

Selecting an RF or Microwave Power Sensor/Meter

Application Note

Introduction

Power measurements are fundamental to the development cycle of any RF or microwave product, from ubiquitous mobile phones to sophisticated radar systems. Not surprisingly, along with the applications, the range of modulation and multiplexing schemes also varies widely. This fact, combined with the availability of new functions in power meters previously

reserved for higher-end analyzers, makes the choice of an RF or microwave power measurement system more complex than ever. Due to the large variance in product offerings and specifications on manufacturer's data sheets, a side by side comparison is the best way to evaluate power sensors before making a purchasing decision. This application note will describe some of the factors to consider when purchasing a USB power sensor.

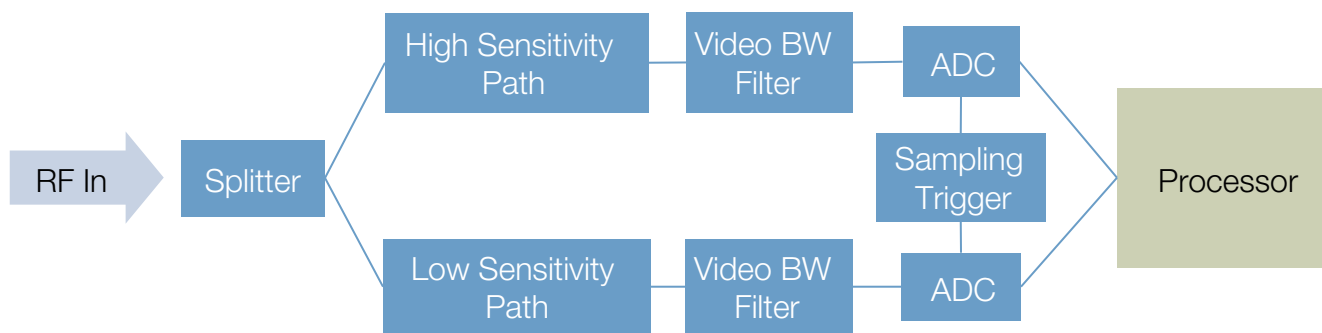


Figure 1. Tektronix PSM Power Sensor Multiple Path Block Diagram.

Basic Factors to Consider

Choosing a USB power sensor involves many of the same criteria as traditional power meters and sensors. Factors like frequency range, dynamic range, accuracy, zero and calibration, speed of measurements, and triggering continue to be critical to the selection process.

Frequency Range – Power sensors are available in a wide degree of ranges that cover frequencies from several kHz to 110 GHz. The most commonly used ranges are through 6 GHz to 20 GHz. Since power sensors are broadband detectors, they detect all RF power at their input across the entire frequency range. Variations in the frequency response of the sensor are accounted for in the calibration table stored within the sensor.

Dynamic Range – Dynamic range is the range of power over which a sensor is capable of making useful measurements. This range depends upon the type of sensor technology used. Diode based sensors have the widest dynamic range usually ranging from -60 dBm to +20 dBm or more. Their wide dynamic range coupled with their quick response time make diodes the preferred solution in most applications. A diode sensor achieves a wide dynamic range by extending the useful range of the diodes beyond their square law region through the use of correction factors, and the use of multiple diode paths. When using multiple paths, the method used to switch between these paths can have an effect on linearity.

Most sensors measure one path at a time and switch at some threshold, typically around mid-range. This transition point becomes a point of potential discontinuity or hysteresis which can cause non-linearity or measurement delays.

Tektronix power sensors continuously digitize both paths simultaneously and use a weighted average over the transition point. This allows for a smooth and continuous transition between measurement channels and makes the full dynamic range of the sensor available all of the time without discontinuities.

Compared to diode based sensors, thermistor-based sensors have a limited dynamic range from -20 dBm to +10 dBm, whereas thermocouple sensors typically have a dynamic range from -35 dBm to +20 dBm.

The typical maximum input power value for most power sensors is +20 to +23 dBm. Exceeding this value will damage a sensor. Power attenuators and couplers can be used to reduce the maximum power at the input of a power sensor, shifting the dynamic range of the sensor. This can help reduce the likelihood of accidental damage, but their use introduces added reflections between sensor and attenuator. These reflections decrease measurement accuracy and require proper matching and more set-up time to calibrate out VSWR mismatches.

