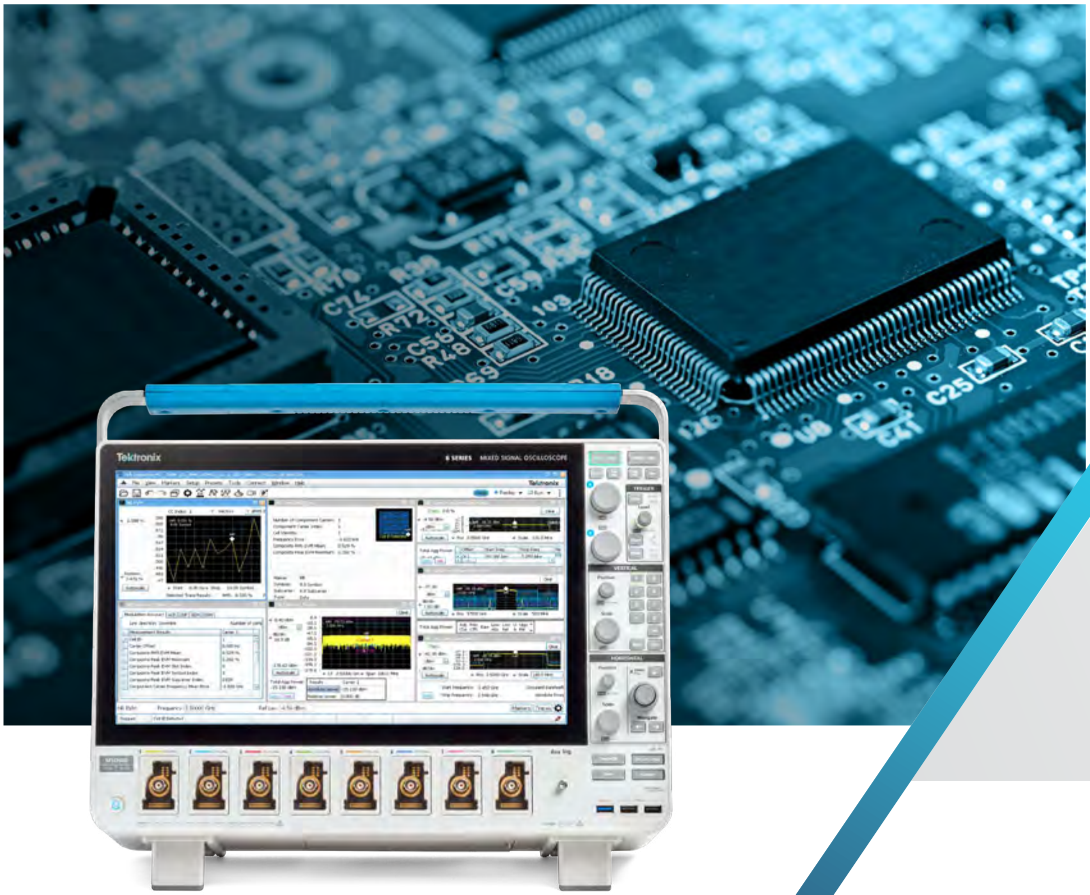
5G NR Multi-Channel System Troubleshooting across Time, RF and Digital Domains

WHITE PAPER



Introduction

An engineer's ability to view signals across multiple domains to analyze several different types of measurements simultaneously with a single instrument is incredibly useful in complex 5G systems where digital, analog, and RF signals interact with each other.

Although a lot has already been done in the development of 5G systems, scientists and engineers still face many challenges including:

- Implementation issues of eMBB (enhanced Mobile Broadband) transceivers, including efficient realization of applied channel (LDPC and polar) codes, energy efficiency of transceiver design, powerful synchronization methods for large FFT size OFDM and DFT-spread-OFDM signals
- Investigation of ultra-reliable URLLC (ultra-reliable low-latency communication) transmission methods for V2X and remote-control communication systems, including effective channel coding, reliable access to radio resources and transceiver design
- Consideration of specific problems of transceiver implementation in the mmWave range of communications
- Massive MIMO structures and algorithms
- Energy-efficient transmission, synchronization and multiple access methods for mMTC (massive machine-type communications, e.g., Internet of Things)
- Modulation and coding for mMTC
- Application of cognitive radio in 5G

Correlating to root-cause on analog, digital, and RF signals

5G systems rely on a symphony of digital, analog and RF signals. Today the testing of RF power amplifiers for synchronization, gain, and timing characteristics must be combined with modern control interfaces such as those using MIPI as the RF Front-End Control Interface (RFFE).

