Debugging SENT Automotive Buses with an Oscilloscope

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APPLICATION NOTE

Tektronix®

Introduction

Increasingly, automotive designs are adopting Single Edge Nibble Transmission (SENT) protocol for low-cost, asynchronous, point-to-point transmission of high-resolution data.

SENT buses are well-defined and are designed to be robust and easy to integrate, but communications can be affected by noise, board layout, reset issues, and subtle differences in implementations. These can sometimes result in bus errors and system malfunctions.

Unlike basic protocol analyzers, oscilloscopes equipped with protocol decoding, can be used to see both the decoded bus traffic, as well as signal quality. This ability to see bus signals and decoded traffic makes oscilloscopes the best choice for visualizing overall system operation. Perhaps more importantly, oscilloscopes can be used to troubleshoot problems at the system level. Automobiles rely on extensive networks of sensors, actuators and displays, and many problems involve bus timing relative to I/O events or values. Oscilloscopes are well-suited for looking at I/O signals and bus transactions at the same instant. Because of this capability, they are the instrument of choice for system-level debugging.

THIS APPLICATION NOTE

- Gives a brief orientation on the physical layer and packet structures of SENT, with a goal of providing just enough detail to help with troubleshooting

- Explains how to set up decoding on an oscilloscope equipped with SENT decoding

- Explains how to interpret fast and slow channel packet data on an oscilloscope equipped with SENT decoding

- Explains what triggering and searching options are available on an oscilloscope equipped with SENT serial triggering and analysis

With the optional serial triggering and analysis capability, Tektronix oscilloscopes become powerful tools for embedded system designers working with SENT buses. In this application note the 5 Series MSO is used to demonstrate SENT serial bus decoding and triggering.
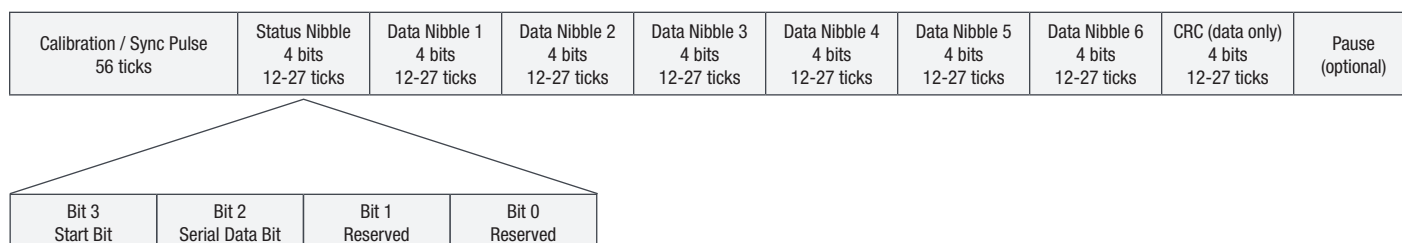
Other Tektronix oscilloscopes also support SENT triggering and analysis. See "Serial Support Using Oscilloscopes and Optional Software" for a complete listing.
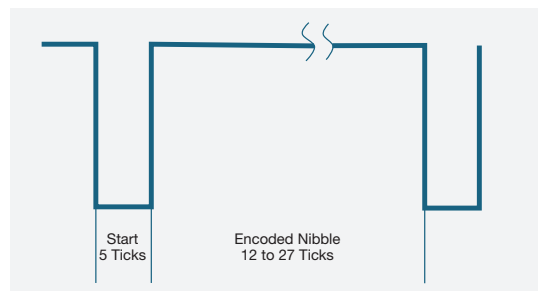
SENT

Also known as SAE J2716, SENT is used for communication between power-train sensors and Electronic Control Units (ECUs). SENT provides higher precision than analog PWM techniques and, at 30 kb/s, it has a higher data rate than LIN.

