

# Probing and Triggering on MIL-STD 1553 Serial Bus Signals

## Application Note

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## Introduction

The differential 1-Mbs MIL-STD 1553 serial bus is widely used today in a broad range of aerospace/defense systems including aircraft avionics equipment, space-based systems, as well as many ground-based military vehicles. With the N5469A (or Option 553), Agilent’s InfiniiVision Series scopes (5000, 6000, & 7000 Series) can now trigger, decode, and perform eye-diagram mask testing on MIL-STD 1553 serial bus signals to help you debug and characterize the electrical/physical layer of your system.

Critical to performing these measurements on an InfiniiVision Series scope is using the proper differential probing technique and understanding how to set up trigger conditions so that you can zero-in on specific MIL-STD 1553 “words” for analysis. This application note describes how to connect the differential active probe between the signal-under-test and the oscilloscope in order to trigger on MIL-STD 1553 differential signals with dual-threshold

levels. In addition, this application note describes how to set up the scope to trigger on specific Command Words transmitted from the Bus Controller (BC), Status Words transmitted from various remote terminals (RT), as well as triggering on various error conditions.



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## Probing the MIL-STD 1553 differential bus

The MIL-STD 1553 bus is a differential bus that can have a wide dynamic range of voltage levels depending upon whether testing at a transmitter or receiver test plane. Making measurements on this bus requires that you select the appropriate differential active probe and follow the connection instructions outlined in this application note.

Agilent recommends the N2791A differential active probe for MIL-STD 1553 applications. This differential probe has a rated bandwidth of 25-MHz with a specified input impedance of 8-M $\Omega$ , and can handle a wide dynamic range of signals without damage.

Differential MIL-STD 1553 signals utilize Manchester II bi-phase encoding which requires that signals transition near the mid-point of each bit field. A low-to-high transition translates into a “zero”, and a high-to-low transition translates into a “one”. In addition, signal edges must transition through both an upper and lower threshold level before being interpreted/decoded as either a “one” or a “zero”.

Triggering on and decoding MIL-STD 1553 Manchester-encoded signals requires that the scope be able to also detect dual-threshold signal crossings. But since Agilent’s InfiniiVision scopes utilize single-threshold triggering for each channel of the scope, dual-threshold triggering and decoding is accomplished by feeding the output of the differential active probe into two channels of the oscilloscope — for instance, channel-1 and channel-2. The scope can then qualify its triggering based on a combination of signal conditions present at both inputs of the scope with independent upper and lower trigger level settings.

To feed the output of the N2791A differential active probe into two channels of the scope, connect the BNC output of the probe to a BNC “Tee” using a BNC “barrel”, and then connect two equal-length BNC cables between both output sides of the BNC “Tee” to the channel-1 and channel-2 inputs of the scope as shown in Figure 2. Note that alternatively you can connect to channel-3 and channel-4. Next, connect the “+/-red” input of the differential probe to the “+” side of the MIL-STD 1553 differential bus, and the “-/-black” input of the differential probe to the “-” side of the MIL-STD 1553 differential bus at the desired test plane.

Note that although two channels of the oscilloscope are used for triggering and decoding based on dual-threshold levels, only one channel of the scope needs to be turned on and viewed. If you connect the output of the differential probe into just one channel of the oscilloscope, although you will be able capture and view your MIL-STD 1553 signals using standard edge triggering, the scope will not be able to intelligently decode and trigger on these signals based on the MIL-STD 1553 protocol.



**Figure 12. Agilent recommends the N2791A 25-MHz differential active probe for MIL-STD 1553 applications.**



**Figure 2. Connecting the N2791A differential active probe to two channels of the oscilloscope.**

## Initial trigger and decode setup

Setting up valid dual-threshold levels for triggering and decoding is actually quite easy with the “Auto Setup” feature within the MIL-STD 1553 Serial setup menu of Agilent’s 7000B Series oscilloscopes. After connecting the output of your differential active probe into two channels of the oscilloscope (channel-1 and channel-2 assumed), first make sure to select the “1/10” Attenuation Factor on the N2791A probe; then follow these easy step-by-step instructions:

1. Press the **[Default Setup]** front panel key.
2. Set **Channel-1 V/div** such the highest amplitude signals are vertically scaled approximately 6 to 7 divisions peak-to-peak.
3. Press the **[Serial]** front panel key.
4. Rotate the general-purpose selection knob to select the **MIL-STD 1553** serial bus mode.
5. Press the **Auto Setup** softkey.

