Application Note

GaN or GaAs, TWT or Klystron - Testing High Power Amplifiers for RADAR Signals using Peak Power Meters

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Abstract

Measuring and characterizing pulsed RF signals used in radar applications present unique challenges. Unlike communication signals, pulsed radar signals are "on" for a short time followed by a long "off" period, during "on" time the system transmits anywhere from kilowatts to megawatts of power. The high power pulsing can stress the power amplifier (PA) in a number of ways both during the on/off transitions and during prolonged "on" periods. As new PA device technologies are introduced, latest one being GaN, the behavior of the amplifier needs to be thoroughly tested and evaluated. Given the time domain nature of the pulsed RF signal, the best way to observe the performance of the amplifier is through time domain signal analysis. This article explains why the peak power meter is a must have test instrument for characterizing the behavior of pulsed RF power amplifiers (PA) used in radar systems.

Radar Power Amplifier Technology Overview

Before we look at the peak power meter and its capabilities, let's look at different technologies used in high power amplifiers (HPA) for RADAR systems, particularly GaN on SiC, and why it has grabbed the attention over the past decade.

The second part of the 20th century has seen the rise and dominance of semiconductor technology in electronics, and the ushering out of the Vacuum Electron Devices (VEDs) commonly referred to as tubes. Aside from rock bands love for the "warm" sound of the tube amplifier, one area in which VEDs maintained their dominance has been PAs that operate up to mega watts of output power at very high frequencies (1 GHz to 100 GHz) found in RADAR systems. Most commonly used VED technologies in RADAR applications today are Traveling Wave Tubes (TWT), Klystrons, Magnetrons and Gyrotrons. TWT amplifiers (TWTA) provide what the RADAR systems need the most multi-octave bandwidths, multi-kilowatt peak power output, support of high frequencies, as well as ruggedness and reliability. Compared to TWTAs, Klystron power amplifiers (KPA) offer better efficiency.

About three decades ago semiconductor based PA solutions called solid state power amplifiers (SSPA) started making modest inroads as an alternative technology for certain RADAR applications. Silicon-based laterally diffused metal oxide (LDMOS) offered a few hundred watts of output power, ruggedness and reliability. Its upper frequency limited to about 3 GHz (S-Band) at high output powers curbed its applicability in RADAR. Gallium arsenide (GaAs), a wide-bandgap semiconductor, overcame the high frequency deficiency of LDMOS, reaching above 100 GHz, yet its lower operating voltage has limited its output power capability. High power GaAs amplifiers have often required paralleling of multiple devices to reach desired power levels at the expense of loss in efficiency. GaAs found common use in RADAR but still was not a viable alternative in most high power RADAR applications. About a decade ago when GaN was introduced it created much excitement since it offered hundreds of watts of output power at very high frequencies; it also provided the ruggedness required in RADAR applications. In the earlier years of GaN the concerns over reliability due to lack of a suitable substrate to get the heat out of the die were addressed by placing GaN on silicon-carbide (SiC) wafer substrate. While GaN provided the heat capacity, SiC provided three times better thermal conductivity. The enhanced thermal performance improved the reliability and ruggedness.

While TWTAs and KPAs are here to stay for the foreseeable future, GaN has established itself as a suitable lower cost alternative for the long run.

Peak Power Meter for Pulsed RADAR Measurements

The most critical analysis of the pulsed RF signal takes place in the time domain. Since peak power meters measure, analyze and display the power envelope of a RF signal in the time domain, they are an essential tool for measuring, analyzing and characterizing anomalies and behavior of high power amplifiers used in pulsed RADAR applications. Figure 1 shows a simplified block diagram of a benchtop peak power meter.

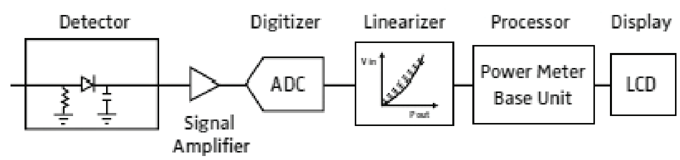


Figure 1. *Peak Power Meter Block Diagram*

The front end of a power meter is the RF envelope detector housed in a power sensor. The detector removes the RF carrier and generates an analog waveform representing the envelope of the RF input signal. The most critical specification of the detector is its response time to a pulsed RF signal or its risetime. If the detector does not have the bandwidth to track the envelope of the signal, accuracy of all measurements including peak, pulse and average power is compromised (Figure 2).

