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

The second part of this article discusses triggering, DAQ, and peak-mode measurements using a sampling power meter.

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Modern communications systems are placing increasingly greater demands on RF design and manufacturing engineers. Finished systems need to be tested to ensure compliance to exact international standards. Component parts are also 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 them for use in their designs. The old stalwart of RF measurements, the standard power meter, is creaking under the strain of these new requirements.

Part I discussed the digital storage oscilloscope (DSO), presenting its capabilities from the user's perspective as well as reviewing developments in DSO technology. Part II will present the capabilities of the sampling power meter from the user's perspective and review its technological developments. Sample measurements complete the article.

User's Perspective

Now with a full understanding of the basic architecture of a DSO, this discussion returns to the sampling power meter and contrasts its requirements.

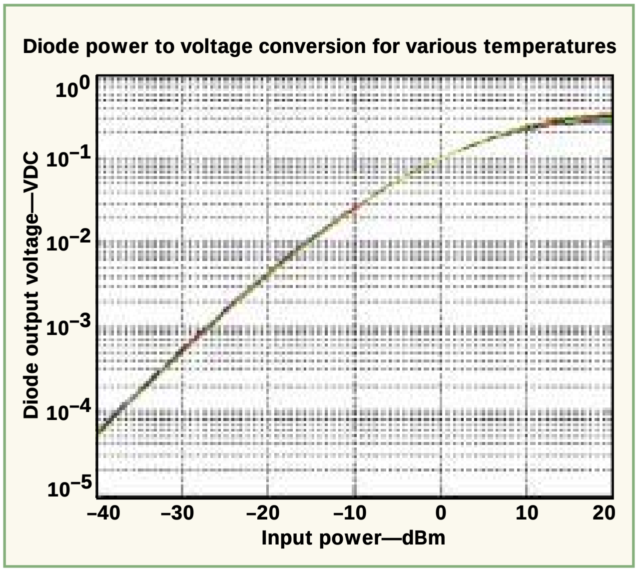
A sampling power meter digitally samples a signal that is derived from the envelope power of the RF input to the sensor. These data are then acquired, or made available for measurement, under the user's control. Several methods and controls allow the user to make different measurements. The essential point to identify at this time is that the sampling power meter is a measurement instrument. Its main purpose is to provide numeric certainty to an uncertain RF world, and great care is taken in these instruments to ensure measurement fidelity. This is in contrast to the DSO, where the emphasis is on the appearance of the waveform.

Compared with a DSO, a sampling power meters has the following distinctions:

- It is a measurement instrument.
- It is capable of nontriggered measurements.
- It is less display oriented.
- It requires complex signal conditioning for the sensor input.
- It requires high instantaneous dynamic range.

Making peak-mode measurements essentially requires the user of the sampling power meter to control the same parameters as the DSO user (i.e., display, trigger, and measurement).

Since the sampling power meter is a measurement instrument that is designed



7. This graph shows the power-to-voltage conversion of a typical diode.

primarily to return numeric measurements, the display controls it offers may not be as comprehensive as those on a DSO. In addition, the space constraints in manufacturing test systems tend to require compact instrument enclosures that preclude DSO-like timebase and amplitude controls.

Often, an engineer or technician must observe a number of measurements simultaneously. For example, pulse droop, overshoot, and average power are often monitored over the dynamic range of a test signal. For this reason, most sampling power meters offer a configurable 1-, 2-, 3-, or 4-line numerical display.

Meters that offer a live trace display (DSO-like waveform display) may also have X and Y scaling in the same manner as on a DSO (e.g., the HP8990/1—now discontinued—or the Boonton 4500A). However, this meter is more likely to have a simplified scaling method tied more closely to the requirements of peak-mode measurements. DSO display controls may be recast as shown in **Table 6** to enable adequate power-envelope trace display.

Triggering for a sampling power meter would be expected to have the following features in addition to the minimum offered by a DSO.

- Internal (level), general-purpose interface bus (GPIB), or external triggering.
- Trigger-out port.
- Three acquisition modes.
- Accuracy.
- Trigger accuracy is an important facet of the power measurement.
- Trigger accuracy should be equivalent to the measurement path.
- Linearity, temperature, and frequency are compensated to obtain the power-level comparison.
- Range.
- Settable in absolute-power value.
- Extended beyond the displayed range.
- Independent of display.

