

- Ability to define as few as 5 bits of data in the UART byte.

- Polarity configurable to either IdleLow or IdleHigh.

- Decoding in **Binary** or **Hex**(adecimal) formats

Triggers can be set on data patterns or Parity errors. Data triggers can be set to find values relative to ranges or individual values. Additional features include:

- Triggering on up to 12 bytes of data in a string up to 2048 bytes long.

- Ability to define the UART byte messages into a single long message packet.

Decoding

Serial Decode Technical Overview

The algorithms described here at a high level are used by all Teledyne LeCroy serial decoders sold for oscilloscopes. They differ slightly between serial data signals that have a clock embedded in data and those with separate clock and data signals.

Bit-level Decoding

The first software algorithm examines the embedded clock for each message based on a default or user- specified vertical threshold level. Once the clock signal is extracted or known, the algorithm examines the corresponding data signal at the predetermined vertical level to determine whether a data bit is high or low. The default vertical level is set to 50% and is determined from a measurement of peak amplitude of the signals acquired by the oscilloscope. It can also be set to an absolute voltage level, if desired. The algorithm intelligently applies a hysteresis to the rising and falling edge of the serial data signal to minimize the chance of perturbations or ringing on the edge affecting the data bit decoding.

NOTE: Although the decoding algorithm is based on a clock extraction software algorithm using a vertical level, the results returned are the same as those from a traditional protocol analyzer using sampling point-based decode.

Logical Decoding

After determining individual data bit values, another algorithm performs a decoding of the serial data message after separation of the underlying data bits into logical groups specific to the protocol (Header/ID, Data Length Codes, Data, CRC, Start Bits, Stop Bits, etc.).

Message Decoding

Finally, another algorithm applies a color overlay with annotations to the decoded waveform to mark the transitions in the signal. Decoded message data is displayed in tabular form below the grid. Various compaction schemes are utilized to show the data during a long acquisition (many hundreds or thousands of serial data messages) or a short acquisition (one serial data message acquisition). In the case of the longest acquisition, only the most important information is highlighted, whereas in the case of the shortest acquisition, all information is displayed with additional highlighting of the complete message frame.

User Interaction

The order of your interaction with the decoder software in many ways mirrors the order of the algorithms. You will:

- Assign a protocol/encoding scheme, an input source, and a clock source (if necessary) to one of the four decoder panels using the Serial Data and Decode Setup dialogs.

- Complete the remaining dialogs required by the protocol/encoding scheme to decode Transitions, Bits and Words.

- Work with the decoded waveform, result table, and measurements to analyze the decode.

Decoding Workflow

While not required, we recommend the following workflow for decoding:

1. Set up the decoder.

2. Acquire a single burst of relevant data, then run the decoder.

   NOTE: If the sampling rate (SR) is insufficient to resolve the signal adequately based on the bit rate (BR) setup or clock frequency, the protocol decoding is turned OFF to protect you from incorrect data. The minimum SR:BR ratio required is 4:1. It is suggested that you use a slightly higher SR:BR ratio if possible, and use significantly higher SR:BR ratios if you want to also view perturbations or other anomalies on your serial data analog signal.

3. Use the various analysis tools to verify that transitions are being correctly decoded. Tune the decoder settings as needed.

4. Run the decoder on acquisitions of the desired length.

You can disable/enable the decoder as desired without having to repeat the set up and tuning provided the basic signal characteristics do not change.

Setting Up the Decoder

The main Serial Decode dialog allows you to preset up-to-four, independent decoders, Decode 1 to Decode 4. Each decoder can use different (or the same) protocols and data sources, or have other variations, giving you maximum flexibility to compare different signals or view the same signal from multiple perspectives.

TIP: After completing setup for one decoder, you can quickly start setup for the other decoders by using the Decode # buttons at the left of the Decode Setup dialog. You don't have to step back to the Serial Decode dialog. Controls with the same label on either dialog share the same function.

1. Touch the **Front Panel Serial Decode button** (if available on your oscilloscope), or choose **Analysis > Serial Decode** from the oscilloscope menu bar to access the Serial Decode dialog.
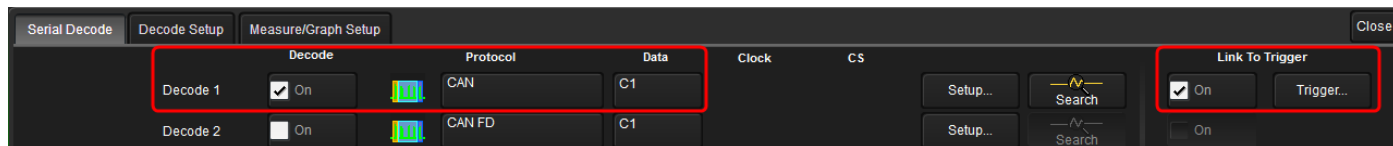

2. On the same row as the **Decode #**:
   - Check **On** to enable the decoder now. This will let you view the decoding on screen as soon as there is an acquisition, which helps to begin tuning. You can if you wish wait until all settings are complete to enable the decoder.

   - Select the desired **Protocol** to use. The selections will depend on the software options installed on your instrument.

   - Select the **(Source) Data** to be decoded. This can be any signal input channel (C*x*), memory (M*x*), or math function (F*x*).

3. Optionally, check Link To Trigger **On** to tie the decoder setup to a serial trigger setup.

4. Touch the **Setup** button (next to Search) to open the Decode Setup dialog. If you use this method rather than the tab, your settings will be correctly pre-selected on the Decode Setup dialog.

5. Go on to complete the settings on the right-hand dialogs next to the Decode Setup dialog.
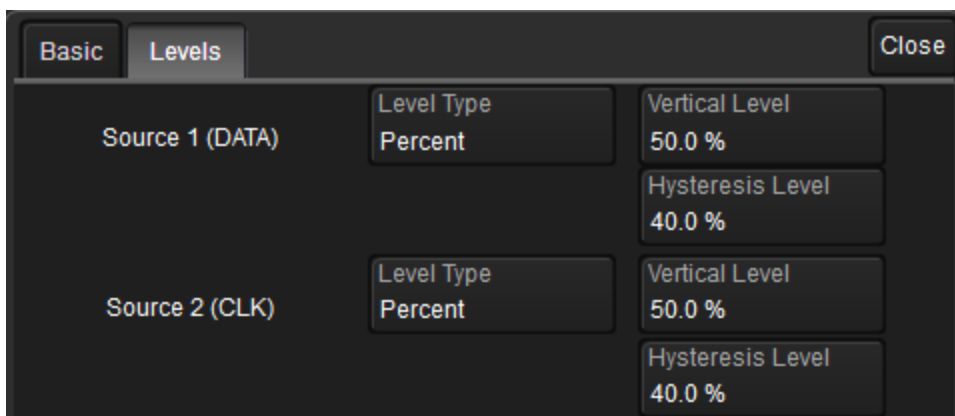
I^{2}C Decoder Settings

Basic Right-Hand Dialog
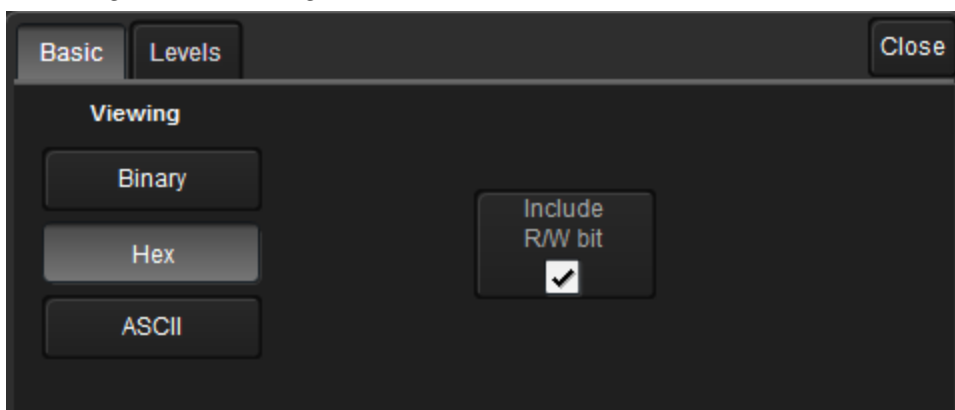
Under **Viewing**, choose to view/enter data in **Binary**, **Hexadecimal**, or **ASCII** formats.

Some engineers consider the address pattern to include the R/W bit (i.e., 8-bits). If your signal utilizes 8-bit addresses, mark **include the R/W bit**.

Levels Right-Hand Dialog

Enter the **Vertical Level** used to determine the edge crossings of the DATA and CLK (Clock) source signals. This value will be used to determine the bit-level decoding. Level is normally set as a Percent of amplitude and defaults to 50%. It can alternatively be set as an absolute voltage by changing the **Level Type** to Absolute. The set Vertical Level appears as a dotted horizontal line across the oscilloscope grid. If your initial decoding indicates that there are a number of error packets, make sure that the level is set to a reasonable value.

NOTE: Data and clock sources can be set to different levels, but they are typically the same level.

Enter a **Hysteresis Level** indicating the amount the signal may rise or fall without affecting bit transition; this helps to compensate for noisy signals. Hysteresis Level must be set in the same manner as you set the Vertical Level: either percent of amplitude or absolute number of grid divisions.