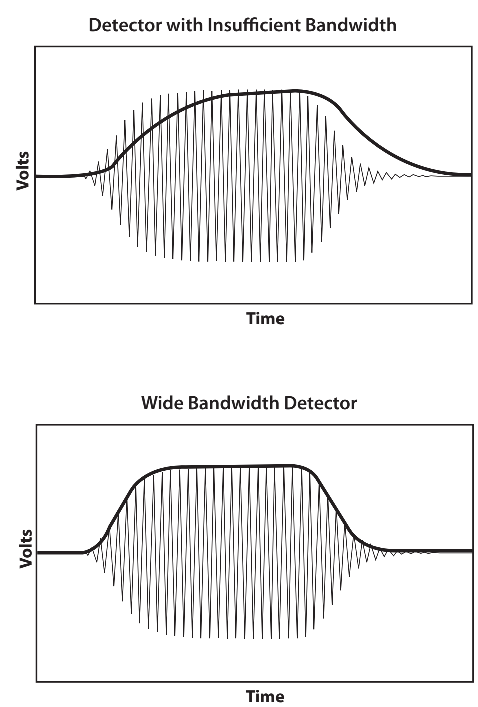


Figure 2. *Impact of risetime and bandwidth capability of the sensor for accurately measuring and displaying the pulse RF signal.*

The detector output is then digitized by an analog-to-digital converter (ADC). The digitized samples are processed by the digital signal processor for linearization and measurement analysis. The processed waveform is displayed in the time domain as power-versus-time along with automated pulse and marker measurements. In Boonton's peak power meters, on the vertical axis the power (or voltage) is displayed in watts, volts or dBm with ability to change the scaling and vertical center. On the horizontal axis timebase can be set as low as 5 ns per division (50 ns span) to zoom in to a specific portion of the waveform such as rising or falling edge to observe fine details of the waveform. Boonton's peak power meters use Random Interleave Sampling (RIS) technique which yields 100 ps resolution on repetitive waveforms. Figure 3a shows a time domain diagram of the conventional sampling and interpolation method, Figure 3b shows the RIS method. Figure 3c shows how the resolution is improved going from conventional to the RIS based method on a Boonton 4500B Peak Power Analyzer.

