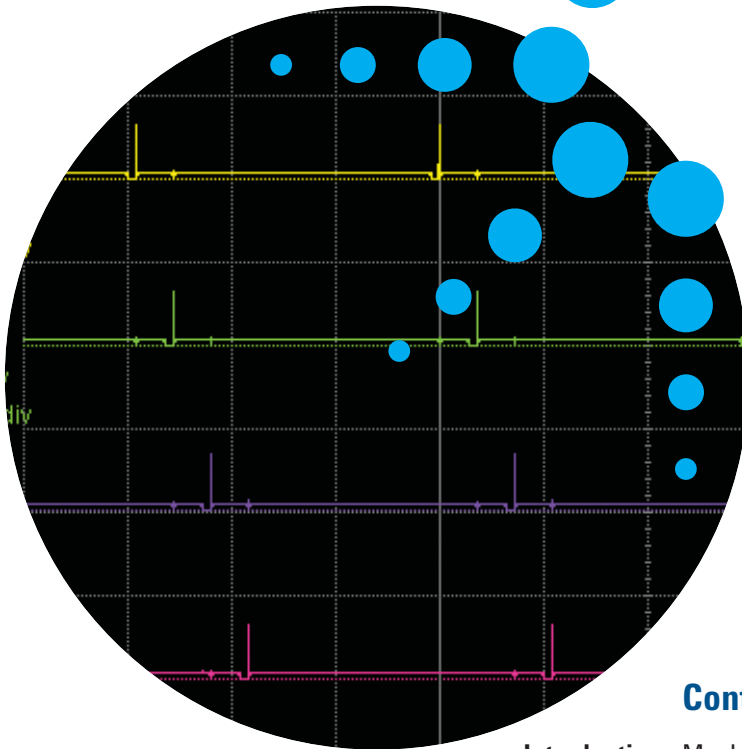
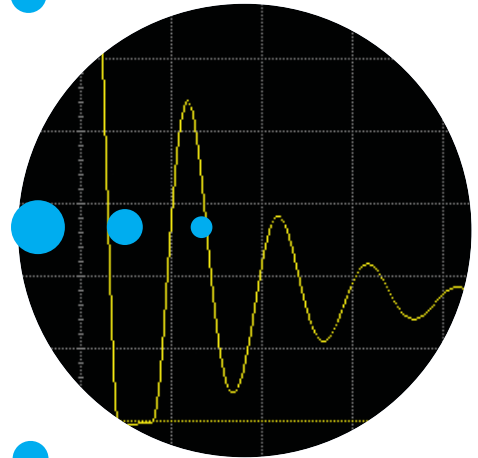
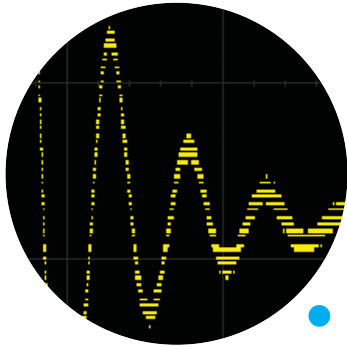


Testing Mechatronic Power Drivers Using the Agilent L4532A/L4534A Digitizer

Application Note



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Agilent Technologies

Introduction

Modern transportation, aerospace/defense and industrial control products all use electronics and software to manage motion control. These electronic-mechanical systems rely on electronic control units (ECUs) to control the surrounding mechanical environment by driving mainly inductive power loads, (solenoids, motors, lamps and relays) in very harsh electrical environments. ECUs generally use power MOSFET or IGBT output drivers to control the loads.

To fully test these high-power drivers, you need to use special measurement techniques with instrumentation that is up to the challenge. Wide voltage ranges and fast rise times are just some of the challenges these drivers present.

Because these power drivers typically are linked to product safety or performance, you must conduct significant design validation testing before you turn the product over to

manufacturing. And in the manufacturing environment, the high volume of many of these applications makes high test speed paramount.

To help you with these measurement challenges, Agilent Technologies has introduced the L4532A and L4534A 20-Msa/s, 16-bit high-voltage digitizers. These digitizers are optimized for high-speed, accurate, high-voltage measurements. This application note will describe key characteristics of these digitizers that will help you successfully solve your mechatronic control test challenges.

Overview: Measurement challenges

As an example, we will demonstrate ways to test the output drivers of an engine control unit with four fuel injector solenoid drivers (Figure 1a). To meet the performance and emissions targets of the engine, the

fuel injectors must inject a precise amount of fuel into each cylinder. A common drive configuration consists of *low-side solenoid drivers*. In this case, there are four drivers and corresponding injectors. The injector outputs fire sequentially, as expected for an internal combustion engine (Figure 1b).

These drivers are low side (that is, they pull the low side of the fuel injector to ground to turn them on), so the “off state” of the solenoid driver is at V_{batt} and the on-state is near ground. A large inductive flyback voltage occurs when the injector driver turns off. When the magnetic field of the driver collapses, the energy is dissipated in the large voltage flyback. The speed with which the magnetic field collapses, and hence the switching speed of the injector, is proportional to the voltage of the flyback. As a result, it is common to see high flyback voltages for high-speed solenoid drivers. In this case, the flyback voltage is 165 V.

