Validating MIPI C-PHY Bus Activity with TekScope™ PC Analysis Software

APPLICATION NOTE

Tektronix®

Introduction

MIPI C-PHY℠ communicates over a C-PHY link, and provides a PHY for the Camera Serial Interface and MIPI Display Interface suitable for mobile camera and display applications.

Demand for increasingly higher image resolutions is pushing the bandwidth capacity of existing host processor-to-camera sensor interfaces.

MIPI C-PHY can be used for low-resolution image sensors to sensors offering up to 60 megapixels, as well as display panels offering 4K and higher resolution.

The C-PHY was designed to coexist on the same IC pins as D-PHY so that dual-mode devices could be developed with low power signaling similar to DPHY. This CPHY-DPHY combination provides a 3 channel C-PHY

C–PHY Technology Overview

MIPI C-PHY accomplishes this by departing from a conventional differential signaling technique on two-wire lanes and introducing three-phase symbol encoding of about 2.28 bits/symbol, to transmit data symbols on three-wire lanes, or "trios," where each trio includes an embedded clock.

This is different from the two-wire differential "lane" used in D-PHY. C-PHY uses 3-phase symbol encoding of about 2.28 bits per symbol on a trio.

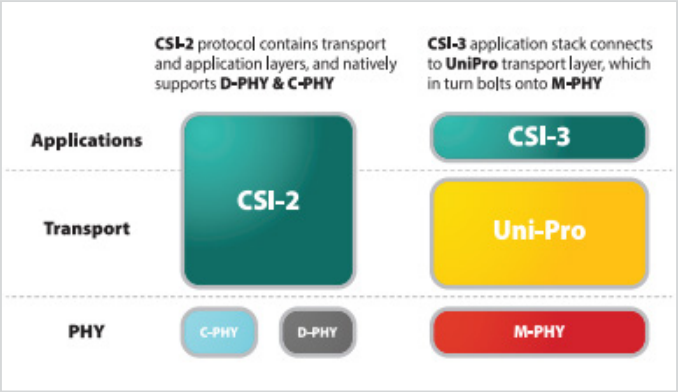
A C-PHY TX lane is composed of a trio, A, B, and C; uses encoded data to pack 16/7 ≈ 2.28 bits/symbol and operating at 2.5 Gsps; and provides an equivalent of 5.7 Gbps per lane. C-PHY v2.0, a trio operating at the rate of 8 Gsym, provides 18.1 Gbps per lane.

The receiver is made of 3 differential RX's, each one looking at the difference between 2 of the 3 signals, (A-B), (B-C), and (C-A).

THIS APPLICATION NOTE

- Gives a brief overview the physical layer and packet structures of C-PHY with the goal of providing just enough detail to help with troubleshooting
- Explains how to set up decoding on an offline Tektronix oscilloscope equipped with C-PHY decoding
- Explains how to interpret serial bus data on an oscilloscope equipped with C-PHY decoding
- Explains what searching options are available on an oscilloscope equipped with C-PHY decoding

With the optional serial analysis capability, Tektronix oscilloscopes and Tek scope offline become powerful tools for embedded system designers working with C-PHY buses. In this application note, TekScope Offline is used to demonstrate-PHY analysis. See Serial Support Using Oscilloscopes and Optional Software for a complete listing.



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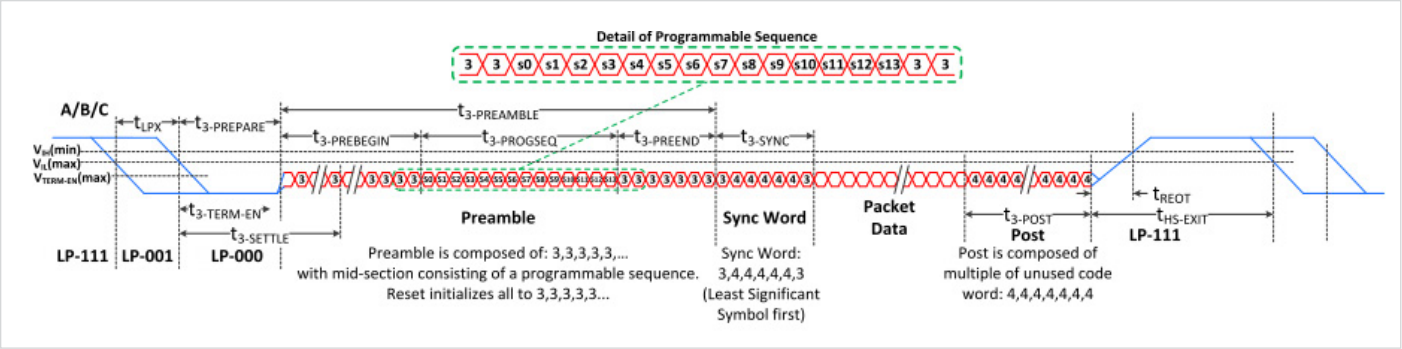
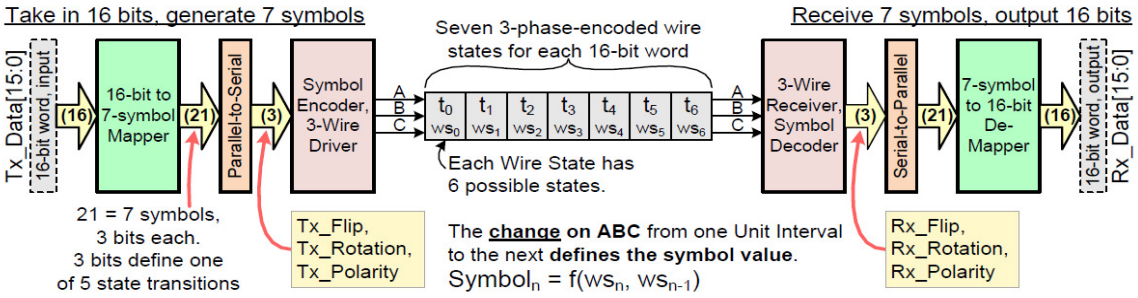


Source: MIPI Alliance/June 2021

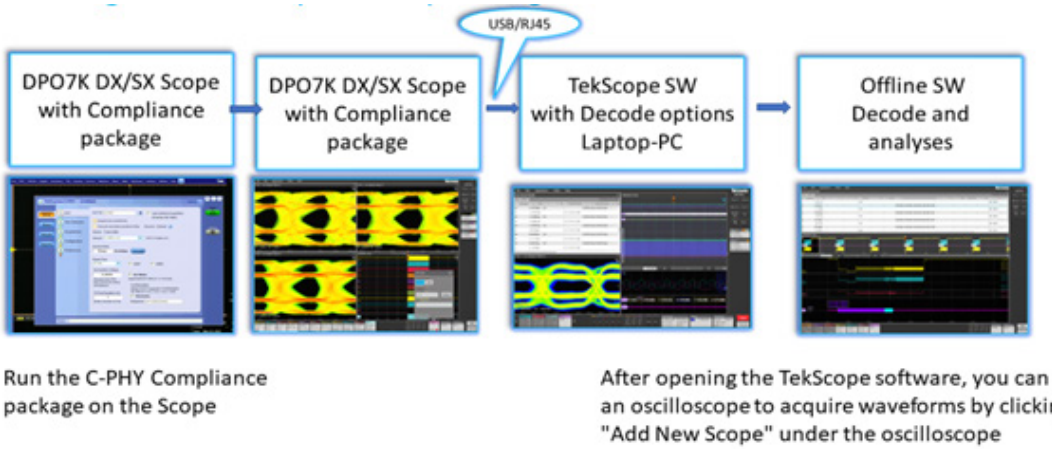
C-PHY outputs do not transmit a signal that is ground referenced. Rather the HS-TX signal rides on a 250 mV common mode voltage level.

Bits encoded by TX, (i.e.,16-bits → 7 symbols → three-wire state levels) decode logic to map 16 bits to 7 symbols and 7 symbols to three wire state levels.



End-to-End Transmission of Data, 16-bit Word Conversion to Channel States

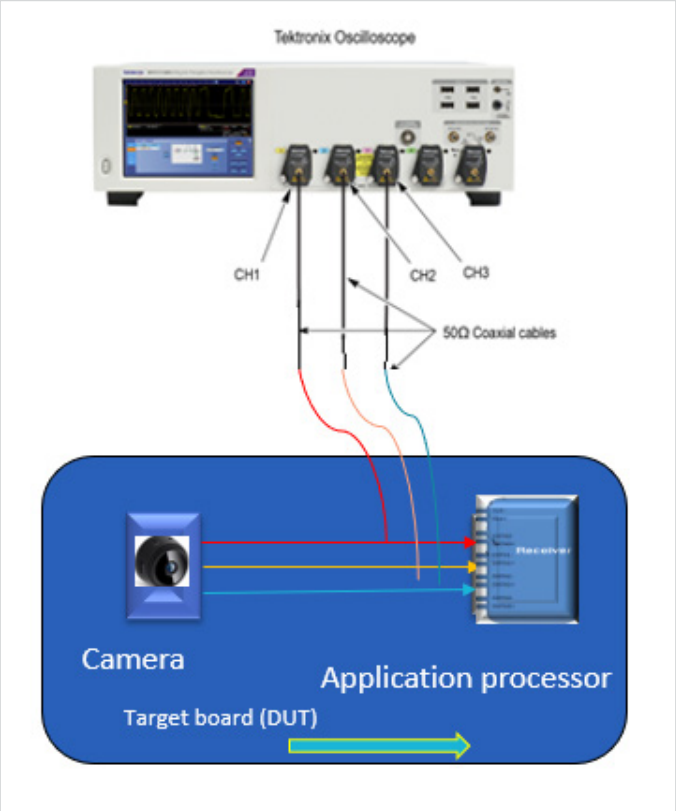
TekScope PC for D-PHY/C-PHY decoding



Flow Diagram to Set Up TekScope Using IP Address: Protocols Decode and Search Option on Any Platform.

Waveform Acquisition

Acquire MIPIC-PHY waveforms on DPO70000SX or MSO 6 Series B oscilloscopes.

