

# Measuring Ultra-Low Power in Wireless Sensor Node Applications Using the Model DMM7510 7½-Digit Graphical Sampling Multimeter

## Introduction

The future of the Internet or the Internet of Things (IoT) is an interconnection of uniquely identifiable embedded devices often referred as IoT smart devices and sensors. A large number of sensor nodes each capable of sensing and wireless communication installed in an area of interest makes a wireless sensor network. Billions of smart sensors push data to the IoT through diverse applications, including home security systems; lighting and HVAC control; utility monitoring; industrial control and automation; bridge, railway, traffic light monitoring; and various other infrastructure and environmental uses. Despite the wide difference in applications, these sensor nodes share architecture similar to wireless IoT smart devices, such as those used in the medical, health, and fitness domains.

One of the most common challenges in all sensor node design is power management. Wireless sensor nodes are often placed in hard-to-reach locations where sourcing from mains power is either inconvenient or impossible. Designers need to closely examine the power consumption associated with different operational states of the microcontroller (MCU) and the transceiver of the wireless sensor node. In a typical sensor node application, a node might sit idle for long periods of time between peak periods of activity for sensor data acquisition and wireless transmission. In other words, the power profile consists of active peaks, that are represented by tens of milliamps at maximum transmit or receive power, and long idle periods, that are characterized by quiescent current as low as tens of nanoamps.

$$Power = I \times V$$

$$Energy = I \times V \times Time$$

Until recently, no single instrument offered the combination of low current measurement range, resolution, and speed capability necessary for these applications. The Keithley Model DMM7510 7½-Digit Graphical Sampling Multimeter will fulfill this need. The Model DMM7510 has an 18-bit sampling A-to-D converter dedicated for digitizing current and voltage at 1Mega-sample per second. The digitizing functions cover the same measurement ranges as the DMM's traditional DC voltage and current functions. In other words, the instrument offers exceptional current measurement capability from 100pA to 10A with a 100kHz analog bandwidth that is suitable for both deep sleep as well as active current measurements. Although voltage is typically regulated in these applications, the Model DMM7510 is also capable of digitizing voltage from 1μV to 1000V and has a higher analog bandwidth of 600kHz. Combining the advanced waveform triggering mechanism, such as edge triggering, pulse

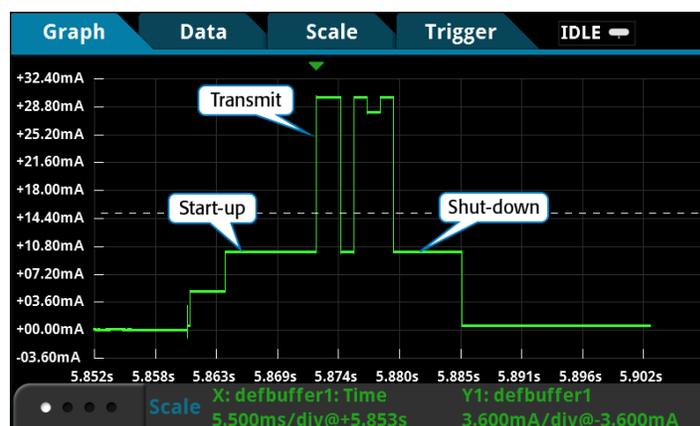
triggering, and window triggering, you can easily capture, view, and interact with these dynamic signals on the Model DMM7510's multi-touch display.

This application note provides an overview on how to characterize the ultra-low power consumption of a typical wireless sensor node application on the front panel of the Keithley Model DMM7510.

## Evaluate a Single Current Pulse Profile

An accurate capture of the current waveform is critical for power consumption calculation and can be easily accomplished on the Model DMM7510. The first step is identifying a single trigger event associated with the current pulse waveform of interest. You can then use the built-in analog edge triggering mechanism on the Graph user interface to set up the trigger span, trigger slope, trigger level, trigger position, and sampling rate. With only a handful of keystrokes to establish these acquisition criteria, you can quickly view the desired waveform on the DMM's graphical display.

*Figure 1* illustrates a typical multi-level active mode current pulse captured by the Model DMM7510. The active mode typically contains current levels as high as tens of milliamps. These multiple current levels represent events such as start-up and shut-down sequences, transmit and receive modes, sensor data conversion, etc.



**Figure 1.** Example multi-level active mode current pulse profile.

*Table 1* summarizes the acquisition criteria involved in capturing the waveform in *Figure 1*. With the exception of the trigger mechanism configuration, which is only available when the measurement function is set to Digitize Current, you are not required to follow the exact sequence of operations listed in the table.

**Table 1. Configurations for Edge Triggered Digitize Current Waveform**

Configure measurement function	
Push the HOME key on the front display.	
On the FUNCTIONS swipe screen, select Digi I to select the Digitize Current function.	
Push the Range button to select 100mA range.	
Swipe to display the SETTINGS swipe screen.	
Set the Sample Rate to 1,000,000.	
Configure acquisition span	
Press the MENU key and select Reading Buffers.	
Set the Capacity to 50,000 for 50ms of readings.	
Configure graph scale	
Press the MENU key and select Graph.	
Select the Scale tab.	
Set the X-Axis Method to All.	
Configure trigger mechanism	
Press the MENU key and select Graph.	
Select the Trigger tab.	
Set Source Event to Waveform.	
Select Analog Edge.	
Set Level to 15mA.	
Set Slope to Rising.	
Set Position to 40% for the pre-trigger position.	

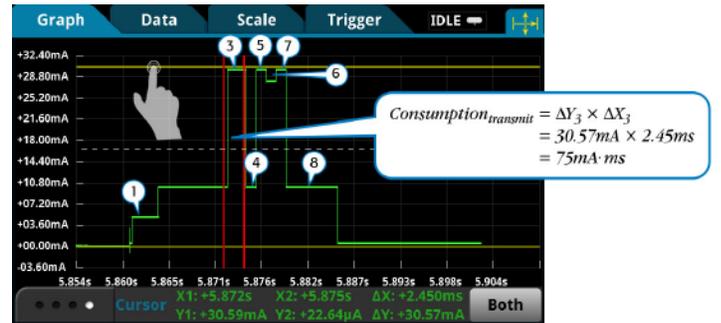
Press the front panel TRIGGER key to begin a single acquisition once all configurations are complete. The pre-trigger data acquisition starts immediately and is displayed on the graph. When the DMM detects a current level that satisfies the trigger condition, the acquisition continues until the completion of post-trigger readings.

You can enable horizontal and vertical cursors to obtain the current over various time intervals. *Figure 2* illustrates the cursor feature on the Model DMM7510. Press the MENU key and select Graph. Swipe the bottom of the graph screen until the Cursor enable button is displayed. Push the Cursor button repeatedly until Both is displayed. Push and drag the horizontal or vertical cursors across the waveform to measure current ( $\Delta Y$ ) and the corresponding interval ( $\Delta X$ ). As with most touchscreen technology, you can easily zoom and pan to any area on the display to position the cursors more accurately on the waveform. The total active current peak consumption in *Figure 2* consists of eight segments. It can be calculated as:

$$Consumption_{totalactivecurrentpeak} = \sum_{k=0}^n Current_k \times Time Interval_k$$

$$= \Delta Y_1 \times \Delta X_1 + \Delta Y_2 \times \Delta X_2 + \dots + \Delta Y_8 \times \Delta X_8$$

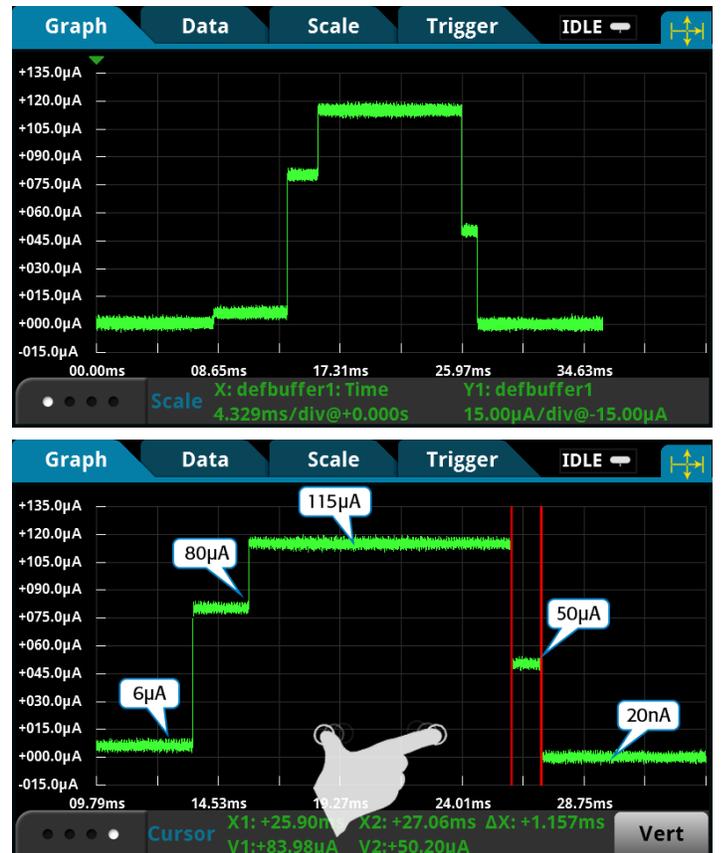
where  $n = 8$



**Figure 2. Power analysis using cursors.**

*Figures 1 and 2* both show a trigger position indicator (▼) and a trigger level control line. You can slide this dashed line up or down to adjust the trigger level and start another acquisition.