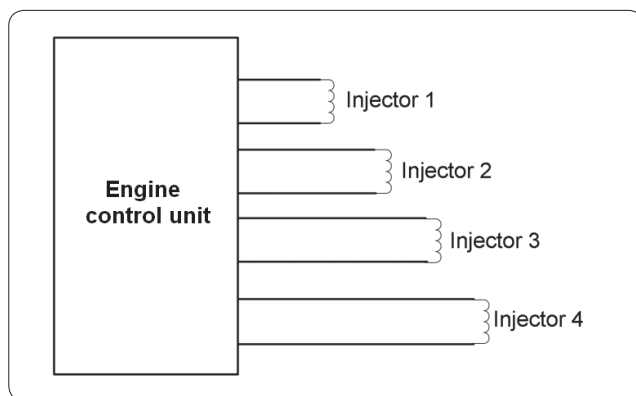


Figure 1a. Engine control unit

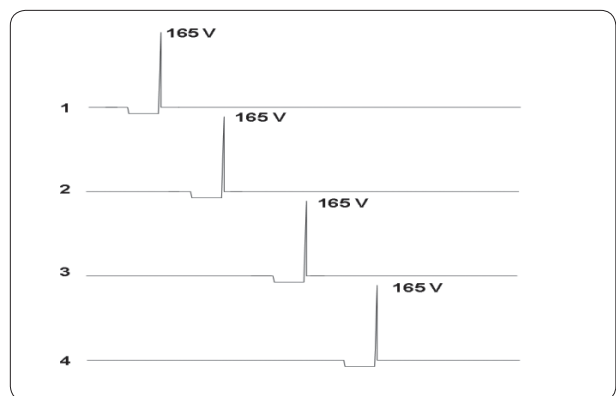


Figure 1b. Fuel injector drive signals

The anatomy of the injector driver is shown in Figure 2a. Key attributes include V_{on} , $V_{flyback}$, t_{on} , t_{pw} and the frequency of ringing, as shown in Figure 2b. Our challenge is to measure these attributes for the four fuel injector drivers as fast and as accurately as possible. We will use the Agilent L4534A 20-Msa/s digitizer to make these measurements. The following L4534A characteristics will make the job easier:

- ± 256 V input range allows direct measurement of the high-voltage pulses.
- 16 bit dynamic range combined with low channel input offsets allows us to measure both the V_{dson} and the $V_{flyback}$ pulse with a single capture.
- Segmented memory and fast rearm times enable us to record many pulses while ignoring inactive periods in between the pulse events.

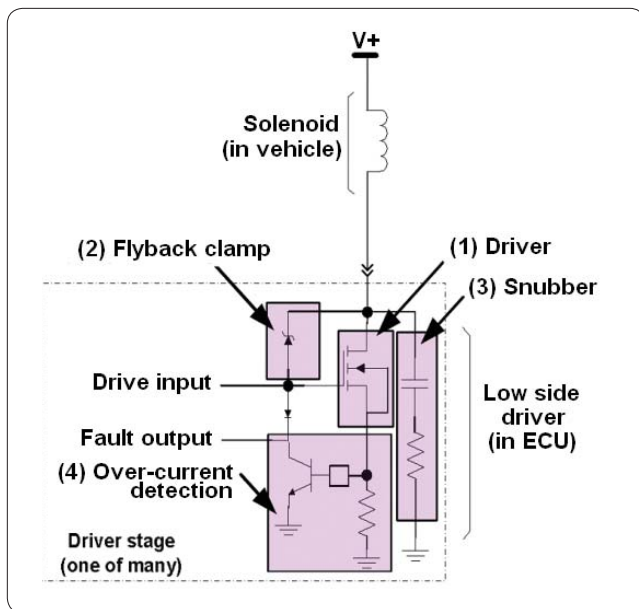


Figure 2a. Anatomy of fuel injector driver

- 32-megasample/channel (optional 128-megasample/channel) deep memory allows us to capture long, detailed waveform events.
- Flexible multi-channel triggering allows various events to initiate waveform acquisition.
- Built-in digitizer on-board measurements simplify returning key waveform attributes.
- The L4534A's built-in LXI interface helps reduce test development and debug time.

The graphical waveform shown in Figure 2b gives you qualitative information. However, for design validation and manufacturing, real

parametric results are required for full statistical characterization and pass/fail decisions. Let's focus on methods to measure the following signal attributes:

- V_{dson} (verify proper nMOSFET V_{dson})
- V_{pk} - flyback voltage peak (verify flyback clamp level)
- Turn on time of the solenoid driver t_{on} (verify pre-drive stage)
- Pulse duration of the flyback t_{pw} (verify solenoid turn off time)
- Frequency of ringing at the end of the flyback pulse (verify correct snubber operation)

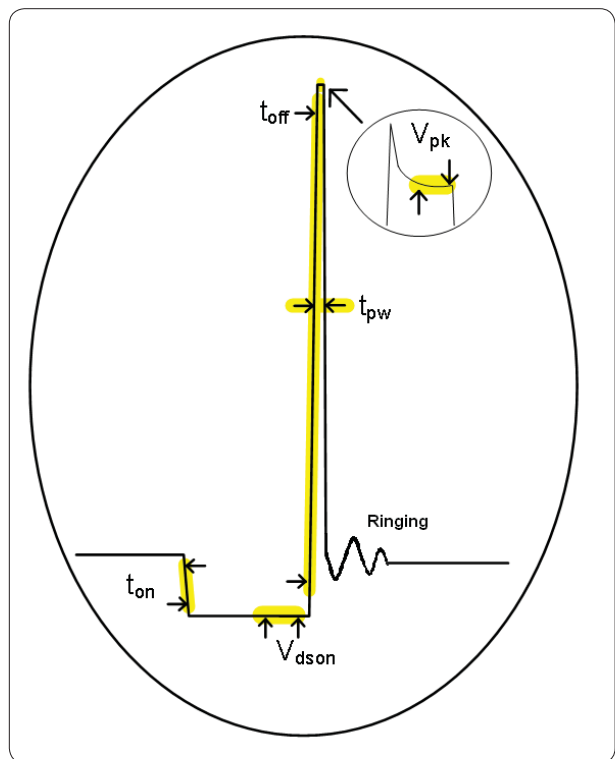


Figure 2b. Key driver attributes to measure

Most engineers have used an oscilloscope for various waveform measurements, and the tendency is to want to use a scope to make these types of measurements. However, for precise parametric results, a high-resolution digitizer works best. Consider the waveforms displayed in Figure 3. Figure 3a is from a typical 8-bit oscilloscope and Figure 3b is from the L4534A 16-bit digitizer. In both cases the instruments are set to similar input ranges and display a single triggered capture. Notice the individual quantization levels in the scope waveform shown in Figure 3a. The L4534A is uniquely suited for these parametric measurements because of its high resolution and accuracy.