SPI Decoder Settings

SPI/Basic Right-Hand Dialog

For SPI and SPI-DDR decoders, the top right-hand dialog will be named after the protocol. For SIOP, SSPI, and SPI-Custom decoders, this dialog will be named Basic. They are the same except for Chip Select and InterFrame settings.
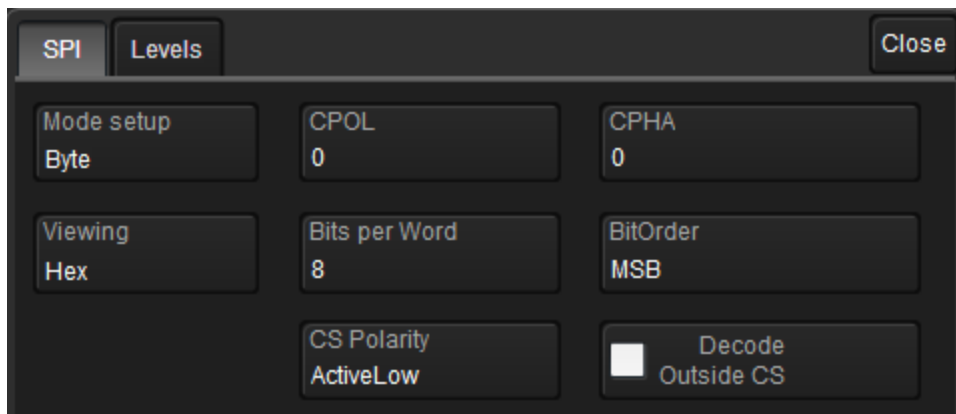
Mode setup - Choose to decode by Byte or Frame.

CPOL (Clock Polarity) and **CPHA** (Clock Phase) - SPI requires that selections be made for the clock polarity and phasing of the data to the clock. SPI microcontrollers and peripherals have settings for CPOL and CPHA that are published in the technical datasheets for those products. Enter those values in this section. SPI Mode 0 = CPOL 0 and CPHA 0. SPI Mode 1 = CPOL 0 and CPHA 1. SPI Mode 2 = CPOL 1 and CPHA 0. SPI Mode 3 = CPOL 1 and CPHA 1.

NOTE: Identical settings for Clock Polarity and Clock Phase are on the SPI serial trigger setup dialog. If you have chosen to link this decoder to the trigger, shared settings are copied from the trigger setup and dynamically updated in both locations.

In **Viewing**, choose to view/enter decoded values in Binary, Hexadecimal, ASCII, or Decimal format.

Bits per Word and **BitOrder** - Enter the number of bits per word and choose from MSB or LSB bit order format.

### SPI AND SPI-DDR VARIATIONS

CS Polarity - Set Chip Select Polarity to either ActiveLow or ActiveHigh.

Decode Outside CS - Check if you want to decode all SPI bytes instead of only those active during the Chip Select.

SIOP AND SPI-CUSTOM VARIATIONS

SIOP, SSPI and SPI-Custom decoders do not use Chip Select. Instead, choose to set the InterFrame period **Auto** (matically) or **Manual**(ly). Auto sets a time that is is (typically) 4x a single bit time and less than the interframe time between different message packets. For a manual setting, enter the **InterFrame Time**.

Levels Right-Hand Dialog
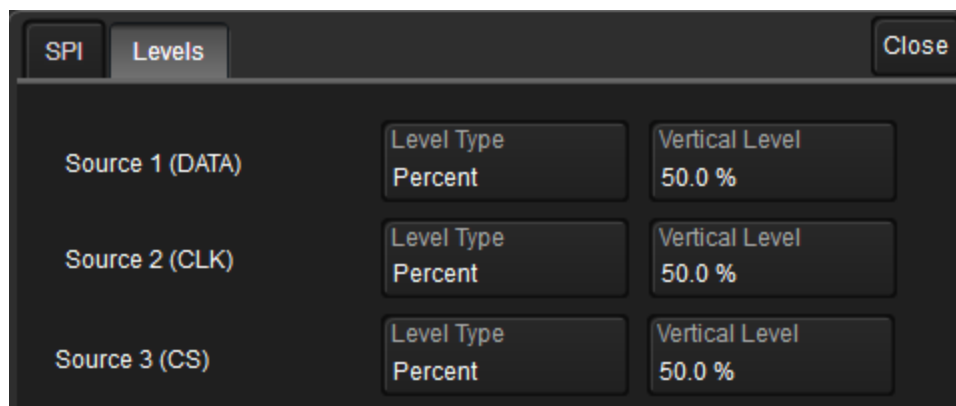
Enter the **Vertical Level** used to determine the edge crossings of the SPI source signals: Data, Clock, and Chip Select (SPI and SPI-DDR decoders only). This value will be used to determine the bit-level decoding. Level is normally set as a Percent of amplitude and defaults to 50%. It can alternatively be set as an absolute number of grid divisions (positive or negative) by changing the **Level Type** to Absolute.

The set Vertical Level appears as a dotted horizontal line across the oscilloscope grid. If your initial decoding indicates that there are a number of error packets, make sure that the level is set to a reasonable value.

UART/RS-232 Decoder Settings

Basic Right-Hand Dialog

Use these controls to define the characteristics of the data signal.
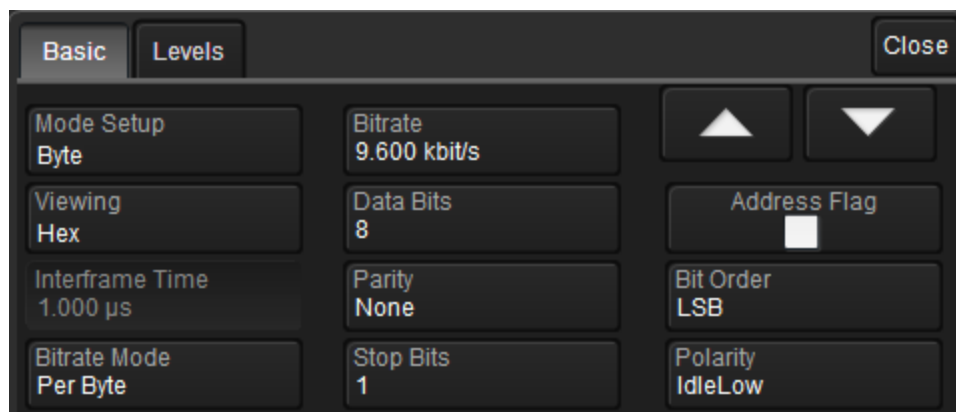
In **Mode Setup**, choose to view the decoding per Byte or per Message frame. The result table will show one Byte or Message per line. If you are using Message mode, also enter the **InterFrame Time** between messages.

In **Viewing**, choose to view/enter values in Binary, Hexadecimal, ASCII, or Decimal format.

Choose a **Bitrate Mode** to determine how the bit rate is calculated:

- Per Byte computes bit rate for each byte separately, then takes the average of those to calculate bit rate of frame. This method of computing bit rate ensures that the gap between each byte is not included in the overall

frame bit rate.

- Per Message computes bit rate using the full length of frame divided by total number of bits.

Enter the **Bitrate** of the bus to which you are connected. If you are not sure about the value, use the Bit Rate measurement parameter to determine the exact bit rate of your signal. The value should be correct within 5%. A mismatched bit rate will cause various confusing side effects on the decoding, so it is best to take time to correctly adjust this fundamental value. Use the arrows to scroll a list of standard bit rates, or touch Bitrate and enter a value.

Enter the number of **Data Bits** per byte (not including the START, STOP, or PARITY bits).

Select the **Parity**. Parity must be Odd or Even to trigger on Parity Error.

Enter the number of **Stop Bits**.

Check **Address Flag** to decode the last bit before the STOP bit to determine if it is an address or data byte.
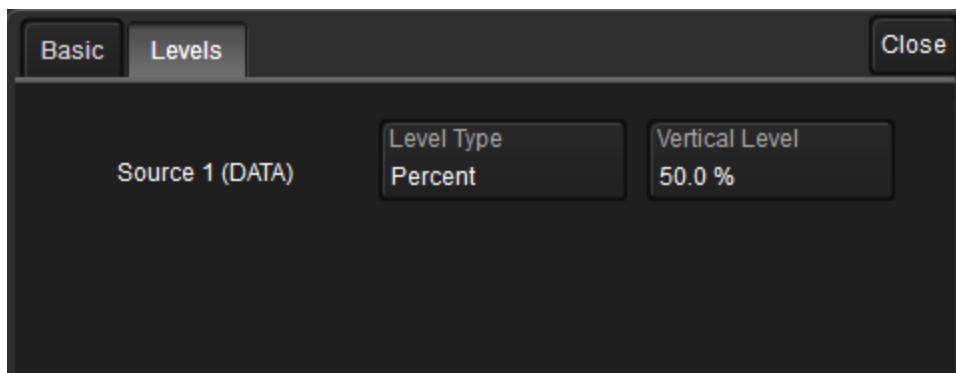
Choose either Most Significant Bit (MSB) or Least Significant Bit (LSB) **Bit Order**.

NOTE: This field defaults to LSB and cannot be changed on an RS-232 trigger.

Select the **Polarity** of the UART signal, either **IdleLow** (Data 1 = High) or **IdleHigh** (Data 1 = Low).