New developments in ultra-low power management have introduced a wide range of ultra-low power MCU families that implement more sophisticated strategies for limiting power consumption with several levels of low power modes. This results in finer levels of granularity beyond simply run or idle modes. For example, there are modes such as standby mode, doze mode, sleep mode, deep sleep mode, etc, with current



**Figure 3. Example of a multi-level idle mode current pulse profile (top). Power analysis using cursors (bottom).**

levels often ranging from tens of microamps to as low as tens of nanoamps.

**Figure 3** is an example of a multi-level idle mode current pulse waveform captured on the 100 $\mu$ A range. The Model DMM7510 is capable of resolving current below a few microamps.

All readings and timestamps are easily accessible through the Reading Table under the main MENU. See **Figure 4**. To save these readings to a thumbdrive, insert a USB thumbdrive in the USB port on the front panel. Press the MENU key. Select **Reading Buffers**, press the desired buffer, and then press **Save to USB**. The data will be saved in the .csv format so it can later be downloaded and imported into a spreadsheet. **TIP:** Press the HOME and the ENTER keys on the front panel at the same time to save a screen capture to a USB thumb drive.

READING TABLE		
Buffer	Active (defbuffer1)	Jump to Refresh
	Time	Measure
10000	12/16 17:38:39.561392	+029.98 mA
10001	12/16 17:38:39.561393	+029.96 mA
10002	12/16 17:38:39.561394	+030.01 mA
10003	12/16 17:38:39.561395	+030.03 mA
10004	12/16 17:38:39.561396	+030.02 mA
10005	12/16 17:38:39.561397	+030.03 mA
10006	12/16 17:38:39.561398	+030.02 mA
10007	12/16 17:38:39.561399	+029.99 mA
10008	12/16 17:38:39.561400	+030.01 mA

READING TABLE		
Buffer	Active (defbuffer1)	Jump to Refresh
	Time	Measure
1	12/11 12:46:06.967874	+002.07 $\mu$ A
2	12/11 12:46:06.967875	+003.23 $\mu$ A
3	12/11 12:46:06.967876	+001.31 $\mu$ A
4	12/11 12:46:06.967877	+000.50 $\mu$ A
5	12/11 12:46:06.967878	+002.82 $\mu$ A
6	12/11 12:46:06.967879	+002.91 $\mu$ A
7	12/11 12:46:06.967880	+000.85 $\mu$ A
8	12/11 12:46:06.967881	+000.34 $\mu$ A
9	12/11 12:46:06.967882	+000.32 $\mu$ A

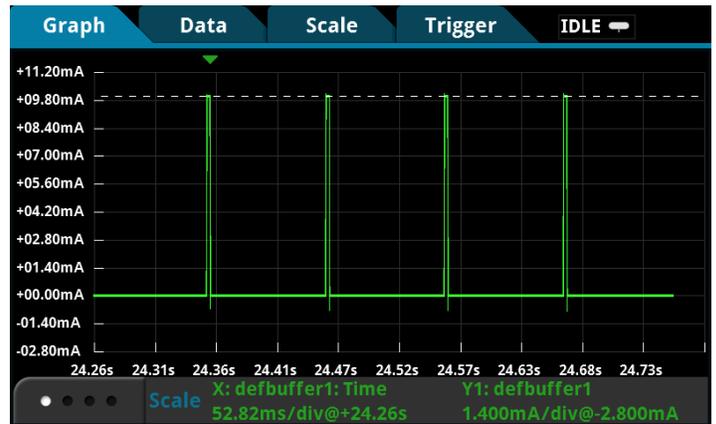
**Figure 4.** Reading tables for the current pulse waveforms in Figures 1 (top) and 3 (bottom).

### Observe Power Profile over a Period of Time

The Model DMM7510 is equipped with a large reading buffer that can store up to 27.5 million time-stamped readings. This is equivalent to 27.5 seconds of data acquired at 1Mega-sample per second. The large buffer allows you to view the sensor node operation over an extended period of time with multiple occurrences of active and idle events. You can simply change the acquisition span or the buffer capacity in the Reading Buffers under MENU, as shown in **Figure 5**.



**Figure 5.** Current pulse capture using the analog pulse trigger mechanism.



**Figure 6.** Increasing acquisition span for extended period of waveform capture.

**Figure 6** displays an example of active transmission, represented by four 3ms, 10mA peak current pulses each separated by a 100ms idle period. In addition to the analog edge trigger mechanism discussed previously, you can use the built-in analog pulse trigger mechanism to initiate an acquisition when a specific profile of current pulse occurs. **Table 2** lists the pulse trigger configuration for the waveform captured in **Figure 6**.

**Table 2. Configurations for Pulse Triggered Digitize Current Waveform**

Configure trigger mechanism	
Press the MENU key and select <b>Graph</b> .	
Select the <b>Trigger</b> tab.	
Set Source Event to <b>Waveform</b> .	
Select <b>Analog Pulse</b> .	
Set Level to <b>10mA</b> .	
Set Pulse Width to <b>500<math>\mu</math>s</b> .	
Set Condition to <b>Greater than 500<math>\mu</math>s</b> .	
Set Position to <b>20%</b> for the pre-trigger position.	

You are able to zoom into a current pulse to show small changes associated with different sensor node activities with a reasonable level of resolution as shown in **Figure 7**. For example, on the 100mA range, the 18-bit digitizer will produce readings at

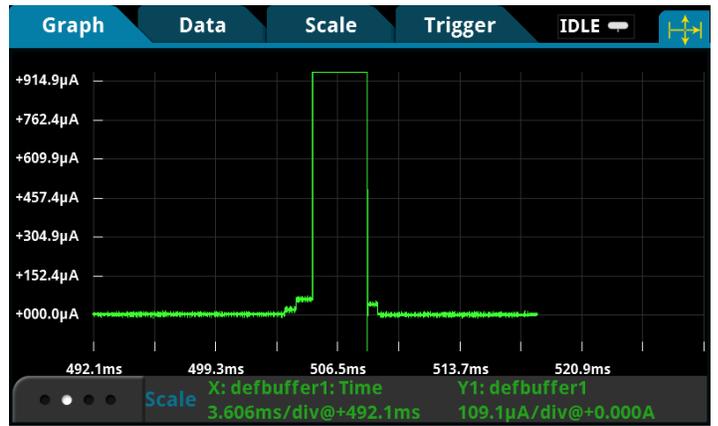


Figure 7. Zooming into a current pulse from a large acquisition period.

1 $\mu$ A. However, the effective resolution will be tens of microamps. Refer to the instrument specifications from Keithley's website ([www.keithley.com](http://www.keithley.com)) for detailed accuracy information for different current and voltage ranges.

## Conclusion

The Model DMM7510 is a must-have instrument for analyzing ultra-low power consumption in wireless sensor nodes and IoT smart device applications. It offers low level and high speed current and voltage measurement capabilities that are unmatched on the market. Combining the touchscreen technology, you can view, analyze and interact with your waveform right on the front panel display. It is compact, simple-to-set-up and packed with powerful features that will meet your ultra-low-power measurement needs.