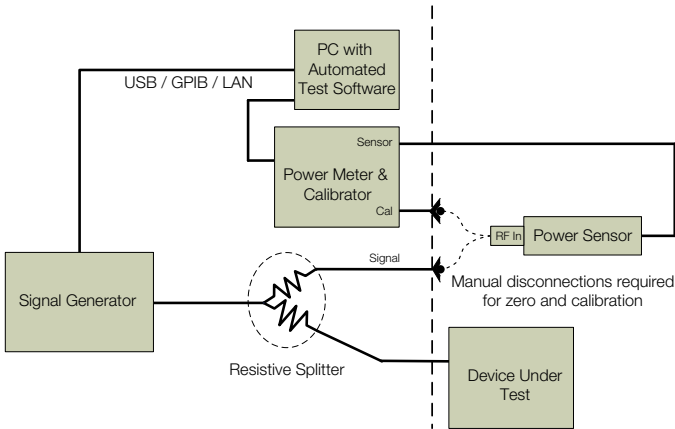


Figure 2a. Test system designed to accommodate zero and calibration of power sensor.

Accuracy – Overall accuracy is a combination of several error sources and is typically calculated by combining the errors in a standardized way. These error sources include: sensor to DUT mismatch, calibration factors, linearity, noise, temperature, and zero-offset. While a complete discussion is outside the scope of this application note, these error factors are usually combined in an RSS fashion. Like Tektronix, most manufacturers follow the ISO Guide to the Expression of Uncertainty in Measurement which explains in excellent detail how uncertainty factors combine. Overall accuracies for power sensors range from 2 to 5% depending upon the manufacturer and the type of detection technology used.

Zero and Calibration – Calibrating a power sensor requires connecting the sensor to an external reference source. Zeroing a sensor usually requires disconnecting the sensor from the device under test. Zero and calibration requirements are important considerations since these requirements can increase test times and incremental expense, especially in automated test systems where every second is valuable. If a

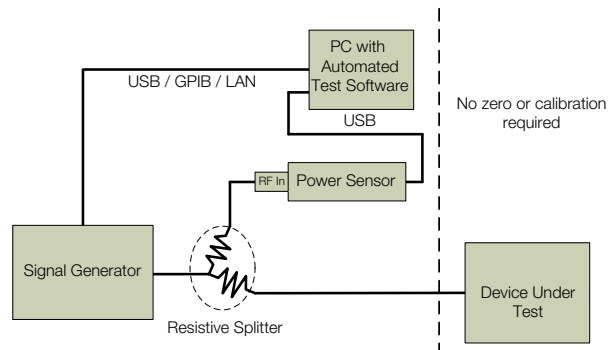


Figure 2b. Simplified test system using power sensor that does not require zero or calibration.

power sensor requires periodic zeroing or calibration, the ATE system must be designed to accommodate these procedures. This usually requires some combination of costly switches, manual setup procedures, or dedicated software. Calibration requires an external reference source and zeroing usually requires the user to disconnect the device under test.

Tektronix sensors have completely eliminated user zero and calibration. This provides excellent measurement stability and accuracy, reduced test times, less wear on connectors, and lower cost of software and switching hardware. The Tektronix PSM sensors employ a patented technique to ensure stability and calibration over the entire temperature range, which makes them more accurate over varying ambient temperatures than any other sensor on the market. Most other power sensors require zeroing, at least under certain conditions, like ambient temperature changes or when measuring low-level signals. Check the instrument's user manual to confirm the conditions that require zero or calibration.

Speed of Measurements – Power sensors typically specify several parameters that relate to measurement speed and the vocabulary used varies between manufacturers. Some typical terms you will see on datasheets include, "sample rate", "reading rate", and "measurement rate". Sample rate is the rate at which analog to digital conversion takes place. Reading rate tells how fast the meter can convert raw samples into measurements. These are important specifications, but the fundamental question is, "How fast can I get settled measurements?" The sample rate of a sensor helps determine a sensor's ability to measure pulse characteristics, but a high sample rate does not directly translate into fast, settled measurements. Reading rate has a more direct impact on measurement speed, but it may not accurately reflect the rate at which an instrument delivers settled power measurements. Settled measurements not only depend on sampling rate, but also on signal noise, signal amplitude, sensor architecture, and the integration time required for a stable measurement. For example, Tektronix power sensors have a real-time sample rate of 500 kilosamples/second, and a reading rate of around 2000 readings/second. Tektronix PSM3000 sensors can make a settled measurement, even at -40 dBm, in approximately one millisecond. The PSM4000 and PSM5000 sensors can take settled measurements at the low end of their dynamic range in approximately 250 μ s. The typical settling time for a classic sensor at the same power levels is generally between one to four seconds. When evaluating power sensors for measurement speed, it is best to evaluate the units side by side, rather than relying solely on datasheets.