When you engage the MIL-STD 1553 “Auto Setup” feature, the scope will automatically do the following:

- Sets the scope’s channel-1 and channel-2 probe attenuation factors to 10:1.
- Sets channel-2 vertical scaling factors (V/div and offset) to match the manually-set channel-1 settings.
- Sets the upper (channel-1) trigger/threshold level to +500 mV.
- Sets the lower (channel-2) trigger/threshold level to -500 mV.
- Turns on MIL-STD 1553 protocol decoding.
- Turns on MIL-STD 1553 triggering.
- Turns off noise-reject triggering.

Assuming that you began setting up this measurement using the scope’s Default setup as suggested above, the scope should now be triggering on the start of any Command or Status Word. If you re-scale the timebase to 5.0  $\mu\text{s}/\text{div}$ , you should observe MIL-STD 1553 protocol decoding on the scope’s display similar to Figure 3. In this case, we can observe an overlay of transmitted and received Command and Status Words (default MIL-STD 1553 triggering mode) while probing near a remote terminal input/output test plane.

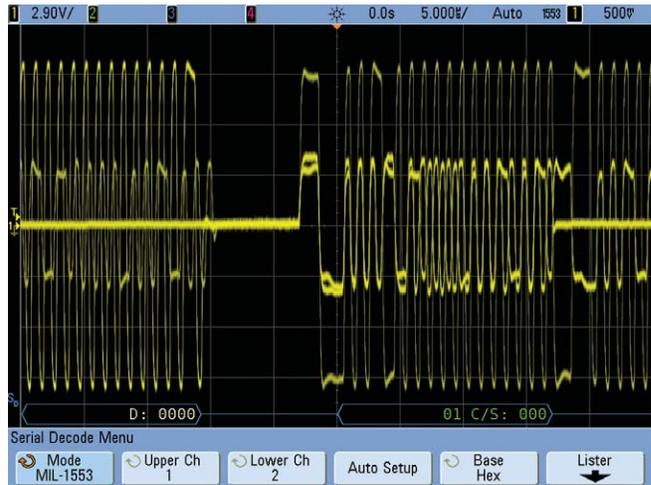


Figure 3. Initial MIL-STD 1553 decode and trigger setup using “Auto Setup”.

## Establishing valid upper and lower trigger/threshold levels

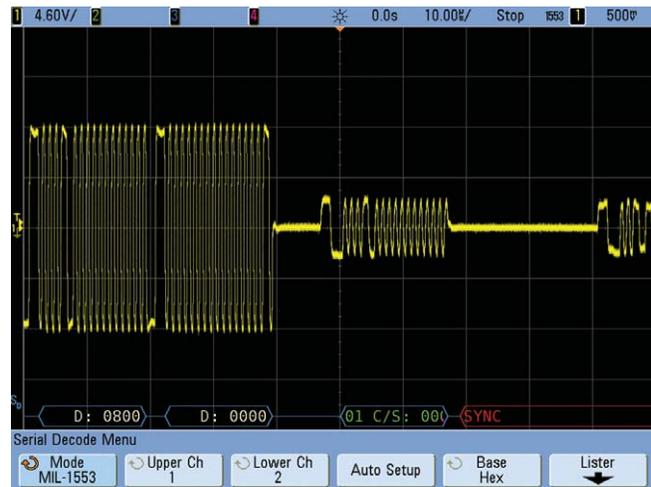
As mentioned earlier, differential MIL-STD 1553 signals can have a wide dynamic range of amplitude levels due to transmission line effects, as well as signal level reductions induced by transformer coupled networks. When probing at a particular test plane, such as at the input/output of a remote terminal, you will observe high-level output signals generated by that remote terminal, as well as lower-level input signals generated by other terminals in the system. If it is important to observe the higher-level output signals, then the scope's optimum vertical settings to observe these signals may not be the optimum settings to also trigger on and decode the lower-level input signals.