Configuring the digitizer: Using the LXI interface as a development tool

An easy way to program the digitizer is to use the LXI Web interface. Regardless of your preferred software control environment, using the LXI Web interface will speed up your programming tasks by giving you an example set of configuration and measurement commands to work from.

To start the Web interface, connect the LAN cable from the PC to the digitizer, observe the LAN IP address on the L4534A front panel and type the IP address into the Web browser to get the L4534A home page (see digitizer *User's Guide, Getting Started* section for assistance).

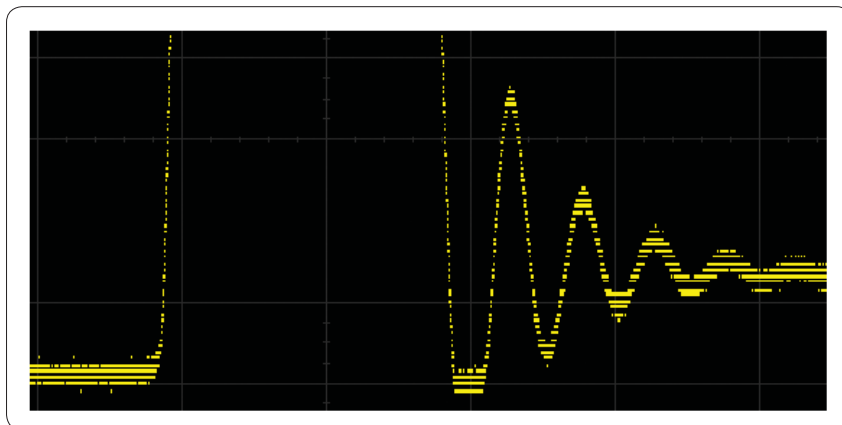


Figure 3a. 8-bit scope waveform capture. Single capture, ± 200 V range (w/probe)