Triggering – For most basic power measurements, triggering is not a critical capability. However, if you need to take measurements on a specific portion of a pulsed signal, or are fighting to reduce test time in high-throughput ATE systems, triggering can be an important consideration.

Basic power sensor triggering usually consists of an external TTL input. This can be useful for synchronizing power measurements with other instruments like signal generators, network analyzers, oscilloscopes, or additional power sensors. In automated test applications, the ability to externally synchronize measurements can be critical to reducing test times and maximizing throughput. Tektronix sensors include both a trigger input and a trigger output to optimize test speeds. The trigger output can tell you when the sensor is performing a measurement and communicate that information to other instruments down the line.

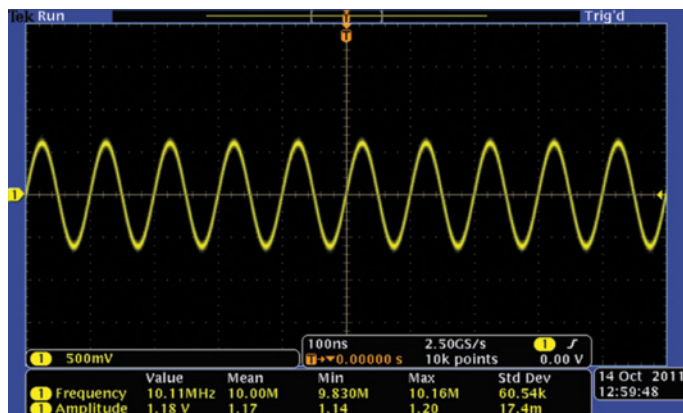


Figure 3. Continuous Wave (CW) signal with constant amplitude and frequency.

More advanced power level triggering is also available in newer sensors. These sensors can synchronize measurements with respect to the incoming RF signals. This type of triggering is important when measuring pulsed signals and taking burst measurements. We will discuss this further in the Burst Measurement and Pulse Profiling section of this application note.

Measurement Capabilities

Choosing the right power sensor for your application obviously depends on the signal characteristics you need to measure. But to some extent, what you can cost-effectively measure may also guide your test strategy. Measurement capabilities of sensors range from basic average power measurements to detailed pulse characteristics you would expect from a vector signal analyzer or dedicated pulse analyzer, but might not expect to see from a power sensor.

Average Power Measurements

Most power meters are capable of delivering accurate average power measurements on continuous wave (CW) signals. These common signals are of constant amplitude and frequency. They are relatively uncomplicated and the capability of performing average power measurements is common to most USB power sensors. Figure 3 shows an example of a CW signal. All Tektronix sensors have the capability of accurately measuring average power. Though all USB power sensors are capable of measuring average power, there is a subset whose average power measurements are referred to as "true average" or "true RMS".

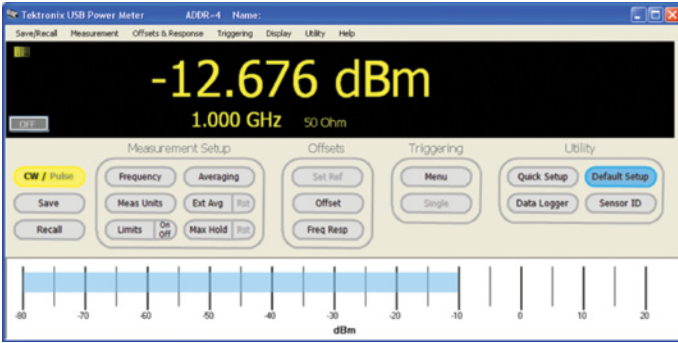


Figure 4. Tektronix power meter application showing a True Average (CW) measurement.

What is a True Average power measurement?

A true average power measurement gives the total power that is incident to the sensor regardless of the modulation bandwidth of the input signal. True average measurements can be made using a sensor with a thermal detection unit or by using a diode detector in its square law region. Thermal sensors produce a true average measurement based on the heat generated by RF energy. A true average diode detector includes capacitance that integrates the energy received by the detector, resulting in a measurement that closely approximates one from the thermal sensor.