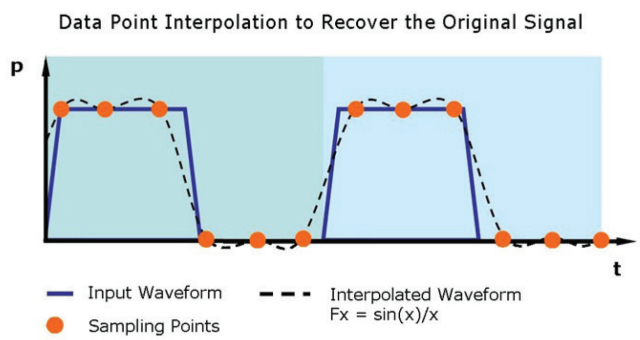


Figure 3a

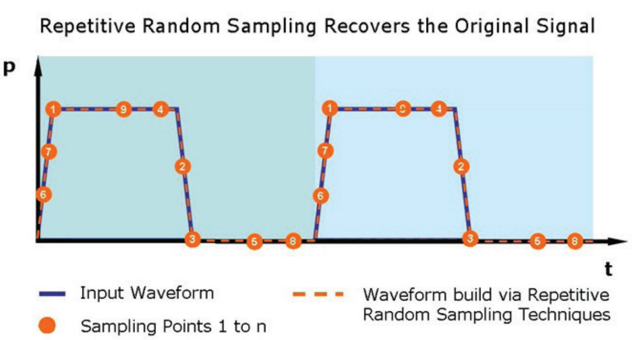
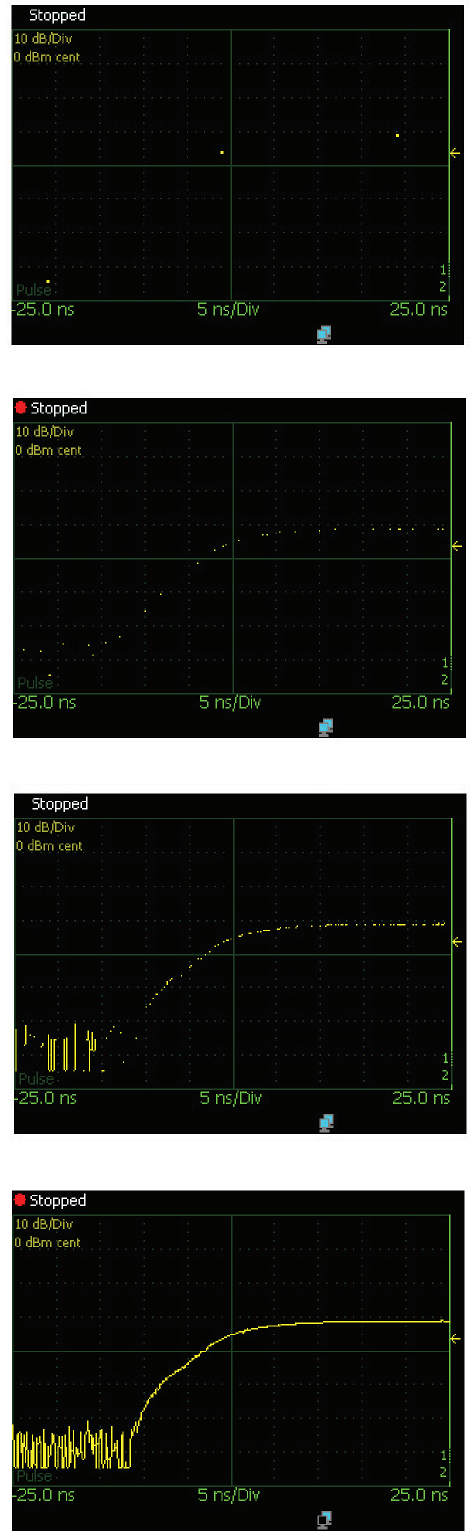


Figure 3b.



(10)

(50)

(200)

Figure 3c. *These four screenshots show how a waveform is built through repetitive sampling techniques. The first sweep (top) shows an initial set of three data points equally 20 ns apart. The remaining three show 10, 50 and 200 sets of additional data. This method achieves the highest resolutions, allowing 'zoom in'' to fast signals.*

Peak power meters can be triggered by the incoming RF signal or by an external gating (baseband) trigger signal applied to auxiliary inputs. Real Time Power Processing™ featured in the 55 series USB Peak Power Sensors allow the sensor to trigger on 100,000 pulses per second, capturing each pulse and glitch events. Advanced triggering features of Boonton peak power meters, like trigger holdoff, delays the re-arming of the trigger which is useful when working with interrogation friend or foe (IFF) RADAR signals.

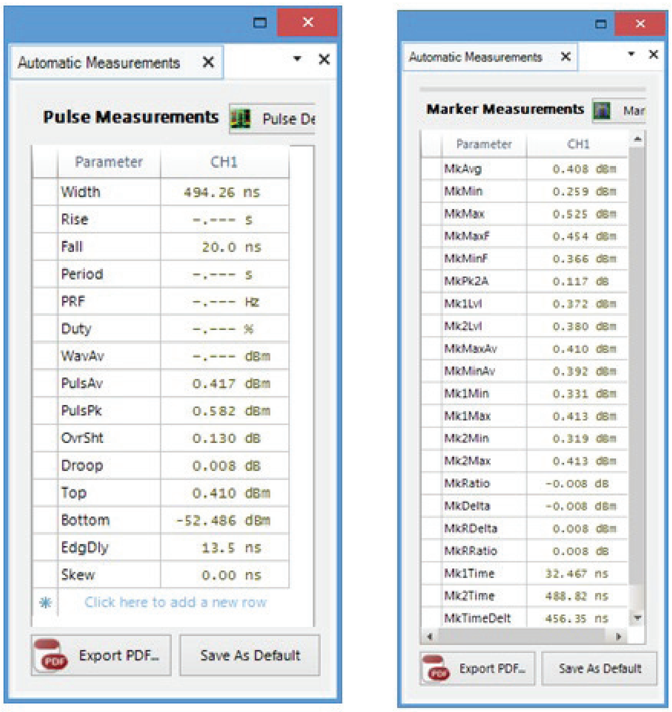


Figure 4. *Automated Pulse & Marker Measurements using 55 Series USB Peak Power Sensor*