NOTE: This field defaults to IdleLow and cannot be changed on an RS-232 trigger.

Levels Right-Hand Dialog

Enter the **Vertical Level** used to determine the edge crossings of the source signal. This value will be used to determine the bit-level decoding. Level is normally set as a Percent of amplitude and defaults to 50%. It can alternatively be set as an absolute voltage by changing the **Level Type** to Absolute. The set Vertical Level appears as a dotted horizontal line across the oscilloscope grid. If your initial decoding indicates that there are a number of error packets, make sure that the level is set to a reasonable value.

Enabling/Disabling the Decoder

Once set up, the decoders can be enabled simultaneously or separately, although this number may be limited depending on the type of source channels selected. Decoders can be easily disabled without disrupting the configuration.

To enable: press the **Front Panel Serial Decode button** (if available on your oscilloscope) or choose **Analysis > Serial Decode** to open the Serial Decode dialog, then check **Decode On** next to the respective decoder.

If **View Decode** is checked (default) for that decoder on the Decode Setup dialog, a result table and decoded waveform appear. The number of rows of data displayed on each table will depend on the **Table#Rows** setting. The default is one, which can be increased, but doing so will decrease the amount of the screen available to display traces.

To disable: deselect the **Decode On** box individually, or touch **Turn All Off**.

Reading Waveform Annotations

When a decoder is enabled, an annotated waveform appears on the oscilloscope display, allowing you to quickly read the results of the decode. A colored overlay marks significant bit-sequences in the source signal. The overlay contains annotations corresponding to the data itself, control and sync bits, any pre/post-message padding, inter-burst periods, etc. Each set of annotations is customized to the protocol or encoding scheme.

The amount of information shown on an annotation is affected by the width of the rectangles in the overlay, which is determined by the magnification (scale) of the trace and the length of the acquisition. Zooming a portion of the decode trace will reveal the detailed annotations.

TIP: An easy way to zoom is to right-click on a row of the result table and choose Zoom.

I^2C Waveform Annotations

These overlays appear on an I^2C waveform or its Zoom trace to highlight key elements of the decoded signal (not all overlays shown on screen capture):

Annotation	Overlay Color
Packet	Navy Blue (behind other fields)
Start/Stop bits	Grey
R/W bits	Hot Pink
Address	Brick Red
Ack	Olive
Nack	Bright Red
Data (payload) bytes	Aqua Blue
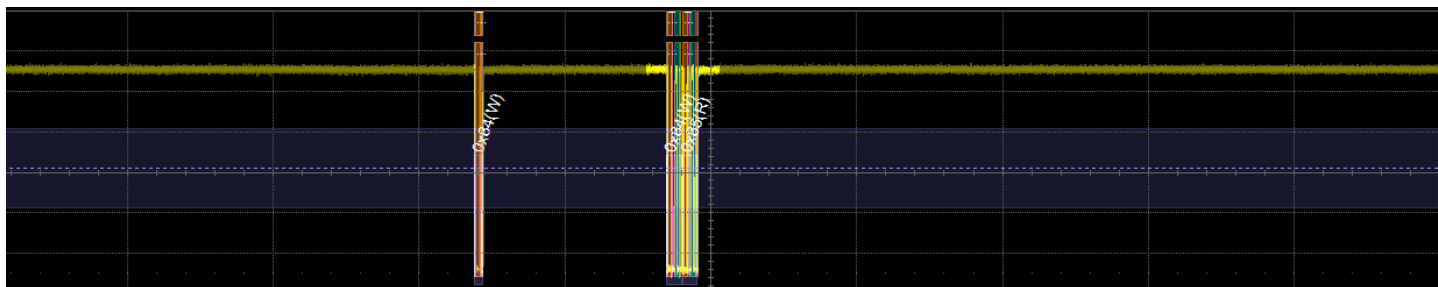
Decoded waveform. At this resolution, little information appears on the overlay.
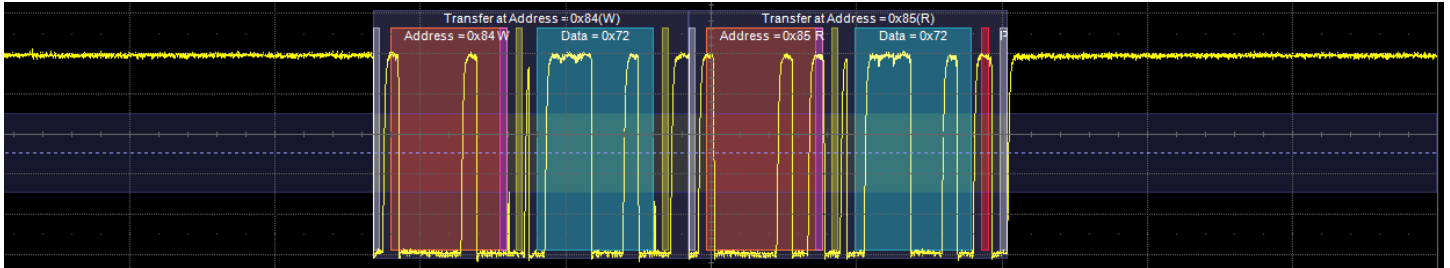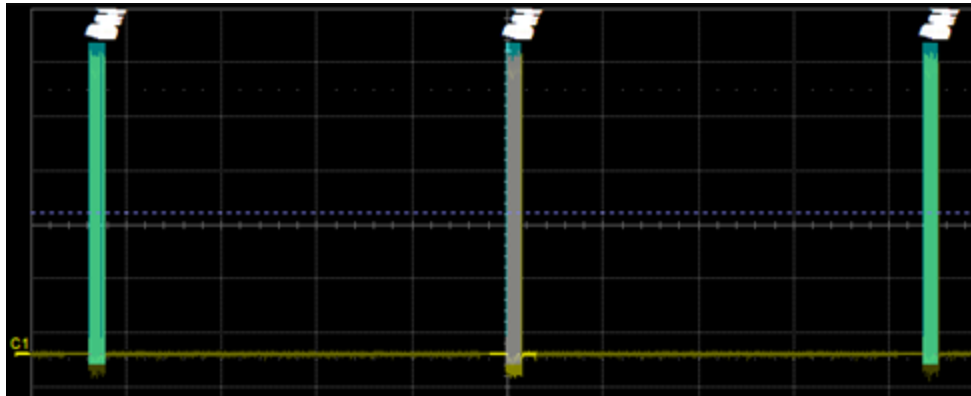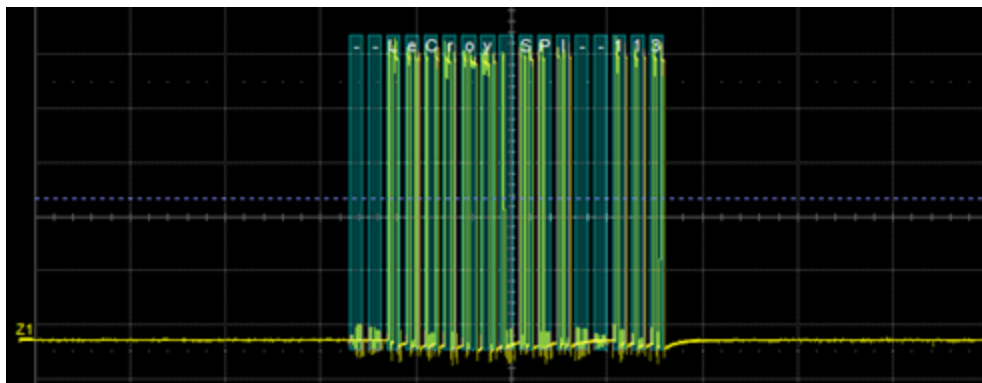
Zoom showing annotation details.

SPI Waveform Annotations

These overlays appear on a SPI waveform or its Zoom trace to highlight data frames of the decoded signal.

Annotation	Overlay Color
Data byte	Green

Decoded SIOP waveform. At this resolution, very little information appears on the overlay.
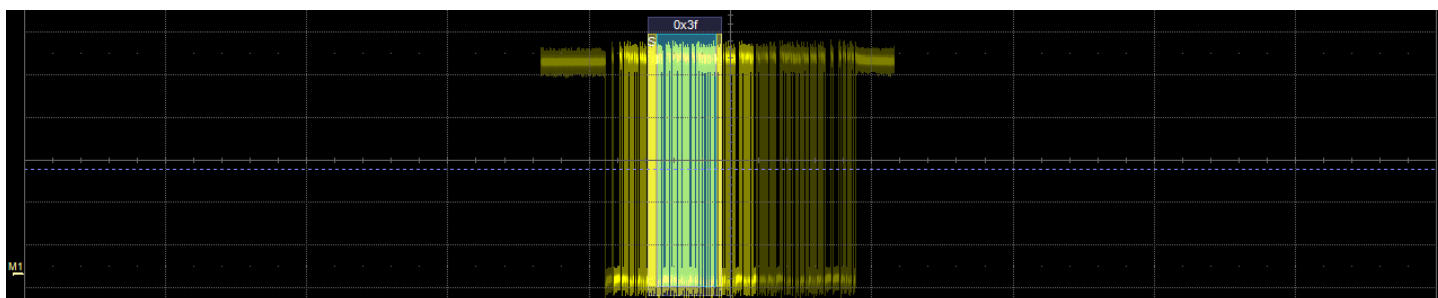

*Zoomed SIOP waveform, showing detailed annotations.*

UART/RS-232 Waveform Annotations

These overlays appear on UART and RS-232 waveforms or their Zoom traces to highlight key elements of the decoded signal.