Since Tektronix PSM3000 sensors are true average sensors, they are well-suited for measurements on broadband modulated signals and can measure all RF energy that is incident on the sensor input, whether that power is pulsed, CW, AM/FM, or in a complex modulated format.

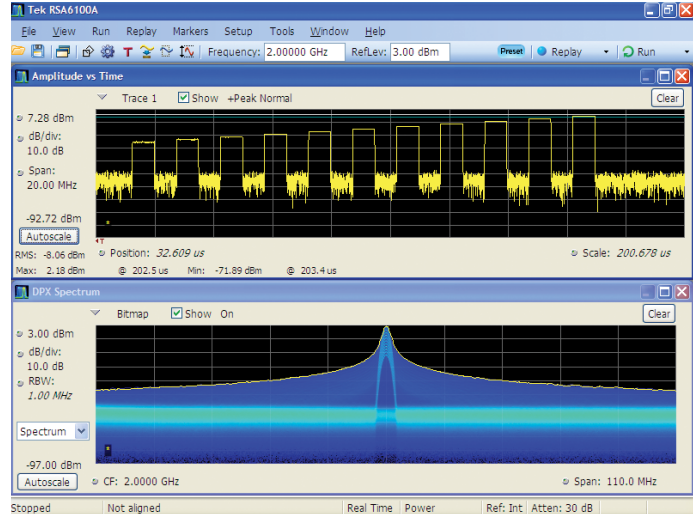


Figure 5. Time and frequency domain screen image of Tektronix RSA6100A with stepped pulse train.

Measurements on Pulsed RF and Microwave Signals

Choosing a sensor for analyzing pulsed signals presents a broader set of alternatives and some additional considerations. Pulsed signals are prevalent in RF applications such as radar, and digital communication formats utilizing time multiplexing.

Pulse Power Measurements

When working with pulsed signals, the average power of the overall signal may still be of interest, but the characteristics of the pulses become more important. Understanding the average and peak power contained within pulses is a critical part of characterizing power amplifiers and other signal path elements in pulsed systems.

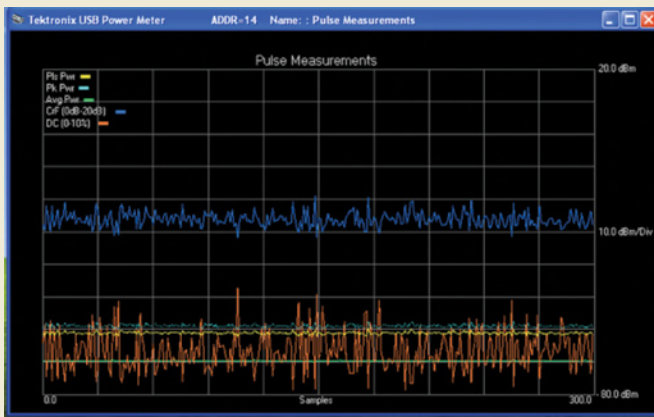


Figure 6. Data Logger screen image within Tektronix Power Meter Application.

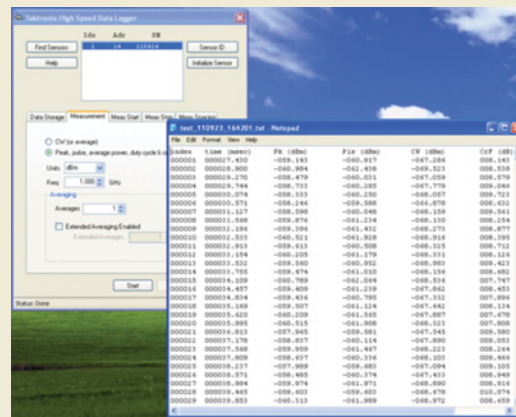


Figure 7. High Speed Data Logger screen image showing sample log of multiple data points.

USB Sensors Offer New Advantages

Today's USB-based power measurement systems have some important advantages over the traditional meter and sensor configuration.

Low Cost – Because USB sensors are connected directly to a PC, no base unit is required. This saves money and since a single computer can be used for multiple sensors, USB sensors are very economical.

Size and Portability – USB power sensors provide flexibility due to their lightweight and compact size. They can be used in applications in which classic power meters are unsuited or cumbersome. Multiple sensors can be embedded in automated test systems or deployed in remote locations. In the lab, their small size takes up less rack and bench space.