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# Measuring Low Level Ripple Voltage using the Model DMM7510 7½-Digit Graphical Sampling Multimeter

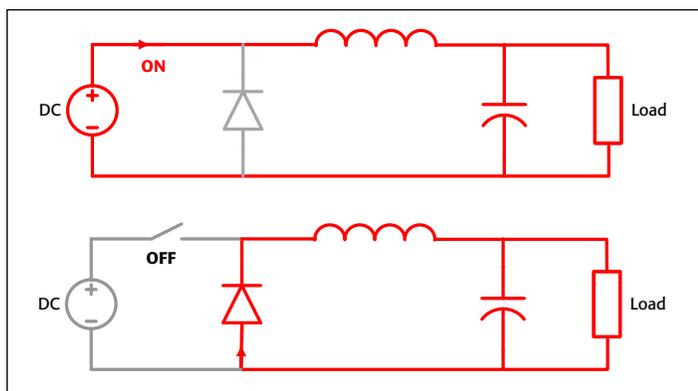
## Introduction

Power conversion is a process that exists in all electronic devices. The term “power supply” is loosely interpreted to describe this process, which conditions the power from the primary source to have specific characteristics required by the load. Digital multimeters (DMMs) is a very common instrument used to evaluate many power supply specifications. However, traditional DMMs often lack the capabilities to measure dynamic behaviors, especially those found in the class of switch mode power supplies (SMPSs). An oscilloscope is typically needed to examine the supply’s ripple voltage, switching voltage, power-up glitches, etc. In many cases, an oscilloscope might not offer the resolution needed to correctly characterize the very low level ripple noise. Keithley’s Model DMM7510 7½-Digit Graphical Sampling Multimeter can sample voltages down to 1μV or current down to 100pA sensitivity at 1μs intervals. In other words, the Model DMM7510 allows you to digitize a variety of dynamic low level voltage and current waveforms with 18-bit accuracy at a 1Mega-sample per second sampling rate. Combining with the instrument’s multi-touch touchscreen interface technology, you can easily capture, view, and interact with both steady-state and dynamic signals from power supplies.

This application note illustrates how to capture, view and characterize the dynamic ripple voltage on a DC-to-DC buck converter on the Model DMM7510’s front panel user interface.

## Understanding the basics of a buck converter

A buck converter is a highly efficient switch mode DC-to-DC voltage step down converter. It stores energy in the form of a magnetic field on an inductor. In the “ON” state, the switch is closed and the input voltage charges up the inductor. In the



**Figure 1. DC-DC buck converter operation.**

“OFF” state, the switch is open and the inductor discharges the stored energy as current flows through the load.

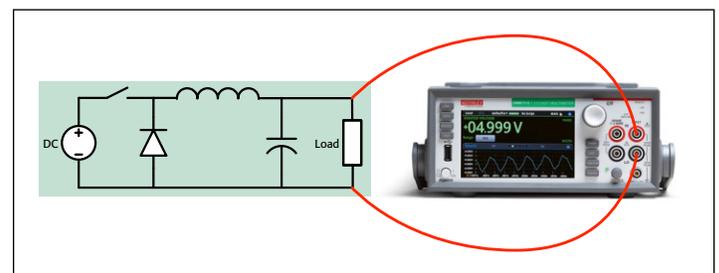
For the purposes of demonstration, this application note uses Texas Instruments LM25088 DC-to-DC buck converter evaluation board (EVM). It produces a steady 5V output from a 5.5V–36V on the input. Modifications were made to the LM25088 EVM to realize a 50kHz switching frequency that is well below the 600kHz analog bandwidth of the instrument at the 10V range. Refer to the instrument specifications from Keithley’s website ([www.keithley.com](http://www.keithley.com)) for additional analog bandwidth requirements for different voltage and current ranges.

## Ripple Noise on the Output Voltage

A small ripple voltage will very likely exist on the output of a buck converter when it is on. This phenomenon is caused by the switching frequency, output capacitance, inductor, load, and any current-limiting features. Because it is an undesirable effect of the design, designers will examine and minimize this noise.

## Making Connections from the Buck Converter to the Model DMM7510

The buck converter can be easily connected to the Model DMM7510 using a standard pair of test leads as shown in **Figure 2**. Properly shielded test wires are recommended when measuring low level signals. To conduct the test, the buck converter is powered by a 12V DC linear power supply. A linear power supply provides a much lower noise output than a switching power supply, ensuring that the waveform produced reflects the noise from the DUT rather than the noise from the input. The output of the buck converter is connected to a 3Ω resistive load.



**Figure 2. Ripple voltage test connections.**

## Setting up the Ripple Voltage Measurement from the Front Panel

The ripple voltage can be easily captured by the Model DMM7510. With only a handful of key strokes to set up the

sampling criteria, you can quickly view the waveform on the DMM's graphical display.

Follow these steps to capture about five 50kHz ripples at a sample rate of 1MSample/s and a sample count of 100 using the Model DMM7510's Digitize Voltage function:

1. Press the **POWER** button on the front panel to turn on the instrument.
2. On the FUNCTIONS swipe screen, select **Digi V** to select the Digitize Voltage measure function.
3. Swipe to display the **SETTINGS** swipe screen.
4. Set the Sample Rate to **1,000,000**.
5. Set the Count to **100**.
6. Swipe to display the **GRAPH** swipe screen.
7. Select the graph icon on the upper right of the swipe screen to open the **Graph** screen.

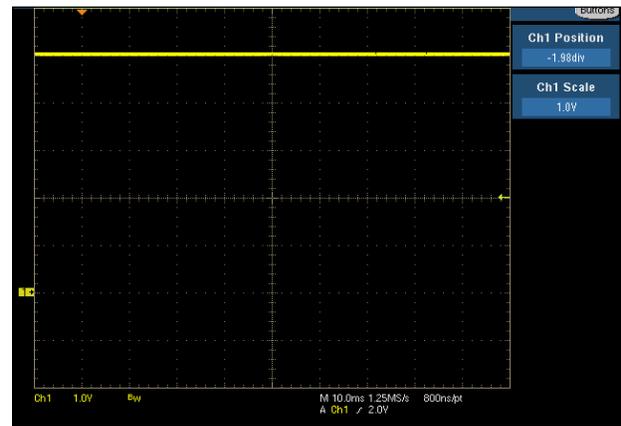
The screen captures in *Figure 3* directly compare the ripples captured on a Model DMM7510 to a typical mid-range oscilloscope. *Figure 3a* illustrates the buck converter output

when both instruments are configured in DC coupling mode. The Model DMM7510 clearly demonstrates superior range and resolution capabilities than the oscilloscope. On the 10V range, the Model DMM7510 is able to capture a dynamic signal as low as tens of millivolts. However, the oscilloscope is incapable of resolving the signal to this resolution and is further limited by the maximum DC offset on its lowest range.

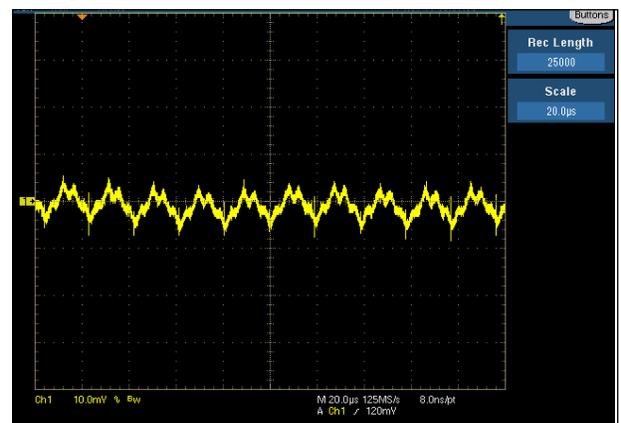
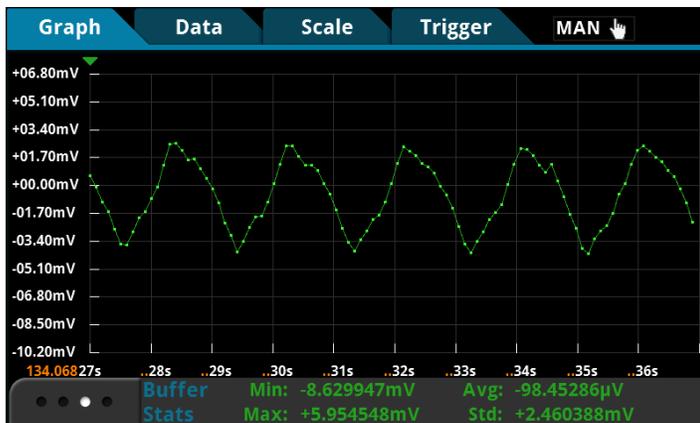
*Figure 3b* illustrates the ripple voltage when both instruments are configured in AC coupling mode. Although the oscilloscope can resolve the ripple to some extent, the Model DMM7510 provides far superior accuracy and precision at these very low signal levels.

