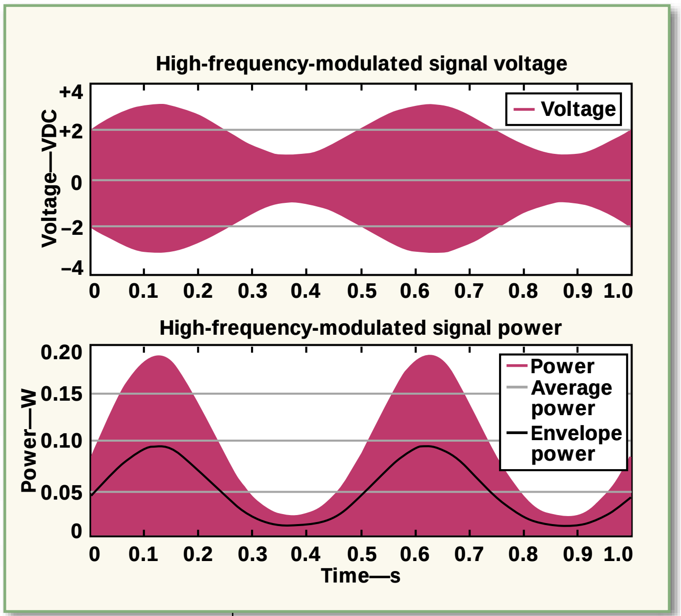
Use A Sampling Power Meter To Determine The Characteristics Of RF And Microwave Devices

This two-part article discusses triggering, DAQ, and peak-mode measurements using a sampling power meter.

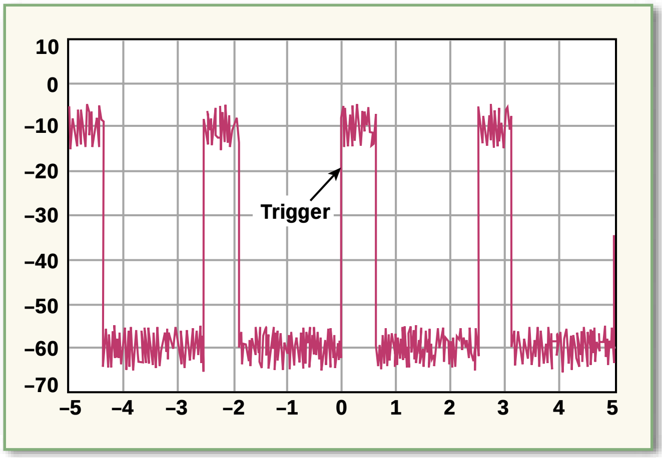
ERIC BREAKENRIDGE
Senior Engineer,
Agilent Technologies UK Ltd., EPSG-Q (EPSGD51T), South Queensferry EH30 9TG, United Kingdom; +44(0) 131 335 7705 FAX: +44(0) 131 335 7388, e-mail: eric_breakenridge@agilent.com

Modern communications systems are placing increasingly greater demands on RF design and manufacturing engineers. Finished systems need to be tested to ensure compliance to exacting international standards. Component parts are increasingly tested using the same types of complex signals as their target application. Wireless-system designers now require full characterization of RF components and subsystems under dynamic signal conditions before they can qualify these devices for use in their designs. And the old stalwart of RF measurements, the standard power meter, is creaking under the strain of these new requirements.

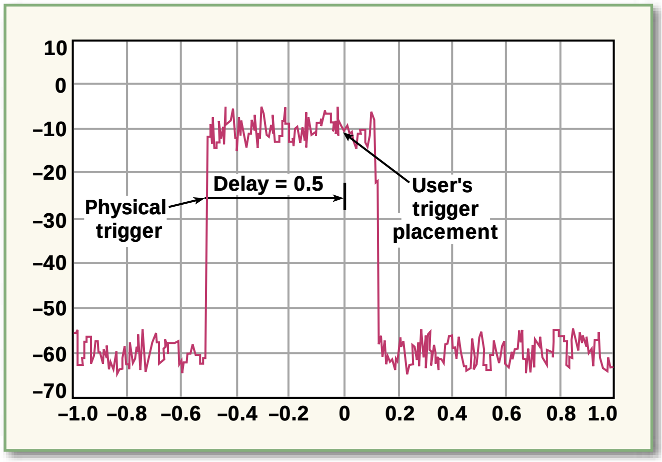


1. These illustrations show the power envelope of a high-frequency-modulated signal.

This two-part article outlines the advantages of using a sampling power meter to determine the characteristics of RF and microwave devices, using the digital sampling oscilloscope (DSO) for comparison. Part I discusses the DSO, presenting its capabilities from the user's perspective and reviewing developments in DSO technology. Part II will cover the sampling power meter, presenting its capabilities from the user's perspective and reviewing technological developments. Sample measurements will com-