In terms of measurement capabilities, peak power meters perform numerous manual, automated marker and automated pulse measurements. Automated pulse measurements (Figure 4) provide measurement values of a number of critical parameters that help characterize the performance of the power amplifier and the RADAR system. Rise and fall time indicate the amplifier's ability to output a pulsed RF signal. Overshoot pinpoints potential ringing problems. Droop shows the amplifier's power supply limitations with prolonged pulse widths. Pulse Width, period, pulse repetition rate and duty cycle measurements provide other time domain characteristics of the signal. There are also a number of automated marker measurements (Figure 4 on the right) that enable time gated measurements. These measurements are performed between two markers and provide average, peak, min and max power readings, as well as peak to average ratio, delta marker of power level and delta time marker measurements.

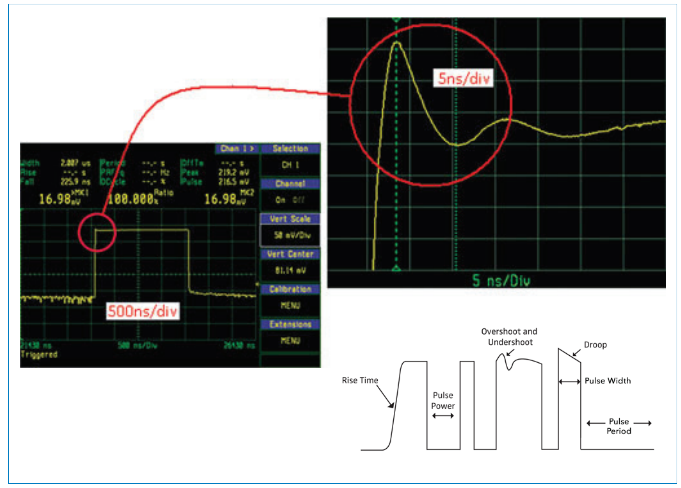


Figure 5. *Some of the pulse characteristics that can be measured using a peak power meter.*

A significant advantage power meters have over other measurement instruments is the size of the power sensor. It is small and light enough to be directly connected to the measurement port without the need for a RF cable which can degrade measurement accuracy due to impedance mismatch and cable loss, especially at higher frequencies.

For automated test environments all Boonton peak power meters can be remotely accessed via various interfaces such as USB, LAN (TCP/IP), RS232 and GPIB, depending on the model.

More reading materials on the topic of power measurements are provided at the end of this article with links to articles and application notes as well as Boonton's newly revised RF Power Measurement Guide that provides practical insights to making measurements for RADAR signals.

Test Set-ups for Making Pulsed RADAR Measurements

Although there are numerous pulsed RF amplifier architectures, two types are considered in this article. The first is a modulating amplifier; the input is CW and the output is pulsed RF where a gating signal modulates the incoming signal to achieve the desired pulse RF signal (Figure 6).

In Figure 6 a dual channel meter measures the input signal power at P1 and the reflected power at P2 in time domain for return loss calculation, as well as monitoring anomalies of the reflected signal. At P3 the output of the amplifier is monitored and measured. Key amplifier parameters that were mentioned in the previous section are measured at P3 and P4 monitors the reflected power of the load. The gating signal that modulates the RF input signal can also trigger the power meter enabling delay and latency measurements. Boonton's highest performance benchtop peak power analyzer, model 4500B, is equipped with waveform math capabilities and is capable of displaying gain and return loss in time domain. The instrument is also equipped with two scope channels. When the gating signal to the amplifier triggers the peak power meter, both the gating signal and the output of the amplifier can be displayed on the peak power meter enabling critical timing measurements, as well as detecting if any amplifier anomalies are caused by the gating signal.

While benchtop models support one (single) or two (dual) channels, the 55 Series USB peak power meters can measure and display up to eight channels on a single GUI window. Using three or four USB sensors, amplifier input and output power, reflected input power and reflected load power can all be measured and displayed on the same trace window or in an automated test set-up via remote programming (up to 16 or 32 channels).