Annotation	Overlay Color
Byte	Navy Blue (behind other fields)
Start/Stop bits	Olive
Data (payload)	Aqua Blue

Decoded UART waveform. At this resolution, little information appears on the overlay.
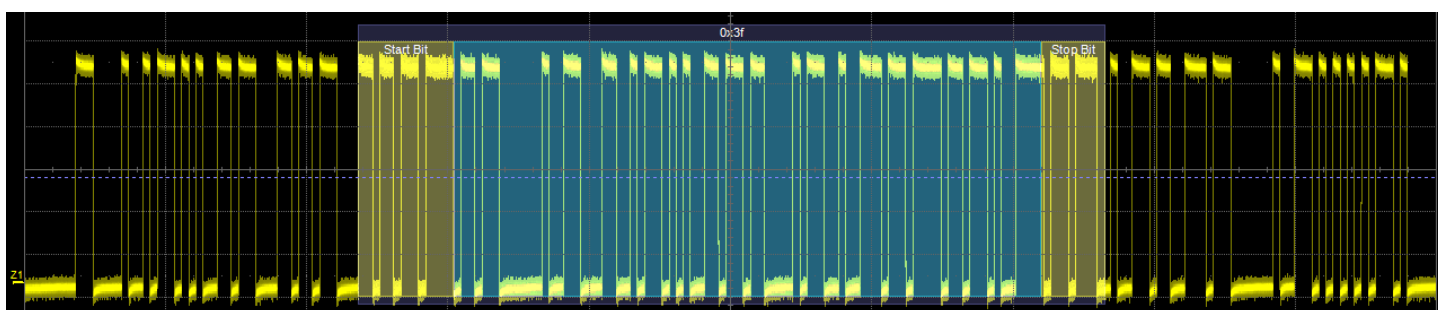
Zoom showing annotation details.

Serial Decode Result Table

By default, a table summarizing the decoder results appears below the grids whenever a decoder is enabled. The result table provides a view of message data as decoded during the most recent acquisition, even when messages are too compact to allow annotation on the waveform trace.

The table is displayed only when the **View Decode** checkbox is marked on the Decode Setup Dialog *and* a source signal has been decoded using that protocol.

You can customize the result table, changing both the number of rows and the columns displayed. The default is one row. On a single-row table, touch the Down arrow at the far right to open a scrollbar that lets you display the previous or next row of data.

You can also export result table data to a .CSV file, and the table itself is useful for navigating and measuring.
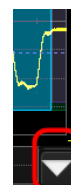
I²C Table Columns

Column	Extracted or Computed Data
Index (always shown)	Number of the line in the table; also number of the message in the annotation overlay on the trace
Time	Time elapsed from start of acquisition to Start of Frame
Address Length	Number of Address field bits, either 7 or 10
Address	Extracted Address field bits, in either binary or hexadecimal
R/W	Extracted Read/Write field bits
Length	Number of Data field bytes
Data	Extracted Data field bytes
Status	List of all I²C errors found in the decode

I2C	Time	Addr Length	Address	R/W	Len...	Data	Status
1	101.666 ms	7	0x84	W	0		
2	104.297 ms	7	0x84	W	1	0x72	
3	104.514 ms	7	0x85	R	1	0x72	

Section of typical I²C decoder result table.

SPI Table Columns

Column	Extracted or Computed Data
Index (always shown)	Number of the line in the table; also number of the message in the annotation overlay on the trace
Time	Time elapsed from start of acquisition to start of message
Data	Extracted data values
Bit Rate/Byte or Bit Rate/Msg	Bit Rate for corresponding byte or message of data, depending on your Mode Setup selection.

SPI-DDR	Time	Data	Bit Rate/Byte
2062	-67.507 µs	0x55	1.249578 Gbit/s
2063	-67.501 µs	0x55	1.252629 Gbit/s
2064	-67.495 µs	0x55	1.252558 Gbit/s
2065	41.906 µs	0x2a	1.354154 Gbit/s

Section of typical SPI result table.

UART/RS-232 Table Columns

Column	Extracted or Computed Data
Index (always shown)	Number of the line in the table; also number of the message in the annotation overlay on the trace
Time	Time elapsed from start of acquisition to start of message
Data	Decoded data payload bytes
Data Length	Data field length
A/D	If the Address flag is checked, this column will show whether the byte is address or payload data.
Parity	Parity bit
Bit Rate	Transmission bit rate per Byte or Message, depending on Mode Setup selection.
Status	Description of all the errors in this message detected by the decoder

Section of typical UART result table.

Customizing the Result Table

Follow these steps to change what data appears in the result table:

1. Press the Front Panel **Serial Decode button** or choose **Analysis > Serial Decode**, then open the **Decode Setup tab**.

2. Touch the **Configure Table** button.

3. On the **View Columns** pop-up dialog, mark the columns you want to appear in the table, clear any columns you wish to remove. Only those columns selected will appear on the oscilloscope display.

   To return to the preset display, touch **Default**.

4. Optionally, set a **BitRate Tolerance** percentage. This will help correct signal jitter while decoding.

5. Touch the **Close** button when finished.

6. Optionally, on the Decode Setup dialog enter the **Table # Rows** to display.

Navigating with the Result Table

Besides displaying the decoded serial data, the result table enables you to quickly Zoom regions of the decoded waveform and control decoder dialogs.

The **first column heading** (top, left-most cell of the table header) bears the name of the corresponding protocol, and the cell's fill color matches the color of the input source. Touching this cell opens the Decode Setup dialog if it has been closed.

Touching the **row number** in the first column opens a Zoom of the corresponding region in the decode trace.

Touching any other **data cell** in the table opens a pop-up menu with several choices of action:

- **Off** turns off the decoder .
- **Zoom** creates a zoom of the region where the data appears (same as touching the row number).
- **Setup** opens the Decoder Setup dialog (same as touching the first column heading).
- **Export** exports the decode results table to a .CSV file.
- **Measure** displays a choice of measurements that can be made on the decoded signal.

Exporting Result Table Data

You can export the decoder result table data to a **.CSV** file.

Export files are by default created in the D:\Applications\<protocol> folder, although you can choose any other folder on the oscilloscope or any external drive connected to a host USB port. The data will overwrite the last export file saved in the protocol directory, unless you enter a new filename.

To export the result table:

1. Press the Front Panel **Serial Decode button**, or choose **Analysis > Serial Decode**, then open the **Decode Setup tab**.
2. Optionally, touch **Browse** and enter a new **File Name** and output folder.
3. Touch the **Export Table** button.

Searching Waveforms

Choosing **Search** on the Decode Setup dialog opens a Zoom of the original decoded waveform and displays the corresponding Zoom dialog with the standard rescaling controls.The default Zoom always presents the found event at the full width of the grid. Use the Zoom dialog to rescale the Zoom to the desired level of magnification.

Enter the search criteria on the Search dialog, then use the navigation buttons to find the previous or next event in the trace that matches the search criteria.

NOTE: If a match is found in an item currently displayed on the result table, that row is highlighted. However, if the item is not already displayed, the Search navigation buttons will not automatically go to that row of the table, although they will navigate the trace. Use the scrollbar at the right of the result table to find the row containing the search result.

I^2C Search Options
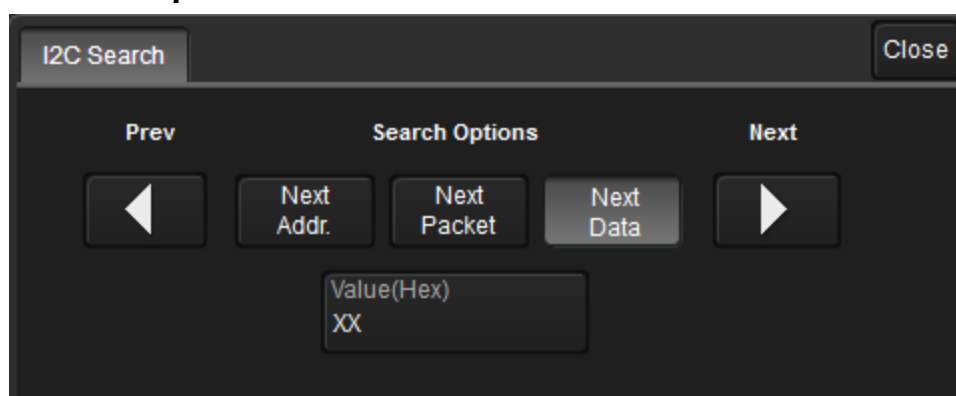
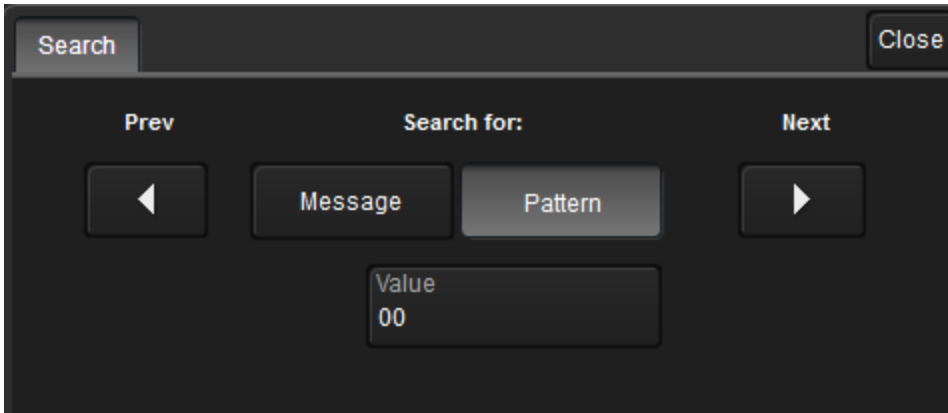Choose to find:

- **Next Address** - beginning of the next message containing the specified Address value. Enter the Address pattern in hexadecimal in the **Value (Hex)** field.