Being able to analyze signals across multiple domains is critical to finding interference, glitches, spurs, drop-outs, and other errors.

In this paper, we will take you through a typical 5G system debug and validation scenario of a wideband RF amplifier.

Test setup

To showcase the benefits of using a multi-domain oscilloscope for analyzing RF amplifier performance, we use the Tektronix 6 Series B MSO oscilloscope as our acquisition hardware.

Figure 1. 6 Series B MSO oscilloscope with SignalVu-PC software installed.

Our device under test is the GVA-123+ from Mini Circuits. It's a small-scale RF amplifier, but it illustrates the measurement issues typical for user equipment and base station applications.

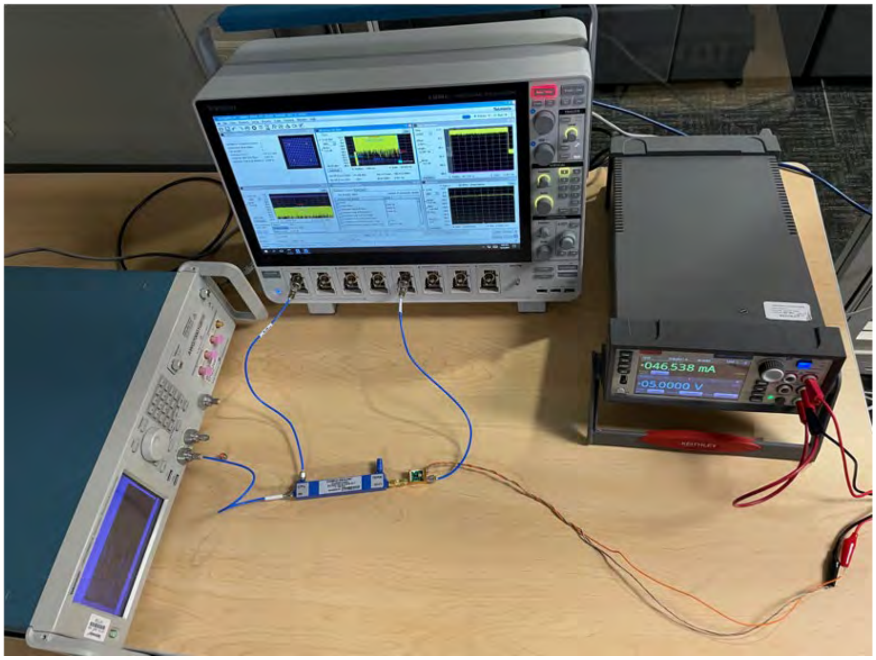


Figure 2. Test setup including the oscilloscope, signal generator, coupler, power supply and DUT.

We've configured the Tektronix AWG70000B Arbitrary Waveform Generator as our signal source, which is producing a single 5G New Radio (NR) carrier at 3.5 GHz center frequency, with a bandwidth of 100 MHz. It's an uplink signal with 30 kHz sub-carrier spacing (SCS), 256-QAM, 11.5 dB OFDM PAPR. The AWG is adjusted for a 250 mV to 500 mV peak-to-peak signal, which is about –11 to –17 dBm composite average power.

We’re using a coupler (ZDC-10-0123) to capture the input signal on channel one of the oscilloscope.

A Keithley Source Measurement Unit (SMU) provides power to the device under test.

We’ve also added a current probe on channel six of the oscilloscope, measuring the current draw of the amplifier.

On the 6 Series B MSO oscilloscope, we are running SignalVu VSA Software with a 5G NR optional plug-in, and we’ve configured it to analyze the signal captured by the scope on channel one.

Measurement example

As an example, we’re looking at our amplifier which is getting good readings, starting out triggering on the RF input.