The second type is a gain only amplifier where the output is an amplified (and often distorted) version of the pulsed RF input signal (Figure 7) with no gating signal supplied to the amplifier. The set-up is ideal for analyzing not only fully assembled amplifiers but also a subassembly such as the driver stage or the final stage of the amplifier or even a semiconductor power transistor like GaN. The set-up uses three peak power meters and a directional coupler to make scalar like gain and return loss measurements of the amplifier.

When evaluating new technologies like GaN, monitoring power droop across the pulse width is critical as it can be an indicator of the limitations of the thermal properties of the GaN device and its package. Time domain peak power measurements can be taken at the output of the amplifier (Figure 9).

Since the power rating of a typical sensor is about +20 dBm, the output of the PA is attenuated to protect the power sensor while making the output power measurement. Before measurements can be taken a thorough calibration procedure is required at the frequencies in which the amplifier is going to be tested to account for losses in the signal path. The losses that need to be calibrated out in the test set-up of Figure 7 and calculations required to compute gain and return loss are provided below.

L1: Loss from Signal Generator output to the FWD port of the directional coupler.

L2: Loss from Signal Generator output to the power amplifier input.

L3: Loss from amplifier output to the 40 dB attenuator output.

L4: Loss from amplifier input into the REV port of the directional coupler.

Once the losses are measured, input, output and reflected power measurements can be made:

P1: Power reading at FWD port of the directional coupler.

P2: Power measured at the 40 dB attenuator output.

P3: Power measured at REV port of the directional coupler.

PA input power = P1+L1-L2

PA output power = P2+L3

PA input reflected power = P3+L4

All Boonton peak power meters are capable of adding an offset to the measurements so the math above can be done by the meter once the losses are measured and entered to each channel as an offset.

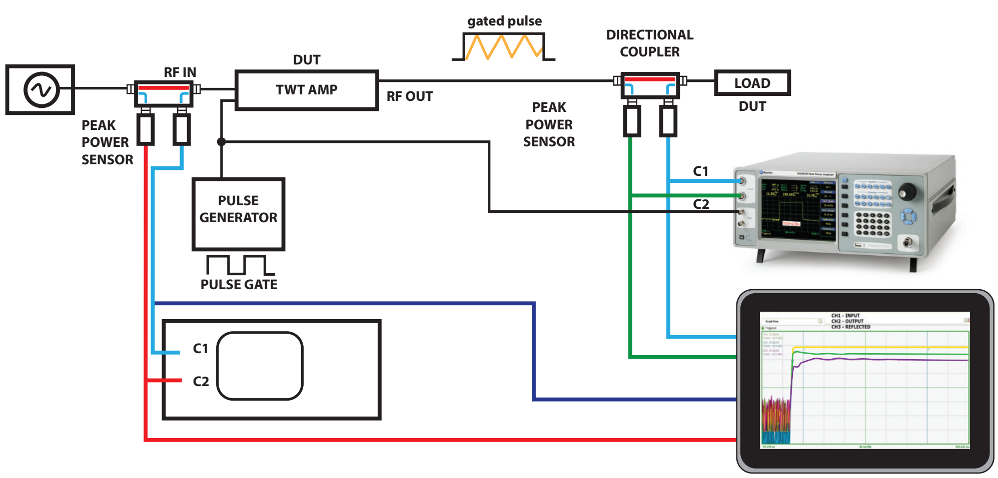


Figure 6. *Test set-up for time domain pulse measurements. The input signal is CW and the output signal is pulsed RF. A gating signal modulates the incoming CW signal.*