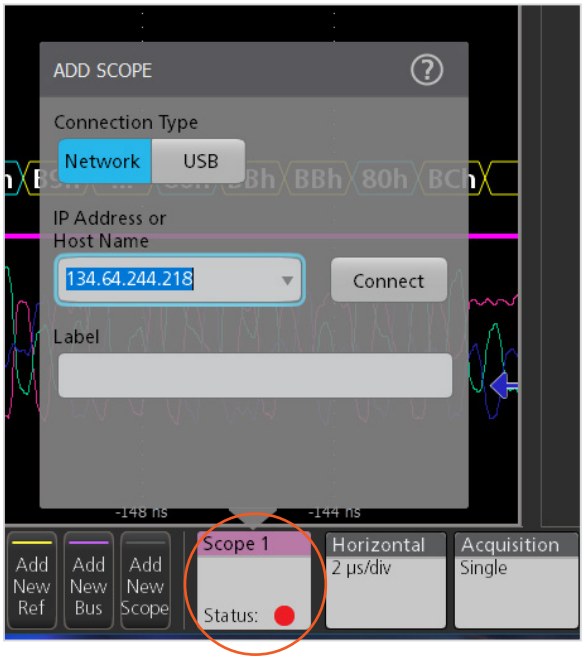


How to Setup TekScope PC

Install TekScope PC software on a laptop/PC, launch the application, and ensure the C-PHY decode option is enabled.

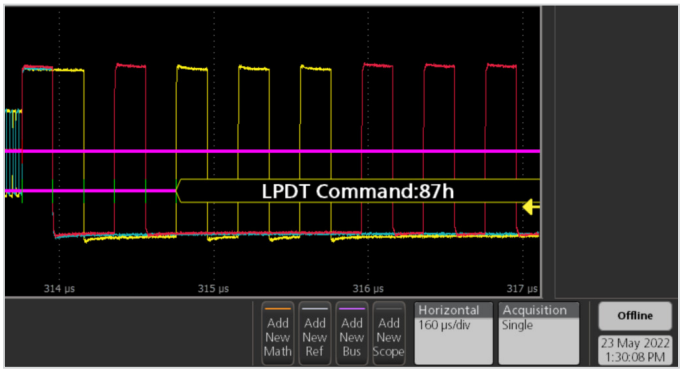
After opening the TekScope software, you can add an oscilloscope to acquire waveforms by clicking “Add New Scope” under the oscilloscope.

In the pop-up dialog box, you can see that the oscilloscope can be connected through the network or USB port; just enter the IP address of the corresponding oscilloscope and click “Connect”; when you have multiple oscilloscopes, you can also use the “Label” name of the oscilloscope.

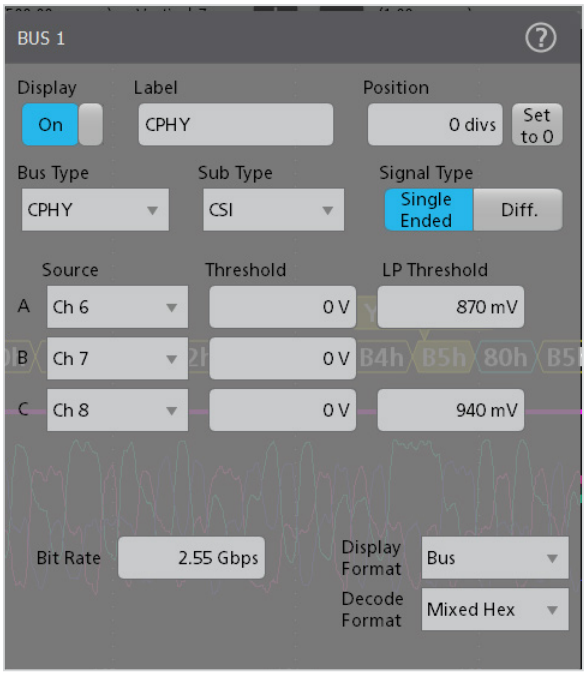


MIPI C–PHY Decoding Settings

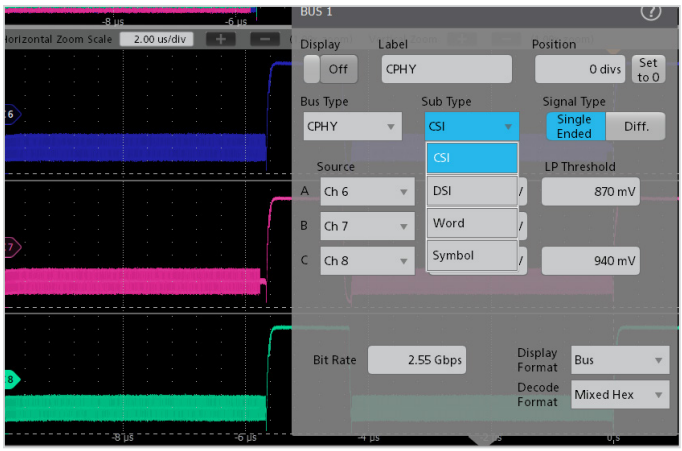
After the oscilloscope acquires the waveform, click “Add New Bus” at the bottom of the software interface to add a new decoding bus:



In the pop-up bus selection interface, by selecting CPHY in the drop-down list of “Bus Type”, you can choose whether it is CSI or DSI decoding in “Sub Type”:



As shown above, the original C-PHY single-ended signals VA, VB and VC can be decoded. At this time, you need to select “Single Ended” in the “Signal Type”. At this time, you can see the signal source “Source” in the interface. “Embodied in three signals A, B, and C, the next step is to determine the decision level of the signal to be decoded.



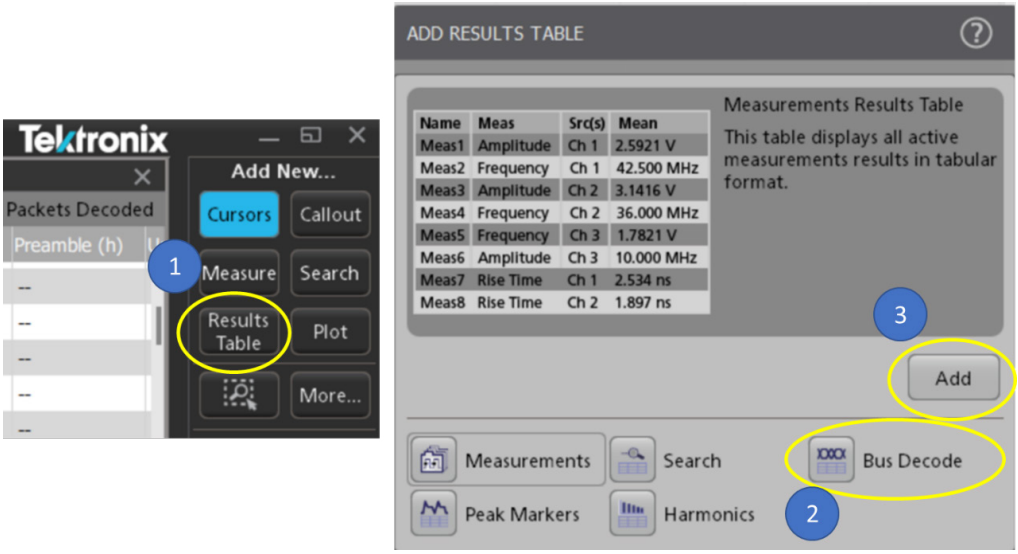
The threshold level in CPHY decoding is divided into two types. The “Threshold” specifies the intermediate decision level of the high-speed “HS” signal, which is usually zero. It can also be modified in more detail according to the specific conditions of the signal, but it must be at the intermediate level. The input in the low-power “LP” Threshold is the distinct level between the LP signal and the HS signal. The setting of this level should not allow the actual signal of the HS to exceed but cannot exceed the maximum level of 1.2V specified by the LP signal.

Under the same interface, the rate of the S signal needs to be given in the input box of “Bit Rate”, then “On” in display selected, so that TekScope can decode correctly. In addition, in “Display Format” and “Decode Format”, you can also customize the display of the bus and decoding according to your own preferences:

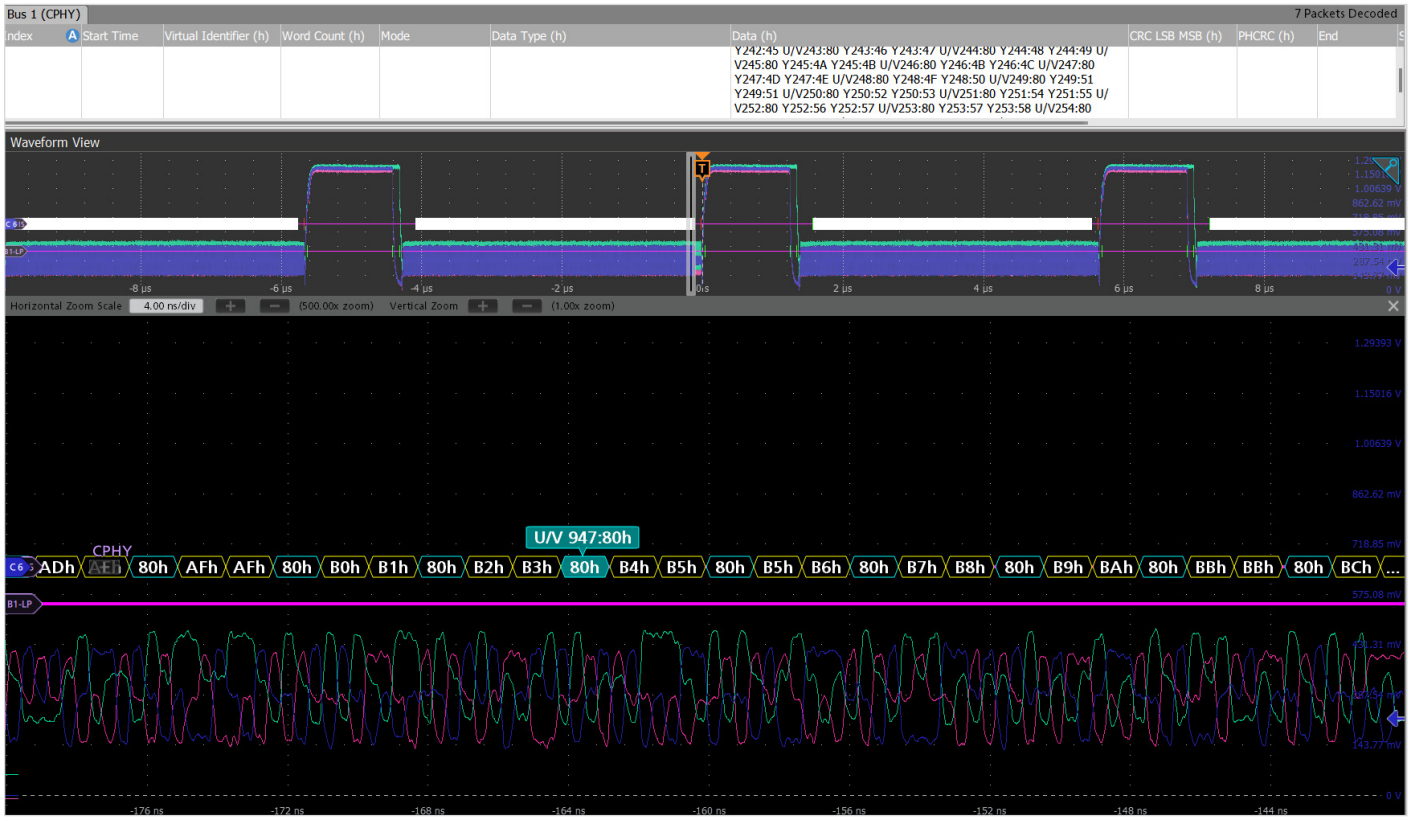
Waveform Decoding Table Opening and Positioning

In order to better facilitate the browsing of decoded signals, TekScope PC can display and locate in tabular form through the decoded result table. There are three steps to use:

1. Select “Results Table” in the first-level menu in the upper right corner of the software interface.
2. Select “Bus Decode” as type of results table.
3. Click “Add” to add decoding result table.