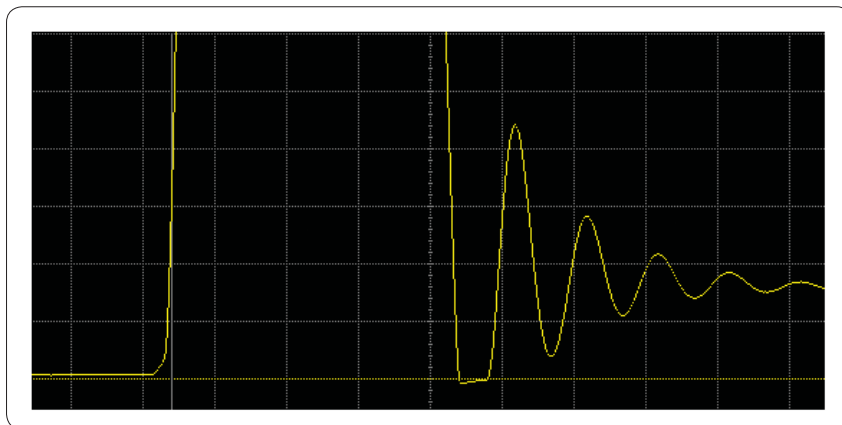


Figure 3b. 16-bit L4534A waveform capture. Single capture ± 250 V range

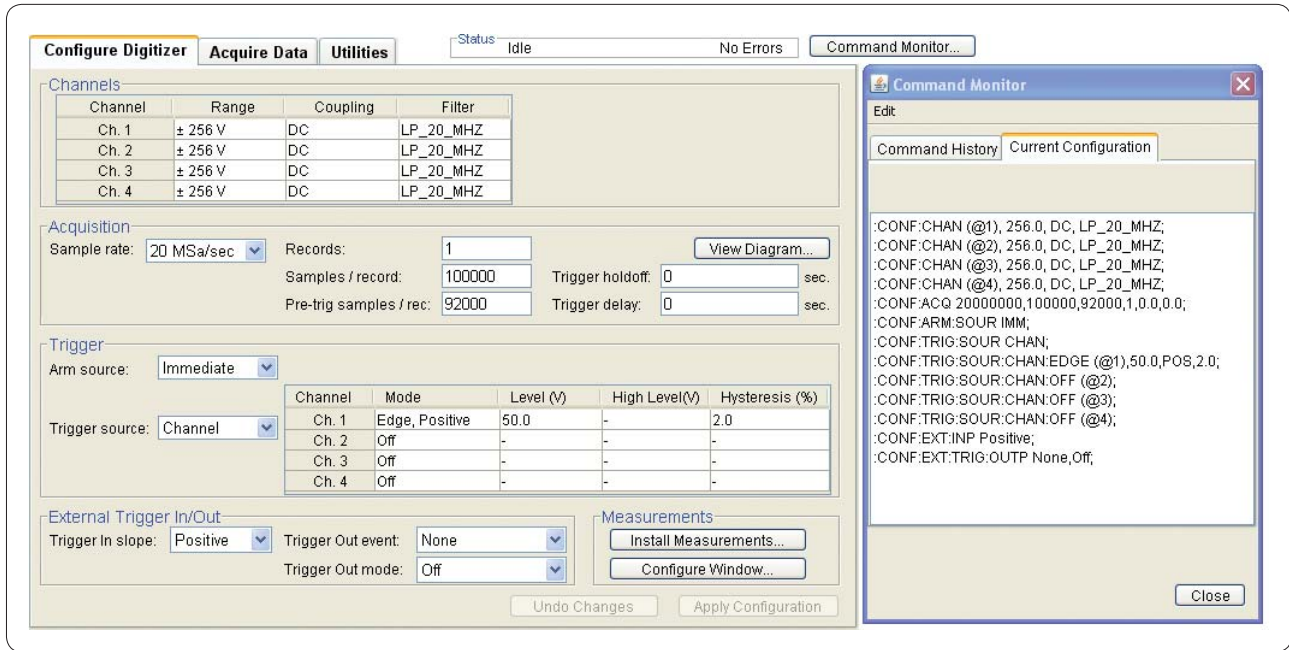


Figure 4. Configuration settings and commands for capturing one solenoid driver channel

Now we can use the LXI Web interface to set up and make our initial measurements. You can use the LXI Web interface **Configure Digitizer** tab to set up the measurements. See Figure 4 for the following discussion.

First we need to select a unique trigger reference on which we can base all of our measurements. In this case, the 50 V rising edge of the flyback pulse is a good trigger point to use. We can use the 50 V rising edge as a specific time from which we can precisely set measurement windows.

Next we need to sample enough points to capture all of the waveform. Since the 50 V edge will be used as the trigger reference, there are many data points *prior* to the trigger that we want to capture. To do this we will use a “pre-trigger” count. We will capture a total of 100,000 samples at 20 Msa/s (capture duration = 5 Msa). Of the 100,000 samples, 92,000 samples will be pre-trigger data and 8000 will be post-trigger data.

Now let’s demonstrate a unique advantage of using the L4534A LXI interface. Press the **Command Monitor** button (upper right of window) to open the Command Monitor window. The **Current Configuration** window displays the digitizer instrument commands representing the current setup. You can think of these commands as a “custom” programming example that can be copied and pasted directly into your test control software.

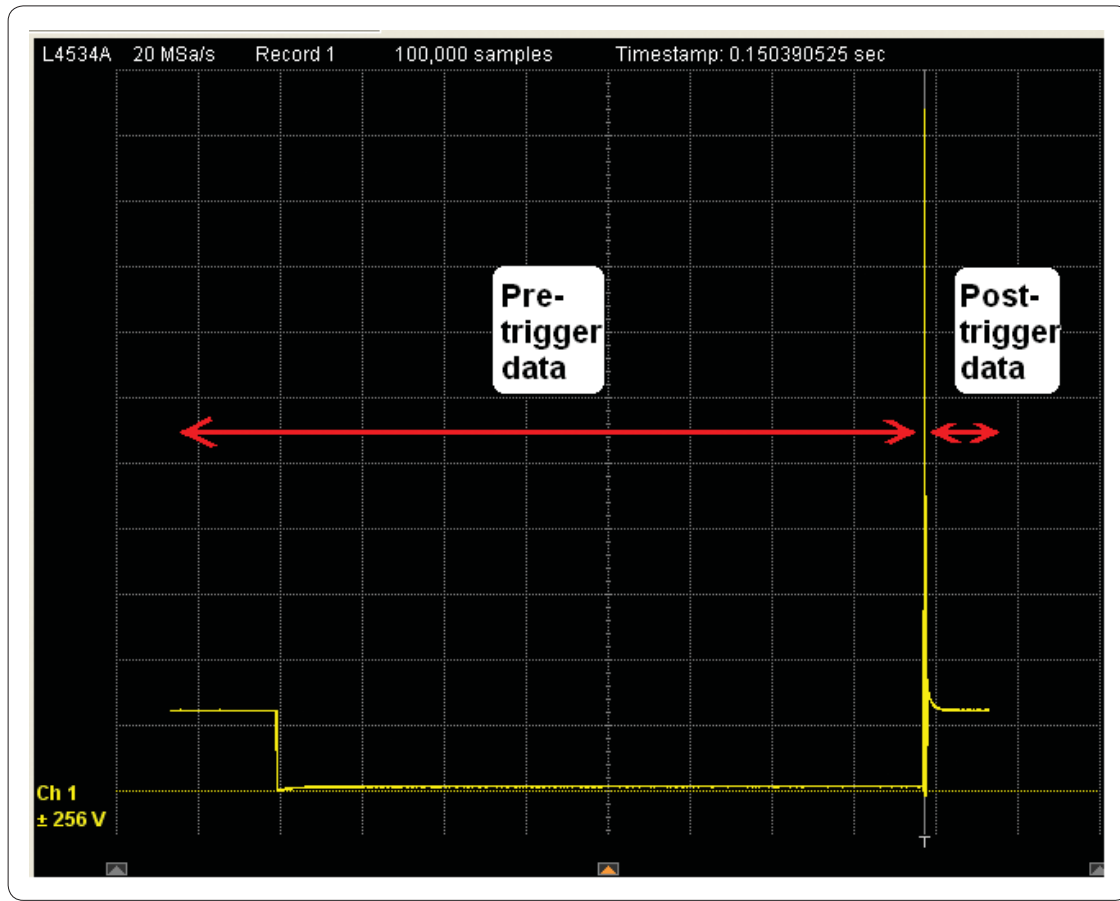


Figure 5. Solenoid driver output (single channel), driving an inductive fuel injector load

Capture and view the waveform: Determine correct measurement windows

Once the digitizer configuration is set, select the **Acquire Data** tab to trigger and acquire the waveform data. Pressing the **Run Once** button will

trigger the digitizer at the next 50 V rising edge; the resulting waveform capture is shown in Figure 5.