- **Next Packet** - beginning of next I^2C packet

- **Next Data** - next instance of data pattern entered in hexadecimal in the **Value (Hex)** field.

Use the **Prev** and **Next** buttons to view the found occurrences.

SPI Search Options

Choose to:

- Find the start of any **Message**, or
- Find a specific data **Pattern**. Also enter the Hexadecial **Value**of the pattern.

Use the **Prev** and **Next** buttons to view the found occurrences.

UART/RS-232 Search Options
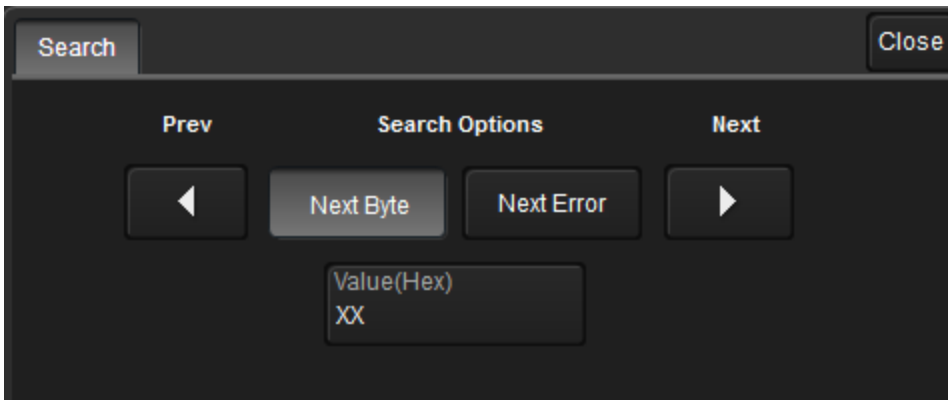
Choose either:

- Beginning of the **Next Byte**. Optionally, enter a specific **Value**(in hexadecimal) for which to search.
- **Next Error**

Use the **Prev** and **Next** buttons to view the found occurrences.

Measuring

If you have installed PROTObus MAG, these general measurements designed for debugging serial data streams can be applied to the decoded waveform. Measurements appear in a tabular readout below the grid (the same as for any other measurements) and are in addition to the result table that shows the decoded data. You can set up as many measurements as your oscilloscope has parameter locations.

NOTE: Depending on the protocol, measurements may appear in a sub-menu of the Measure Setup menu, and may have slightly different names. For example, the CAN sub-menu has measurements for CANtoValue instead of Message to Value, etc. The measurements are the same.

Measurement	Description
View Serial Encoded Data as Analog Waveform	Automatically sets up a Message to Value parameter and then tracks the assigned measurement. In doing so, a Digital-to-Analog Conversion (DAC) of the embedded digital data is performed and the digital data is displayed as an analog waveform.
Message to Value	Extracts and converts a specific portion of the data/payload in the message and displays it as an analog value.
MsgToAnalog (Message to Analog)	Computes time from start of first message that meets conditions to crossing threshold on an analog signal. Result is negative if analog event precedes message. You must choose the digital input in Source1 and the analog input in Source 2 for this measurement to work properly.
AnalogToMsg (Analog to Message)	Computes time from crossing threshold on an analog signal to start of first message that meets conditions. Result is negative if message precedes analog event. You must choose the analog input in Source 1 and the digital input in Source 2 for this measurement to work properly.
MsgToMsg (Message to Message)	Computes time difference from start of first message that meets conditions to start of next message.
DeltaMsg (Delta Message)	Computes time difference between two messages on a single decoded line.
Time@Msg (Time at Message)	Computes time from trigger to start of each message that meets conditions.
BusLoad	Computes the load of user-defined messages on the bus (as a percent).
MsgBitrate	Computes the bitrate of user-specified messages on decoded traces.
NumMessages (Number of Messages)	Computes the total number of messages in the decoding that meet conditions.

Graphing Measurements

Measure and graph options include simplified methods for plotting measurement values as:

- **Histogram** - a bar chart of the number of data points that fall into statistically significant intervals or bins. Bar height relates to the frequency at which data points fall into each interval/bin. Histogram is helpful to understand the modality of a parameter and to debug excessive variation.

- **Trend** - a plot of the evolution of a parameter over time. The graph's vertical axis is the value of the parameter; its horizontal axis is the order in which the values were acquired. Trending data can be accumulated over many acquisitions. It is analogous to a chart recorder.

- **Track** - a time-correlated accumulation of values for a single acquisition. Tracks are time synchronous and clear with each new acquisition. Track can be used to plot data values and compare them to a corresponding analog signal, or to observe changes in timing. A parameter tracked over a long acquisition could provide information about the modulation of the parameter.

To graph a measurement, just select the plot type from the Measure/Graph dialog when setting up the measurement.

All plots are created as Math functions, so also select a function location (Fx) in which to draw the plot. The plot will open along side the deocoding in a separate grid.

Using the Measure/Graph Dialog

The Measure/Graph dialog, which appears behind the Decode Setup dialog when measurements are supported, is a quick way to apply parameters specifically designed for serial data measurement and simultaneously graph the results.
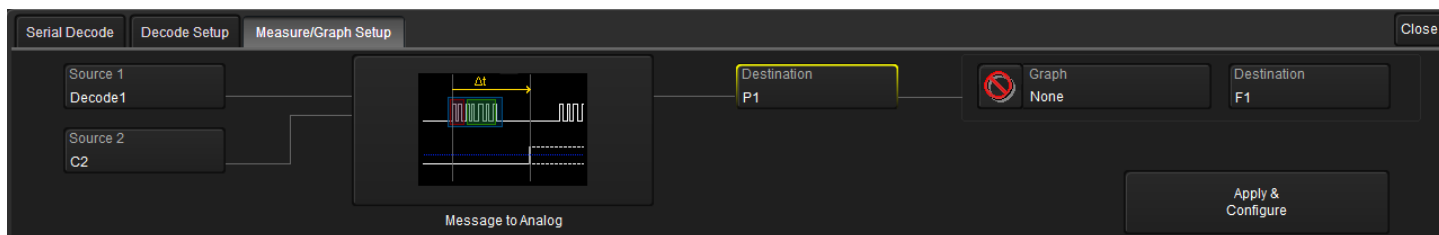
1. Select the **Measurement** to apply and the **Destination** parameter location (Px) in which to open it.

2. The **Source 1** decode is preselected; change it if necessary. If the measurement requires it, also select Source 2.

3. Optionally, choose a **Graph** format and the **Destination** math function location (Fx) in which to open it.

4. Optionally, set a measurement gate or filter. Touch **Apply & Configure** and make all required settings on the Measure right-hand dialogs that appear.

NOTE: The Serial Decode measurements are also available from the main Measure setup menu. You can use the standard Measure functionality to set up as many measurements as your oscilloscope has parameter locations.

Using the Result Table

To quickly apply serial data measurements when the serial data setup dialogs are closed:

1. Touch any **data cell** of the decode result table.

2. From the pop-up menu, select **Measure** to display the Select Operation... dialog.

3. Touch any measurement operation to select it.

4. On the next dialog, choose a **parameter** location (P1-Px) in which to run the measurement.

5. To [filter or gate the parameter](#), touch the Px cell of the readout table and make the desired settings on the right-hand dialogs that appear.

Using the Decode Setup Dialog

You can also access serial data measurements by touching the **Measure button** on the Decode Setup dialog. Follow Steps 3 to 5 above to set up the measurements. Measurements are set on the source of whichever Decoder (1-4) is currently selected on the Decode Setup dialog.