Link direction: Uplink

Number of component carriers:

Measurement Results	Carrier 1
Cell ID	0
Carrier Offset	0.000 Hz
Composite RMS EVM Mean	0.587 %
Composite Peak EVM Maximum	6.448 %
Composite Peak EVM Slot Index	0
Composite Peak EVM Symbol Index	4
Composite Peak EVM Subcarrier Index	2159
Component Carrier Frequency Mean Error	631.070 mHz
Component Carrier IQ Origin Offset Mean	-71.447 dBc

Total Agg Power: -0.984 dBm

Results	Carrier 1
Absolute power	-993.046 mdBm
Relative power	0.000 dB

Number of Component Carriers: 1
Component Carrier Index: 1
Cell Identity: 0
Frequency Error: -249.868 mHz
Composite RMS EVM Mean: 0.584 %
Composite Peak EVM Maximum: 5.918 %

Marker: MR
Symbols: 0.0 Symbol
Subcarrier: -1637.0 Subcarrier
Type: Data
Magnitude: 1.026

Figure 3. In this measurement the EVM shown in the constellation display is as expected.

Then suddenly, you see variations when we introduce a disturbance where we're getting moments of high distortion and you wonder, what's causing this?

Link direction: Uplink

Number of component carriers:

Measurement Results	Carrier 1
Cell ID	0
Carrier Offset	0.000 Hz
Composite RMS EVM Mean	1.792 %
Composite Peak EVM Maximum	9.076 %
Composite Peak EVM Slot Index	0
Composite Peak EVM Symbol Index	12
Composite Peak EVM Subcarrier Index	2159
Component Carrier Frequency Mean Error	-428.215 mHz
Component Carrier IQ Origin Offset Mean	-63.840 dBc

Total Agg Power: -2.651 dBm

Results	Carrier 1
Absolute power	-2.651 dBm
Relative power	0.000 dB

Number of Component Carriers: 1
Component Carrier Index: 1
Cell Identity: 0
Frequency Error: -428.215 mHz
Composite RMS EVM Mean: 1.792 %
Composite Peak EVM Maximum: 9.076 %

Marker: MR
Symbols: 0.0 Symbol
Subcarrier: -1637.0 Subcarrier
Type: Data
Magnitude: 1.015

Figure 4. In this measurement the EVM is higher than expected.

You can see in the two screen captures above that our 5G EVM in the constellation diagram is pulsing between good and bad. We can look at our power versus time display and we can also see that our power sometimes drops out.

So, we have all of the RF domain indications that something is wrong, and we'd like to know more about its root cause.

You suspect it has something to do with the power supply. And if you had a traditional VSA, you'd be stuck and still guessing. But with the 6 Series MSO, because it can look at both analog, digital, and RF at the same time, we can correlate to root cause.

If we look at our current probe measuring on Channel 6 and our RF output on Channel 5, we can see that the current is dropping periodically.