Figure 4 shows an example where the scope has been scaled to display the output signals (higher level) for approximately 4 divisions of peak-to-peak deflection, which may be an appropriate setting for viewing the output (higher level) signals. But at this setting, the input signals (lower level) are displayed with just 1 division of peak-to-peak deflection. This is insufficient deflection for reliable MIL-STD 1553 oscilloscope triggering and decoding. In this case, we observe an erroneous "Sync" error that wasn't actually present in the system.

One possible solution is to manually "tweak" the upper and lower threshold levels until the erroneous decoded errors are eliminated. The ideal upper trigger/threshold level is approximately 1/3 division above the idle level, and the ideal lower trigger/threshold level is approximately 1/3 division below the idle level.

You can adjust the upper threshold level by pressing the **Upper Ch** softkey and then adjust the trigger level knob. After setting the upper level to approximately 1/3 division above the idle level, note the absolute trigger level setting (in volts) displayed in the upper right-hand corner of the display. Then press the **Lower Ch** softkey and adjust the trigger level knob until the absolute lower trigger level (Ch2) is the opposite polarity of the upper (Ch1) setting. For instance, if you manually adjusted the upper threshold level to +650 mV, then you should manually adjust lower threshold level to -650 mV.

If the signal swing (deflection) of the lower-level signals (input) are less than approximately 2 divisions peak-to-peak, then it may not be possible to establish a stable /reliable threshold level for triggering and decoding these lower-level input signals by simply "tweaking" the upper and low threshold levels.

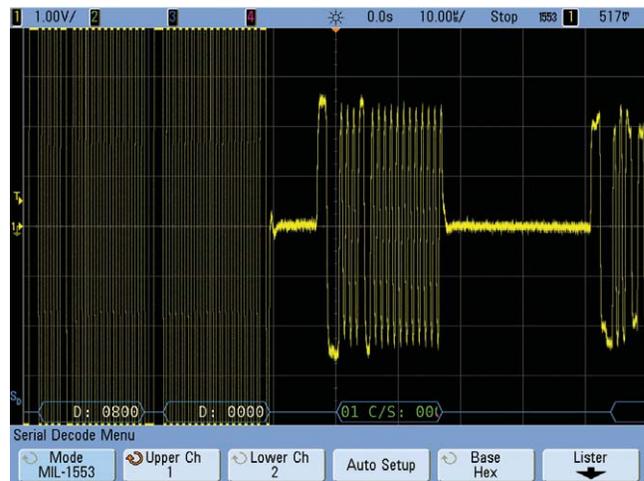


**Figure 4. Insufficient signal swing produces erroneous "Sync" error.**

## Establishing valid upper and lower trigger/threshold levels

Another possible solution to establish reliable triggering and decoding on the lower-level signals is to re-scale the scope's channel-1 V/div setting to optimally scale the lower-level input signals for more deflection — to perhaps 4 division peak-to-peak. This will mean that the higher-level output signals may be scaled off-screen. But if you are primarily interested in performing measurements on the lower-level input signals anyway, then even though the higher-level output signals will be scaled off-screen, the scope will still be able to trigger on and decode both the higher- and lower-level signals as shown in Figure 5. However, you will not be able to perform parametric measurements, such as rise time and V p-p, on the higher-level output signals since they will have been “clipped” by the scope's limited dynamic range of its ADC system. Also, if you re-scale channel-1 vertical settings, don't forget to either manually re-adjust channel-2's vertical settings, or simply press the Auto Setup softkey again.

We can now see in Figure 5 that the Data Words that preceded the Status Word (RTA = 01) were properly decoded even though the peaks of these words were scaled off-screen. But at least now the lower-level input signals at this particular remote terminal have sufficient deflection for reliable triggering and decoding — and we no longer see the erroneous “Sync” errors. In addition, at these vertical settings we can now perform more accurate analog parametric measurements on our received/input signals.



**Figure 5. Re-scaling V/div to establish more reliable triggering and decoding on received/input signals.**

## Triggering on specific Command & Status Words

Without “intelligent” MIL-STD 1553 triggering, it can be difficult-to-impossible to set up a conventional analog or digital oscilloscope to synchronize acquisitions/sweeps on specific MIL-STD 1553 Words and/or messages. And when characterizing an active MIL-STD 1553 system, rarely is an external synchronization signal available to use as an oscilloscope external trigger source.