Zoom in on the high-voltage flyback portion of the waveform as shown in Figure 6. The A and B markers show the area of the high-voltage flyback where we need to focus our attention. In large extended test systems there are generally long cable runs

that contribute cabling inductance and noise. By selecting the waveform data between the markers as shown, we can get a better measurement of the flyback pulse by averaging out the noise of the test system, as well as sampling the peak *after* any system overshoot (if present) has settled.

Now use the LXI Web interface to return a measurement from the waveform. Set the markers to **Manual** and select the area of the flyback as shown in Figure 6. To add the VAV measurement to channel 1, press the **View Measurements** button to open the **Installed Measurements** window, and press **New...** . Select the **Vave** measurement and set the **Area** to **Window**. Press the **OK** button

to close the window. Finally, press the measurement window **Set to Markers** button to set the window correctly for the average voltage measurement. In this case, the L4534A returned a value of 164.68 volts.

Now that we've seen how a measurement is made using the Web browser, let's see what the corresponding command sequence would be to get the same results.

The software command to set the window and query the VAV results is:

```

Set window >> MEAS:WIND:DEF 50,100
Query average voltage>> MEAS:VAV? (@1), WIND
    
```

Likewise, we can set the appropriate window and query the built in measurements for the other desired parameters, as shown in Figure 7.

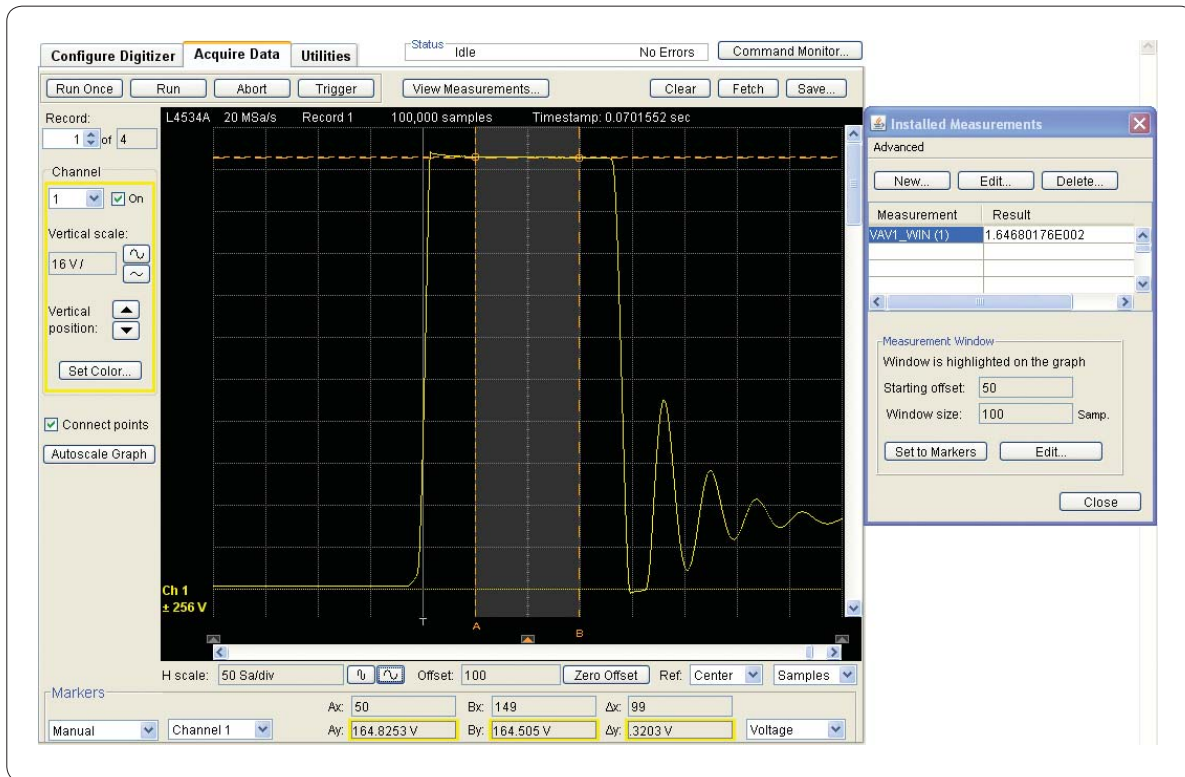
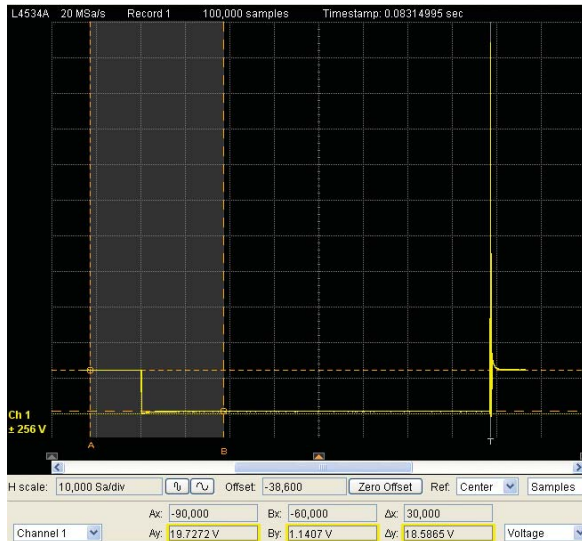
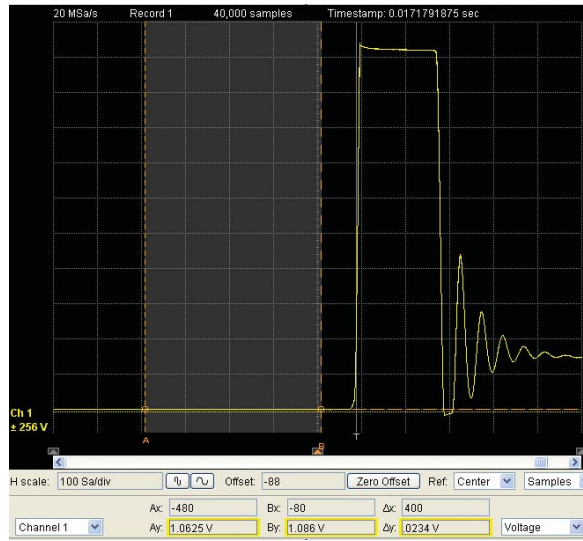