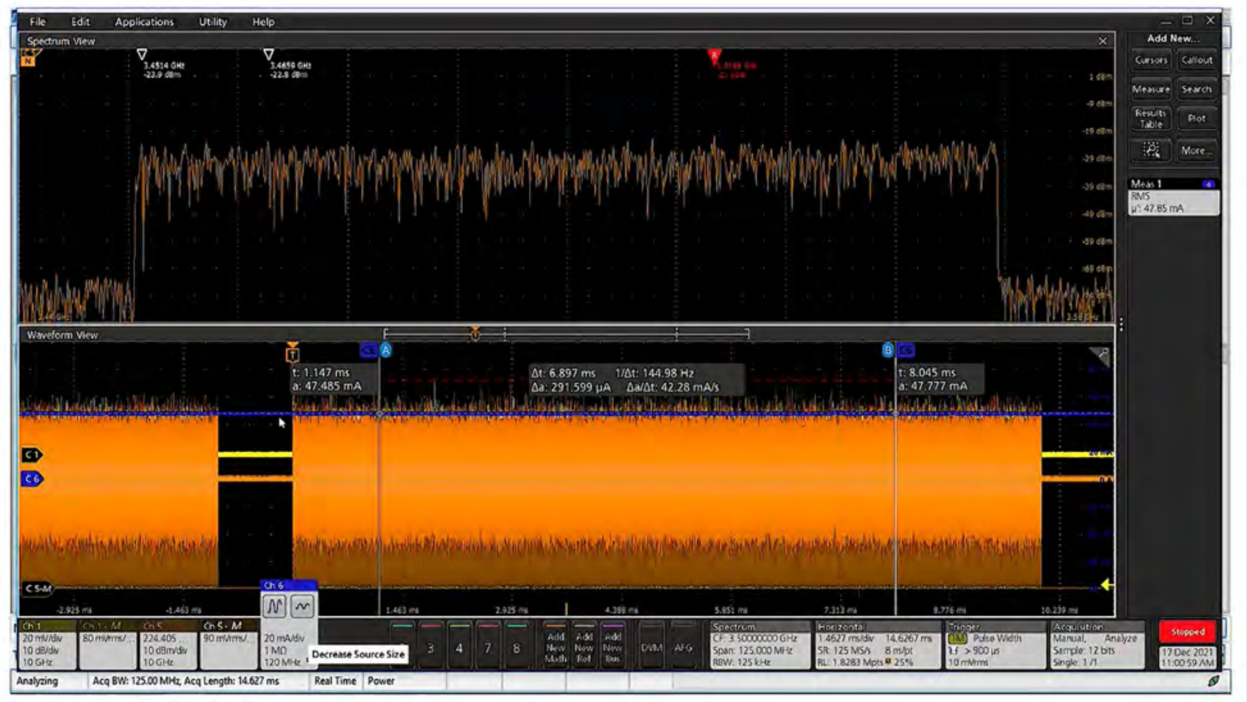
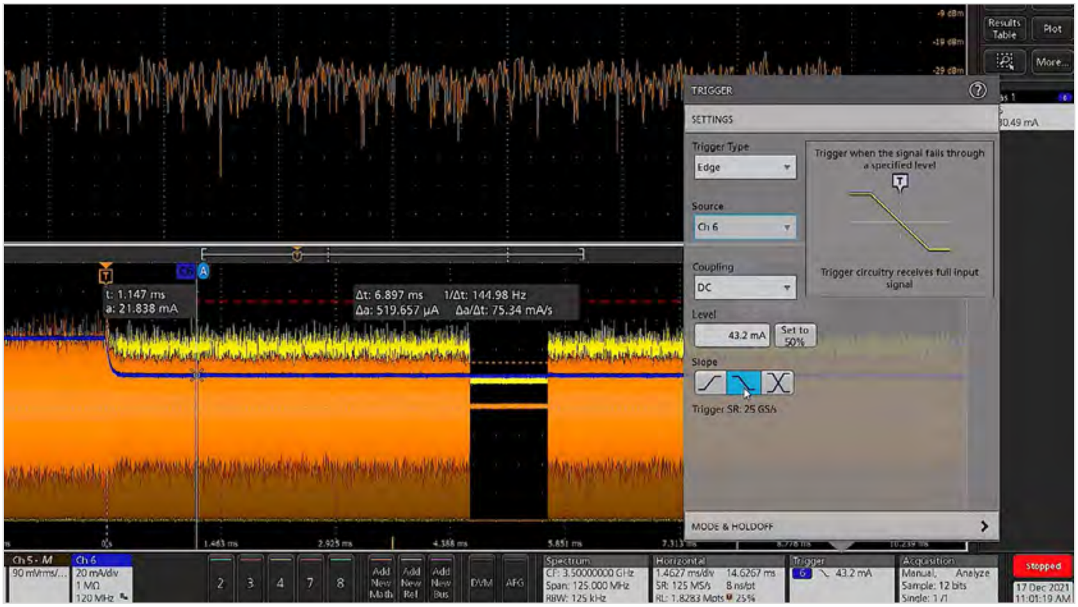


Figure 5. In this acquisition, the power supply is delivering 48 mA (Channel 6, blue) and the output of the power amplifier (Channel 5, orange) is nominal.

Figure 6. In this acquisition, the power supply is delivering 22 mA (Channel 6, blue) and the output of the power amplifier (Channel 5, orange) has dropped.