HOW IT WORKS

A typical SENT transmission looks like this:

Calibration / Sync Pulse 56 ticks	Status Nibble 4 bits 12-27 ticks	Data Nibble 1 4 bits 12-27 ticks	Data Nibble 2 4 bits 12-27 ticks	Data Nibble 3 4 bits 12-27 ticks	Data Nibble 4 4 bits 12-27 ticks	Data Nibble 5 4 bits 12-27 ticks	Data Nibble 6 4 bits 12-27 ticks	CRC (data only) 4 bits 12-27 ticks	Pause (optional)

Bit 3 Start Bit	Bit 2 Serial Data Bit	Bit 1 Reserved	Bit 0 Reserved

The physical layer of the SENT interface consists of a signal line, a +5V supply voltage line, and a ground. The signal line logic levels are low < 0.5V and high > 4.1V.

Start 5 Ticks   Encoded Nibble 12 to 27 Ticks

SENT transmits data in 4-bit nibbles between two falling edges, hence the name "Single Edge Nibble". Timing of the SENT bus is measured in ticks, with each tick typically 3 µs wide. Each nibble starts with a logic-low period of at least 5 ticks, followed by a variable-length logic-high period representing the encoded data value. A 0000 binary data value is represented by a logic-high duration of 12 ticks. A 0001 binary data value is represented by a logic-high duration of 13 ticks, and so on, up to a 1111 binary data value is represented by a logic-high duration of 27 ticks.

The SENT "fast channel" message begins with a sync pulse where the time between successive falling edges is 56 clock ticks. The SENT message is 32 bits long, consisting of:

• 4 bits of status / communication information (12-27 ticks)

• six, 4-bit nibbles of data (representing one or two measurement channels, 12-27 ticks per nibble)

• 4 bits of CRC for error detection (12-27 ticks)

Optionally, a 20-bit message (where the 12 data bits represent one measurement channel) can be sent, followed by a pause pulse, resulting in the same overall message rate.

For example, when two 12-bit fast channels are used, the transmission looks like this:

Sync	Status	FC1 MSN	FC1 MidN	FC1 LSN	FC2 LSN	FC2 MidN	FC2 MSN	CRC Nibble	Pause (optional)

The SENT standard also supports "slow channel" messages, where data is transmitted 1-2 bits at a time via bits 2 and 3 of the 4-bit status / serial communication nibble in 16 or 18 successive fast channel messages. These bits are accumulated to build the slow channel message.

For example, the "Enhanced Serial Message with 12-bit Data and 8-bit ID Format" is identified by the initial bit pattern "11111100" and transmits an 8-bit ID value, a 6-bit CRC, and a 12-bit data value:

SENT Message	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Status Bit 3	1	1	1	1	1	1	0	0	ID Bits 7-4				0		ID Bits 3-0			0
Status Bit 2	CRC (6 bits)						Data (12 bits)											
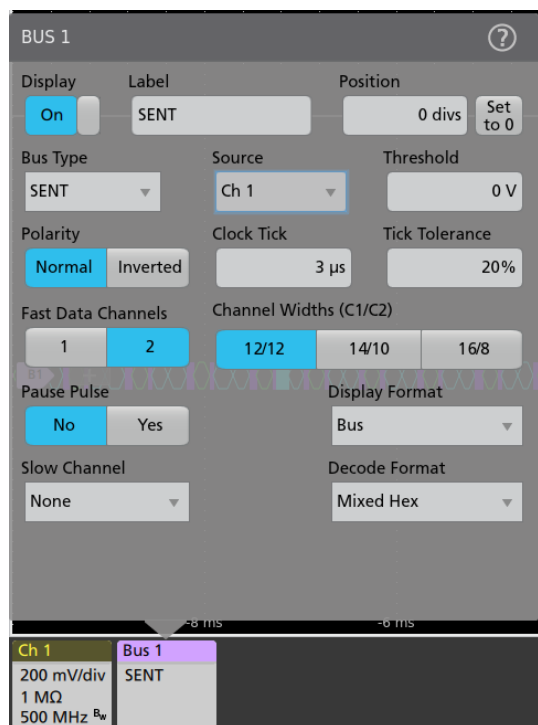
SETTING UP SENT BUS DECODING

On Tektronix oscilloscopes equipped with SENT decoding and triggering, pressing the front panel Bus button enables you to define inputs to the scope as a bus. To enable the oscilloscope to decode the packet data, you enter some basic parameters, including:

- Input channel

- Voltage threshold

- Signal polarity

- Number of fast channels and channel format

- Number of slow channels and channel format

- Pause pulse

The SENT bus is a single-ended, ground-reference signal. Although the oscilloscope can acquire and decode the bus using standard single-ended probing, the signal fidelity and noise immunity may be improved by using differential probing.
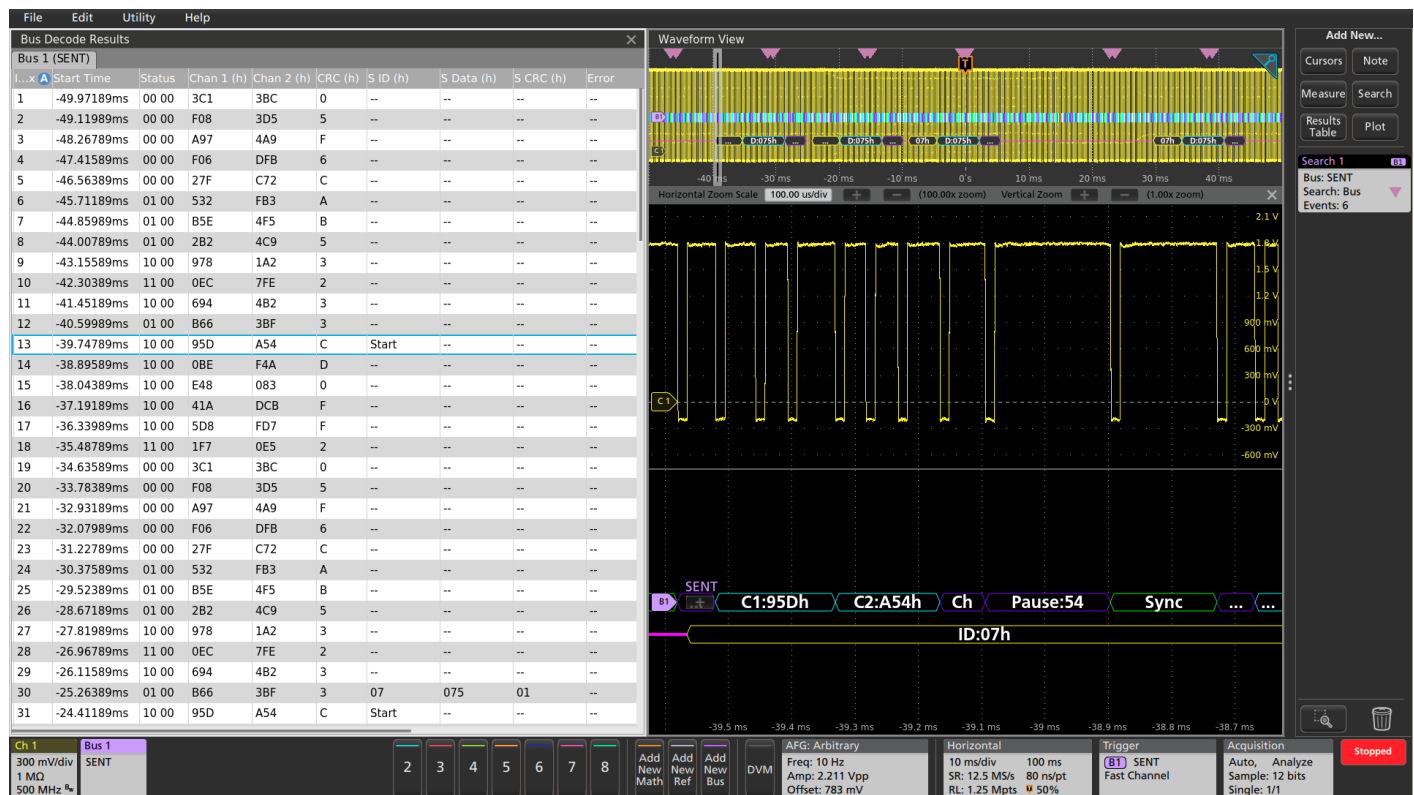
INTERPRETING THE SENT BUS

The time-correlated waveform and bus decode display is a familiar and useful format for many hardware engineers. The decoded bus waveform indicates the elements of a SENT fast-channel message.