When using a standard edge crossing trigger condition, which is basically all that is available on most standard oscilloscopes, the resultant oscilloscope display will show a repetitive overlay of all input and output Words (Data, Command, and Status) as shown in Figure 6. But if you need to perform parametric testing, such as transition times, voltage swing, etc., to confirm that your system meets minimum input and/or output specifications, you need to use a scope with “intelligent” MIL-STD 1553 triggering so that you can easily “zero-in” on specific input or output Words and/or messages for analog characterization.

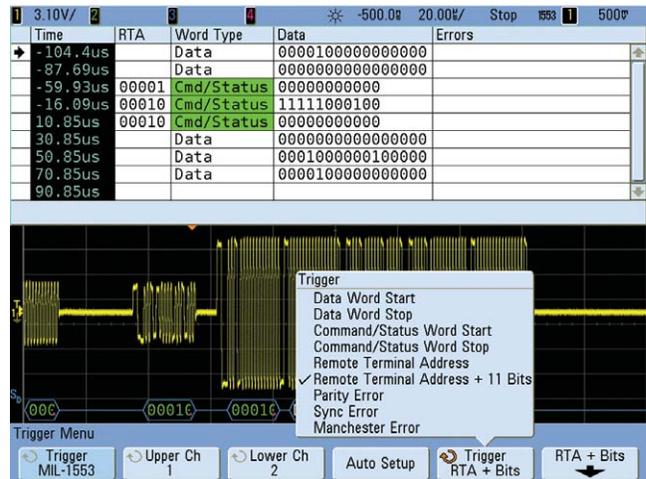


**Figure 6. Conventional oscilloscope edge triggering fails to isolate specific input/output Words and messages for analog parametric characterization**

Agilent’s InfiniiVision Series scopes provide a wide range of “intelligent” MIL-STD 1553 triggering possibilities when licensed with the MIL-STD 1553 trigger and decode option (N5466A) as shown in Figure 7. The range of possible MIL-STD 1553 triggering modes includes:

- Data Word Start
- Data Word Stop
- Command/Status Word Start
- Command/Status Word Stop
- Remote Terminal Address
- Remote Terminal Address + 11 Bits
- Parity Error
- Sync Error
- Manchester Error

In addition to being able to trigger on three different types of specific error conditions (Parity, Sync, & Manchester), one of the most useful triggering modes is the “Remote Terminal Address + 11 Bits” mode. With the “RTA + 11 Bits” triggering mode, you can set up the scope to trigger on specific Command or Status Words in order to isolate measurements on specific types of Words and message transfers.



**Figure 7. InfiniiVision’s MIL-STD 1553 triggering modes**

## Triggering on specific Command & Status Words

If you need to measure the analog characteristics of received/input signals while probing at a specific remote terminal, you will need to set up the scope to trigger on either Command Words generated from the bus controller, or trigger on Status Words generated by other remote terminals in the system. Unfortunately, the protocol structure of Command Words and Status Words are very similar. They both begin with a 3-bit sync field based on the same high-to-low transition. Although the MIL-STD 1553 protocol specification includes an instrumentation bit (bit #10), use of this bit to differentiate between Command and Status Word is optional and is often not used in today's systems because it limits the number of available sub-addresses.

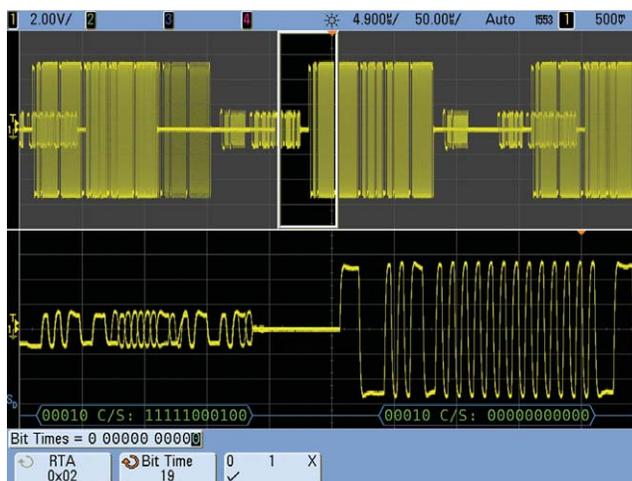
In addition to being able to specify remote terminal addresses (RTA) to qualify triggering on, Agilent's InfiniiVision Series scopes also allow you to specify the contents of the 11 bits that follow the RTA field (bits #9 through #19). Using this field for additional trigger qualification can be critical for setting up the scope to trigger on specific transmit or receive Command Words, or to trigger on specific Status Words.