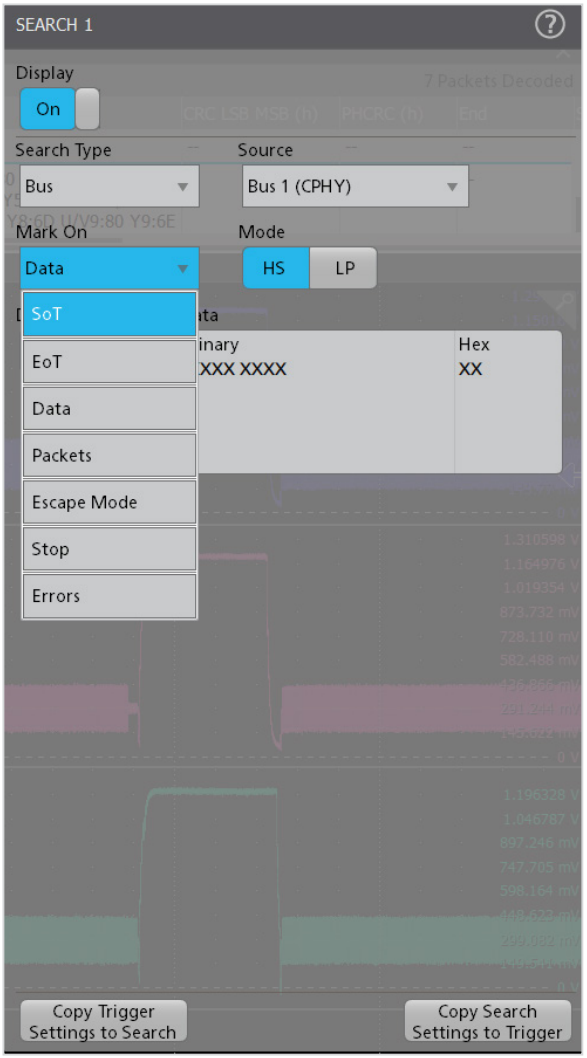


The decoding table lists all the decoding fields and results, and clicking on any decoding result, the software will automatically jump to the corresponding waveform, which is very convenient for positioning and debugging of the decoded waveform. Labeling takes the same color. And the decoding table supports output in csv format, right-click the decoding table and select “Save Table”.

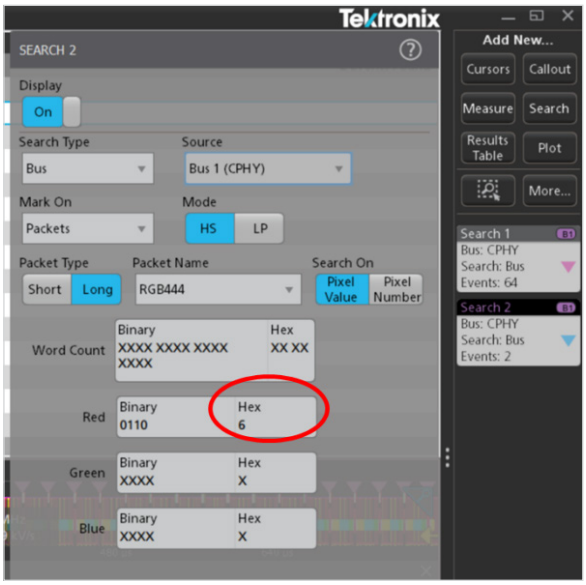


Using the Decode Search Function of TekScope PC

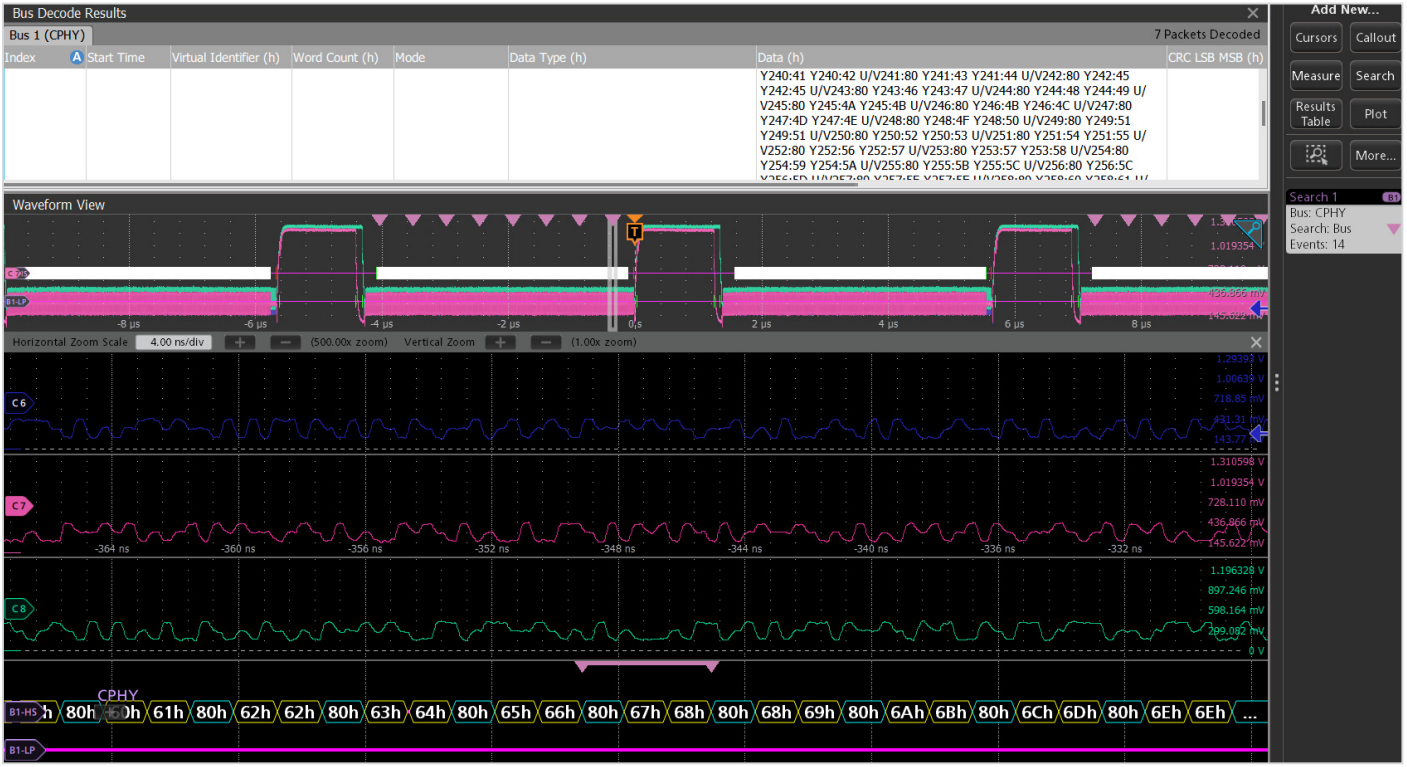
TekScope PC can also search and mark based on bus decoding. For CPHY bus decoding, various data types and detailed data can be searched. As shown in the figure below, various data such as SOT, EOT, Data, Packets, etc. Specific searches are possible. Just click the “Search” button on the first-level menu in the upper right corner of the software, then select the previously defined CPHY bus in “Source”, and finally, select the corresponding search criteria in the “Mark On” drop-down list to define it.

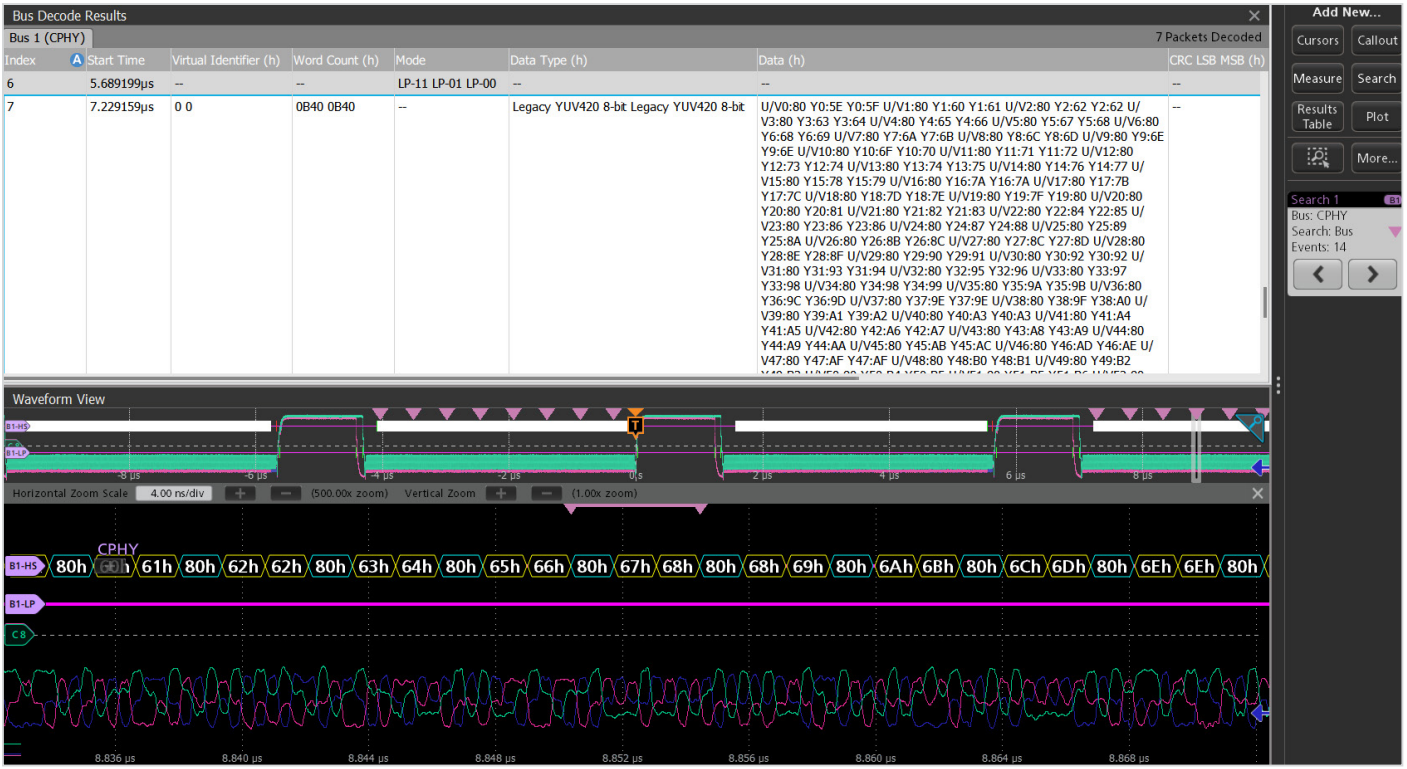


The following example is the search condition for pixels whose RED data is “0x06” in RGB444 encoding under the search Long Packet type:



Through a similar operation in the third point “Results Table”, adding “Search”, the previously defined search results can be displayed in a list. Similarly, there is a corresponding timestamp in the result list and you can click to automatically jump. Convenient.