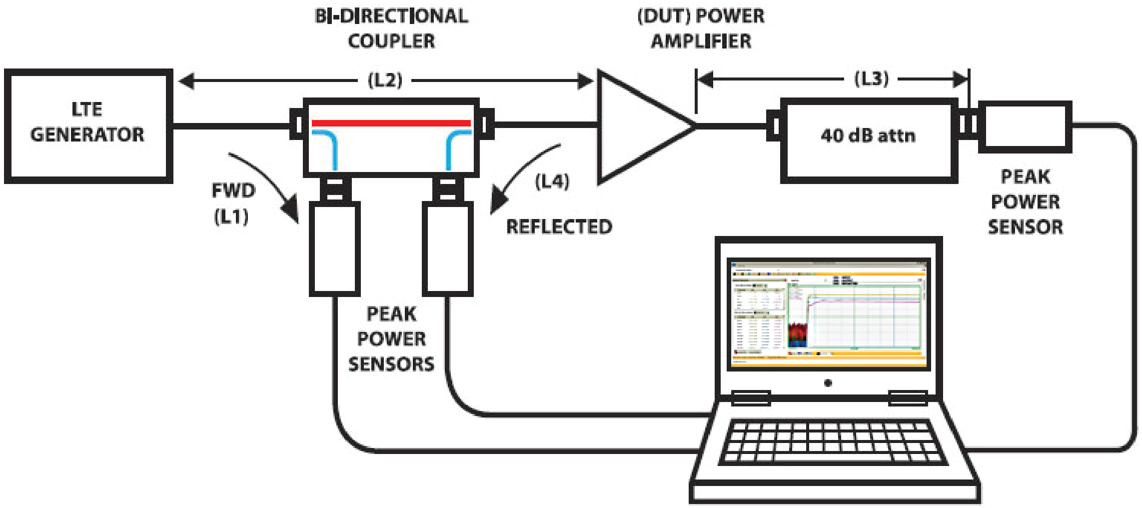


Figure 7. Test set-up showing time domain scalar-like gain and return-loss measurements using three sensors and one directional coupler.

The input, output and reflected power measurements can be used to compute gain (S21) and input return loss (S11).

PA Gain (dB) = PA output power (dBm) – PA input power (dBm)

PA input return loss (dB) = PA input power (dBm) – PA input reflected power (dBm)

The 4500B can perform these measurements in time domain using waveform math.

It is important to note that in both test set-ups, Figure 6 and Figure 7, the directional couplers need to have excellent directivity in order to make accurate power measurements, especially for return loss calculations. Unused ports of the couplers must be terminated with 50 ohms during measurements.

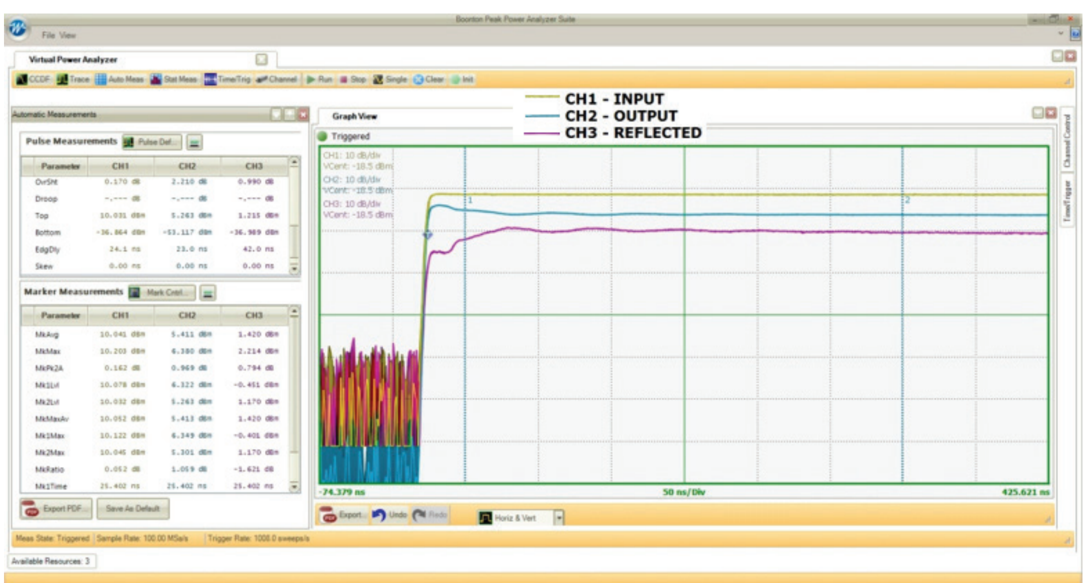


Figure 8. The screenshot captures the input, output and reflected waveforms of the pulsed RF signal. Blue trace is output of the DUT1 (note overshoot and ringing), purple trace is the reflect signal from the input port of the load DUT2.