Figure 8 shows an example of the scope setup to trigger on a Command Word received from the BC while probing at the input/output test plane of remote terminal #2. In this example, the RTA was set to qualify on "2", while the following 11 bits were set to qualify on "1 11110 XXXXX". The first "1" in this 11-bit string is the transmit/receive bit (bit #9). So in this case, we've specified to trigger on a transmit condition. The next five bits (11110) is the sub-address field (bits #10 through #14). So in this case, we specified to trigger on a sub-address equal to 30 (decimal). We've set the data word count/mode code bits (bits #15 through #19) to all don't cares. With the scope triggering on this condition, not only can we see the lower-level input Command Word that we are triggering on, but we can also see the following higher-level output Status Word response from the remote terminal (#2).

Figure 9 shows an example of scope setup to trigger on a responding Status Word. In this example, the RTA was again set to qualify on "2", while the following 11 bits were set to all zeros (0 00000 00000).



**Figure 8. Setting up the scope to trigger on a specific Command Word with the transmit bit set.**



**Figure 9. Triggering on an output Status Word from remote terminal #2.**

## Triggering on error conditions

Another powerful triggering tool that can enhance your ability to debug MIL-STD 1553 systems is the ability to setup the scope to trigger on specific error conditions. Agilent InfiniiVision Series scopes with the MIL-STD 1553 trigger and decode option can trigger on “Sync Errors”, “Parity Bit Errors”, and “Manchester Encoding Errors”. Figure 10 shows an example of a “Sync” error trigger. In this case, the “high time” and “low time” of the sync field failed to meet the 1.5 bit time requirement.



Figure 10. Triggering on a “Sync” error condition

Figure 11 shows an example of triggering on a Parity Bit error. In this case, the polarity of the parity bit of a transmitted Data Word was the opposite polarity of what it should have been based on the content of the Word.

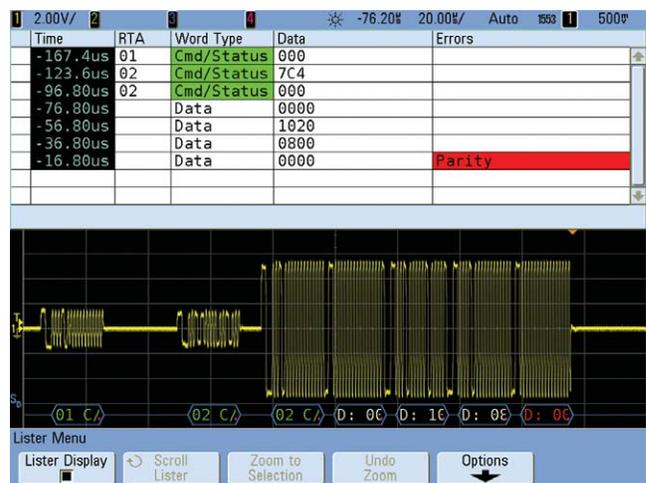


Figure 11. Triggering on a “Parity” error condition.

Figure 12 shows an example of triggering on a Manchester encoding error. In this case, a particular bit within this Word failed to contain an edge transition during the middle of its bit time.