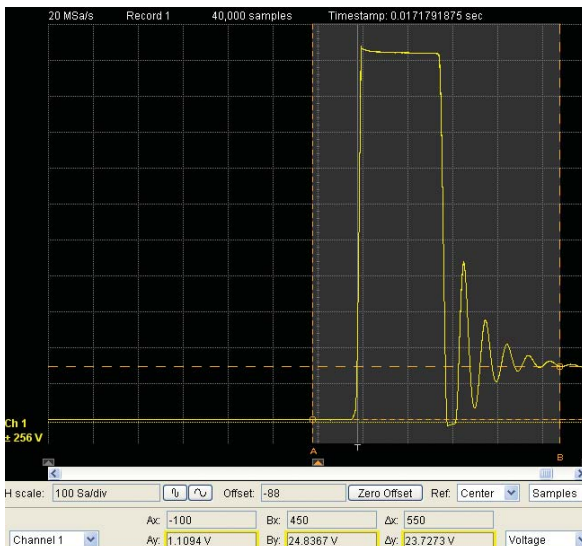
Figure 6. Setting window and average voltage (VAV) result for voltage measurement



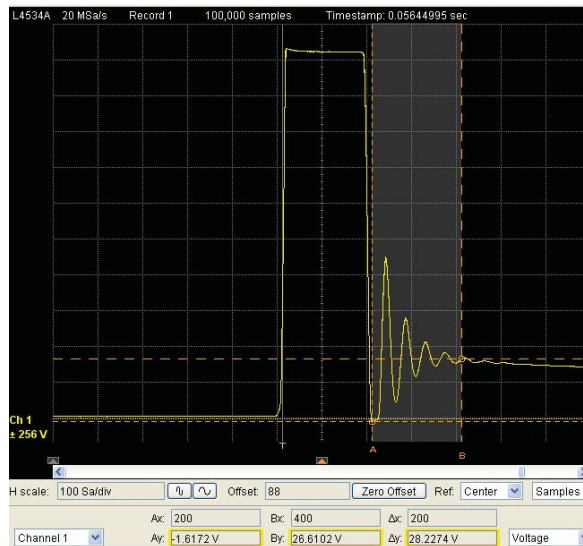
(a) Window for t_{on} time
MEAS:WIND:DEF -9000, 30000



(b) Window for V_{dson} voltage measurement
MEAS:WIND:DEF -480, 4000



(c) Window for t_{pw} time measurement
MEAS:WIND:DEF -100, 550



(d) Window for ringing frequency measurement
MEAS:WIND:DEF 200, 200

Figure 7. Determine the appropriate windows for measurements of interest

Using the LXI Interface to view and determine the correct windows makes it a simple matter to configure the digitizer to return the attributes of interest. To the right are the commands for the various built-in measurements we will use for examples. See the programmers guide for additional assistance.

```
MEASure:VAVerage[:VERBose]? (@<channel>)[,<mode>][,<rec_num>]
MEASure:FALL:TIME[:VERBose]? (@<channel>)[,<num_edge>][,<rec_num>]]
MEASure:PWIDth[:VERBose]? (@<channel>)[,<num_pos_pulse>][,<rec_num>]]
MEASure:RISE:FREQuency[:VERBose]? (@<channel>)[,<num_edge>][,<rec_num>]]
```


When you measure voltage values such as average voltage (VAV), it is simple enough to specify the window of interest. However, when measuring timing events such as t_{on} (Figure 7a), pulse width t_{pw} (Figure 7c) or ringing frequency (Figure 7d), you will also need to determine proper edge threshold levels.

You can use different methods to determine edge thresholds.

Standard method with percent

The L4534A can calculate a waveform top and base, and you can specify the threshold to be a percent of that calculated top and base. The L4534A calculates the top and base on the *mode* (most common) top and base value. For simple waveforms such as pulses and sine waves, this method works well. The detected edges are calculated as a percent of the top and base.

Absolute method

For more complicated waveforms, you can specify an absolute top and base value, as well as the specific threshold values. For example, in cases where there are decaying sine waveforms and other unique waveforms, the top and base may be difficult to calculate. It may be best to simply specify an absolute value for edge detection in these cases.