Filtering Serial Decode Measurements

After applying a measurement to the decoded waveform on the Measure/Graph dialog, set filter conditions on the right-hand dialogs that appear next to the P*x* dialogs.
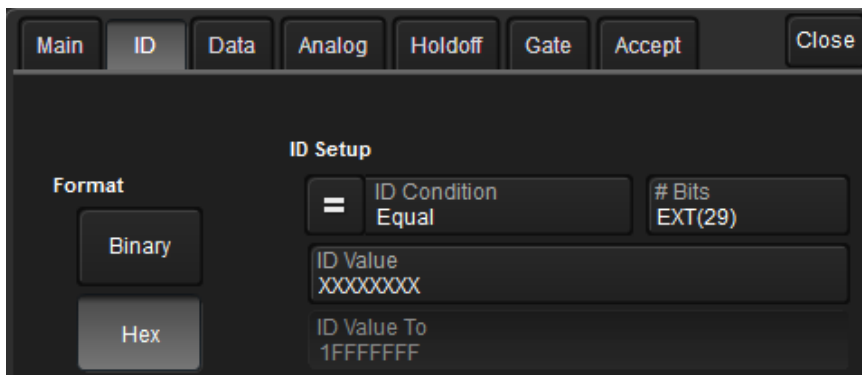
NOTE: Not all measurements support all filter types.
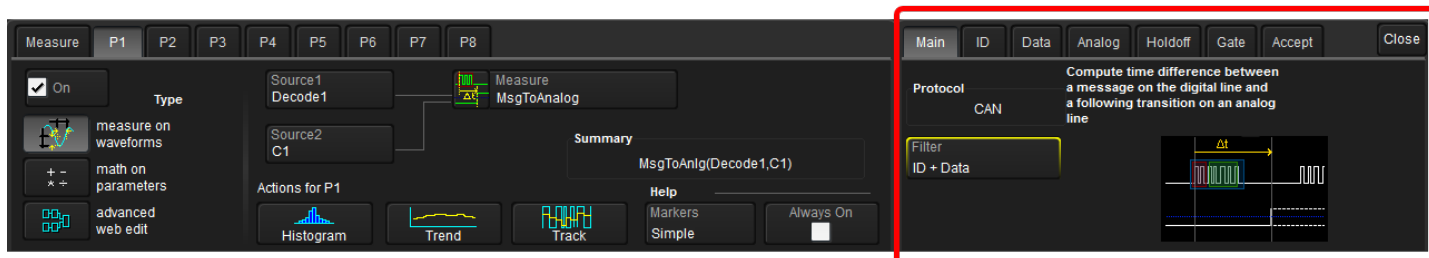
Frame ID Filter

This filter restricts the measurement to only frames with a specific ID value.

1. On the Main dialog, in **Filter** choose ID or ID+Data.

2. Open the **ID tab** that appears.

3. Choose to enter the frame ID value in **Binary** or **Hex**(adecimal) format.

4. Using the **ID Condition** and **ID Value** controls, create a condition statement that describes the IDs you want included in the measurement. To set a range of values, also enter the **ID Value To**. On the pop-up dialog that appears when you touch ID Value:

    - Use the Left and Right arrows to position the cursor.

    - Use Back to clear the previous character (like Backspace), Use Clear to clear all characters.

Data Filter

This restricts measurements to only frames containing extracted data that matches the filter condition. It can be combined with a Frame ID filter by choosing ID+Data on the Main dialog.

Use the same procedure as above to create a condition describing the **Data Value(s)** to include in the measurement. Use "X" as a wild card ("Don't Care") in any position where the value doesn't matter.

Optionally, enter a **Start Position**within the data field byte to begin seeking the pattern, and the **# Bits** in the data pattern. The remaining data fields positions will autofill with "X".

NOTE: For MsgtoMsg measurements, the data condition is entered twice: first for the Start Message and then for the End Message. The measurement computes the time to find a match to each set of conditions.
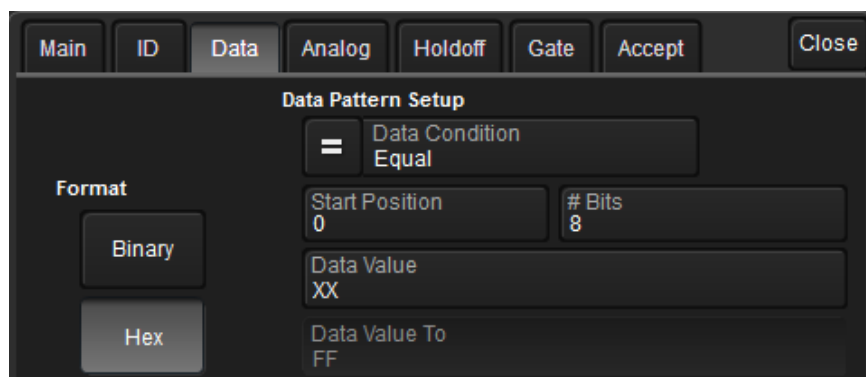
Analog Filter

This filter applies only to parameters that measure the decoded waveform relative to an analog signal: AnalogtoMsg and MsgtoAnalog. It allows you to set the crossing level and slope of the Analog signal event that is to be used in the measurement. Level may be set as a percentage of amplitude (default), or as an absolute voltage level by changing Level Is to Absolute. You can also use Find Level to allow the oscilloscope to set the level to the signal mean.
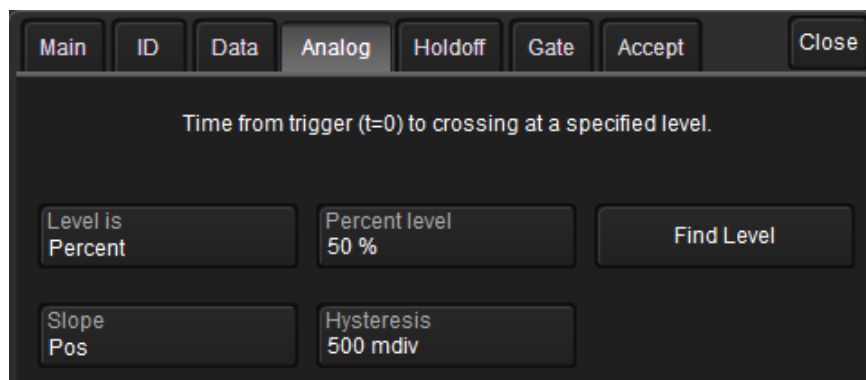
The optional Hysteresis setting imposes a limit above and below the measurement Level, which precludes measurements of noise or other perturbations within this band. The width of the band is specified in milli-divisions.

Observe the following when using Hysteresis:

- Hysteresis must be larger than the maximum noise spike you wish to ignore.

- The largest usable hysteresis value must be less than the distance from the Level to the closest extreme value of the waveform.

Value Conversion Filter

This filter applies only to the MsgtoValue parameter. It enables you to apply a value conversion to extracted data. The converted values appear in the result table.

1. Under Data to Extract, begin by entering the **Start position** and the **# Bits** to extract.

2. Choose the **Encoding** type if the signal uses encoding, otherwise leave it Unsigned.

3. Under Conversion, enter the **a. Coefficient** and **b. Term** that satisfy the formula:
   *Value = Coefficient * Raw Value + Term*.

4. Optionally, enter a **Unit** for the extracted decimal value.

Holdoff, Gate, and Accept

Certain measurements support holdoff, gating, or additional qualifiers (Accept). You will see the tab appear among the Measure set up dialogs when the function is supported. When applied to serial data measurement, these functions work exactly as they do elsewhere in the oscilloscope:

- **Holdoff** specifies the amount of time or number of events to wait before starting the measurement.

- **Gate** specifies the Start Div and Stop Div that bound the portion of the acquisition to include in the measurement.

- **Accept** allows you to set qualifiers based on waveform state, either the measurement source or a second "gating" waveform, or to only accept measurement values that fall within pre-defined ranges.

See the oscilloscope *Operator's Manual* or *Getting Started Manual* for more information.

Triggering

Serial Trigger Technical Overview

TD options provide advanced serial data triggering in addition to decoding. Serial data triggering is implemented directly within the hardware of the oscilloscope acquisition system. The serial data trigger scrutinises the data stream in real time to recognise "on-the-fly" the user-defined serial data conditions. When the desired pattern is recognised, the oscilloscope takes a real-time acquisition of all input signals as configured in the instrument's acquisition settings. This allows decode and analysis of the signal being triggered on, as well as concomittant data streams and analog signals.

The serial trigger supports fairly simple conditions, such as "trigger at the begining of any packet," but the conditions can be made more restrictive depending on the protocol and the available filters.

The trigger and decode systems are independant, although they are seamlessly coordinated in the user interface and the architecture. It is therefore possible to trigger without decoding and decode without triggering.

Requirements

Serial trigger options require the appropriate hardware (please consult support), an installed option key, and the latest firmware release.

Restrictions

The serial trigger only operates on one protocol at a time. It is therefore imposible to express a condition such as "trigger on I2C frames with ID = 0x456 followed by UART packet with Adress 0xEBC."

The serial trigger system operates on streams whose bit rate does not exceed one-fifth (1/5) the sample rate.

Linking Trigger to Decoder

A quick way to set up a serial trigger is to link it to a decoder by checking the **Link to Trigger On** box on the Serial Decode dialog. Linking decoder to trigger allows you to configure the trigger with the exact same values that are used for decodiing the signal (in particular the bit rate), saving the extra effort needed to re-enter values on the serial trigger set up dialogs.

While the decoder and the trigger have distincts sets of controls, when the link is active, a change to the bit rate in the decoder will immediately propagate to the trigger and vice-versa.

I²C Trigger Setup

If you have not linked the trigger to a pre-set decoder, or if you wish to further refine it, you can enter the trigger criteria manually. Access the serial trigger dialog:

- Touch the Trigger descriptor box or choose **Trigger > Trigger Setup** from the Menu Bar.
- Touch the **Serial** Type button, and the **I²C** Standard button.

Then, working from left to right, make the desired selections from the Trigger dialog.