Test System Integration – USB power sensors connect to the PC with readily available cables and hubs. Common Microsoft programming environments are typically supported through dedicated API's or USBTMC. Tektronix sensors may be controlled through a Windows API which supports the following languages: C++, C#, LabView, and VB.net. All Tektronix sensors include sample code, drivers, a programmer's manual, and code generators designed to exercise discrete functions and allow programmers to become familiar with the various calls.

Familiar Windows User Interface – A software interface is an essential part of any USB-based power meter. For customers new to USB power meters, it is important that the software be user-friendly and easy to understand. Tektronix power meters include an easy to use software suite whose intuitive interface is designed to simulate a traditional bench meter to make the transition to a USB-based system as easy as possible. Familiar toolbars and drop-down menus allow most users to get up and running quickly.

Performance – The high transfer rate available in USB 2.0 and the processing power of widely-available PCs ensure that the performance of these compact power sensor units meets or surpasses the performance of traditional power meters.

Data Collection – Because USB sensors interface directly to PCs, data collection on the PC is seamless. Tektronix USB power sensors offer two distinct types of data logging capabilities, each with a different purpose:

- Data Logger – This function within the Tektronix Power Meter application allows the user to track readings from the virtual front panel over time.
- High Speed Data Logger – Tektronix offers this function as a separate software application. This application allows you to rapidly collect raw data points to be post-processed later with software analysis tools.

Compatibility with Other Instruments – USB power sensors can be integrated with other test devices that have built-in computing power such as signal generators, spectrum analyzers, and oscilloscopes. This eliminates the need for a separate PC, reducing cost and saving space on your lab bench. Tektronix PSM Series power sensors are currently compatible with the following Tektronix products:

- Oscilloscopes
 - MSO5000 - DPO5000 - DPO7000
 - DPO/DSA/MSO7000 - DSA8300
- Spectrum Analyzers
 - RSA5000 - RSA6000
- Arbitrary Waveform Generators
 - AWG5000 - AWG7000

Duty Cycle Correction Method

One approach to measuring pulse power is to assume a constant duty cycle value and a square pulse envelope. For square pulses (with minimal overshoot, steep rise and fall times), and well-defined duty cycle, pulse power can be calculated by dividing the average power by the duty cycle. This method is simple, may be used with low cost average power sensors, and will give good results as long as the duty cycle is known and the pulses are square. All Tektronix sensors include a facility for specifying duty cycle in software. This allows the software to calculate the pulse power, based on the known duty cycle. This is the only way to measure pulse power on the PSM3000 True Average series and other average-only power sensors. However, this method introduces error when the duty cycle is not constant and the pulse amplitude and shape is variable.

Direct Pulse Measurement Methods

The PSM4000 and PSM5000 can measure pulse power directly, not as a calculated measurement like the duty cycle method used with CW sensors. Pulse power measurements are performed within the sensors, using signal processing on the sampled power data. Directly measuring pulse power, instead of basing the measurement on an assumed duty cycle, allows Tektronix power sensors to reduce uncertainty in pulsed power measurements.

Peak Power Measurements

In addition to measuring the average power contained within the pulse, peak power is also an important parameter. Peak power is the highest power point of the signal waveform, which in the case of a pulse, is usually the overshoot on the rising edge, but can occur elsewhere if significant ringing occurs. Peak power measurements are an important tool for evaluating signals on the input of power amplifiers. Peaks outside the amplifier's specifications will cause distortion. High peak power levels from radar transmitters can cause out-of-band and spurious emissions that can impact other spectrum uses.

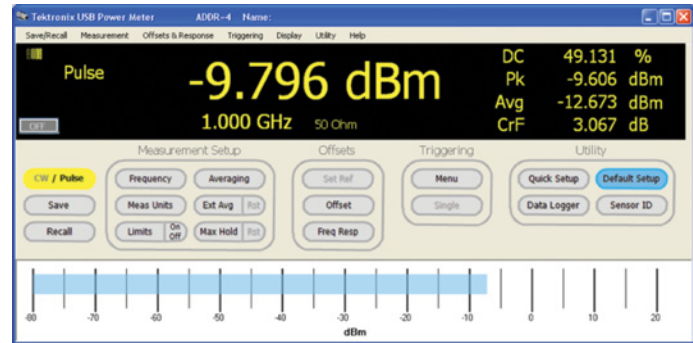


Figure 8. Tektronix power meter application showing a Peak / Pulse power measurement.

The PSM4000 and PSM5000 use a combination of sampling techniques and signal processing to deliver accurate peak and pulse power measurements.