So, let’s change our perspective to trigger on the current in the time domain rather than the RF pulse in the frequency domain.

To do so, we’re going to change the trigger source to the current probe on Channel 6, and since we know that proper operation occurs at 47 mA, we’ll set the trigger on 43 mA and we’ll catch it when it’s decreasing. Instead of a pulse limit, we’ll set it to trigger on the current edge.



Trigger Type: Edge

Source: Ch 6

Coupling: DC

Level: 43.2 mA

Trigger when the signal falls through a specified level

Trigger circuitry receives full input signal

Trigger SR: 25 GS/s

t: 1.147 ms
a: 21.838 mA

Δt: 6.897 ms 1/Δt: 144.98 Hz
Δa: 519.657 μA Δa/Δt: 75.34 mA/s

Ch 6: 20 mA/div, 1 MΩ, 120 MHz

Spectrum: CF: 3.50000000 GHz, Span: 125.000 MHz, RBW: 125 kHz

Horizontal: 1.4627 ms/div 14.6267 ms, SR: 125 MS/s 8 ns/pt, RL: 1.8283 Mpts 25%

Trigger: 6 43.2 mA

Acquisition: Manual, Analyze, Sample: 12 bits, Single: 1/1

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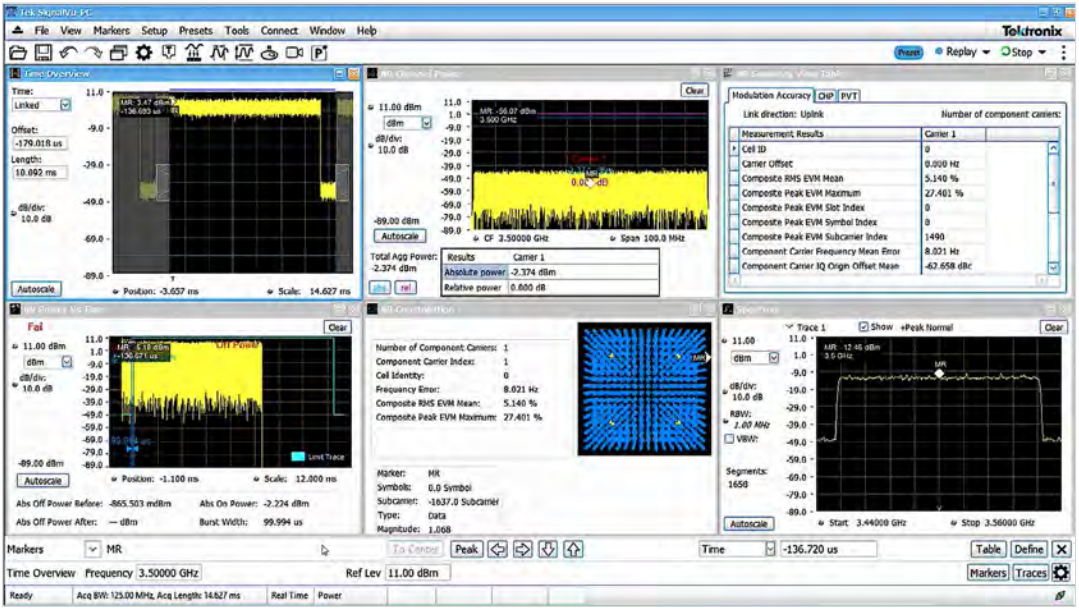
Figure 7. The trigger is set to capture on a decrease in current, to consistently acquire the undercurrent condition.

Now we’re correlating the cause of our RF drop with the oscilloscope and when we go back to SignalVu, we can now catch the moment when the current starts dropping out.