2. This oscillograph shows a typical triggered display.



3. This oscillograph shows a trace display with trigger delay.

plete the article. The most accurate way to quantify an RF signal is to use an average-power meter. RF power will continue to be the standard measure by which any RF signal is quantified, verified, and referred back to national transfer standards. Unfortunately, the measurement requirements of modern communications systems go beyond the capabilities of this instrument. For example, peak power, which is an increasingly important measurement for safety and system characterization, cannot be measured with an average-power meter. Although peak power is often equated to pulse power, which, in turn, can be inferred from the combination of measured average power and known duty cycle for a repetitive pulsed signal, the average-power meter cannot directly measure peak power.

Peak-mode measurements are defined as measurements of the envelope power of an RF signal, which is the average power of the signal over several periods of the RF carrier wave **(Fig. 1).** Envelope-power measurements thus allow engineers to examine the effects of modulation or transient conditions without examining the details of the RF carrier waveform. A sampling power meter is capable of performing peak-mode measurements. It can provide RF engineers with answers to questions such as: What is the maximum power output from this device? What is the pulse droop? What is the maximum output power before the signal's peak-to-average ratio is reduced? Does the output signal meet the Global System for Mobile Communications (GSM) power-mask specification?

To answer these questions, the sampling power meter must have some features that are not present on the average-power meter. The first essential feature is triggering. Triggering allows the user to make measurements in the time domain, relative to some known event (i.e., the trigger). For example, the average power in an RF pulse can be calculated most accurately by computing the mean of the envelope power during the time that the pulse is on. Determining when the pulse is on is usually a known function of time relative to the leading edge or some other time stamp of the signal. Another example of a time-domain measurement is rise time—the time that is required for the RF pulse to transition from an "off" to an "on" state.

However, not all signal types have a regular time stamp that permits time-relative measurements. Nor will a user always require this measurement. But one can still derive important measurements from sampling and acquiring the envelope power. Peak power, average power, and peak-to-average ratio all can be calculated without the need for a trigger.

The second distinguishing feature of a sampling power meter is the speed at which it can track, sample, and measure the RF signal's envelope power.

The simplest method of adding peak measurements to a power meter is to change the detector architecture to sense the peak power rather than the average power. As this architecture only enables the measurement of peak power, it does not answer all of the questions previously outlined. For that reason, this discussion concentrates on instruments that are capable of various peak-mode measurements. These instruments exclu-

Table 1: DSO display controls

CONTROL	UNITS	DESCRIPTION
Time base	Seconds per division	Controls the time span of the displayed waveform
Trigger position	Left, center, right	Controls where the trigger instant is displayed
Trigger delay	Seconds	Allows the user to effectively select the trigger event position at some arbitrary point in time. This is useful when the physical trigger event (perhaps an external signal) is synchronous, but not coincident, with the points of interest in the displayed waveform.
Amplitude range	Volts per division	Sets the y-axis scaling
Input offset	Volts	Offsets the center of the display

Table 2: Oscilloscope settings

Time base	1 per division
Trigger position—left, center, right	Center
Trigger delay	0
Amplitude range	10 per division
Input offset	30

sively use diode sensors, followed by sampling-acquisition architecture.

During their development, sampling power meters have taken two paths. One path was to combine the power-detection diode output with a digital oscilloscope. The second path was to speed up an average-power meter to such an extent that it delivers peak-mode measurements. But upon examining the functional requirements of a sampling power meter, it is clear that neither of these architectures are optimal. To offer some common ground with engineers who are unfamiliar with sampling power meters, the following discussion refers to the capabilities of the DSO. It also provides a basis for comparing and contrasting the two devices.

Triggering allows the user to make measurements that are time-relative to the trigger instant. This section describes the controls that users need to take advantage of this characteristic. **Table 1** shows the traditional display controls that a DSO offers.

These controls may not always appear under display controls, but they do control the appearance of the displayed waveform. **Figure 2** shows a scope-type display, and **Table 2** shows its settings.