NOTE: If you do not see the Serial Trigger buttons, it may be because you have activated only -D and not -TD options. Go to Utilities > Status > Options to check the installed options.
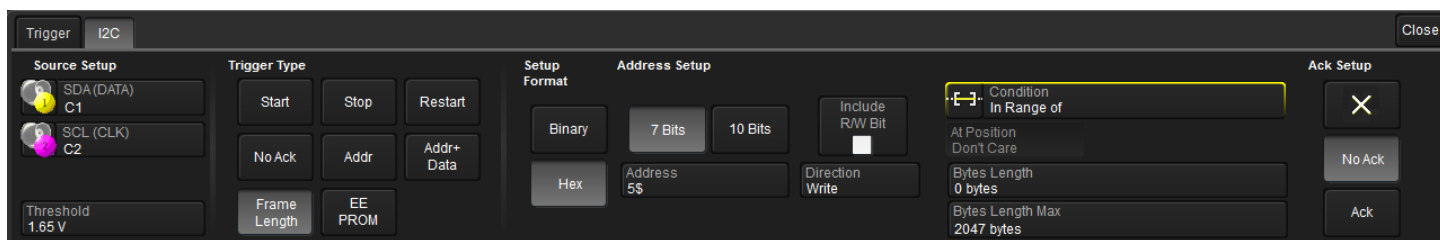
Source Setup

In **DATA**, select the data source input channel.

In **CLK**, select the clock source input channel.

Use the **Threshold** control to adjust the vertical level for the trigger. Much like an Edge trigger, you must specify the level at which to process the incoming signal to determine whether the serial data pattern is meeting the set trigger condition. This value is used for both data and clock signals.

Trigger Type

These buttons determine which frames/fields are included in the trigger search and which controls are activated on the Trigger setup dialog.

Start triggers upon finding the next Start Frame.

Stop triggers upon finding the next Stop Frame.

Restart triggers upon finding the next Restart.

No Ack triggers upon finding the next packet with no ACK field value.

Address triggers upon finding the next packet containing the specified address. Complete the Address Setup and Ack Setup fields described below.

Address+Data triggers upon finding matching Address field values *and* data patterns. Complete Address Setup, Data Pattern Setup, and Ack Setup fields described below.

Frame Length triggers upon finding packets that satisfy the frame length conditions. Complete the Condition and ByteLength fields under Data Pattern Setup.

EEPROM triggers upon finding matching EEPROM data patterns. Complete Data Pattern Setup and Ack Setup fields described below.

Setup Format

Choose to display/enter values in **Binary** or **Hex**(adecimal) format. The selection propagates throughout the entire I^{2}C trigger setup. Toggling between formats does not result in loss of information, but will transform the appearance of values.

Address Setup

Choose whether the signal utilizes a **7-bit** or **10-bit** Address length.

Mark **Include R/W bit** if the Read/Write bit is included in the address value (i.e., 8-bit Address values).

Enter the **Address Value**. To use wildcards ("Don't Care" values) in any bit or nibble position, enter an X.

NOTE: When Hex values are converted to Binary, any non-nibble length wildcards are shown as $.

Choose a **Direction** of Read, Write, or Don't Care for the Address value.

NOTE: Address values are always MSB format.

Data Pattern Setup

Create a condition statement that describes the Data field pattern upon which to trigger. This condition is added to the Address condition.

Use **Data Condition** (Boolean operator) and **Data Value** together to specify the data patern upon which to fire the trigger. If less than 12 bytes of data is entered in Data Value, the data is assumed to begin at the 0 (i.e., first) data byte in the I^{2}C message. If this is not desired, then add preceding or trailing wildcard (X) nibbles to the pattern. To use a range of values, choose In Range or Out Range.

When setting a range, enter the start value in Data Value and the stop value in **Data Value To**.

NOTE: When more than one byte of data is entered as a data value, the data is treated as Most Significant Byte (MSB) First. In Hexadecimal format, data must be entered as full bytes even though the minimum required acceptable entry is a nibble. If less than a full byte is entered, then wildcards (XX) precede the pattern values entered.

Use **At Pos.** and **Byte Pos.** together to mark a specific position in the Data field the matching Data Value must occupy. You can select any position in an up-to-2048 byte data pattern, starting with Byte 0 (the first data byte).

Length defaults to the length, in bytes, of the pattern set in Data Value. If the length is changed to a lesser value, it truncates the beginning of the value. If the length is increased, wildcards (XX) are appended to the beginning of the value.

NOTE: This field appears as Bytes Length when using a Frame Length trigger, in which case you must manually specify a length from 0 (first byte only) to 2047 bytes, and also the **Bytes Length Max** of up to 2047 bytes if you are setting a range.

Ack Setup

Choose whether to add an Acknowledge bit condition to the other trigger conditions: **X** (Don't Care), **No Ack** or **Ack**.

SPI Trigger Setup

If you have not linked the trigger to a pre-set decoder, or if you wish to further refine it, you can enter the trigger criteria manually. Access the serial trigger dialog:

- Touch the Trigger descriptor box or choose **Trigger > Trigger Setup** from the Menu Bar.

- Touch the **Serial** Type button, and the SPI Standard buttons:

Then, working from left to right, make the desired selections from the Trigger dialog.
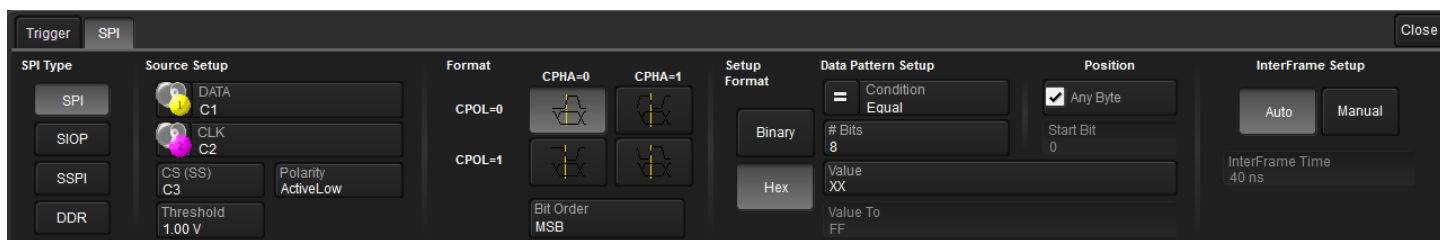
SPI Type

Choose the type of SPI encoding used on the input signal: **SPI**, **SIOP** , **SPI-DDR**, or **SSPI**.

Source Setup

In **DATA**, select the data source input channel.

In **CLK** (Clock), select the clock source input channel.

For SPI and SPI-DDR signals, enter the **CS (Chip Select)** input channel and **Polarity**.

Use the **Threshold** control to adjust the vertical level for the trigger. Much like an Edge trigger, you must specify the level at which to process the incoming signal to determine whether the serial data pattern is meeting the set trigger condition. This threshold is used for all input channels.

Format

For SPI and SIOP signals, choose the **CPOL** (Clock Polarity) and **CPHA** (Clock Phase), the phasing of the data to the clock. SPI microcontrollers and peripherals have settings for CPOL and CPHA that are published in the technical datasheets for those products. Choose the button containing the graphic that corresponds with your needs: SPI Mode 0 = CPOL 0 and CPHA 0. SPI Mode 1 = CPOL 0 and CPHA 1. SPI Mode 2 = CPOL 1 and CPHA 0. SPI Mode 3 = CPOL 1 and CPHA 1.

NOTE: There is only one option for SSPI signals. These settins are not used by SPI-DDR.

Choose either MSB or LSB **Bit Order** format.

Setup Format

Setup format determines how you will view/enter the data pattern trigger criteria. Choose either **Binary** or **Hex** (adecimal) format.

Data Pattern Setup

Use **Condition** and **Value** together to describe the data pattern upon which to trigger. All values that meet the criteria will fire the trigger. Up to 12 bytes (96 bits) of data can be entered in Value. If using ranges, also enter the **To Value**.

In **# Bits**, enter the total bits in the trigger pattern (regardless of the data field length in the signal). If the Value entry is shorter than #Bits, it will be padded to this total number using "don't care" characters ("X" if the trigger condition is = or Not =, "O" otherwise).

Position

Check **Any Byte** to begin searching for the data pattern at any point in the message.

Otherwise, clear Any Byte and enter the **Start Bit** to begin searching for the pattern.

InterFrame Setup

InterFrame Setup is used to determine the position of data in SPI packets. Since packets can include several words, and sometimes a signal is encoded over several words, it's important to establish a bit numbering scheme with a 0 point where counting begins.

Choose **Auto** or **Manual** mode. Manual enables the **InterFrame Time** field where you can provide a specific value. Auto mode sets the InterFrame time to four times the length of a bit.