Modulation Accuracy | CHP | PVT

Link direction: Uplink

Measurement Results	Carrier 1
Cell ID	0
Carrier Offset	0.000 Hz
Composite RMS EVM Mean	5.140 %
Composite Peak EVM Maximum	27.401 %
Composite Peak EVM Slot Index	0
Composite Peak EVM Symbol Index	0
Composite Peak EVM Subcarrier Index	1490
Component Carrier Frequency Mean Error	8.021 Hz
Component Carrier IQ Origin Offset Mean	-62.658 dBc

Total Agg Power: -2.374 dBm

Results	Carrier 1
Absolute power	-2.374 dBm
Relative power	0.000 dB

Number of Component Carriers: 1
Component Carrier Index: 1
Cell Identity: 0
Frequency Error: 8.021 Hz
Composite RMS EVM Mean: 5.140 %
Composite Peak EVM Maximum: 27.401 %

Marker: MR
Symbols: 0.0 Symbol
Subcarrier: -1637.0 Subcarrier
Type: Data
Magnitude: 1.068

Abs Off Power Before: -865.503 mdBm
Abs On Power: -2.224 dBm
Abs Off Power After: — dBm
Burst Width: 99.994 us

Time Overview: Frequency 3.50000 GHz, Ref Lev 11.00 dBm

Acq BW: 125.00 MHz, Acq Length: 14.627 ms

Figure 8. When triggering on the undercurrent condition, we consistently see high EVM in the constellation diagram.

Here we see that the current is perfectly correlated with the RF drop on the scope screen. Sure enough, now that we've triggered on the dropout in current, we no longer have a flickering constellation or EVM display, and we have a much better look at our real problem. You can see that our EVM is always poor because we've triggered on the moment of failure.

Now let's see if we trigger on when the current is in spec and see what happens to our RF measurements. To do so, we'll simply change our trigger direction to rising, and now we're capturing when the current is in spec. In the scope application, our RF energy level comes back as expected, and looking in the SignalVu VSA application, every capture of the 5G signal is meeting spec.

Trigger Type: Edge
Source: Ch 6
Coupling: DC
Level: 43.2 mA
Set to 50%
Slope
Trigger SR: 25 GS/s

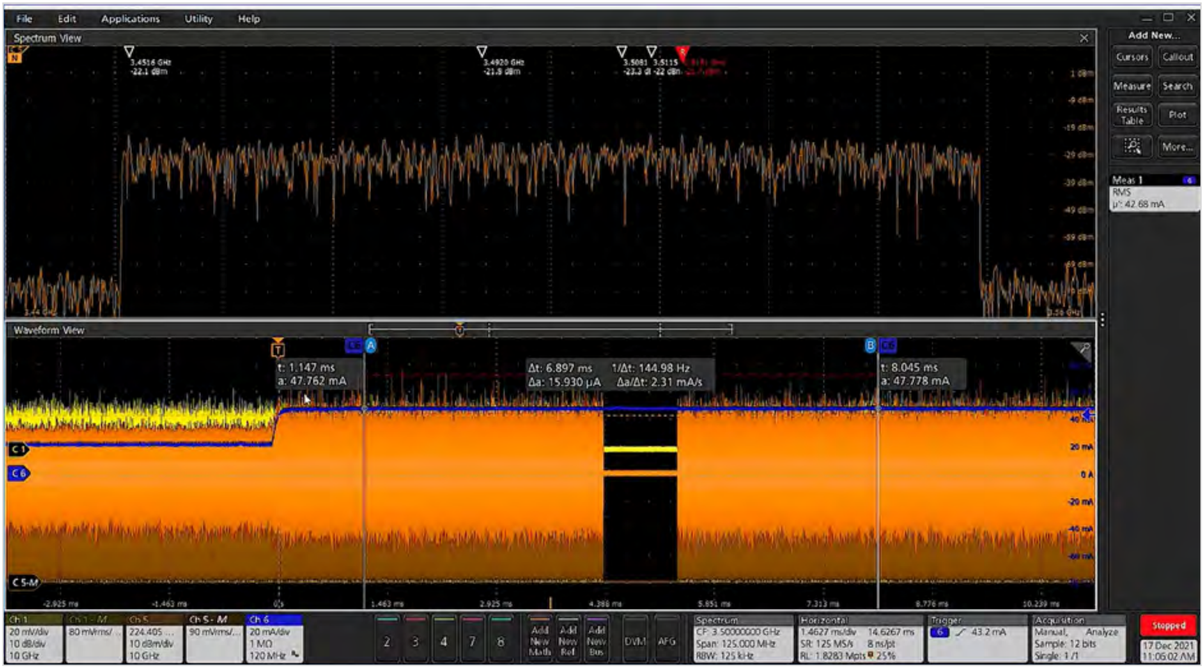
Trigger when the signal rises through a specified level

Trigger circuitry receives full input signal

Trigger: 6 43.2 mA

Acquisition: Manual, Analyze; Sample: 12 bits; Single: 0 /1

Figure 9. With a few button presses, the trigger is set to capture on an increase in current, to consistently acquire when the current returns to normal.