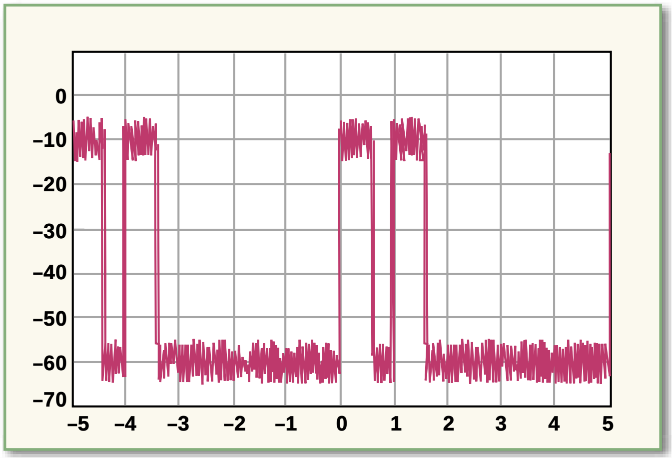
With these controls, the user can inspect the measured waveform anywhere within the limits of the instrument. For example, the signal shown in Fig. 2 can be viewed as shown in **Fig. 3** and as described in **Table 3.**

Table 3: Alternative settings

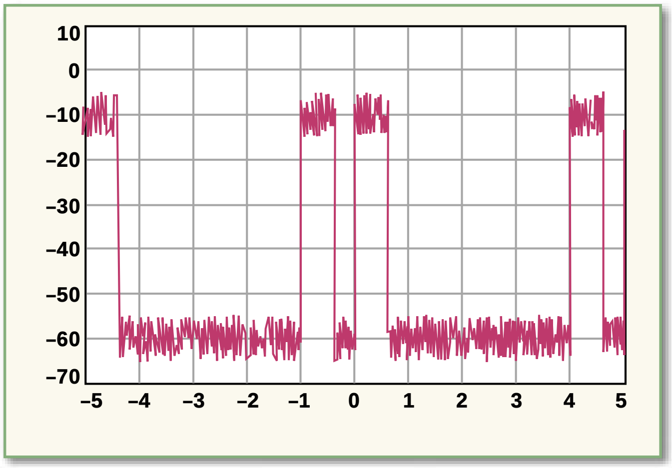
Time base	0.2 per division
Trigger position—left, center, right	Center
Trigger delay	0.5
Amplitude range	10 per division
Input offset	30

Thus, the user can control where the signal appears within the display by varying the controls described before **(Table 4).**

The purpose of this article is not to explain the operation of the trigger circuits of digital oscilloscopes. However, it is worth introducing some of the concepts conventionally applied within these instruments. They commonly have a settable comparator circuit that changes state whenever the input signal crosses a particular level. The instrument stores the time at which that event occurred to allow all of the input-signal samples to be tied to the trigger instant. The trigger circuit generally runs at all times. The acquisition system digitizes and stores the input signal at the achievable rate. If the acquisition system had stored the required number of samples to display the waveform at the current display settings and a trigger occurs, then the acquisition is stopped and the sampled data are transferred to the display. The acquisition system then has a little "dead" time to enable data transfer before restarting.



4. This oscillograph shows a double-pulse signal.



5. This oscillograph shows a double-pulse signal triggered on the second rising edge.

This strategy works well in many situations. Consider the waveform displayed as an oscilloscope trace **(Fig. 4),** assuming the same settings as for Fig. 2.

Since the acquisition system and trigger run asynchronously, it is possible to trigger on either of the rising edges. So, the oscilloscope display may appear as shown in **Fig. 4** or **5**, or, more likely, as shown in **Fig. 6.** This situation can be avoided by using the trigger hold-off function.

Trigger hold-off stops the trigger system from providing an output every time the input voltage crosses the trigger level. The action of the trigger system is "held-off" for a user-settable time interval after every trigger event. In the double-pulse example, if the hold-off time is set to 2, the trigger system will be disabled for the second of the two pulses. The trigger is then returned to the stable triggered display shown in **Fig 4.**

This is a form of trigger filtering or qualification. Various filters—highpass, lowpass, or bandstop—are often switched into the signal path before the trigger to help provide stable triggers. Advanced digital oscilloscopes can also provide more sophisticated trigger qualification, such as triggering, if the pulse is greater than or less

Table 4: Trigger controls

CONTROL	SETTINGS/ UNITS	DESCRIPTION
Trigger source	External Channel 1 Channel 2	This enables selection of the trigger source. Thus, the instrument can be triggered from one of the measurement channels or from an external source. The external trigger input is usually not displayed and normally has a restricted functionality
Trigger mode	Normal Auto level	This determines whether the trigger level is set up manually by the user or automatically by the instrument
Internal level	Volts	This allows the trigger level to be set anywhere on the current display
Delay	±seconds	This delays the displayed trigger from the actual trigger. Allows the user to effectively select the trigger-event position at some arbitrary point in time. This is useful when the physical trigger event (perhaps an external signal) is synchronous, but not coincident, with the points of interest in the displayed waveform
Trigger hold-off	Seconds	This allows the trigger system to be stopped (held off) for a length of time
Slope	Rising or falling	This determines whether the trigger system looks for a low-to-high or high-to-low transition

than a set time interval.