SENT FAST CHANNEL BUS ELEMENT	INDICATED BY
Sync (56 ticks wide)	Sync
Status	01 00
Data	Data:075h
CRC	S CRC:01h
Pause	Pause
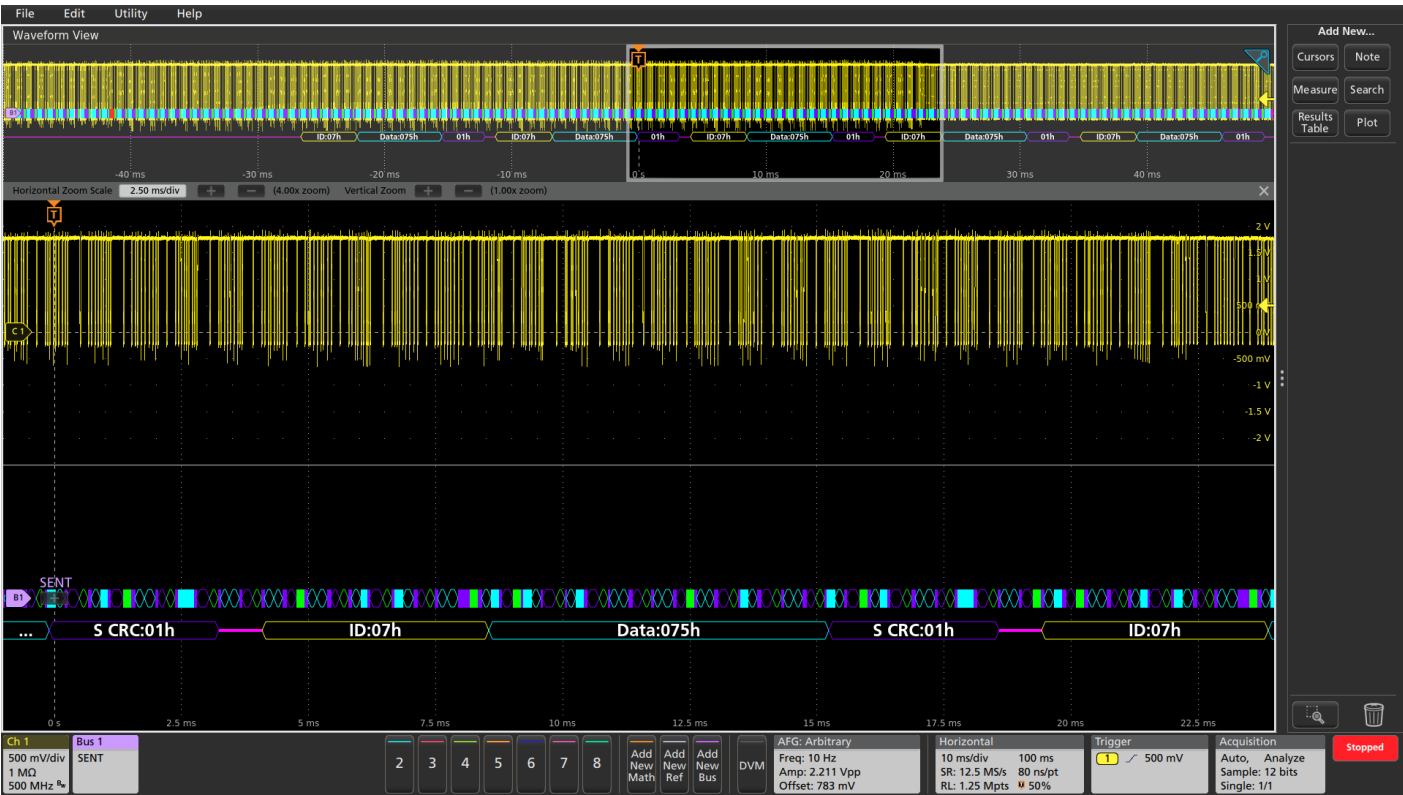
The decoded SENT bus can display both fast and slow channel packets in a single waveform display, with the slow channel packets shown below the fast channel packets.