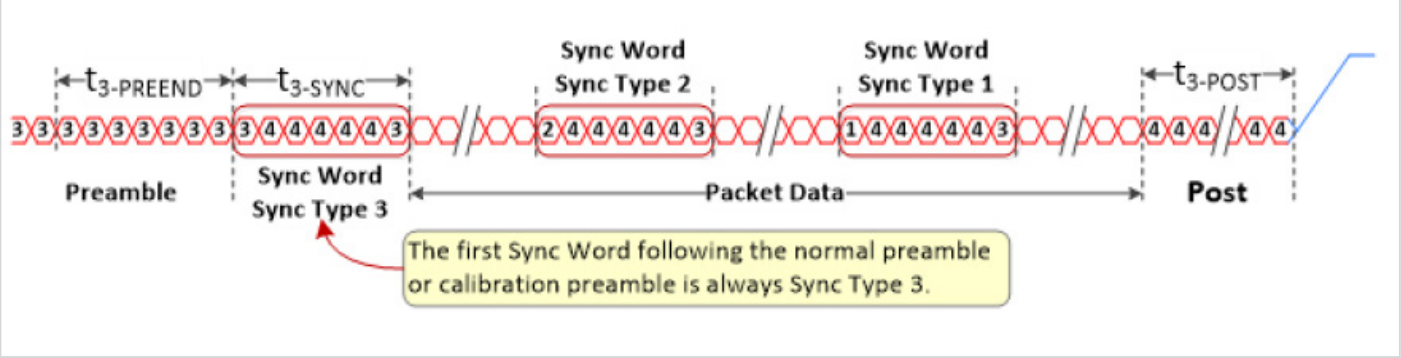




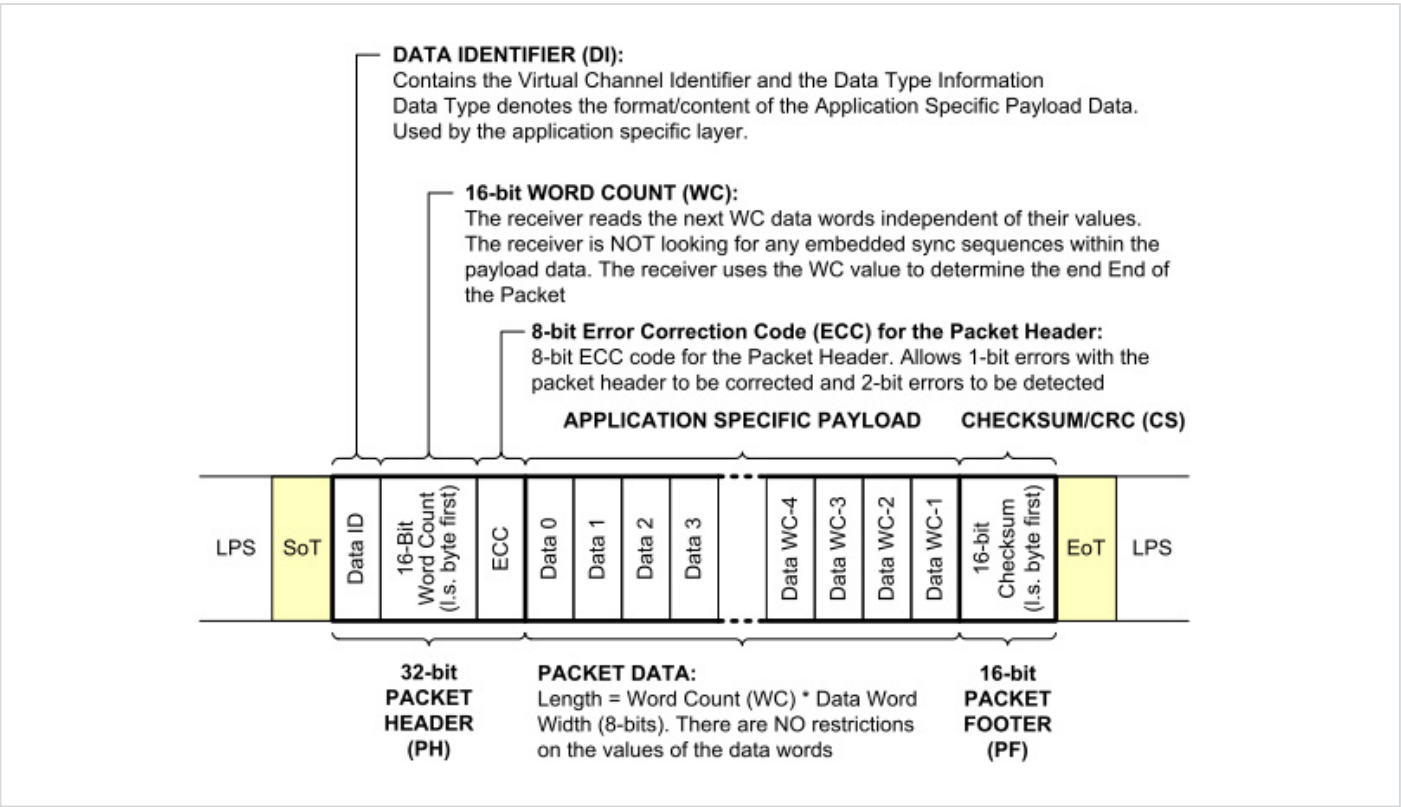
To sum up, TekScope PC supports remote acquisition, bus decoding, search and positioning functions on the MIPI waveform of the oscilloscope on the personal computer, which is convenient for engineers who need to perform MIPI decoding and analysis on the oscilloscope remotely. TekScope PC saves oscilloscope resources and facilitates data sorting and remote collaboration. It offers fast speed and comprehensive functionality, and supports multiple oscilloscope platforms such as Tektronix DPO70000 and MSO Series 6B oscilloscopes, making it very helpful for engineers who have MIPI bus decoding and analysis requirements.

Interpreting the C–PHY Bus

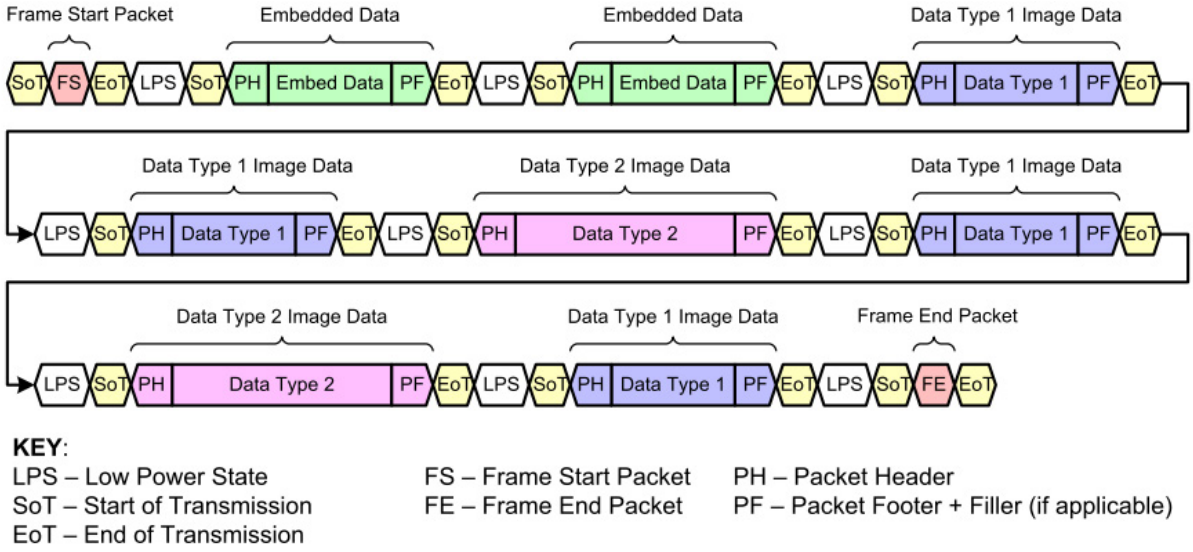
The time-correlated waveform and bus decode display is a familiar and useful format for most engineers. The decoded bus waveform indicates the elements of a C-PHY message. The TekScope acts as a protocol analyzer, displaying both bus/ waveforms and logic states/waveforms for the corresponding bus.