Real-time Sampling

The key to both pulse and peak power measurements lies in the sampling used to capture the pulse data. As shown in Figure 1, analog-to-digital converters are used to convert the sensor detector output into digital form. The faster an instrument samples (i.e., the higher the sample rate), the finer the time resolution. This results in more precise measurements overall and a better ability to capture peaks. The real-time sample rate of all Tektronix sensors is 500 kS/s, which is driven by the clock rate of the converters.

Since the power envelope is being sampled, the likelihood of capturing an accurate peak improves with longer records. Thus, the measurement time must be long enough to capture a few cycles of modulation. On Tektronix meters this is done by adjusting the number of averages, which extends measurement time. As averaging is increased, the sensor can make more reliable and accurate calculations of pulse power, crest-factor, and duty-cycle.

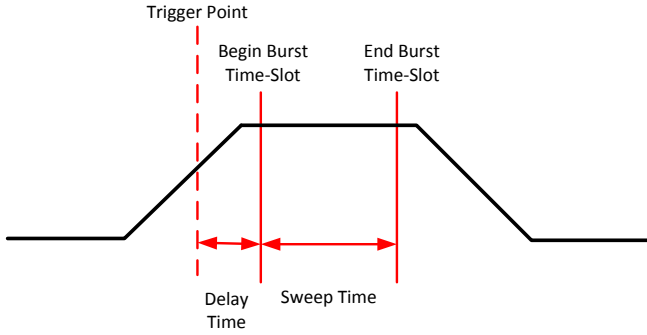


Figure 9. Diagram of a burst time slot.

Burst Measurements

Burst signals, like GSM/Edge as well as other TDMA signals, are pulsed RF waveforms characterized by long pulse widths and long periods. In many cases, the power in a particular part of the burst is of interest.

Tektronix PSM4000 and PSM5000 sensors provide time-gated burst measurements by allowing users to specify a burst measurement window. The user creates this window by setting a delay and sweep time, as shown in Figure 9. The sensors then measure the average power, peak power, and minimum power within the specified gate. With Tektronix sensors, burst measurements may be internally or externally triggered. The automatic internal trigger provides an easy way

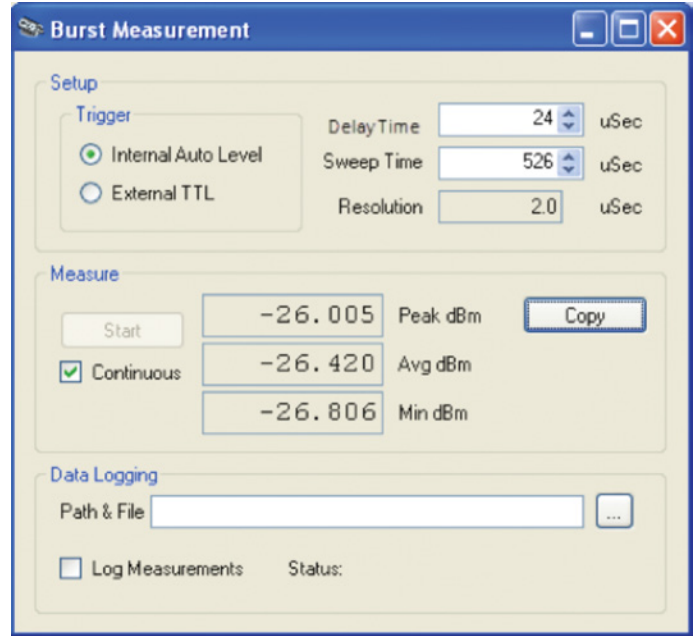


Figure 10. Tektronix power meter application Burst Measurement window.

to synchronize the measurement. When the auto trigger is selected, the instrument automatically determines the trigger level by sampling the incoming signal, examining the data for maximums and minimums, and then setting the trigger level between these maximum and minimum points. As the signal varies, the auto trigger level adjusts accordingly.