Continuing with the DSO example, it is commonplace for these types of instruments to offer manual and automatic measurements that go beyond counting the graticules on the display. **Table 5** defines some of the measurements featured on most DSOs.

Technology Overview

The major challenges in designing a digital oscilloscope are to get the signal from the probe to the display as fast as possible, and to make the display behave similar to an analog oscilloscope. Anything beyond that could be considered "nice-to-have" features. The oscilloscope is also a very good time-measurement instrument, so anything that helps preserve the time accuracy is a worthwhile investment.

The acquisition system for a digital oscilloscope can be described generally as a set of switchable gain amplifiers followed by a fast analog-to-digital converter (ADC). The ADC resolution usually is not more than 8 b, but its sample rate is extremely fast. The voltage range that the ADC must cope with

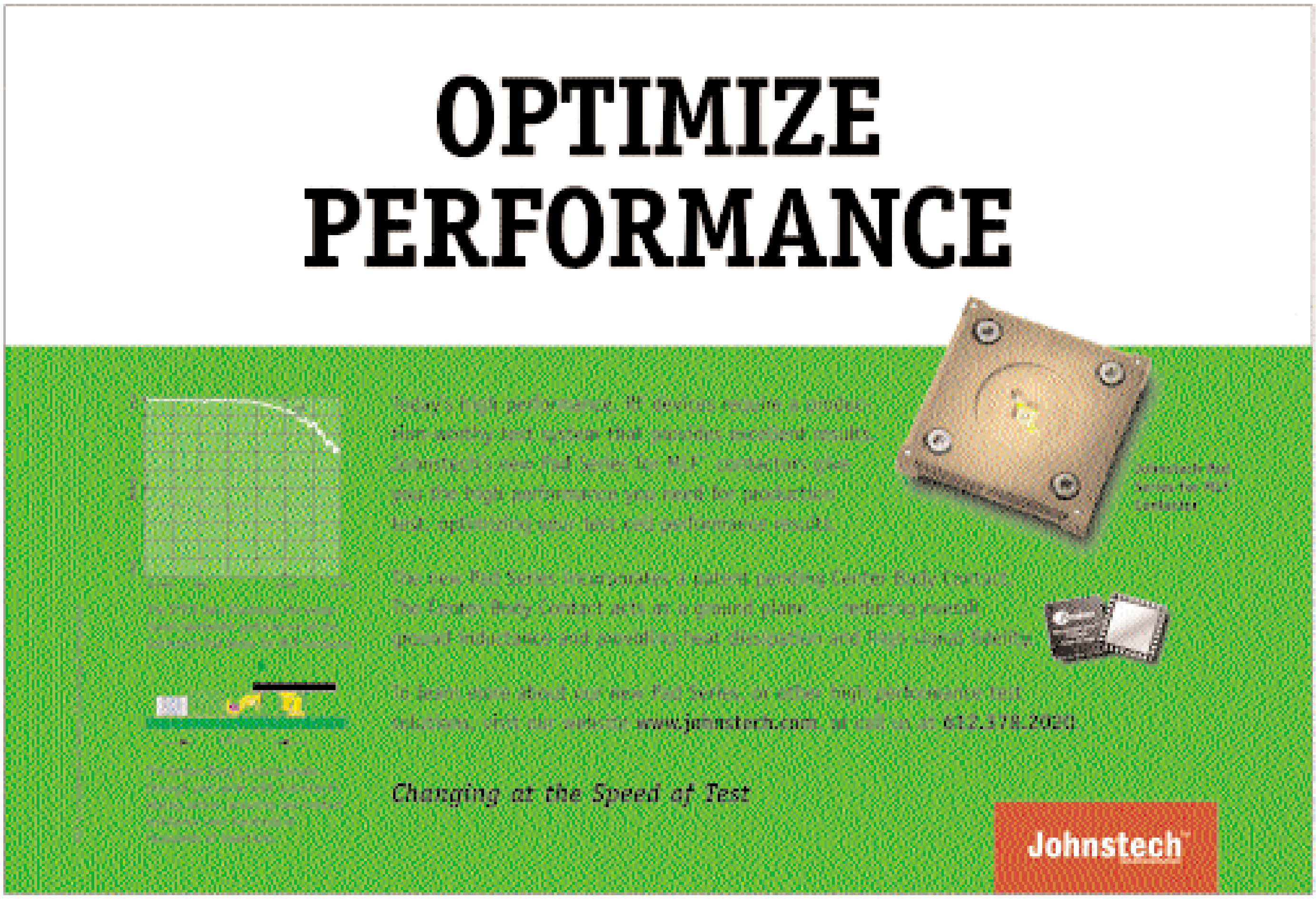


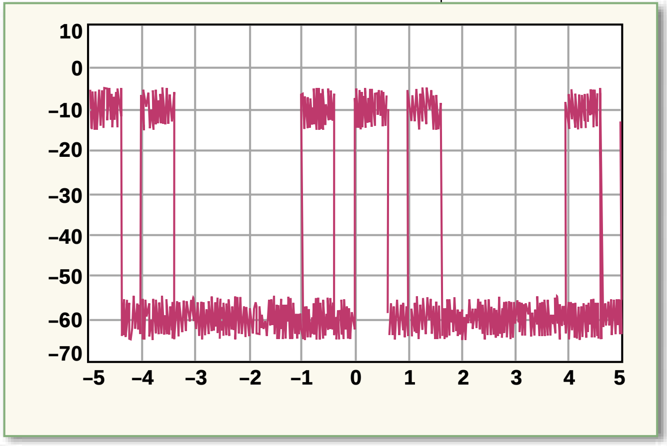
Table 5: DSO measurement definitions

MEASUREMENT		UNITS	DESCRIPTION
Voltage	Average	Volts	Displays the average of the voltage waveform
	Peak-to-peak		Displays the peak-to-peak voltage of the waveform
	RMS		Displays the RMS calculation of the voltage waveform
	Pulse top		Displays the voltage at the top of the pulse signal
	Pulse bottom		Displays the voltage at the bottom of the pulse signal
Voltage marker	V1, V2	Volts	The waveform voltage at markers V1 and V2
	Delta V		The difference in voltage between markers V1 and V2
Time marker	t1, t2	Seconds	The time points on the waveform at markers t1 and t2
	Delta t		The difference in time between markers t1 and t2
	1/delta t	Hertz	The reciprocal of delta t
Time	Rise time	Seconds	The time it takes for a signal to rise from 10 to 90 percent of the pulse height
	Fall time	Seconds	The time it takes for a signal to fall from 90 to 10 percent of the pulse height
	Period	Seconds	The time required for one full repetition of the waveform
	Frequency	Hertz	The frequency of the signal (the reciprocal of period)
	Duty cycle	Percentage	The ratio of high-to-low pulse intervals for a pulsed waveform

dynamically is well within the capability of an 8-b ADC due to the manual range switching (the volts-per-division control). The normal use of an oscilloscope is visual inspection of the waveform on the screen, so any instantaneous dynamic range beyond what is visible on the screen is wasted.

Trigger