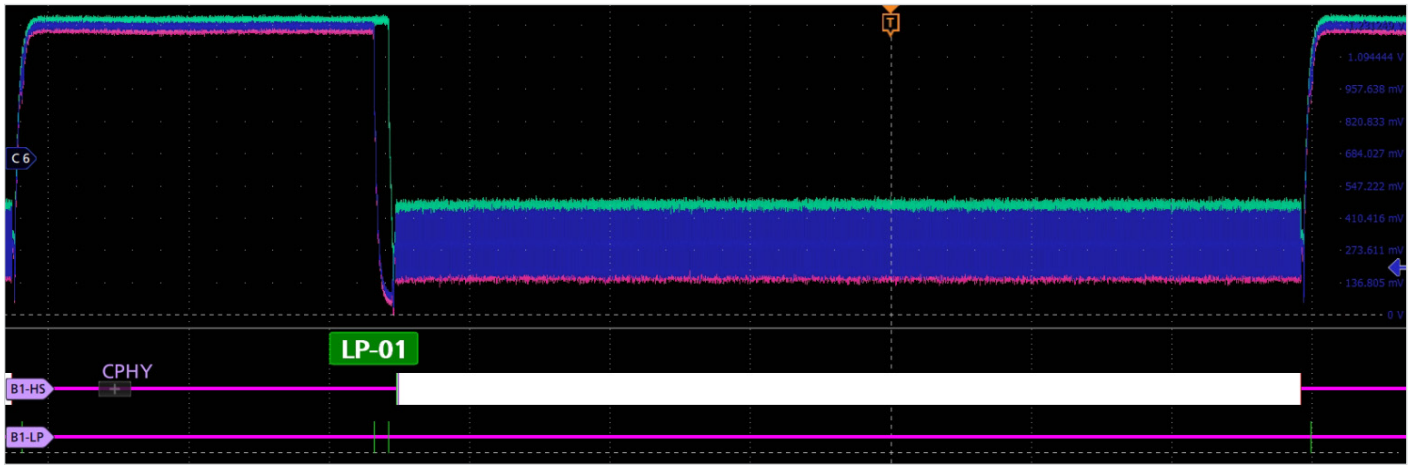


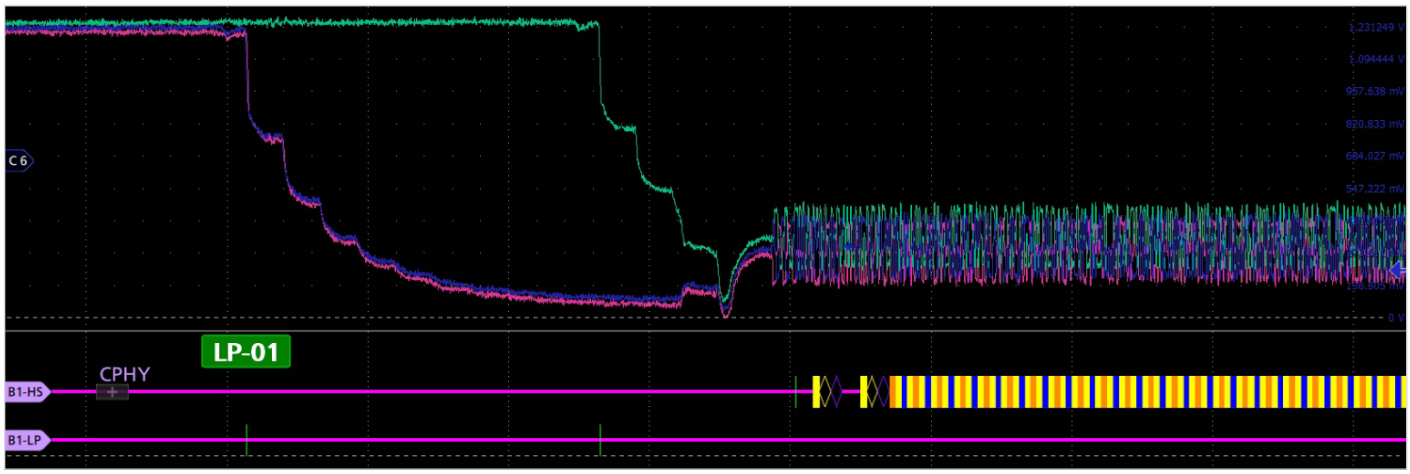
PHY Layer Signals and Preamble.

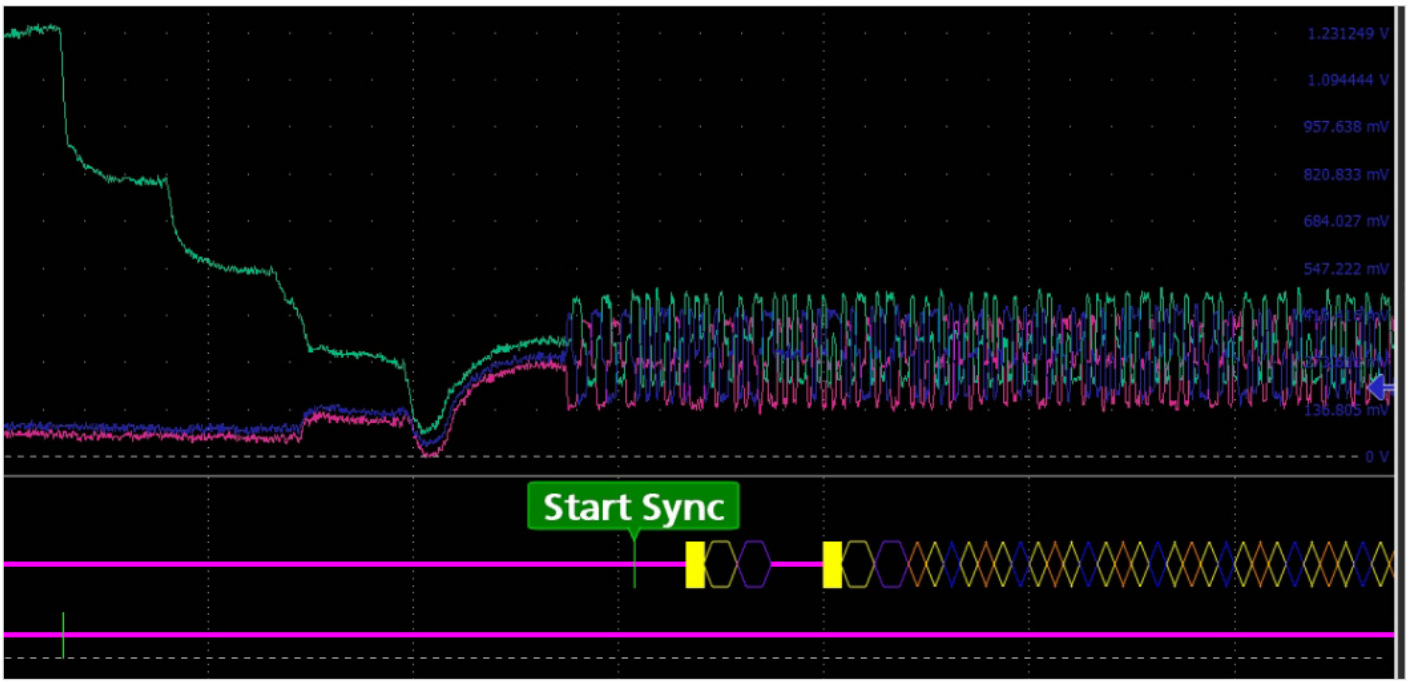


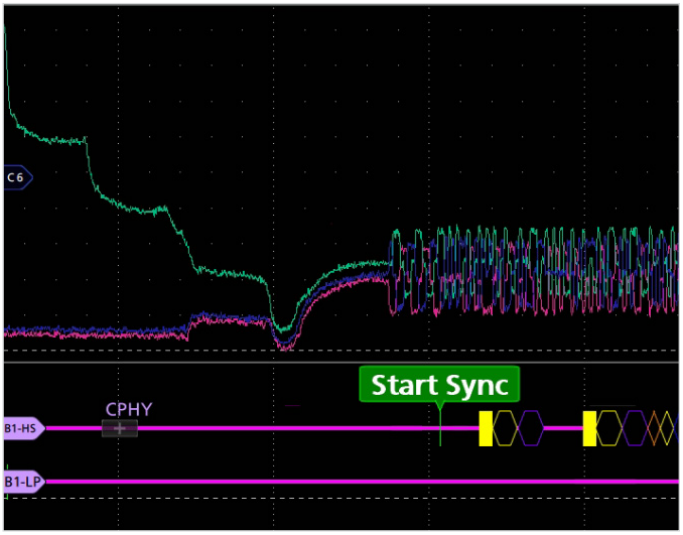
Definition of Each Segment.

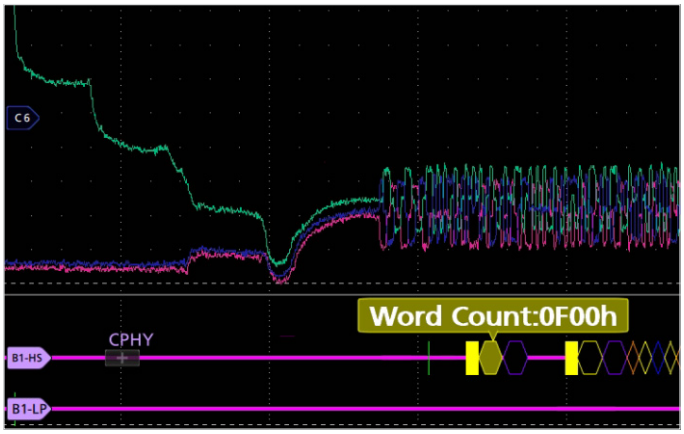

Frame Start Packet
Embedded Data
Embedded Data
Data Type 1 Image Data
SoT FS EoT LPS SoT PH Embed Data PF EoT LPS SoT PH Embed Data PF EoT LPS SoT PH Data Type 1 PF EoT
Data Type 1 Image Data
Data Type 2 Image Data
Data Type 1 Image Data
LPS SoT PH Data Type 1 PF EoT LPS SoT PH Data Type 2 PF EoT LPS SoT PH Data Type 1 PF EoT
Data Type 2 Image Data
Data Type 1 Image Data
Frame End Packet
LPS SoT PH Data Type 2 PF EoT LPS SoT PH Data Type 1 PF EoT LPS SoT FE EoT
KEY:
LPS – Low Power State
SoT – Start of Transmission
EoT – End of Transmission
FS – Frame Start Packet
FE – Frame End Packet
PH – Packet Header
PF – Packet Footer + Filler (if applicable)