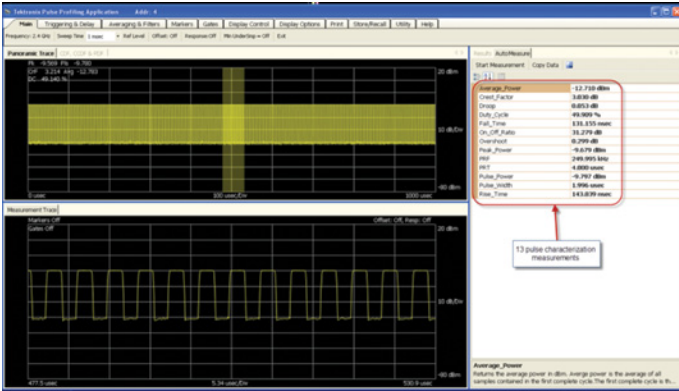


Figure 11. Tektronix Pulse Profiling application showing pulsed signal with 13 different pulse characterization measurements.

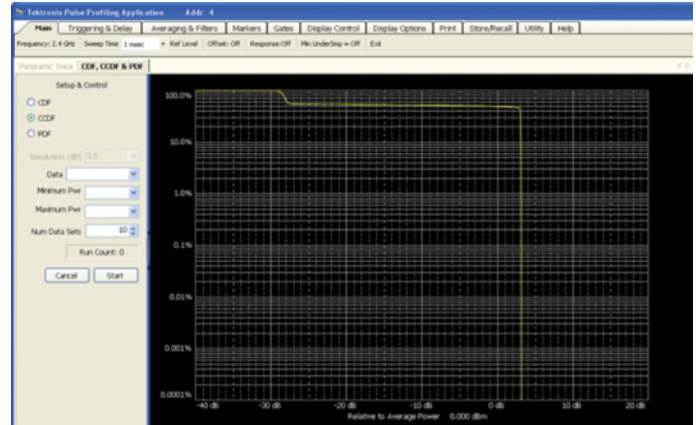


Figure 12. Tektronix Pulse Profiling application CCDF display screen.

Characterizing RF and Microwave Pulses – Pulse Profiling

In applications like commercial cellular transmission analysis or pulsed radar, a more detailed view of the modulation envelope may be of value. Not only are the pulse average and peak power needed, but measurements such as overshoot, rise-time and fall-time are important as well. Visualization of the modulation envelope allows for better qualitative analysis of the signal. The Tektronix PSM5000 Series uses equivalent-time sampling to provide a 20.8 ns resolution time-domain view of the pulse envelope without requiring a sophisticated analyzer (see *Equivalent-time Sampling*, page 10). This pulse profiling capability is rare among USB power sensors and distinguishes Tektronix sensors.

In electronic communications, bandwidth is the width of the range of frequencies that a signal uses. It is the difference between the highest-frequency signal component and the lowest-frequency signal component. Similarly, the ability of a pulse profiling system to measure the frequencies contained in a signal's modulation envelope is referred to as video bandwidth. Higher video bandwidth means that a system can measure higher frequency components and therefore faster rise and fall times. The video bandwidth on the Tektronix PSM5000 Series is 10 MHz.

Tektronix PSM5000 series sensors come with a Pulse Profiling application (shown in Figure 11) that provides 13 measurements including:

- Rise Time
- Pulse Width
- Pulse Repetition Frequency
- Pulse Power
- Average Power
- Overshoot
- On/Off ratio
- Fall Time
- Pulse Repetition Time
- Duty Cycle
- Peak Power
- Crest Factor
- Droop

The Tektronix Pulse Profiling application can also provide statistical signal analysis:

- Probability Distribution Function (PDF)
- Cumulative Distribution Function (CDF)
- Complementary Cumulative Distribution Function (CCDF)

These statistical tools give a probabilistic view of power levels that occur within a signal.