### Analyzing the Ripple Voltage Measurement from the Front Panel

As with any touch screen technologies, you may pinch to zoom with your fingers to change the scale of the graph; you may pan the waveform left or right; you may touch any point on the waveform to show details of the reading including timestamps; you may also enable horizontal and/or vertical cursors to analyze



**Figure 3a.** DC-coupled ripple voltage from the Model DMM7510 (left) and from a typical mid-range oscilloscope (right).



**Figure 3b.** AC-coupled ripple voltage from the Model DMM7510 (left) and from a typical mid-range oscilloscope (right).

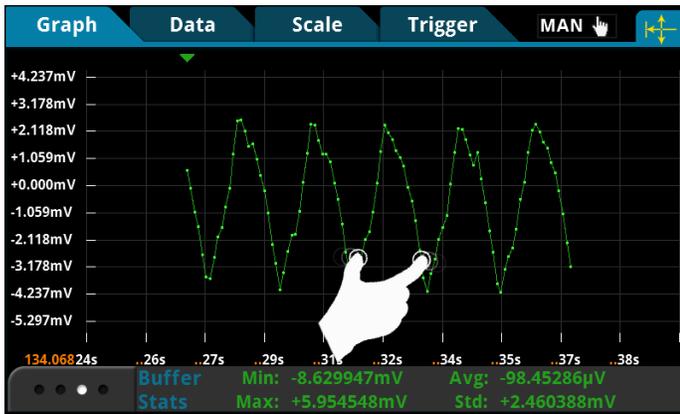


Figure 4a. Zooming.

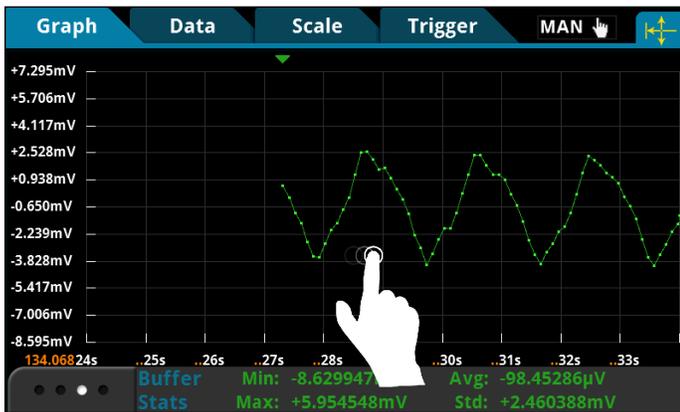
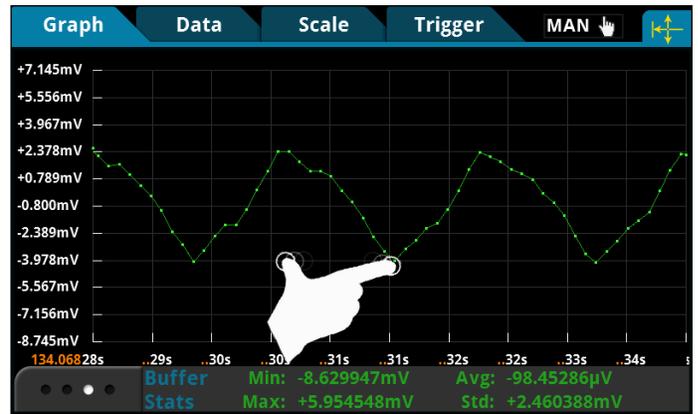
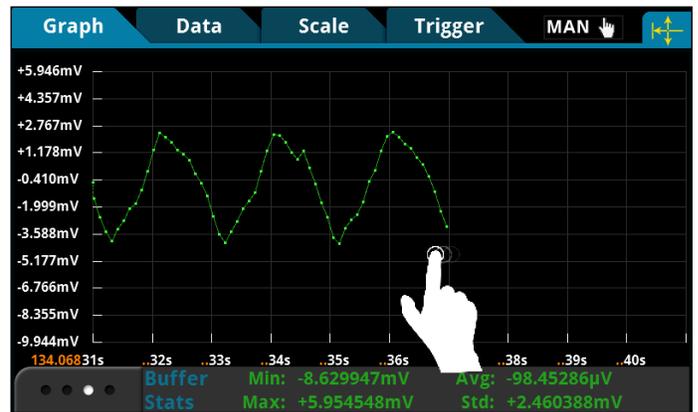


Figure 4b. Panning.



the waveform. *Figure 4* highlights some of the multi-touch interactions that you are able to perform on the Model DMM7510 touchscreen.

The cursors are conveniently located in one of the graph swipe screens. Follow these steps to enable the horizontal cursors for obtaining a quick visual ripple peak-to-peak voltage measurement:

1. Push the **CONT** (Continuous) trigger mode indicator to select the **MAN** (Manual) trigger mode. This stops data acquisition until the **TRIGGER** key is pressed.
2. Swipe the bottom of the graph screen until the **Cursor** enable button appears.
3. Push the Cursor button a couple of times until **Horiz** is displayed. The horizontal cursors will appear on the graph.
4. Push and drag the yellow horizontal cursor lines to the ripple peaks.
5. The  $\Delta Y$  value shown on the graph swipe bar gives the ripple peak-to-peak value.

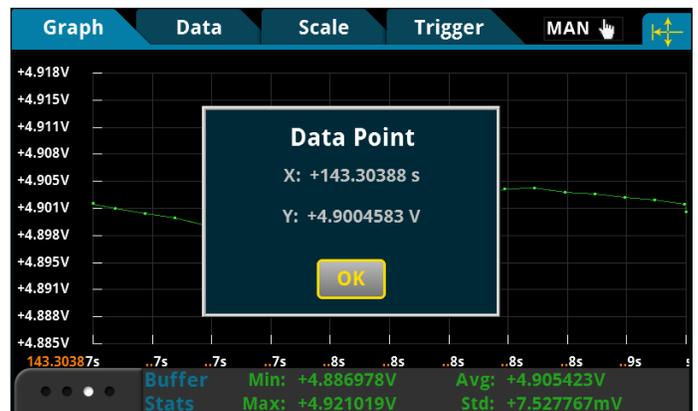


Figure 4c. Data point.

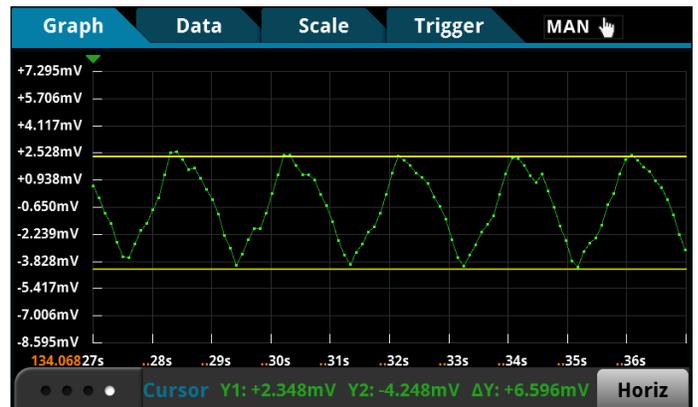
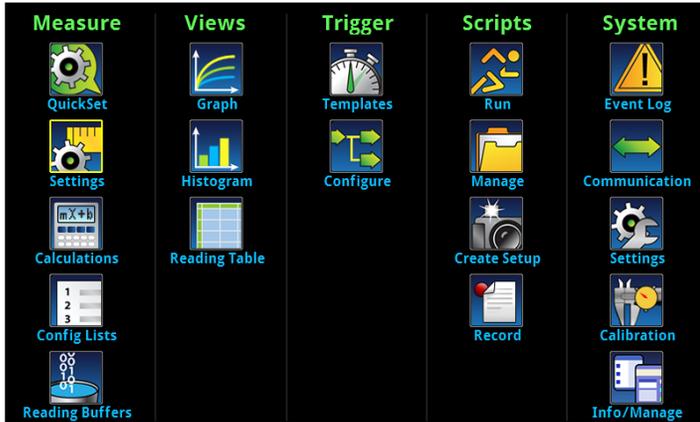


Figure 4d. Horizontal cursors.