Meas 1: RMS μ': 42.68 mA

t: 1.147 ms
a: 47.762 mA

Δt: 6.897 ms 1/Δt: 144.98 Hz
Δa: 15.930 μA Δa/Δt: 2.31 mA/s

t: 8.045 ms
a: 47.778 mA

Ch 1: 20 mV/div, 10 dB/div, 10 GHz
Ch 1 – M: 80 mVrms/...
Ch 5: 224.405 ..., 10 dBm/div, 10 GHz
Ch 5 - M: 90 mVrms/...
Ch 6: 20 mA/div, 1 MΩ, 120 MHz

Spectrum: CF: 3.50000000 GHz; Span: 125.000 MHz; RBW: 125 kHz
Horizontal: 1.4627 ms/div 14.6267 ms; SR: 125 MS/s 8 ns/pt; RL: 1.8283 Mpts 25%
Trigger: 6 43.2 mA
Acquisition: Manual, Analyze; Sample: 12 bits; Single: 1 /1

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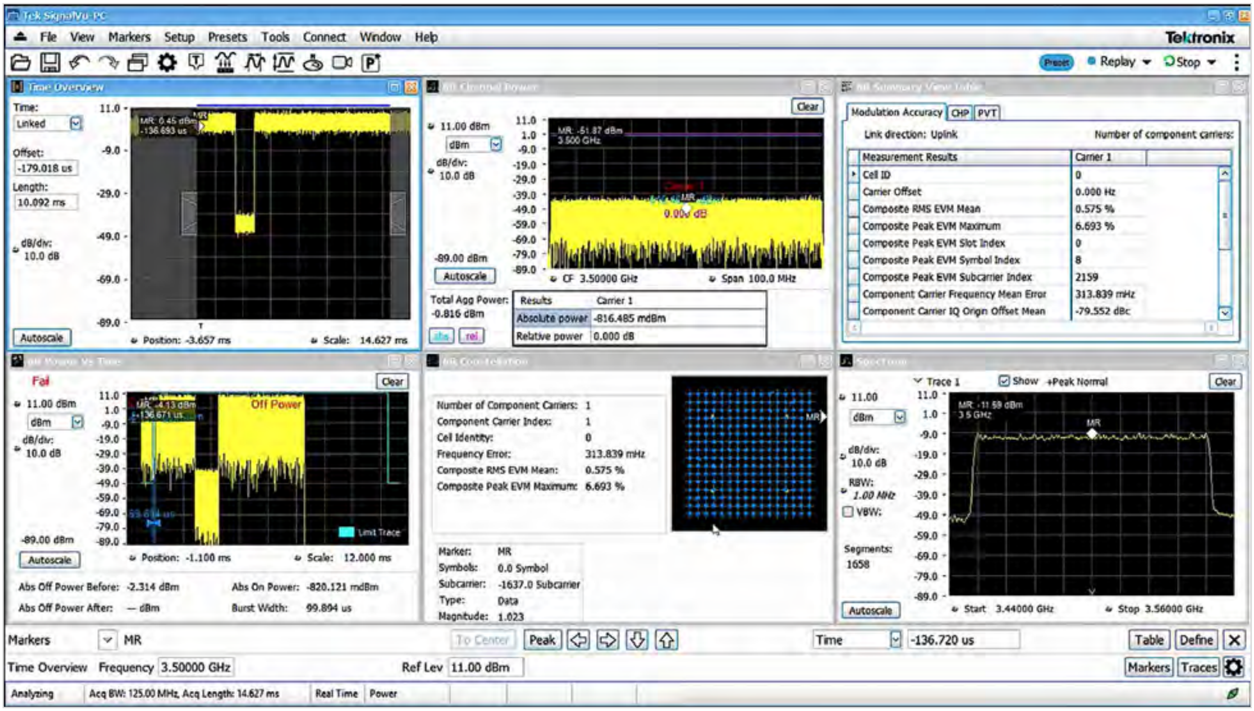
Figure 10. Triggering on the rising edge of the current times measurements when the current is back to normal.