SENT SLOW CHANNEL BUS ELEMENT	INDICATED BY
Identifier	ID:07h
Data	Data:075h
CRC	S CRC:01h

l...x A	Start Time	Status	Chan 1 (h)	Chan 2 (h)	CRC (h)	S ID (h)	S Data (h)	S CRC (h)	Error
1	-49.97189ms	00 00	3C1	3BC	0	--	--	--	--
2	-49.11989ms	00 00	F08	3D5	5	--	--	--	--
3	-48.26789ms	00 00	A97	4A9	F	--	--	--	--
4	-47.41589ms	00 00	F06	DFB	6	--	--	--	--
5	-46.56389ms	00 00	27F	C72	C	--	--	--	--
6	-45.71189ms	01 00	532	FB3	A	--	--	--	--
7	-44.85989ms	01 00	B5E	4F5	B	--	--	--	--
8	-44.00789ms	01 00	2B2	4C9	5	--	--	--	--
9	-43.15589ms	10 00	978	1A2	3	--	--	--	--
10	-42.30389ms	11 00	0EC	7FE	2	--	--	--	--
11	-41.45189ms	10 00	694	4B2	3	--	--	--	--
12	-40.59989ms	01 00	B66	3BF	3	--	--	--	--
13	-39.74789ms	10 00	95D	A54	C	Start	--	--	--
14	-38.89589ms	10 00	0BE	F4A	D	--	--	--	--
15	-38.04389ms	10 00	E48	083	0	--	--	--	--
16	-37.19189ms	10 00	41A	DCB	F	--	--	--	--
17	-36.33989ms	10 00	5D8	FD7	F	--	--	--	--
18	-35.48789ms	11 00	1F7	0E5	2	--	--	--	--
19	-34.63589ms	00 00	3C1	3BC	0	--	--	--	--
20	-33.78389ms	00 00	F08	3D5	5	--	--	--	--
21	-32.93189ms	00 00	A97	4A9	F	--	--	--	--
22	-32.07989ms	00 00	F06	DFB	6	--	--	--	--
23	-31.22789ms	00 00	27F	C72	C	--	--	--	--
24	-30.37589ms	01 00	532	FB3	A	--	--	--	--
25	-29.52389ms	01 00	B5E	4F5	B	--	--	--	--
26	-28.67189ms	01 00	2B2	4C9	5	--	--	--	--
27	-27.81989ms	10 00	978	1A2	3	--	--	--	--
28	-26.96789ms	11 00	0EC	7FE	2	--	--	--	--
29	-26.11589ms	10 00	694	4B2	3	--	--	--	--
30	-25.26389ms	01 00	B66	3BF	3	07	075	01	--
31	-24.41189ms	10 00	95D	A54	C	Start	--	--	--

For firmware engineers, the Results Table format may be more useful. This time-stamped display of bus activity can be easily compared to software listings, and allows easy calculation of the execution speed.

When the SENT bus contains both fast and slow channel data, the Results Table provides side-by-side readouts of the two data channels. Notice that, since the slow channel data is spread across 18 successive fast channel packets, there are 18 fast channel messages from the start to the completion of the slow channel data message.