## Saving Data to a USB Drive

To save the ripple voltage readings to a thumb drive, start by inserting a USB thumb drive into the USB port on the left side of the front panel. Press the **MENU** key. Select **Reading Buffers**, press the desired buffer, and then press **Save to USB**. You can customize the name of the file. The data will be saved in the .csv format so it can later be downloaded and imported into a spreadsheet. **TIP:** Press the **HOME** and the **ENTER** keys on the front panel at the same time to save a screen capture to a USB thumb drive.



## Setting Up the Ripple Voltage Measurement using SCPI Commands

The following SCPI command sequence will perform the exact same ripple voltage measurement as that performed using the front panel controls. At the end of the command execution, you will see the same waveform displayed on the front panel as shown in *Figures 3* and *4*.

Command	Description
*RST	• Reset the Model DMM7510.
:SENS:DIG:FUNC "VOLT"	• Set the instrument to measure digitize voltage.
:SENS:DIG:VOLT:RANG 10	• Set range to 10V.
:SENS:DIG:VOLT:INP AUTO	• Set the input impedance to 10GΩ.
:SENS:DIG:VOLT:SRATE 1000000	• Set the sample rate to 1e6.
:SENS:DIG:VOLT:APER AUTO	• Enable automatic aperture.
:SENS:DIG:COUN 100	• Set the sample count to 100.
:TRAC:POIN 100	• Set defbuffer1 to store 100 points.
:TRAC:CLE	• Clear defbuffer1.
:TRAC: TRIG: DIG	• Digitize the signal.
:TRAC:DATA? 1, 100, "defbuffer1", READ	• Read the first 100 measurement and relative timestamp values from defbuffer1.
:TRAC:DATA? 1, 100, "defbuffer1", REL	

## Setting Up the Ripple Voltage Measurement Using TSP Commands

The following TSP script is designed to run from Keithley's Test Script Builder (TSB) software. TSB is a free software tool that can be downloaded from Keithley's website ([www.keithley.com](http://www.keithley.com)). By default, the Model DMM7510 is configured to use the SCPI command set. You must select the TSP command set before sending TSP commands to the instruments. Follow these steps to change the command set: Press MENU -> Settings -> Command Set. Select TSP commands.

Like the SCPI commands, these TSP commands will perform the exact same ripple voltage measurement by configuring the sample rate to 1MS/s and the sample count to 100 using the digitize voltage function. The same waveform shown in *Figures 3* and *4* will be displayed on the front panel at the end of the script execution.

```

--Reset the instrument to default settings.
reset()
--Create a local variable to store the number of samples
numofsamples = 100
--Set the measure function to digitize voltage to capture
the ripple waveform
dmm.digitize.func = dmm.FUNC_DIGITIZE_VOLTAGE
--Voltage range must be fixed when using digitize voltage
dmm.digitize.range = 10
--Set sample rate to 1 Msample per second to sample a 50
kHz voltage ripple
dmm.digitize.samplerate = 1e6
--Set aperture to auto to get the highest accuracy
measurement for the
    configured sampling rate
dmm.digitize.apertw:e = dmm.APERTURE_AUTO
--Set sample count to the number of samples to capture
about 5 ripples
dmm.digitize.count = numofsamples
--Set the input impedance to auto so it selects 10 G for
the 10V range
dmm.digitize.inputimpedance = dmm.IMPEDANCE_AUTO
--Set the buffer to align with the number of samples
(optional)
defbufferl.capacity = numofsamples
--Clear buffer
defbufferl.clear()
--Make sure your signal is connected to the DMM. Digitize
now.
dmm.digitize.read()

--Print the digitized readings
if defbufferl.n > 0 then
    print("Ripple Voltage:")
    print("Total Count:", defbufferl.n)
    printbuffer(1, defbufferl.n, defbufferl)
    print("Timestamps:")
    printbuffer(1, defbufferl.n, defbufferl.
relativetimestamps)
else
    print ("No data collected")
end
print ("Test Ended")

```

## Conclusion

The Model DMM7510 7½-Digit Graphical Sampling Multimeter is the ideal instrument for capturing very- low level DC and dynamic voltage and current signals on power supplies. The touchscreen user interface allows users to view, analyze, and interact with the waveform right on the instrument. It is compact, simple to set up and a perfect must-have instrument for your bench.

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# Characterizing Power-up and Power-down Transients Using the Model DMM7510 7½-Digit Graphical Sampling Multimeter

## APPLICATION NOTE



# Characterizing Power-up and Power-down Transients Using the Model DMM7510 7½-Digit Graphical Sampling Multimeter

## Introduction

Most electronic systems contain analog circuits, microprocessors, DSPs, ASICs, and/or FPGAs, which require multiple supply voltages. In order to ensure reliable and repeatable operation of these systems, transient behaviors such as the power-up and power-down timing, ramp rates, and the magnitude of different supply voltages need to be appropriately controlled. Voltage and current sizing, monitoring, sequencing, and tracking are essential in characterizing the transient performance of power supplies.

Digital multimeter (DMM) is a very common instrument used to evaluate many specifications of power supplies. However, traditional DMMs often lack the ability to measure dynamic events such as power-up and power-down transients. The new Keithley Model DMM7510 7½-Digit Graphical Sampling Multimeter has a secondary 18-bit sampling A-to-D converter dedicated to digitizing rapidly changing voltage and current at 1Mega-sample per second. The digitizing functions employ the same measurement ranges as the DMM's traditional DC voltage and current functions. In other words, the digitizer offers exceptional dynamic range—from 1 $\mu$ V to 1000V and 100pA to 10A—which is suitable for many applications. The advanced waveform triggering mechanisms such as edge, pulse, and window triggering, allow you to easily capture, view, and interact with these transient signals on the Model DMM7510's multi-touch display.

## Background

Power-up and power-down transients are identified as step functions in the input voltage that result from a relay or switch closure. Achieving a clean or monotonic, rise or fall from various power supplies can be a major concern. You may encounter a sag in the input voltage due to a large inrush current and finite power source impedance, which could cause catastrophic problems with under-voltage lockout circuits, inrush current-limiting circuits, and even generic power supplies. For example, FPGAs contain auxiliary analog circuitry such as a phase-lock loop (PLL) controlled by a voltage controlled oscillator (VCO). The VCO would change frequencies and/or phase, causing the PLL to lose synchronization when the supply voltage droops during power-up. You may also encounter a slow ramp rate that could lead to anomalous, sometimes destructive, consequences.

This application note illustrates how to capture, view, and characterize power-up and power-down transients of a switch-mode power supply (SMPS) on the front panel of the Keithley Model DMM7510.

## Switch-Mode Power Supply

A buck converter is a highly efficient switch mode DC-to-DC voltage step-down converter. The following discussion is based on Texas Instruments' LM25088 DC-to-DC buck converter evaluation board (EVM). It gives a steady 5V output from a 5.5V–36V on the input. A proper power-up/power-down inspection can ensure that the device turns on or off within a reasonable time without any unexpected behaviors. These asynchronous transient events can be captured using the analog waveform triggering capability on the Model DMM7510.

## Making Connections from the Buck Converter to the Model DMM7510

The buck converter can be connected to the Model DMM7510 using a standard pair of test leads, as shown in *Figure 1*. Properly shielded test wires are recommended when measuring low-level signals. To conduct the test, the buck converter is powered by a programmable DC power supply. The output of the buck converter is connected to an 8 $\Omega$  resistive load.

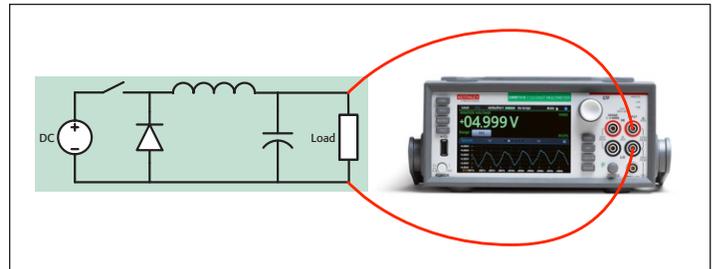


Figure 1. Power-up/power-down test connections.

## Setting Up the Power-up Test from the Front Panel

The power-up transient can be easily captured by the Model DMM7510. With only a handful of keystrokes to establish the acquisition criteria, you can quickly view the waveform on the DMM's graphical display. We will utilize the built-in analog edge triggering mechanism on the Graph user interface to set up the sampling rate, trigger span, trigger slope, trigger level, as well trigger position.