This is an extremely important part of the oscilloscope. All of the timing information obtained in the data acquisition (DAQ) is referred back to the instant at which the input signal crossed the trigger threshold. To determine this instant to a greater accuracy than the clock period would allow, extremely fast comparator circuits and high-resolution pulse-stretching techniques are used. With a common implementation of this type of circuit, the time between the (asynchronous) trigger instant and the sampling clock is captured as charge on a capacitor. The capacitor is then discharged with a longer time constant than its charge-time constant. The time for discharge can then be counted at the clock frequency. The ratio of charge to discharge times is used to calculate the time instant of the trigger event relative to the sampling clock.



6. This oscillograph shows a double-pulse signal with indeterminate triggering.

Timebase

An oscilloscope's timebase can be a source of unexpected effects if it is not well-controlled. Where there is a long trigger delay, instability in the underlying clock signal can manifest itself as apparent movement of the displayed waveform.

Current oscilloscopes can now offer advanced measurements that allow users to gain greater insight into signal characteristics. Fast Fourier transform (FFT) analysis allows users to examine what frequency components are present in the signal, while probability displays allow users to determine the likelihood of events. These measurements make use of the power of modern processors to post-process the acquired signals.

Developments

The future of the digital oscilloscope has been ensured through the use of a modern user interface, fast sampling, deep memories, and digital signal processing (DSP). The latest oscilloscopes have intuitive user interfaces with online help, tutorials, and the new perspective of probability. Modern electronics have the ability to process signals so fast that waveform display rates have reached a point where it is difficult for the user to obtain further information from the instrument. Probability-enhanced displays can provide the user with more information by highlighting the parts of a repetitive waveform with the highest probability, while showing the low-probability excursions. Thus, the user can quickly obtain a picture of how a circuit is performing.

The second part of this article will expand the discussion to cover the underlying technology to help the reader understand a sampling power meter. Sample measurements will complete the article. MRF