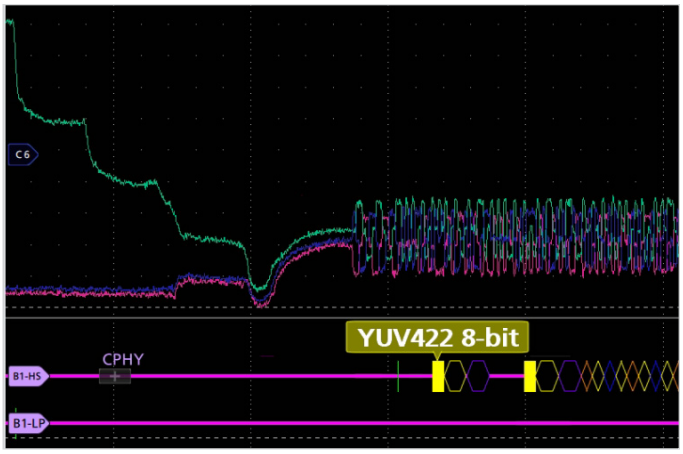

C6
LP-01
CPHY
B1-HS
B1-LP

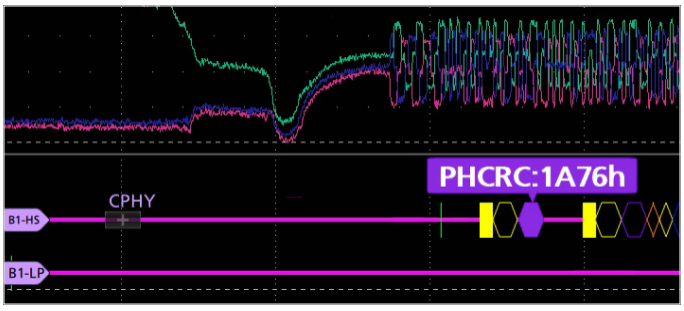

C6
LP-01
CPHY
B1-HS
B1-LP

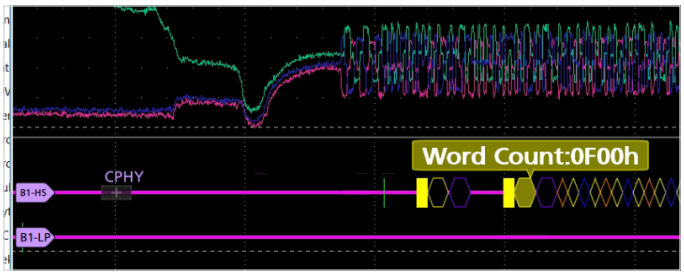

1.231249 V
1.094444 V
957.638 mV
820.833 mV
684.027 mV
547.222 mV
136.805 mV
0 V
Start Sync

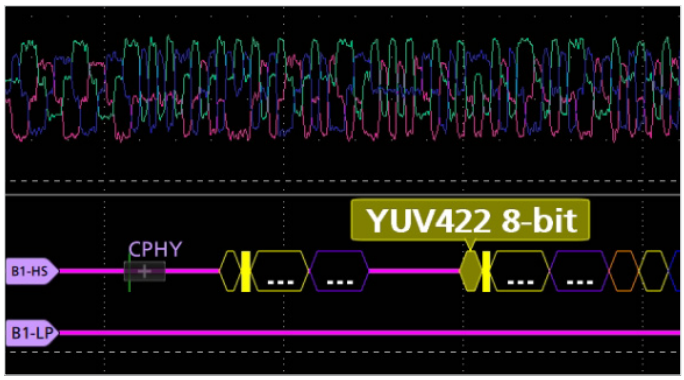

C6
Start Sync
CPHY
B1-HS
B1-LP

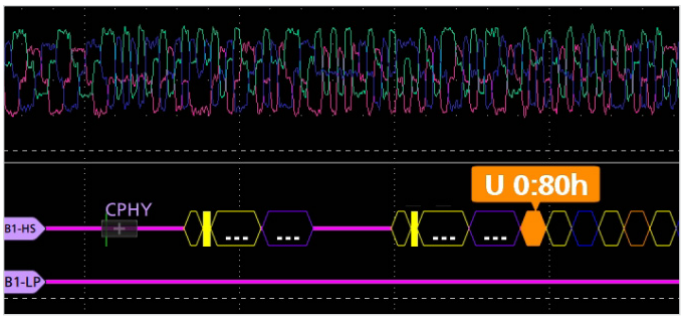

C6
Word Count:0F00h
CPHY
B1-HS
B1-LP

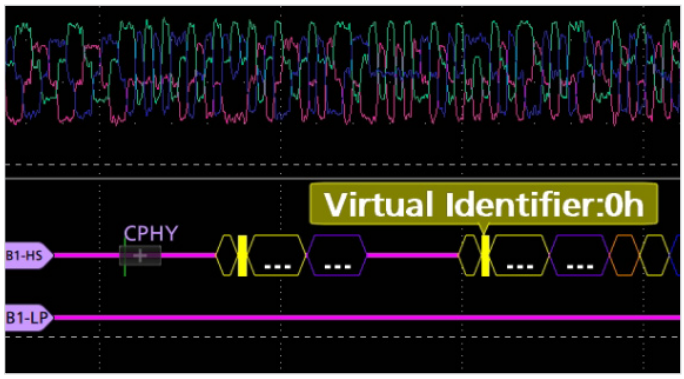

C6
YUV422 8-bit
CPHY
B1-HS
B1-LP

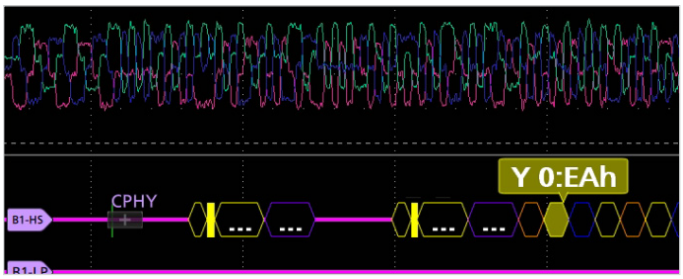

PHCRC:1A76h
CPHY
B1-HS
B1-LP

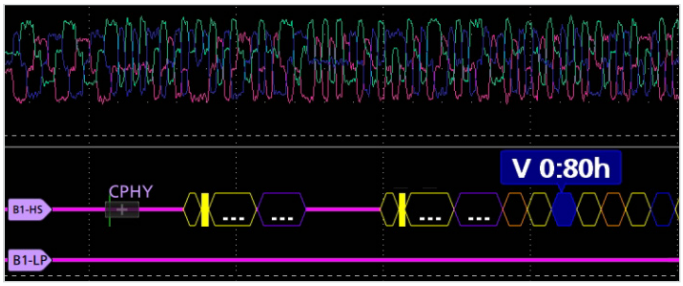

Word Count:0F00h
CPHY
B1-HS
B1-LP

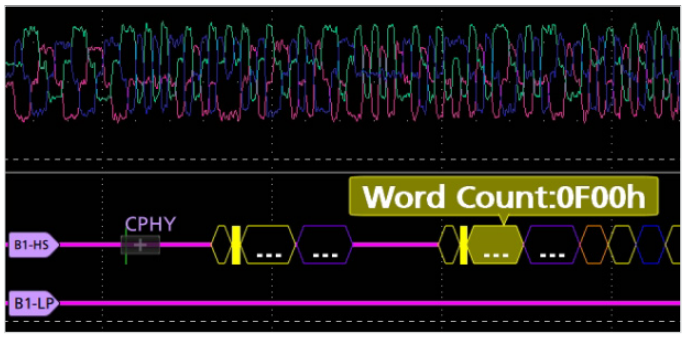

YUV422 8-bit
CPHY
B1-HS
B1-LP

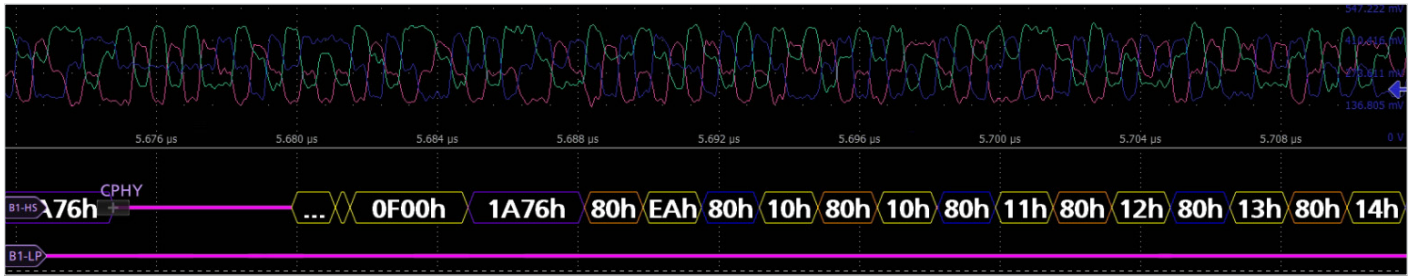

U 0:80h
CPHY
B1-HS
B1-LP

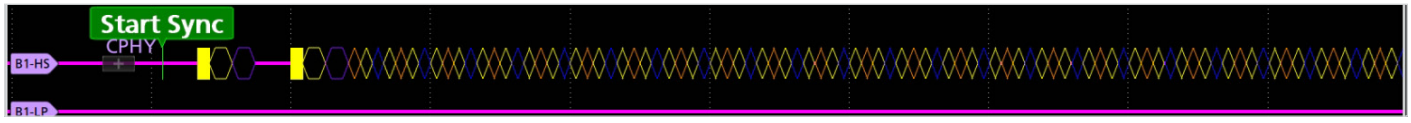

Virtual Identifier:0h
CPHY
B1-HS
B1-LP


Y 0:EAh
CPHY
B1-HS


V 0:80h
CPHY
B1-HS
B1-LP

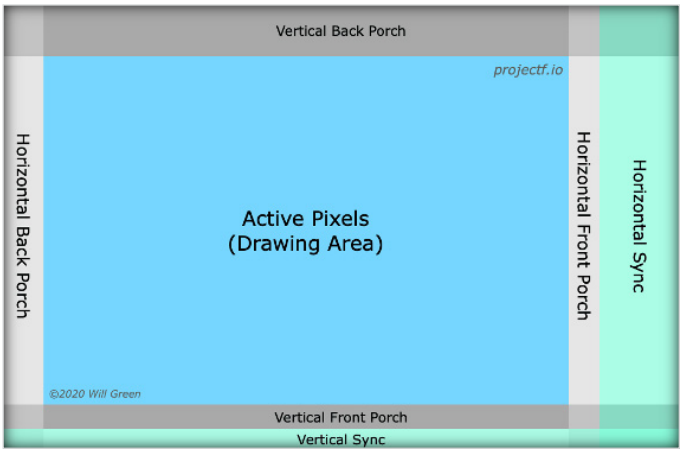

Word Count:0F00h
CPHY
B1-HS
B1-LP


5.676 µs
5.680 µs
5.684 µs
5.688 µs
5.692 µs
5.696 µs
5.700 µs
5.704 µs
5.708 µs
CPHY
B1-HS
B1-LP
0F00h
1A76h
80h
EAh
80h
10h
80h
10h
80h
11h
80h
12h
80h
13h
80h
14h


Start Sync
CPHY
B1-HS
B1-LP

Data Rate vs. Resolution

Video signals have two phases: drawing pixels and the blanking interval. The sync signals occur within blanking intervals and is separated from pixel drawing by the front porch and back porch. Horizontal sync demarcates a line and vertical sync a frame.