1. Press the **POWER** button on the front panel to turn on the instrument.
2. On the **FUNCTIONS** swipe screen, select **Digi V** to select the Digitize Voltage function.
3. Swipe to display the **SETTINGS** swipe screen.

4. Set the Sample Rate to 1,000,000.
5. Press the MENU key.
6. Select **Reading Buffers**.
7. Set the Capacity to 10,000 for 10ms of readings.
8. Press the MENU key.
9. Select **Graph**.
10. Select the **Scale** tab.
11. Set the X-Axis Method to **All**.
12. Select the **Trigger** tab.
13. Set Source Event to **Waveform**.
14. Select **Analog Edge**.
15. Set Level to 3 V.
16. Set Position to 50% for the pre-trigger position.
17. Select the **Graph** tab to view the graph.
18. To start capturing the buck converter power-up behavior, press the **TRIGGER** key on the front panel.

The pre-trigger data acquisition starts immediately and is displayed on the Graph. Turn on the input supply. When the



buck converter output voltage crosses the 3V trigger level, the DMM acquires the remaining 50% of readings until it returns to IDLE. **Figures 2** through **4** are a variety of power-up screen captures from the buck converter under different supply conditions. All figures contain both a trigger position indicator (▼) and a trigger level control line. You can slide this dashed line up or down to adjust the trigger level and start another acquisition.

**Figure 2** illustrates clean power-up and power-down events when input and load conditions are optimal. The result is a monotonic rise or fall of the buck converter output. **Figure 3** illustrates possible abnormal power-up behavior from reduced input current limits. The waveform on the left shows a drop in the output voltage as a result of the insufficient in-rush current required by the initial input capacitor. The waveform on the right never recovers and the output oscillates below the expected 5V output value.

**Figure 4** illustrates several phenomena, including a soft-start staircase sequence, a normal output ramp, and a slight overshoot toward the end of power-up. The Model DMM7510 combines the dynamic measurement range, 18-bit resolution, and a huge reading buffer to maximize the effectiveness of the digitizer. With a single trigger acquisition, the entire power-up is captured with millivolt accuracy, which can reveal the tiniest irregularity

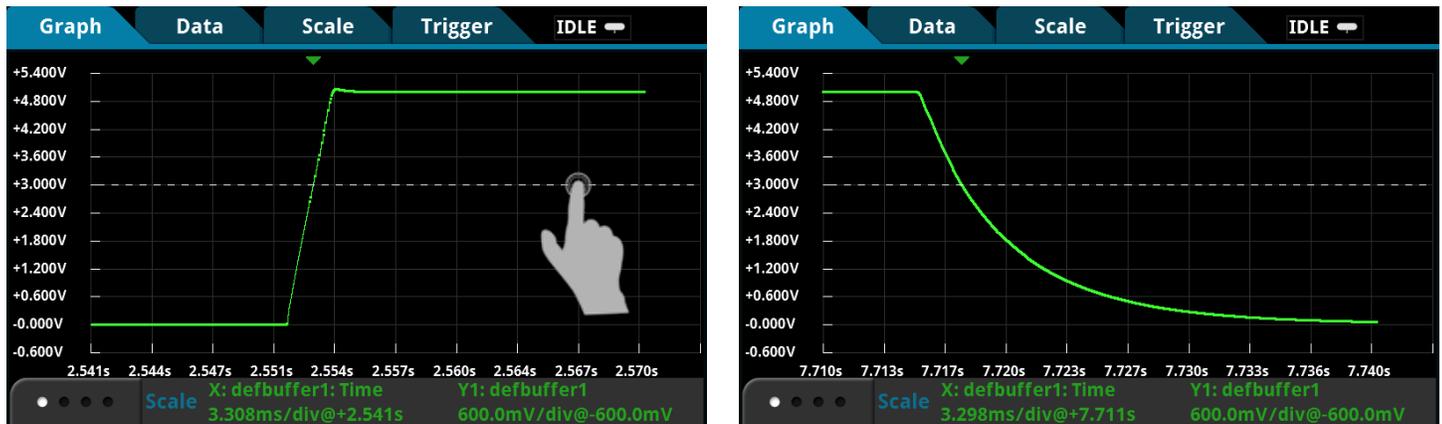


Figure 2. Monotonic power-up (left) and power-down (right) behavior on the buck converter.

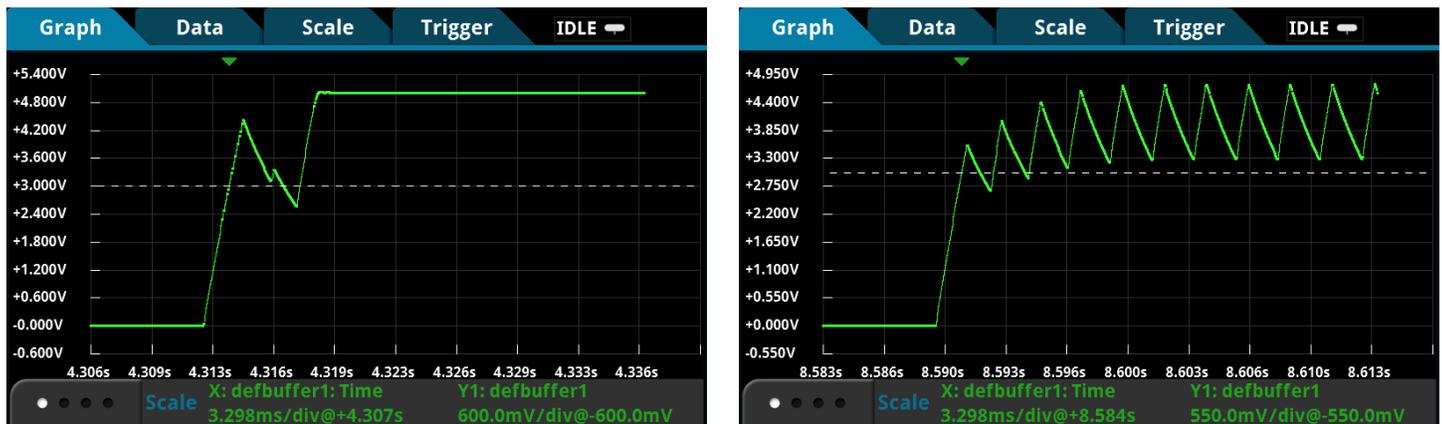


Figure 3. Examples of power-up anomalies (temporary output voltage dip on the left and permanent failure to power-up on the right) on the buck converter.

in the design. You can easily zoom and pan to any area on the waveform to examine the details of these individual occurrences. You can also enable horizontal and vertical cursors for further analysis. See the Appendix for programming examples on analog edge trigger.

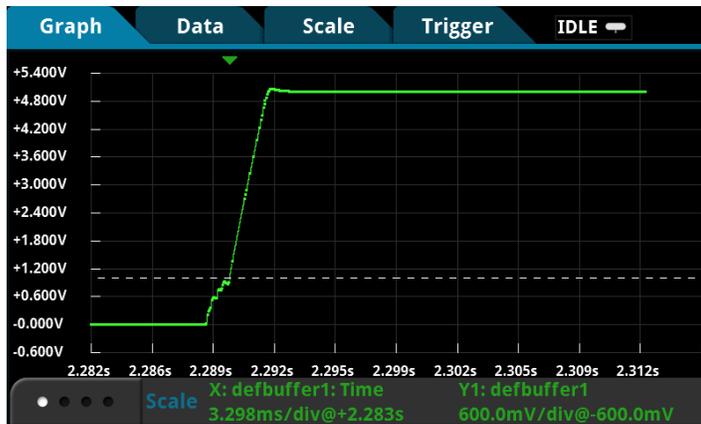


Figure 4a. A complete capture of buck converter power-up with soft-start sequence.

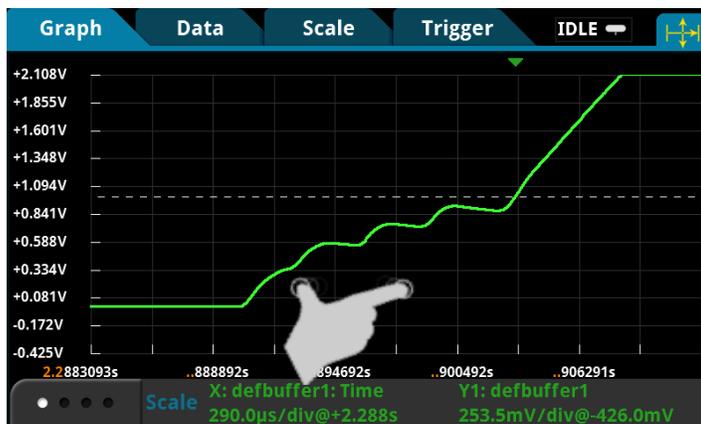


Figure 4b. Panning and zooming into the soft-start behavior (top) and output voltage overshoot before reaching steady state (bottom).