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.
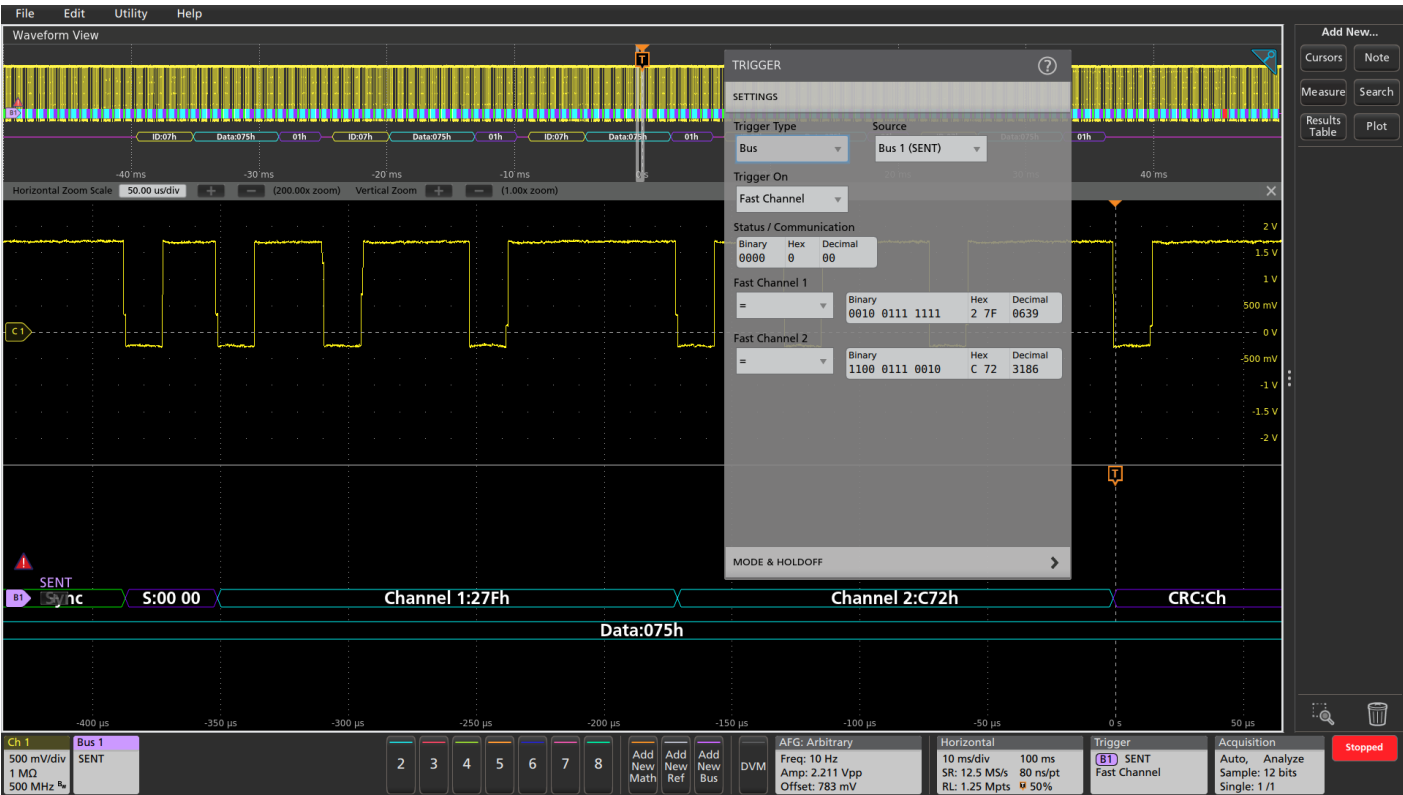
TRIGGERING ON THE SENT BUS

When debugging a system based on one or more serial buses, one of the key capabilities of the oscilloscope is isolating and capturing specific events with a bus trigger. When the bus trigger is correctly set up, the oscilloscope will capture all the input signals and one specified bus event will be positioned at the trigger point. This example demonstrates triggering on status value of 0000 binary, fast channel 1 data value 0x27F, and fast channel 2 data value 0xC72.