Key definitions:

Pixel Clock: Time base at which individual Pixels are transferred

Refresh Rate: Number of times the screen refreshes

Resolution: Number of Pixels in the Screen

Color depth: Number of bits used to represent a color of pixel

The pixel clock can be derived as follows:

Example Resolution 1280×720p60

Pixel Clock = Horizontal Samples × Vertical Lines × Refresh Rate

where Horizontal Samples and Vertical lines include the horizontal and vertical blanking intervals.

A resolution of 1280×720p with refresh rate of 60 refreshes/s implies =1650×750.

1650 × 750_× 60= 74.25 MHz

Bandwidth = Pixel Clock × Pixel Size(in bits)

Data Rate = BW/no of lanes. Refresh rate= 60/120/240

Pixel Size = 8/10/16/18/24 Lanes = 1/2/4

Data rate = Pixel Clock × color depth Color depth = 24 bits (888, 256 levels) for 8b/10 conversion

Then the required data rate per lane = 2.227 Gbps/Lane.

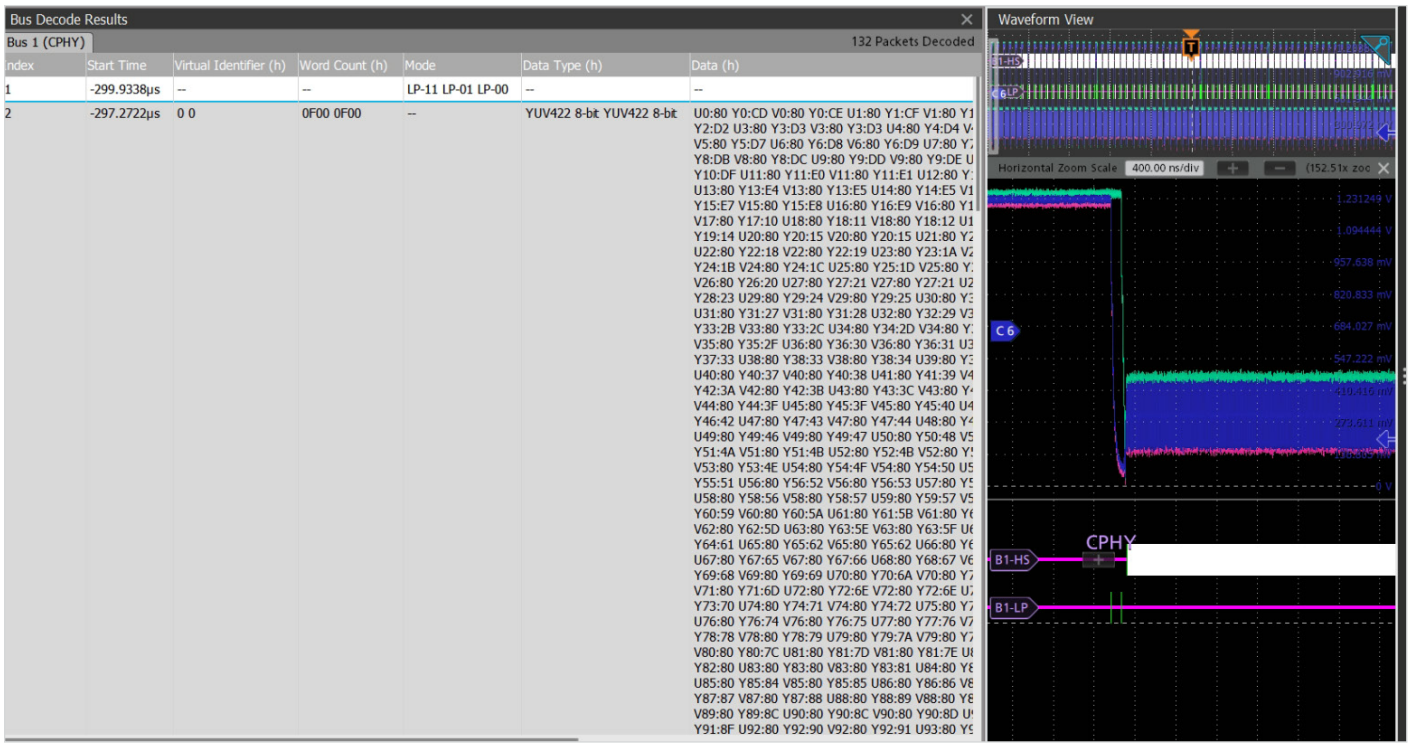
The screen below was captured using a 420 legacy patterns; the video packet contains Y, U/V.

Decoding on a C–PHY BUS

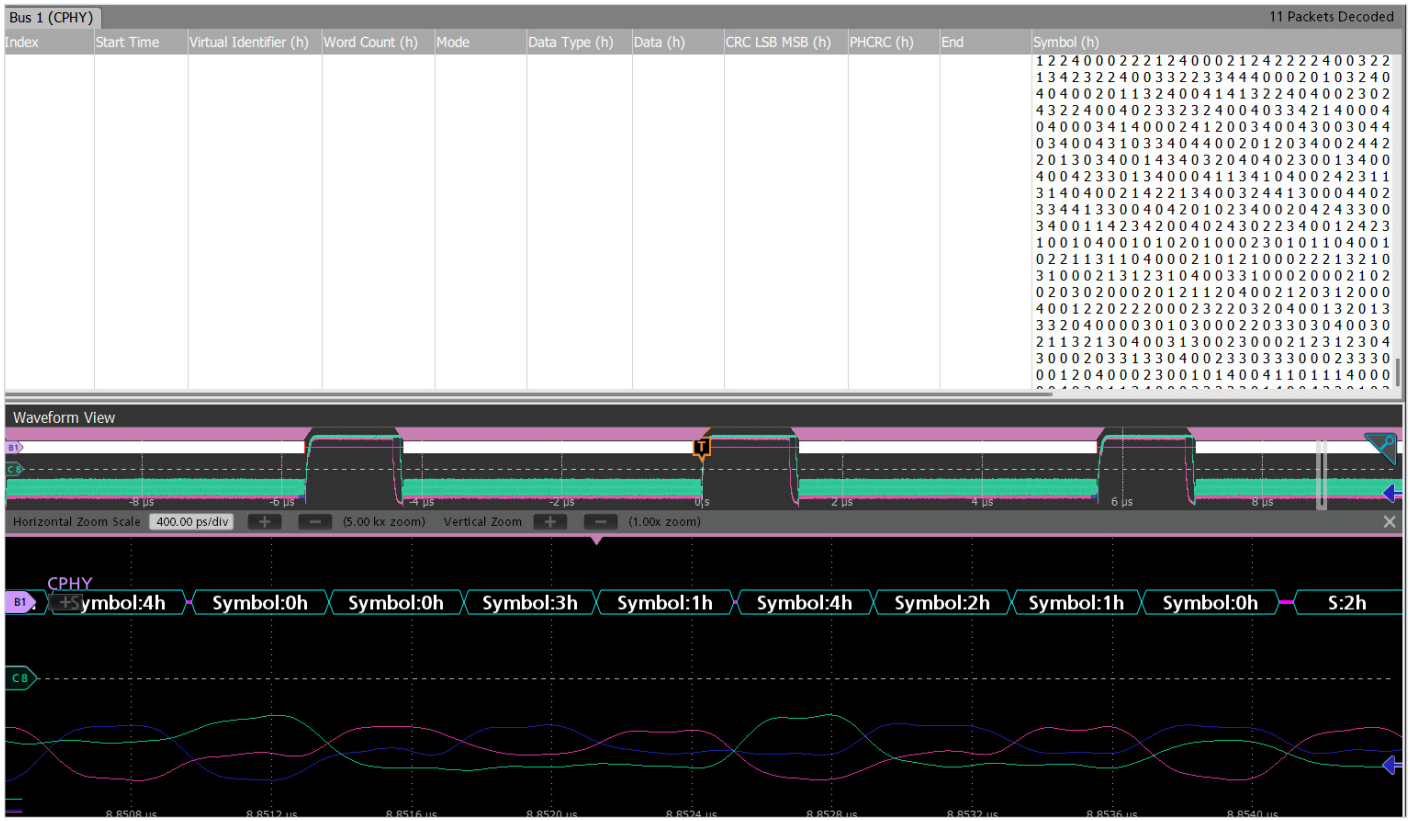
The transmitter is CSI, and sending 420 8 bit legacy video packets, the data rate is 2.5 GSPS.

As shown earlier (see "End-to-End Transmission of Data" figure near the start of this note) packet structures are defined for low-level protocol communication: long packets and short packets. The format and length of Short and Long Packets depends on the choice of physical layer. For each packet structure, the "Exit from the Low Power State Followed by the Start of Transmission (SoT) Sequence" indicates the start of the packet. The "End of Transmission (EoT) Sequence" followed by the low power state indicates the end of the packet.

C-PHY Bus Element	Indicated by:
SoT – Start of Transmission EoT – End of Transmission LPS – Low Power State PH – Packet Header PF – Packet Footer + Filler (if applicable) FS – Frame Start FE – Frame End	

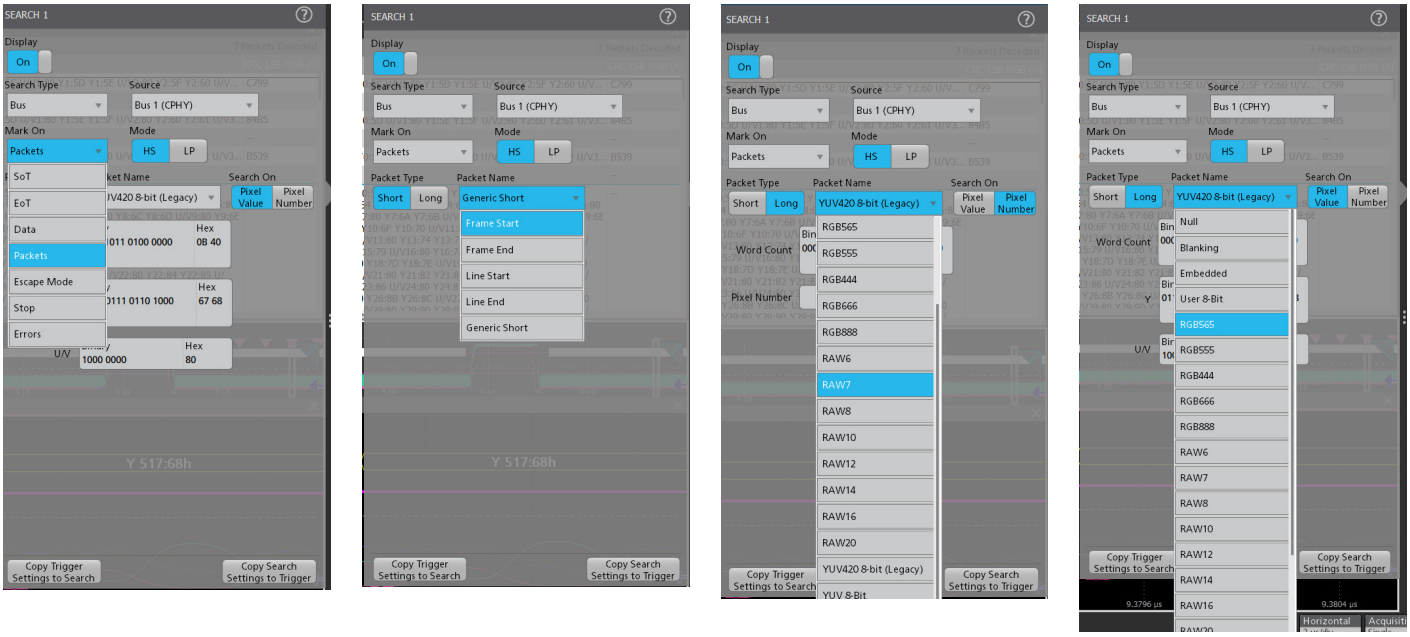


Physical layer signal and its Corresponding Decoded Information



Searching the C–PHY Bus

On a Tektronix oscilloscope you can use the automated search to find all the bus events that meet a specified set of search criteria and determine how many of them occurred.