Time: Linked

Offset: -179.018 us

Length: 10.092 ms

dB/div: 10.0 dB

Position: -3.657 ms

Scale: 14.627 ms

MR: 0.45 dBm, -136.693 us

MR: -51.37 dBm, 3.500 GHz

CF 3.50000 GHz

Span 100.0 MHz

Total Agg Power: -0.816 dBm

Results	Carrier 1
Absolute power	-816.485 mdBm
Relative power	0.000 dB

Modulation Accuracy | CHP | PVT

Link direction: Uplink

Number of component carriers:

Measurement Results	Carrier 1
Cell ID	0
Carrier Offset	0.000 Hz
Composite RMS EVM Mean	0.575 %
Composite Peak EVM Maximum	6.693 %
Composite Peak EVM Slot Index	0
Composite Peak EVM Symbol Index	8
Composite Peak EVM Subcarrier Index	2159
Component Carrier Frequency Mean Error	313.839 mHz
Component Carrier IQ Origin Offset Mean	-79.552 dBc

MR: -4.13 dBm, -136.671 us

Position: -1.100 ms

Scale: 12.000 ms

Abs Off Power Before: -2.314 dBm

Abs Off Power After: — dBm

Abs On Power: -820.121 mdBm

Burst Width: 99.894 us

Number of Component Carriers: 1

Component Carrier Index: 1

Cell Identity: 0

Frequency Error: 313.839 mHz

Composite RMS EVM Mean: 0.575 %

Composite Peak EVM Maximum: 6.693 %

Marker: MR

Symbols: 0.0 Symbol

Subcarrier: -1637.0 Subcarrier

Type: Data

Magnitude: 1.023

MR: -11.59 dBm, 3.5 GHz

RBW: 1.00 MHz

☐ VBW:

Segments: 1658

Start 3.44000 GHz

Stop 3.56000 GHz

Markers: MR

Time: -136.720 us

Time Overview Frequency 3.50000 GHz

Ref Lev 11.00 dBm

Analyzing | Acq BW: 125.00 MHz, Acq Length: 14.627 ms | Real Time | Power

Figure 11. When measurements are taken at normal current levels, the EVM is consistently in spec.

So, when our current is out of spec, our RF output and EVM is out of spec. Therefore, we've correlated the cause of the drop in RF performance to the periodic drop in current in our power supply.

In this simple demo we are using the SMU to step current up and down. As a 5G designer, you may know more about the underlying reasons for a current variation, which could be from your DPD algorithm or a coefficient loading error.

With an oscilloscope-based solution, it's also possible to measure and calculate precise amplifier power efficiency metrics, such as power added efficiency (PAE).

This device doesn't have a digital bus, but if it did, we could trigger on the digital bus and correlate problems to the digital bus activity.

Tektronix Solution Summary

Synchronized, multi-channel spectrum analysis and time domain waveforms speed 5G troubleshooting.

5G systems rely on a symphony of digital, analog and RF signals. Being able to analyze signals across multiple domains is critical to finding interference, glitches, spurs, drop-outs, and other errors.

In 4, 5 and 6 Series MSO oscilloscopes, behind each input is a 12-bit ADC inside a custom ASIC. Each ADC sends high-speed digitized data down two paths. This approach enables independent control of the time domain and frequency domain acquisitions, allowing optimization of both waveform and spectrum views of a given signal. This unique Spectrum View feature enables synchronized measurements across time, RF and digital domains, on up to 8 channels.

The 6 Series MSO is available with a frequency range up to 10 GHz, with up to 2 GHz of analysis bandwidth, giving it the ability to directly measure Sub 6 (FR1) 5G signals. Learn more online:

- 5G Testing
- 6 Series B MSO Mixed Signal Oscilloscope
- Spectrum Analyzer Software

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