## Simultaneous Voltage and Current Measurement Using Two Model DMM7510s

The Model DMM7510 is a very powerful high-end multimeter packed with sophisticated modern technologies. The next

demonstration explores the advanced instrument programming and integration valuable to applications seeking simultaneous voltage and/or current digitizing solutions.

The buck converter power-up transient analysis can be more involved than merely monitoring the output voltage. The input voltage, input current, output voltage, and load current are all signals of importance. The key is to synchronize these signals to a single triggering event to uncover critical information of about the design of the buck converter. The example below uses two Model DMM7510s to demonstrate this capability.

Connecting two Model DMM7510s to monitor two different signals on the buck converter simply involves connecting each standard pair of test leads from the circuit to each DMM. A TSP-Link<sup>®</sup> cross-over cable is used to daisy-chain the two DMMs together for synchronizing the analog waveform trigger event on both. Keithley Instruments' TSP-Link<sup>®</sup> interface is a high-speed trigger synchronization and communication bus that test system builders can use to connect multiple instruments in a master and subordinate configuration. Once connected, all the instruments in this system can be programmed (using TSP commands only) and operated under the control of the master instrument. This allows the instruments to run tests more quickly because they can be decoupled from frequent computer interaction. Furthermore, multiple instruments are used as if they are part of the same physical unit for simultaneous multi-channel testing.

Figure 5 is a connection diagram for simultaneous input current and output voltage measurement. The current measurement is made via a standard pair of test leads connected in series with the input high side of the power supply.

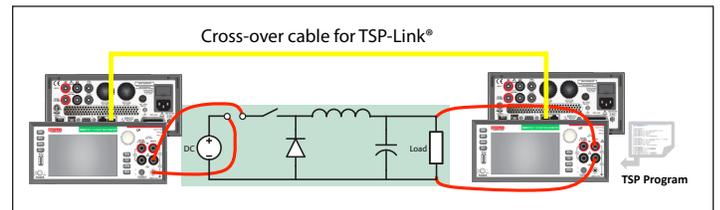


Figure 5. Connection for simultaneous input current and output voltage measurement

The Model DMM7510 has a dynamic current measurement range from 0.1nA to 10A with a 100kHz analog bandwidth. Compared to the current probe solution for oscilloscopes, the ultra-low noise performance and the simplicity of current connection using the Model DMM7510 often make it a better choice than current probing solutions. The screen captures in Figure 6 are the results of a synchronized single trigger capture of both input current and output voltage using a TSP script. The synchronization achievable over the TSP-Link<sup>®</sup> interface is less than a few hundreds of nanoseconds. Once the individual signals are acquired, you can overlay these two waveforms on a single display. You can also split the waveforms into individual lanes for a different viewing experience. The buck converter clearly displays current-limiting behavior during the soft-start sequence. Again, you can zoom and pan any area on these

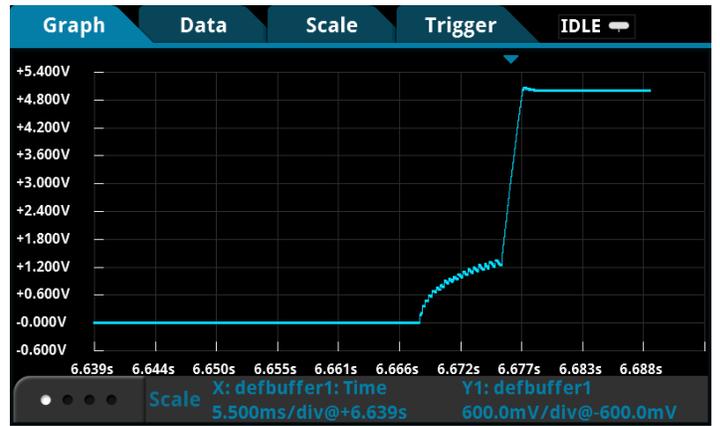
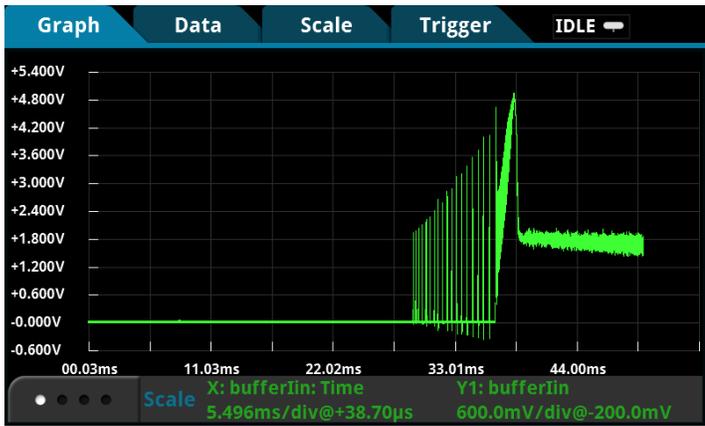


Figure 6a. Individual waveform display of simultaneous input current and output voltage measurement.

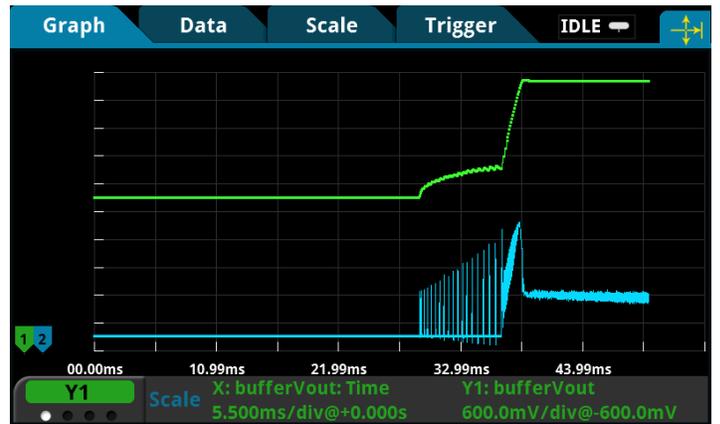
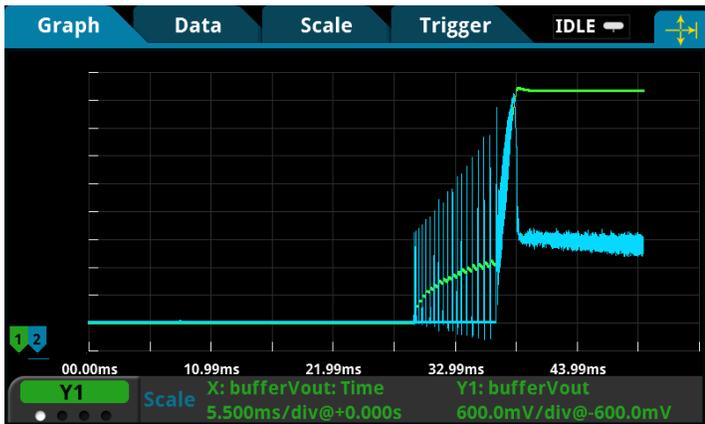


Figure 6b. Combining input current and output voltage onto a single display.