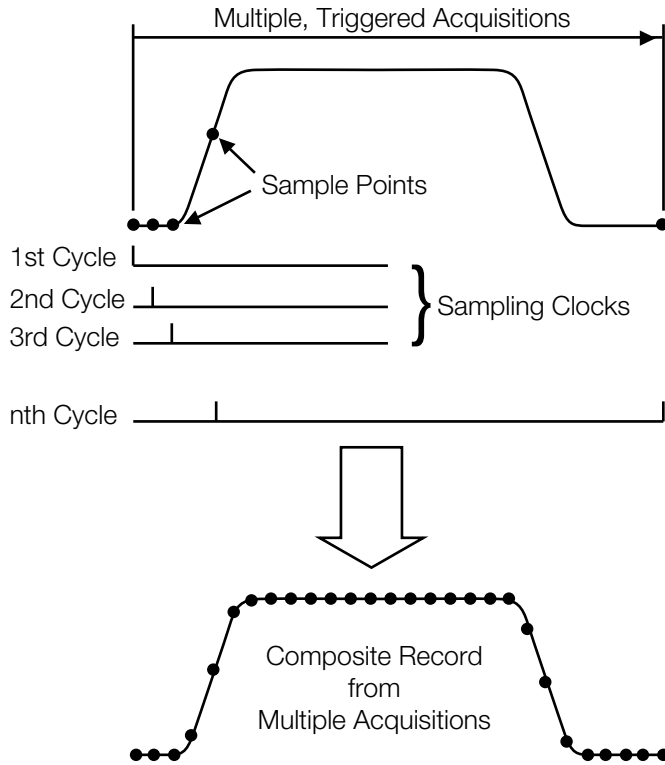


Figure 13. Equivalent-time sampling.

Equivalent-time Sampling

When visually representing a signal’s envelope, the faster the meter’s sample rate, the more accurately it can display a signal’s characteristics. For repetitive pulsed signals, a sensor can use equivalent-time sampling to effectively sample at a much faster rate, enabling it to recreate a signal envelope with greater fidelity. Equivalent-time sampling is a technique in which a representative waveform is created with a series of samples taken from identical repetitive waveforms. It allows the sensor to accurately capture signals whose frequency

Feature	PSM3000 Series	PSM4000 Series	PSM5000 Series
Frequency Range	10 MHz to 26.5 GHz	10 MHz to 20 GHz	50 MHz to 20 GHz
Dynamic Range	-55 dBm to +20 dBm	-60 dBm to +20 dBm	-60 dBm to +20 dBm
Measurement Speed	2000 readings/s	2000 readings/s	2000 readings/s
Measurements			
True Average Power	X		
Average (CW) Power		X	X
Duty Cycle Corrected Pulse Power	X	X	X
Peak Power, Pulse Power, Duty Cycle		X	X
Measurement Logging	X	X	X
Pulse Width, Rise/Fall, Overshoot, Droop			X
Time Gated Measurements			X
Pulse Waveform Display with Markers			X

Table 1. Tektronix PSM Series USB Power Sensors.

components are higher than the sensor’s real-time sample rate; however, the signal must be repetitive. When using the Pulse Profiling software, Tektronix PSM5000 series sensors achieve a 48 MS/s equivalent-time sampling rate by gathering the necessary number of samples across several triggers. The repetitive input signal generates the multiple triggers needed for equivalent-time sampling and allows the measurement system to gather the succession of data needed to reconstruct the composite waveform image.

Conclusion

A wide variety of RF and Microwave power measurement options are available today. For USB-based power meters, many of the traditional power sensor/meter specifications still come into play. However, USB sensor/meters can help simplify the chore of selecting a solution by eliminating the need to commit to a particular mainframe. Thanks to the high transfer rates available in USB 2.0 and the power available in widely-available PCs, new features are available in these compact instruments that have historically required specialized analyzers.

Contact Tektronix:

- ASEAN / Australasia (65) 6356 3900
- Austria* 00800 2255 4835
- Balkans, Israel, South Africa and other ISE Countries +41 52 675 3777
- Belgium* 00800 2255 4835
- Brazil +55 (11) 3759 7627
- Canada 1 (800) 833-9200
- Central East Europe and the Baltics +41 52 675 3777
- Central Europe & Greece +41 52 675 3777
- Denmark +45 80 88 1401
- Finland +41 52 675 3777
- France* 00800 2255 4835
- Germany* 00800 2255 4835
- Hong Kong 400-820-5835
- India 000-800-650-1835
- Italy* 00800 2255 4835
- Japan 81 (3) 6714-3010
- Luxembourg +41 52 675 3777
- Mexico, Central/South America & Caribbean 52 (55) 56 04 50 90
- Middle East, Asia and North Africa +41 52 675 3777
- The Netherlands* 00800 2255 4835
- Norway 800 16098
- People's Republic of China 400-820-5835
- Poland +41 52 675 3777
- Portugal 80 08 12370
- Republic of Korea 001-800-8255-2835
- Russia & CIS +7 (495) 7484900
- South Africa +27 11 206 8360
- Spain* 00800 2255 4835
- Sweden* 00800 2255 4835
- Switzerland* 00800 2255 4835
- Taiwan 886 (2) 2722-9622
- United Kingdom & Ireland* 00800 2255 4835
- USA 1 (800) 833-9200

*** If the European phone number above is not accessible, please call +41 52 675 3777**

Contact List Updated 10 February 2011

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