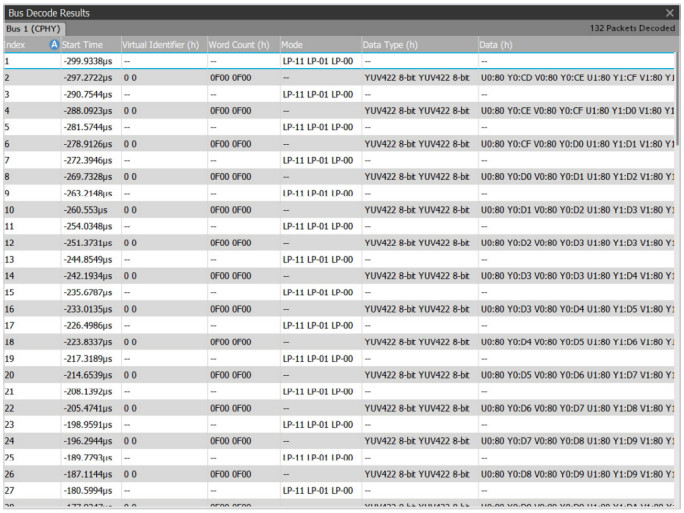
In this example, the search condition is set to look for every message of “Packet’s”.

KEY: SoT – Start of Transmission EoT – End of Transmission LPS – Low Power State
PH – Packet Header PF – Packet Footer + Filler (if applicable)
FS – Frame Start FE – Frame End
LS – Line Start LE – Line End

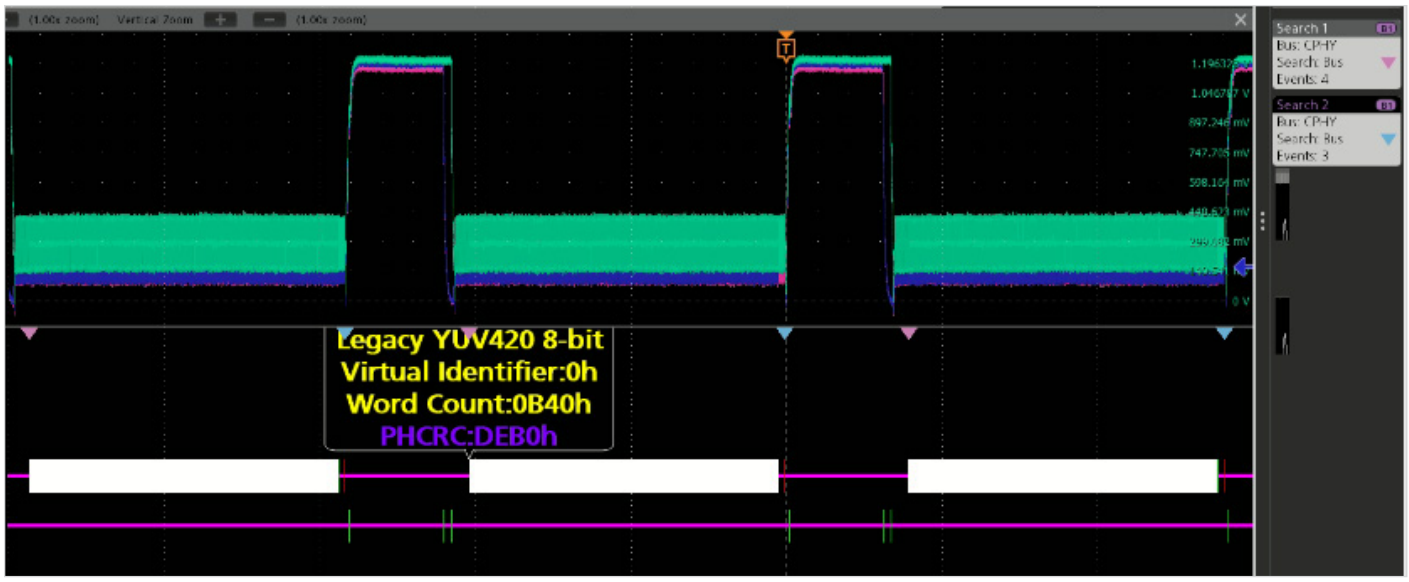
In this second example, the search condition is set to look for every read or write to-or-from address 0x3F.

Here is the list of search options that can help you pinpoint specific activity and show the corresponding timing waveforms.

For relating activity to firmware, the Results Table format is a useful addition. This time-stamped display of bus activity can be easily compared to software listings and allows easy calculation of the execution speed. The Results Table also provides linkage back to the waveform displays. You can tap a line in the tabular display and the oscilloscope automatically zooms in on the corresponding bus signals and resulting decoded bus waveform, shown in the lower section of the screen.



Result Table with Decoded Packets

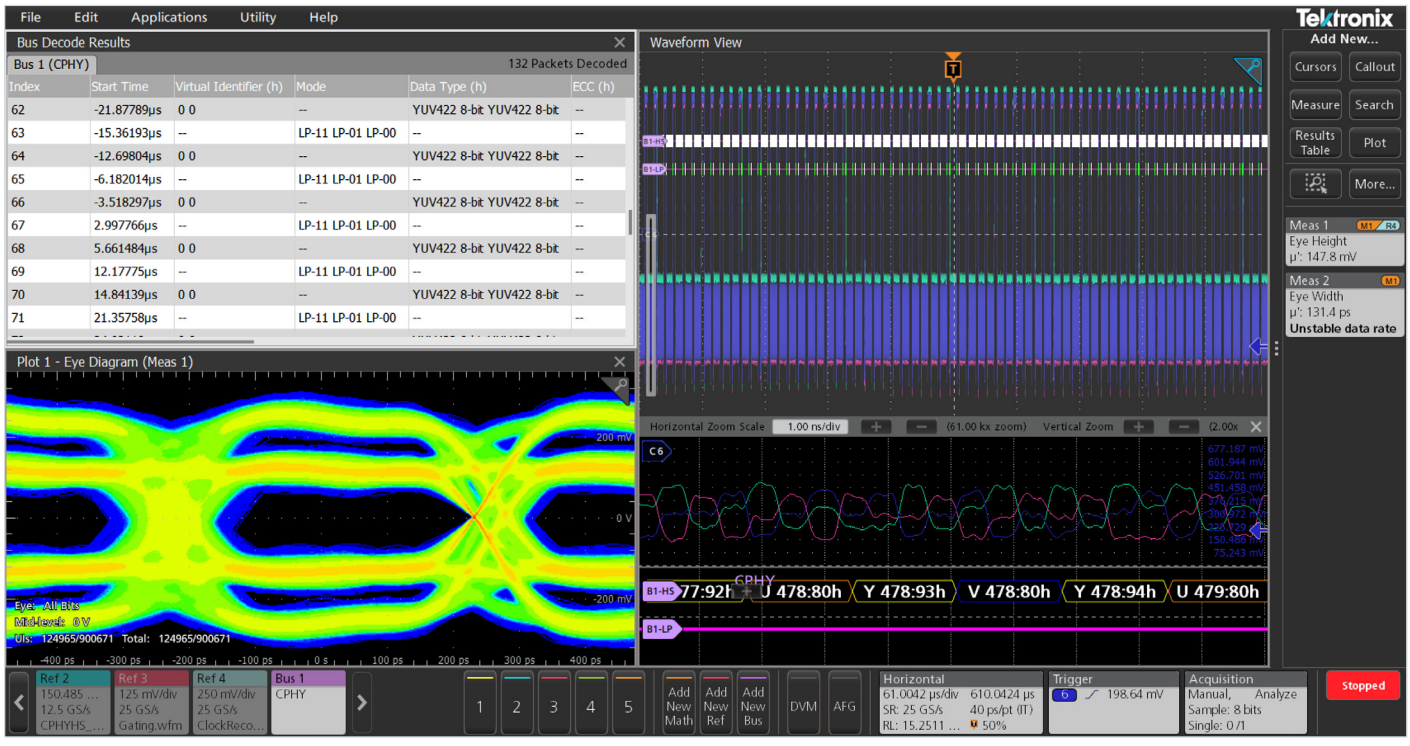


The search setup specifies bus events of interest and allows the oscilloscope to find and mark all the specified bus events. In this example, the automatic search is looking for two different types of events.

The result badges on the righthand side of the display show the number of captured searches with their color-coded markers and number of events. The results table at the top of the display shows the entire decoded message in tabular form, along with a precise start and stop timestamp.

In the example above, two searches were configured. The pink triangles indicate the results of a search for a SOT. Four events matching this condition were found. The blue search condition occurred three times and the locations within the acquisition can be seen in the center of the display.

By placing the cursor A and B between the HS regions, an eye diagram is plotted using the Jitter analysis tool and recovered clock.



Conclusion

This application note offers a brief overview of the physical layer and packet structures of C-PHY. It covered how to set up decoding on an oscilloscope equipped with C-PHY decoding and how to interpret serial bus data on an oscilloscope equipped with C-PHY decoding. It also explained searching options.

With the optional serial bus analysis capability, Tektronix oscilloscopes become powerful tools for embedded system designers working with C-PHY buses. The 5 Series MSO oscilloscope was used to demonstrate C-PHY serial bus decoding and search in this application note. Other Tektronix oscilloscopes also support C-PHY analysis. See Serial Support Using Oscilloscopes and Optional Software for a complete listing.

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