TRIGGER ON	DESCRIPTION
Start of Packet	Triggers when sync pulse is detected.
Fast Channel	Triggers when the specified status/communication bit pattern and the specified fast channel data value(s) occur.
Slow Channel	Triggers when the specified message ID bit pattern and the specified slow channel data value occur.
Error	Triggers whenever incorrect CRC values occur.
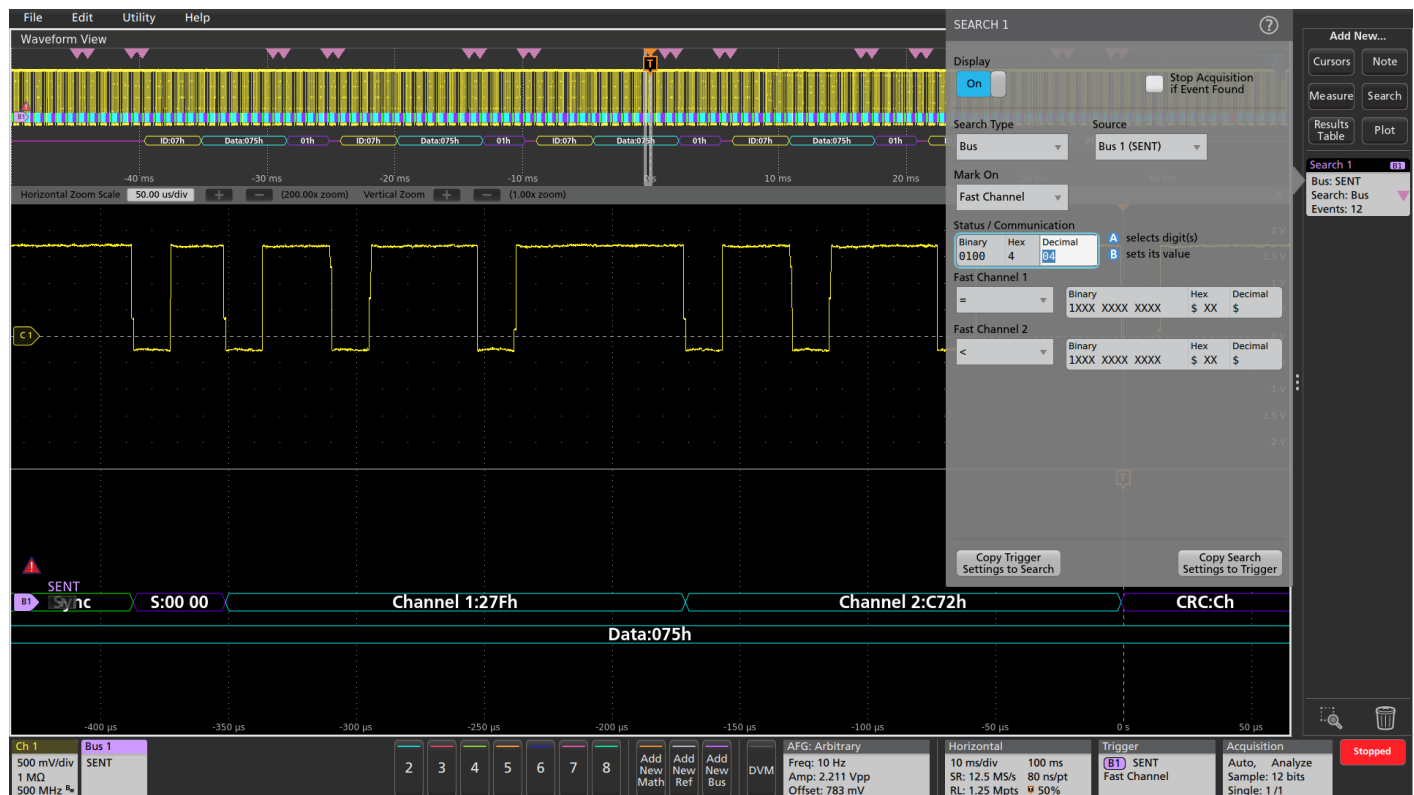
SEARCHING THE SENT BUS

On a Tektronix oscilloscope, you can use the automated Wave Inspector search to find all the bus events that meet search criteria and determine how many of them occurred. The setup is similar to the bus trigger setup, and allows the oscilloscope to find and mark all of the specified bus events. In this example, the automatic search is looking for specified fast channel data values. This data pattern occurs 12 times in the acquired waveforms and the positions of the specified serial data packets are shown with the pink bracket icons.

SEARCH ON	DESCRIPTION
Start of Packet	Marks when sync pulse is detected.
Fast Channel	Marks when the specified status/communication bit pattern and the specified fast channel data value(s) occur.
Slow Channel	Marks when the specified message ID and the specified slow channel data value occur.
Pause Pulse	Marks when a pause pulse of the specified duration occurs.
Error	Marks whenever an incorrect frame length or incorrect CRC value occurs.

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