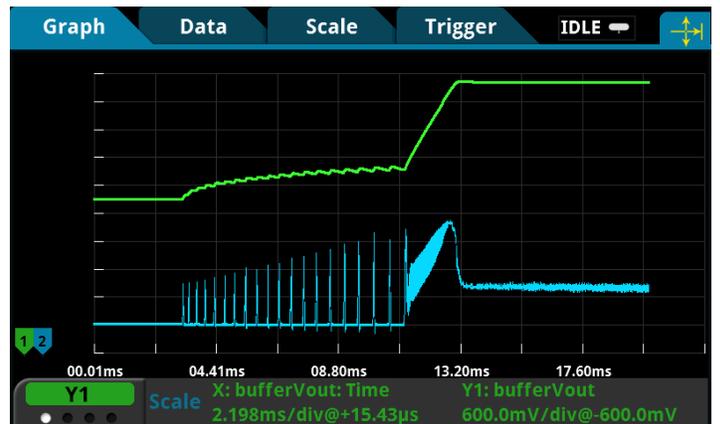
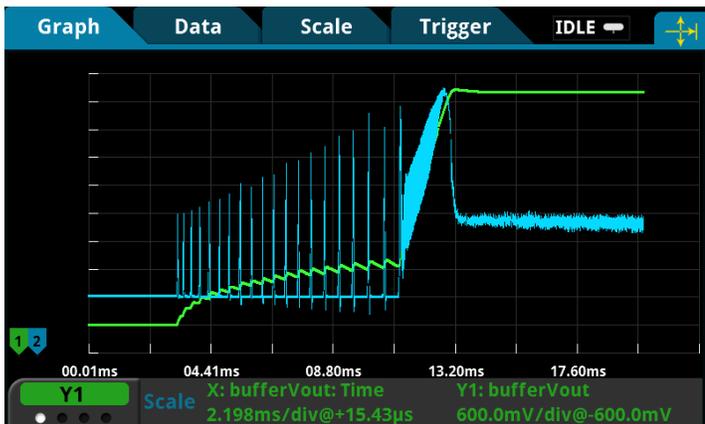


Figure 6c. Zooming.

waveforms to examine the dynamic behaviors in detail. For more information and support on TSP programming and simultaneous measurement, refer to the Reference Manual for the Model DMM7510 or the Keithley website ([www.keithley.com](http://www.keithley.com)).

All readings and timestamps are easily accessible through the Reading Table under the main MENU. You can select any defined buffer in the instrument to display. To save these readings to a

thumbdrive, start by inserting a USB thumbdrive into the port on the front panel. Press the **MENU** key. Select **Reading Buffers**, press the desired buffer, and then press **Save to USB**. The data will be saved in the .csv format, so it can later be downloaded and imported into a spreadsheet. **TIP:** Press the **HOME** and the **ENTER** keys on the front panel at the same time to save a screen capture to a USB thumb drive.

READING TABLE		
Buffer	bufferVin	Jump to Refresh
	Time	Measure
1	12/09 16:03:52.768413	+113.64734 $\mu$ V
2	12/09 16:03:52.768414	+16.668238 $\mu$ V
3	12/09 16:03:52.768415	+16.668238 $\mu$ V
4	12/09 16:03:52.768416	+210.62650 $\mu$ V
5	12/09 16:03:52.768417	+113.64734 $\mu$ V
6	12/09 16:03:52.768418	+307.60567 $\mu$ V
7	12/09 16:03:52.768419	+210.62650 $\mu$ V
8	12/09 16:03:52.768420	+210.62650 $\mu$ V
9	12/09 16:03:52.768421	+113.64734 $\mu$ V

READING TABLE		
Buffer	Active (bufferVout)	Jump to Refresh
	Time	Measure
1	12/09 17:03:56.676559	+201.43459 $\mu$ V
2	12/09 17:03:56.676560	+201.43459 $\mu$ V
3	12/09 17:03:56.676561	-89.358032 $\mu$ V
4	12/09 17:03:56.676562	+201.43459 $\mu$ V
5	12/09 17:03:56.676563	+7.5727182 $\mu$ V
6	12/09 17:03:56.676564	+201.43459 $\mu$ V
7	12/09 17:03:56.676565	+298.36553 $\mu$ V
8	12/09 17:03:56.676566	+104.50366 $\mu$ V
9	12/09 17:03:56.676567	+7.5727182 $\mu$ V

Figure 6d. Reading tables for input current and output voltage.

## Conclusion

The Model DMM7510 7½-Digit Graphical Sampling Multimeter broadens the utility of a traditional DMM to applications such as capturing a wide range of dynamic voltage and current signals on

power supplies. You can view, analyze and interact directly with waveforms right on the front panel display. It is compact, simple to set up, and the perfect next-generation bench instrument for research and development.

## Appendix

### Setting Up the Voltage Power-up Measurement Using SCPI commands

The following SCPI command sequence performs the power-up measurement by configuring the sample rate to 1MS/s, the analog rising edge trigger level to 3V, and the buffer size to 10,000 readings using the digitize voltage function on the Model DMM7510. The waveforms produced will be similar to those shown in *Figures 2, 3 or 4*, depending on the physical setup.

Command	Description
*RST	• Reset the Model DMM7510.
:SENS:DIG:FUNC "VOLT"	• Set the instrument to measure digitize voltage.
:SENS:DIG:VOLT:RANG 10	• Set range to 10V.
:SENS:DIG:VOLT:INP AUTO	• Set the input impedance to 10G $\Omega$ at 10V.
:SENS:DIG:VOLT:SRATE 1e6	• Set the sample rate to 1,000,000.
:SENS:DIG:VOLT:APER AUTO	• Enable automatic aperture.
:SENS:DIG:COUN 1	• Set the sample count to 1 (optional).
:TRAC:POIN 10000	• Set defbuffer1 to store 10,000 points.
:TRAC:CLE	• Clear defbuffer1.
:SENS:DIG:VOLT:ATR:MODE EDGE	• Enable analog edge trigger.
:SENS:DIG:VOLT:ATR:EDGE:SLOPe RIS	• Set the edge trigger to rising slope.
:SENS:DIG:VOLT:ATR:EDGE:LEV 3	• Set the edge trigger level to 3V.
:TRIG:BLOC:DIG 1, "defbuffer1", INF	• Set up a trigger model that digitizes voltage indefinitely while waiting for the edge trigger event and digitizes 50% post trigger readings.
:TRIG:BLOC:WAIT.2, ATR	• Start the trigger model.
:TRIG:BLOC:DIG 3, "defbuffer1", 5000 INIT	• Wait for the trigger model to complete.
*WAI	• Retrieve the readings from the buffer.
:TRAC:DATA? 1, 100, "defbuffer1", READ	• Retrieve the relative timestamps from the buffer.
:TRAC:DATA? 1, 100, "defbuffer1", REL	

## Setting Up the Voltage Power-up Measurement Using TSP Commands

The following TSP script is designed to be run from Keithley Instruments' Test Script Builder (TSB) software, a free software tool that can be downloaded from the website ([www.keithley.com](http://www.keithley.com)). By default, the Model DMM7510 is configured to use the SCPI command set, so before sending TSP commands to the instruments, the TSP command set must be selected instead. Perform these steps to change the command set: Press MENU -> Settings -> Command Set. Select TSP commands.

The TSP script performs a similar power-up measurement as the front panel operation on the Model DMM7510. And it generates waveforms similar to those illustrated in *Figures 2 to 4*, depending on the physical setup.

```
--Reset the instrument to default settings
reset()
--Create a local variable to store the number of samples
numofsamples = 10000
--Set the measure function to digitize voltage to capture the power-up behavior
dmm.digitize.func = dmm.FUNC_DIGITIZE_VOLTAGE
--Voltage range must be fixed when using digitize voltage
dmm.digitize.range = 10
--Set the sample rate to 1 Msample per second to capture any small glitch
dmm.digitize.samplerate = 1e6
--Set aperture to auto to get the highest accuracy measurement for the sampling rate configured
dmm.digitize.aperture = dmm.APERTURE_AUTO
--Changing count is optional.The reading buffer capacity determines the actual count.
dmm.digitize.count = 1
--Set the input impedance to auto so it selects 10 G for the 10 V range
dmm.digitize.inputimpedance = dmm.IMPEDANCE_AUTO
--Set the buffer size to the number of samples to capture both pre and post triggered data
defbuffer1.capacity = numofsamples
--Clear buffer
defbuffer1.clear()
--Select analog edge trigger to capture the power-up behavior
dmm.digitize.analogtrigger.mode = dmm.MODE_EDGE
--Set edge slope to detect a rising edge
dmm.digitize.analogtrigger.edge.slope = dmm.SLOPE_RISING
--Set edge level trigger to 3 V for the 5 V steady- state output
dmm.digitize.analogtrigger.edge.level = 3

--Define a trigger model that will capture 50% pre and 50% post triggered data
trigger.model.setblock(1,trigger.BLOCK_DIGITIZE, defbuffer1, trigger.COUNT_INFINITE)
trigger.model.setblock(2,trigger.BLOCK_WAIT, trigger.EVENT_ANALOGTRIGGER)
trigger.model.setblock(3,trigger.BLOCK_DIGITIZE, defbuffer1, numofsamples/2)

trigger.model.initiate()
--Waits for the trigger model to finish collecting data before proceeding
waitcomplete()

print("test ended")
```

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