Measurements

Figure 8 shows three waveforms measured using the test set-up in Figure 7 using the 55 Series Peak Power Sensors. The input waveform is displayed on CH1, reflected waveform on CH3 and the output on CH2. Note that automated measurements performed on all three channels are displayed to the left of the trace display window. The measurements can be transferred to a spreadsheet to perform the necessary gain and return loss calculations, as well as other parameters of interest. In an automated test environment the same measurements can be accessed through remote programming to perform gain and return loss computations as well. Droop measurement capabilities are shown in Figure 9 using the Boonton 55318 USB Peak Power Sensor. Power droop can be measured either using the automated pulse measurements or using automated marker measurements as well as horizontal markers. The automated marker measurements can display the droop placing markers at the desired points on the waveform and using MkRatio. Alternatively reference lines can be placed on the vertical axis at the desired high and low points of the pulse to measure the droop. Automated Pulse measurements are computed automatically based on pulse definition irrespective of marker or reference line placements.

Conclusion

VED based amplifiers have dominated the PAs used in the aviation and warfare RADAR systems for the past seven decades. However, new semiconductor based SSPAs, have made inroads to various RADAR applications, especially GaN based ones. Regardless of technology used in the RADAR PA, high resolution highly accurate time domain power measurements are critical to understand the amplifier performance and behavior. Peak power meters are an essential measurement tool for time domain power analysis to test RADAR power amplifiers for R&D, quality, manufacturing, field support and system calibration.

Boonton Peak Power Meter Solutions

Boonton has been developing power meters for six decades, almost as long as RADAR systems have been around. Just as VED based amplifiers have evolved so have power meters. Boonton peak power meters have been successfully used in civilian and military aviation, warfare and weather RADAR systems for decades and have become the instrument of choice in RADAR signal testing.