For the t_{on} and t_{pw} measurements, the standard method with percent will work well. The programming commands for the standard method are:

```
Declare Percent levels>> MEAS:THR:METH (@1), Percent
Specify the levels to use>> MEAS:THR:PERC (@1), 90.0, 50.0, 10.0
```

Since the ringing waveform shown in Figure 7d is decaying, it is best to specify the absolute method levels to use. In this case it is appropriate to set the thresholds ~ 20 volts. The levels are set using the following commands:

```
Declare Absolute levels>> MEAS:THR:METH (@1), Absolute
Specify the levels to use>> MEAS:THR:ABS (@1), 21.0, 20.0, 19.0
```

Table 1 lists the commands, and the associated results for the complete flyback pulse measurement.

Because the reference is 50 volt rising edge, the placement of the various measurement windows will be consistent and correct every time.

Also, keep in mind the 16-bit resolution and low offset of the L4534A input stages. The high resolution and accuracy allows for measurements of the high flyback voltage (Figure 4: ~165 volt) and the low V_{dson} voltage of the drivers (Figure 7b: ~1 volt) in a single waveform capture. The results are “real” values that can be used for statistical analysis as well as pass/fail determinations.

Table 1. Programming commands and results for single-channel measurement

! Setup Channel ranges		
CONF:CHAN (@1), 250, DC, LP_20_MHZ		
! Setup timebase & trigger		
CONF:ACQ 20000000,100000,98000,1,0,0,0,0		
CONF:ARM:SOUR IMM		
CONF:TRIG:SOUR CHAN		
CONF:TRIG:SOUR:CHAN:EDGE (@1),50,POS,2,0		
MEAS:THR:RESET(@1)		
SYST:ERR?	+0, "No error"	
! Start Acq		
INIT		
*OPC?	1	
! Query OBM for $V_{flyback}$ peak		
MEAS:WIND:DEF 50, 101		
MEAS:VAV? (@1), WIND, 1	164.795	Volts
! Query OBM for V_{dson}		
MEAS:WIND:DEF -480, 400		
MEAS:VAV? (@1), WIND, 1	1.112	Volts
! Query OBM for T_{pw}		
MEAS:WIND:DEF -100, 550		
MEAS:PWID? (@1),1,1	9.48E-06	Seconds
! Query OBM for T_{on}		
MEAS:WIND:DEF -90000, 30000		
MEAS:FALL:TIME? (@1),1,1	9.93E-08	Seconds
! Set edge thresholds to absolute		
MEAS:THR:METH (@1), Absolute		
MEAS:THR:ABS (@1), 25.0,24.0,23.0		
! Query OBM for ringing frequency		
MEAS:WIND:DEF 200, 200		
MEAS:RISE:FREQ? (@1),1,1	3.85E+05	Hertz

Using segmented memory: Capturing multiple channels

For test purposes, this ECU generates a test pattern, with all four injectors fired sequentially, as shown in Figure 8. The goal of this section will be to capture all four solenoid driver pulses as they are generated by the ECU, and use the on-board measurements to return attributes as previously done in the single-channel case.

The L4534A supports segmented memory, which means the digitizer can be set up to accept multiple waveform captures, and each waveform capture can be placed into its own memory space. This example shows how to divide the waveform memory into four segments (records).

We will configure the L4534A to capture one record of data for each 50 V trigger event and place it into segmented memory, as shown in Figure 9.

The L4534A will be set to start acquisition when a trigger event is detected on *any of the channels*. This is important to note, since once the digitizer is armed and the ECU sequential outputs begin, the first trigger received will be from channel 1, the waveforms will be captured (from all four channels) and placed into record 1. The next trigger will be

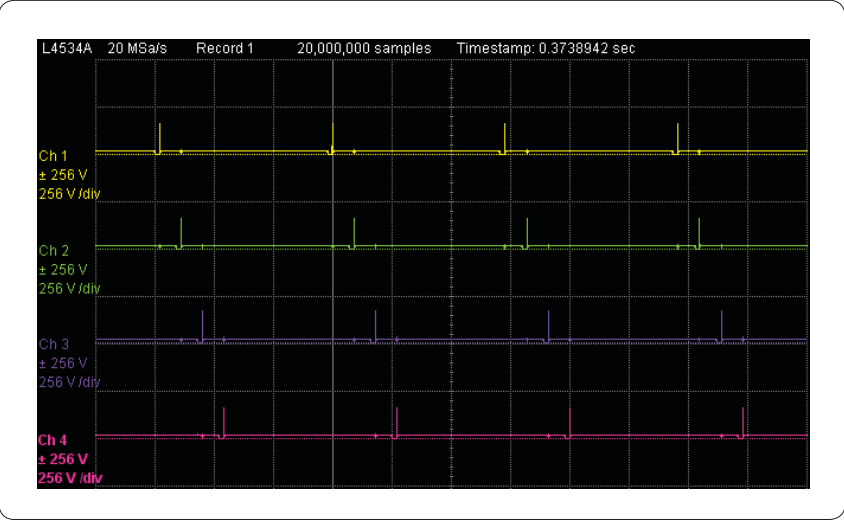
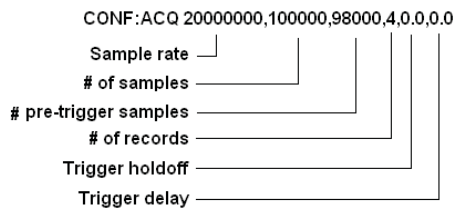


Figure 8. Sequential fuel injector driver outputs from ECU. Note 256 V/div scale

from channel 2 and waveforms will be placed into record 2 and so on. The injector drive output for each of the injector driver channels will be captured in its corresponding record, as shown in Figure 9.