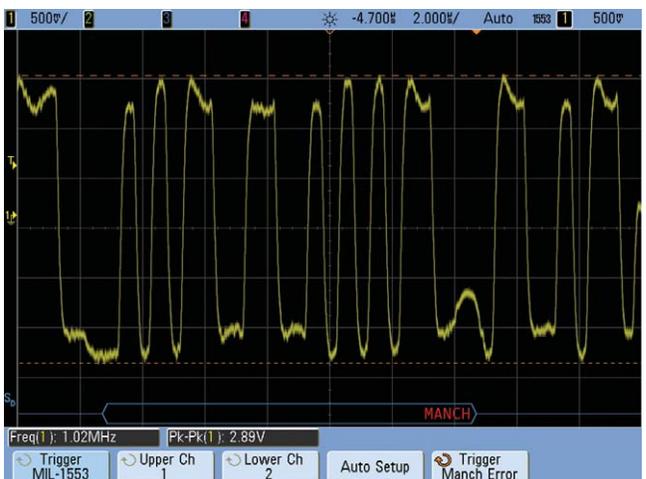


Figure 12. Triggering on a “Manchester” encoding error condition.

## Summary

Characterizing the signal integrity of MIL-STD 1553 systems can be greatly enhanced by using an oscilloscope with built-in MIL-STD 1553 protocol decoding and triggering. When licensed with the N5469A (Option 552) trigger and decode option, Agilent's InfiniiVision Series oscilloscopes (5000, 6000, & 7000 Series) can trigger on and perform analog

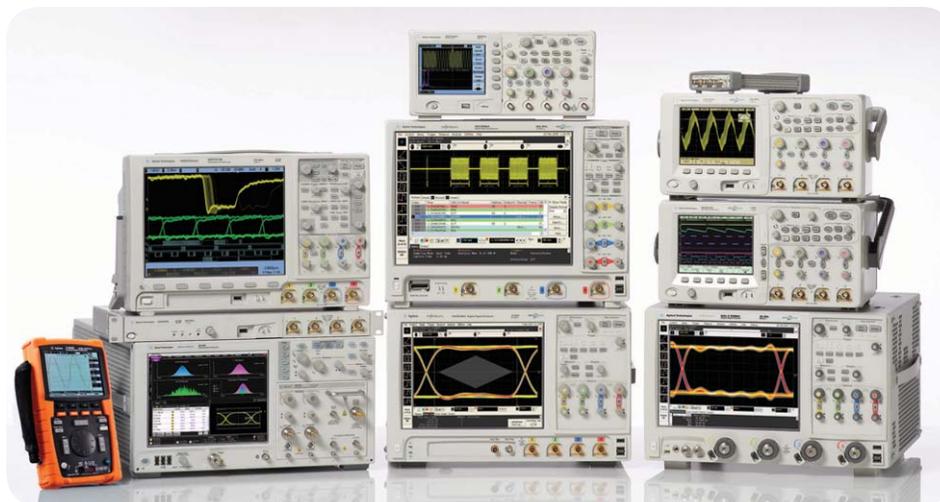
parametric measurements on specific types of MIL-STD 1553 Words and messages. For probing MIL-STD 1553 differential signals, Agilent recommends using the N2791A 25-MHz differential active probe connected to two input channels of an InfiniiVision Series oscilloscope as outlined in this application note.

## Related literature

Publication title	Publication type	Publication number
<i>MIL-STD 1553 Trigger and Decode Option</i>	Data sheet	5990-4924EN
<i>Agilent 7000B Series InfiniiVision Oscilloscope</i>	Data sheet	5990-4769EN
<i>Agilent 6000 Series InfiniiVision Oscilloscopes</i>	Data sheet	5989-2000EN
<i>Agilent 5000 Series InfiniiVision Oscilloscopes</i>	Data sheet	5989-6110EN
<i>N2791A 25-MHz Differential Active Probe</i>	Data sheet	5990-3780EN
<i>Evaluating Oscilloscopes for Best Waveform Update Rate</i>	Application note	5989-7885EN
<i>Evaluating Oscilloscope Bandwidths for your Applications</i>	Application note	5989-5733EN
<i>Evaluating Oscilloscope Sample Rates vs. Sampling Fidelity</i>	Application note	5989-5732EN
<i>Evaluating Oscilloscope Vertical Noise Characteristics</i>	Application note	5989-3020EN

To download these documents, insert the publication number in the URL: <http://cp.literature.agilent.com/litweb/pdf/xxxx-xxxxEN.pdf>

For the most up-to-date and complete application and product information on Agilent's InfiniiVision Series oscilloscopes, please visit our product Web site at: [www.agilent.com/find/7000](http://www.agilent.com/find/7000)



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