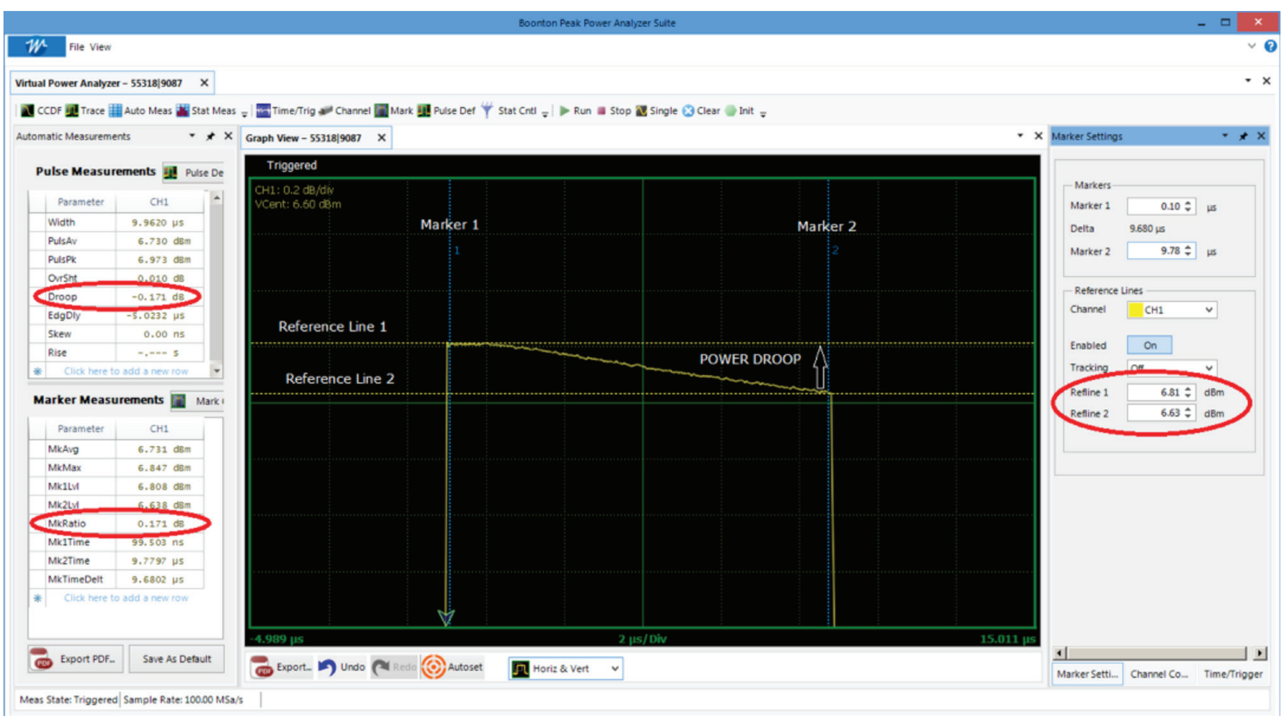


Figure 9. Droop Measurement using 55318 USB Peak Power Sensor. Blue vertical lines 1 and 2 are markers placed for automated marker measurements. Yellow dashed horizontal lines are reference lines. Automated Pulse measurements are computed automatically based on pulse definition irrespective of marker or reference line placements.

The 4500B is the top performance benchtop peak power analyzer. It is the instrument of choice for capturing, displaying, analyzing and characterizing RF power in both the time and statistical domains for pulsed RF application. 4500B has been deployed at weather, civilian and military aviation and electronic warfare RADAR system testing. Aside from RADAR applications, time gated power measurements are required for communications signals such as 802.11ac WLAN and TDD-LTE. Waveform math and memory channels as well as two scope channels to monitor external trigger signals on the same display as the incoming RF envelope signal are unique to the 4500B.

The 4540 series combines a peak power meter, an average power meter and a voltage meter, into a leading edge instrument for accurate RF measurements. Like the 4500B it features high dynamic range and rise time of less than 7ns and provides great detail in signal waveform analysis. It is ideal for capturing, displaying and analyzing RF power in time and statistical domains. 4540 meters are used widely by high power amplifier manufacturers in R&D and manufacturing test racks.

The 55 Series USB Peak Power Sensors, the latest addition to the family of peak power meters, delivers benchtop performance in an USB form factor. Powered by Real Time Power Processing™, currently available only in the 55 series, the sensor is able to make 100,000 triggered measurements per second making it ideal for capturing high PRI/PRR/PRF RADAR signals without missing a pulse and glitch events. Industry leading 3 ns risetime is meant to handle the most challenging RADAR signals. 195 MHz video bandwidth makes it ideal for making time gated power and crest factor measurements for broadband communication signals like 802.11ac WLAN, TDD-LTE and FDD-LTE.

Boonton Resources on RADAR Testing & More

Technical Articles and application notes on RADAR and peak power meters

[1] RF Power Measurement Reference Guide
http://www.boonton.com/resource-library/power-measurement-reference-guide

[2] Importance of peak power measurements for RADAR systems
http://www.boonton.com/resource-library/articles/the-importance-of-peak-power-measurements-for-radar-systems

[3] RADAR Testing
http://www.boonton.com/resource-library/application-briefs/radar-testing

[4] Boonton 4540 RF Power Meter Application in a Transponder Type Pulsed RADAR System by Michael Mallo, Rockee Zhang and Andrew Huston of RADAR Innovations Laboratory, the University of Oklahoma
http://www.boonton.com/applications/radar/4540-pulsed-radar

[5] What Real Time Power Processing™ means - 100,000 triggered measurements / second
http://www.boonton.com/resource-library/articles/real-time-usb-power-sensor

[6] Characterizing RADAR interference immunity
http://www.boonton.com/resource-library/articles/characterizing-radar

[7] What trigger fidelity & high resolution timebase mean for RADAR
http://www.boonton.com/resource-library/articles/4540-article

[8] Application Note on definitions of automated pulse and marker measurements
http://www.boonton.com/applications/radar/numerical-parameters-analysis-of-boonton-4540-peak-power-meter

[9] Advanced Trigger Capabilities of Peak Power Meters
http://www.boonton.com/applications/communications/4500b-advanced-trigger-capabilities

[10] Why replace crystal detector with a peak power meter for RADAR
http://www.boonton.com/resource-library/application-briefs/crystal-detector-sellsheet

Videos on capabilities of Boonton peak power meters for RADAR and communications applications:
http://www.boonton.com/resource-library?brand=Boonton&go=videos

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