Setting up for the four record captures is simple programmatically with the configure acquisition (**CONF:ACQ**) command. Notice that the fourth parameter is the number of records:



Once you have captured the four records, you can use the on-board measurements to extract the results similar to the way we did for the single-channel case. The complete instrument command sequence for a four-segment capture is shown

in Table 2. You will notice that the commands are a simple extension of the single-segment version, with the record number appended to the end of the MEAS command.

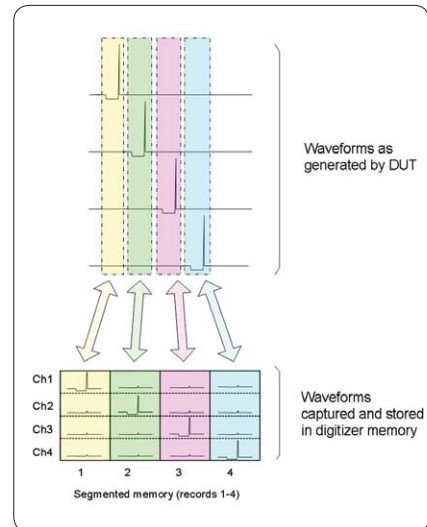


Figure 9. Multi-record capture and resulting placement of waveforms in segmented memory

Table 2. Programming commands and results for multi-channel, multi-record measurement

! Setup Channel ranges		
CONF:CHAN (@1), 250, DC, LP_20_MHZ		
CONF:CHAN (@2), 250, DC, LP_20_MHZ		
CONF:CHAN (@3), 250, DC, LP_20_MHZ		
CONF:CHAN (@4), 250, DC, LP_20_MHZ		
! Setup timebase & trigger		
CONF:ACQ 20000000,100000,98000,4,0,0,0,0		
CONF:ARM:SOUR IMM		
CONF:TRIG:SOUR CHAN		
CONF:TRIG:SOUR:CHAN:EDGE (@1),50,POS,2,0		
CONF:TRIG:SOUR:CHAN:EDGE (@2),50,POS,2,0		
CONF:TRIG:SOUR:CHAN:EDGE (@3),50,POS,2,0		
CONF:TRIG:SOUR:CHAN:EDGE (@4),50,POS,2,0		
MEAS:THR:RESET (@1:4)		
SYST:ERR?	+0, "No error"	
! Start Acq		
INIT		
*OPC?	1	
! Query OBM for $V_{flyback}$ peak		
Meas:WIND:DEF 50, 101		
MEAS:VAV? (@1), WIND, 1	164.750	Volts
MEAS:VAV? (@2), WIND, 2	165.152	Volts
MEAS:VAV? (@3), WIND, 3	166.829	Volts
MEAS:VAV? (@4), WIND, 4	165.114	Volts
! Query OBM for V_{dson}		
MEAS:WIND:DEF -480, 400		
MEAS:VAV? (@1), WIND, 1	1.110	Volts
MEAS:VAV? (@2), WIND, 2	1.088	Volts
MEAS:VAV? (@3), WIND, 3	1.060	Volts
MEAS:VAV? (@4), WIND, 4	1.529	Volts

(Continued on next page)

Table 2. Programming commands and results for multi-channel, multi-record measurement (Continued)

! Query OBM for t_{pw}		
MEAS:WIND:DEF -100, 550		
MEAS:PWID? (@1),1,1	9.49E-06	Seconds
MEAS:PWID? (@2),1,2	9.63E-06	Seconds
MEAS:PWID? (@3),1,3	9.81E-06	Seconds
MEAS:PWID? (@4),1,4	9.91E-06	Seconds
! Query OBM for T_{on}		
MEAS:WIND:DEF -90000, 30000		
MEAS:FALL:TIME? (@1),1,1	9.74E-08	Seconds
MEAS:FALL:TIME? (@2),1,2	1.06E-07	Seconds
MEAS:FALL:TIME? (@3),1,3	2.52E-07	Seconds
MEAS:FALL:TIME? (@4),1,4	1.11E-07	Seconds
! Set edge thresholds to absolute		
MEAS:THR:METH (@1:4), Absolute		
MEAS:THR:ABS (@1:4), 25.0, 24.0,23.0		
! Query OBM for ringing frequency		
MEAS:WIND:DEF 200, 200		
MEAS:RISE:FREQ? (@1),1,1	3.85E+05	Hertz
MEAS:RISE:FREQ? (@2),1,2	3.78E+05	Hertz
MEAS:RISE:FREQ? (@3),1,3	3.67E+05	Hertz
MEAS:RISE:FREQ? (@4),1,4	3.70E+05	Hertz

Conclusion

Using the L4534A with built-in measurements gives you a quick and convenient way to return key parametric results. The 16-bit resolution and the 250 V input range provides a wide dynamic range and highly accurate “measurement engine” for your digitizing, DVM and timing measurements needs. You get real parametric results that are suitable for statistical analysis or determining pass/fail status.

Specifically, the L4532A and L4534A provide:

- ± 256 V input range, which allows you to directly measure the high-voltage flyback pulses.
- Wide 16-bit dynamic range with low channel input offsets, which gives you the ability to measure both the V_{dson} and the $V_{flyback}$ pulse with a single capture.

- Segmented memory and fast rearm times lets you record many pulses, while ignoring inactive periods in between them.
- The 32-megasample/channel (optional to 128 megasample/channel) deep memory allows long, detailed capture of waveform events.
- Flexible multi-channel triggering allows various events to initiate waveform capture.
- Built in on-board measurements simplify returning key driver attributes.
- The L4534A LXI built-in interface helps reduce test development and debug time.

For more information please see the Agilent Web site:

www.agilent.com/find/lxidigitizers

Related Agilent literature

Publication title	Pub number
<i>High-Resolution LXI Digitizers Data Sheet</i>	5989-9636EN



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