In Manual mode, the time between each bit reading transition on the CLK signal is read. Inside a word, this time is equal to the length of a bit. At the end of a word, the time until the next transition can be bigger than a bit length. This specific time separation length (i.e., InterFrame Time) defines how the bits are numbered. When the read InterFrame Time is greater than the one you provided, the bit counter is reset to 0 (as shown in the following image).
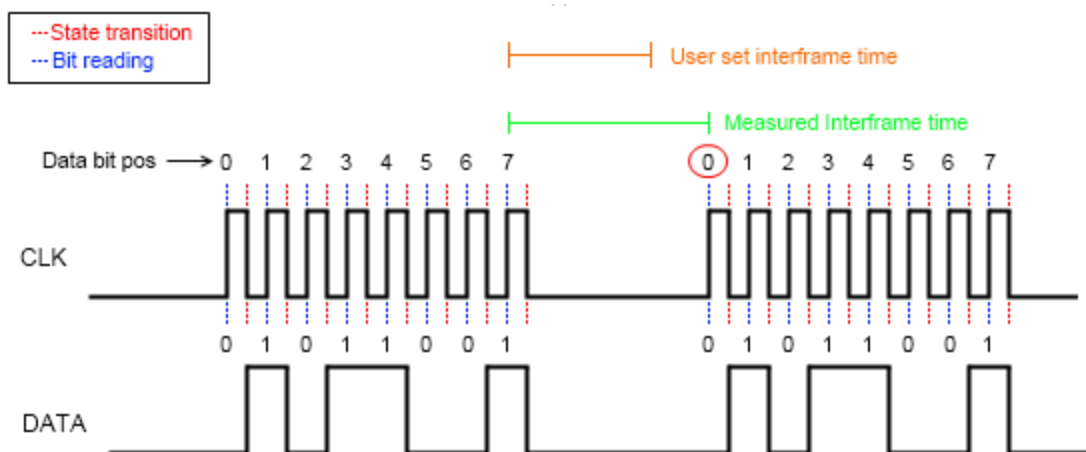
When the read InterFrame Time is smaller than the one you provided, subsequent bits are considered part of the same packet and continue to accrue sequentially.
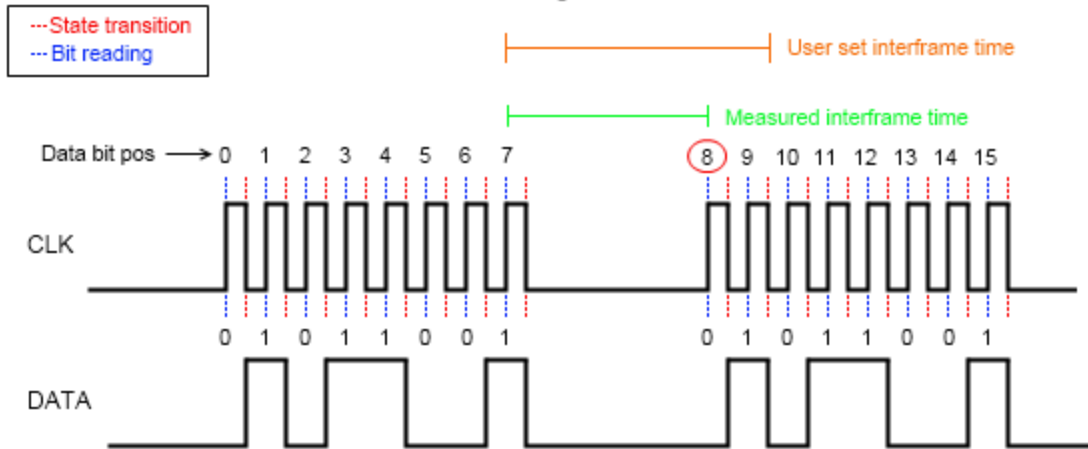

UART/RS-232 Trigger Setup

If you have not linked the trigger to a pre-set decoder, or if you wish to further refine it, you can enter the trigger criteria manually. Access the serial trigger dialog:

- Touch the Trigger descriptor box or choose **Trigger > Trigger Setup** from the Menu Bar.

- Touch the **Serial** Type button, and the **UART** or **RS-232** Standard button.

Then, working from left to right, make the desired selections from the Trigger dialog.

NOTE: If you do not see the Serial Trigger buttons, it may be because you have activated only -D and not -TD options. Go to Utilities > Status > Options to check the installed options.
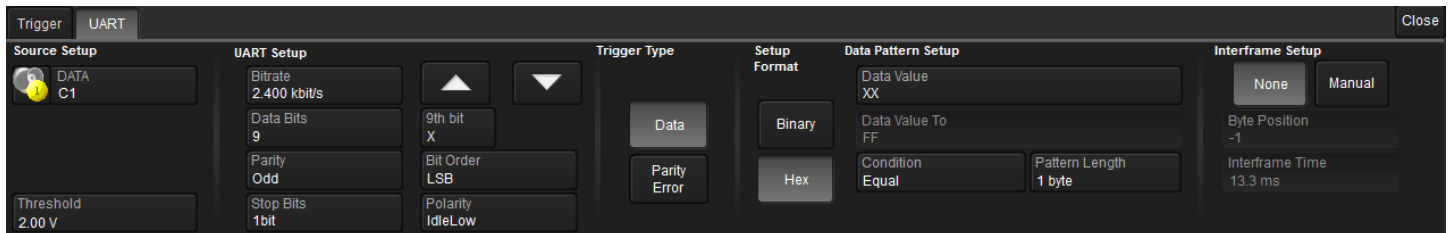
Source Setup

In **DATA**, select the data source input channel.

Use the **Threshold** control to adjust the vertical level for the trigger. Much like an Edge trigger, you must specify the level at which to process the incoming signal to determine whether the serial data pattern is meeting the set trigger condition.

UART/RS-232 Setup

Use these controls to define the characteristics of the data signal.

Enter the **Bitrate** of the bus to which you are connected. This bitrate selection is dynamically linked to the decoding bitrate (they are always the same value). Use the arrows to scroll a list of standard bit rates, or touch Bitrate and enter a value.

Enter the number of **Data Bits** per byte (not including the START, STOP, or PARITY bits). To trigger on UART messages with a 9th DATA bit used as an Alert, enter 9 in Data Bits, then specify whether the 9th **Alert** bit is a 0, 1, or X (don't care).

Select the **Parity**. Parity must be Odd or Even to trigger on Parity Error.

Enter the number of **Stop Bits**.

Choose either Most Significant Bit (MSB) or Least Significant Bit (LSB) **Bit Order**.

NOTE: This field defaults to LSB and cannot be changed on an RS-232 trigger.

Select the **Polarity** of the UART signal, either **IdleLow** (Data 1 = High) or **IdleHigh** (Data 1 = Low).

NOTE: This field defaults to IdleLow and cannot be changed on an RS-232 trigger.

Trigger Type

Choose to trigger on a user-defined **Data** pattern or a **Parity Error**.

Setup Format

Choose to display/enter data values in **Binary** or **Hex**(adecimal) format. The selection propagates throughout the entire trigger setup. Toggling between formats does not result in loss of information, but will transform the appearance of values.

Data Pattern

Use **Data Condition** and **Data Value** together to describe the Data field pattern upon which to trigger. To use a range of values, choose In Range or Out Range. When using a range, also enter the **Data Value To**.

Enter the data **Pattern Length**. This value defaults to the length, in bytes, of the Data Value entry. If the length is changed to a lesser value, it truncates the beginning of the value. If the length is increased, "don't care" bytes are appended to the beginning of the data pattern.

InterFrame Setup

InterFrame Setup is used to define the position of data in UART/RS-232 packets. Choose **None** or **Manual** mode. Manual enables the **Byte Position** and **InterFrame Time** fields for you to enter the values.

Using the Decoder with the Trigger

A key feature of Teledyne LeCroy trigger and decode options is the integration of the decoder functionality with the trigger. While you may not be interested in the decoded data per se, using the decoded waveform can help with understanding and tuning the trigger.

Stop and Look

Decoding with repetitive triggers can be very dynamic. Stop the acquisition and use the decoder tools such as Search, or oscilloscope tools such as TriggerScan, to view events of interest. Touch and drag the paused trace to show time pre- or post-trigger.

Optimize the Grid

The initial decoding may be very compressed and impossible to read. Try the following:

- Increase the height of the trace by *decreasing* the gain setting (V/Div) of the source channel. This causes the trace to occupy more of the available grid.

- Change your Display settings to turn off unnecessary grids. The Auto Grid feature automatically closes unused grids. On many oscilloscopes, you can manually move traces to consolidate grids.

- Close setup dialogs.

Use Zoom

The default trigger point is at zero (center), marked by a small triangle of the same color as the input channel at the bottom of the grid. Zoom small areas around the trigger point. The zoom will automatically expand to fit the width of the screen on a new grid. This will help to see that your trigger is occurring on the bits you specified.

If you drag a trace too far left or right of the trigger point, the message decoding may disappear from the grid. You can prevent "losing" the decode by creating a zoom of whatever portion of the decode interests you. The zoom trace will not disappear when dragged and will show much more detail.

Saving Trigger Data

The message decoding and the result table are dynamic and will continue to change as long as there are new trigger events. As there may be many trigger events in long acquisitions or repetitive waveforms, it can be difficult to actually read the results on screen unless you stop the acquisition. You can preserve data concurrent with the trigger by using the **AutoSave** feature.

- AutoSave waveform creates a .trc file that copies the waveform at each trigger point. These files can be recalled to the oscilloscope for later viewing. Choose **File > Save Waveform** and an Auto Save setting of **Wrap** (overwrite when drive full) or **Fill** (stop when drive full). The files are saved in D:\Waveforms.

- AutoSave table creates a .csv file of the result table data at each trigger point. Choose **File > Save Table** and an Auto Save setting of **Wrap** or **Fill**. The files are saved in D:\Tables.

⚠ **CAUTION.** If you have frequent triggers, it is possible you will eventually run out of hard drive space. Choose Wrap only if you're not concerned about files persisting on the instrument. If you choose Fill, plan to periodically delete or move files out of the directory.

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