Table 6: Display controls and counterparts on a sampling power meter

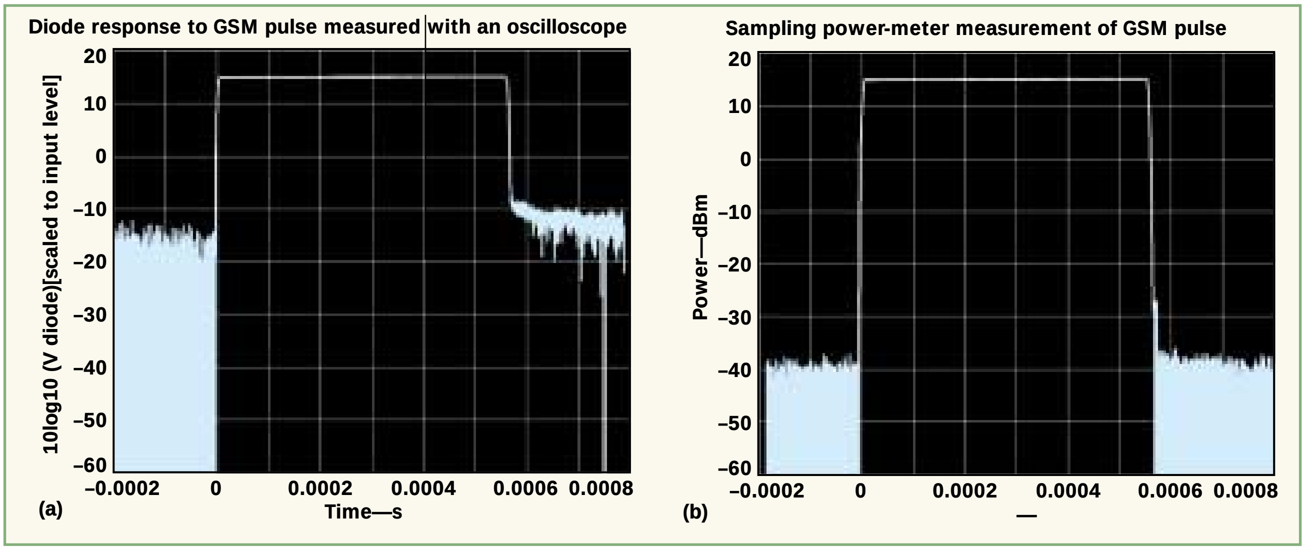
DSO		SAMPLING POWER METER		
Control	Units	Control	Units	Description
Time base	Seconds per division	Trace start	Seconds	Controls the start time of the trace relative to the trigger
Trigger position	Left, center, right	Trace length	Seconds	Controls the time span of the displayed waveform
Trigger delay	Seconds			
Amplitude range	Volts per division	Trace maximum	Watts/dBm	Sets the top of the trace
Input offset	Volts	Trace minimum	Watts/dBm	Sets the bottom of the trace

Note that free-run acquisition is distinct for the sampling power meter since there is no attempt to find and synchronize to a trigger.

What measurements do users of a sampling power meter want to perform? Basically, there are two: peak (envelope) power or average power. When measuring power, the user may wish to define where the power is measured. The user may want more than one metric from the power envelope. So now there are two measurement categories: triggered (i.e., time relative) and nontriggered (i.e., not time relative). Since the sampling power meter is a measurement instrument, the sampled power envelope is not always required for display or inspection. The user may wish only that the sampling power meter returns a specific measurement. In power measurements, users are also interested in combinations of power. For example, the user may wish to know how much the average power changes from one pulse to the next, or from the start of the pulse to the end. The user of a sampling power meter will typically require some or all of the measurements listed in **Table 7.**

Using a fast-responding diode sensor allows the sampling power meter to track power-envelope variations and return measurements quickly. Unfortunately, diodes deliver a voltage that is proportional to power only over a portion of their operating range **(Fig. 7).** With an input power below 2 20 dBm (depending on the load), a diode will deliver a voltage with a linear conversion factor from watts to volts. Above this level, the conversion factor reduces and changes from being proportional to power to being proportional to voltage. The power-to-voltage conversion law is not only dependent on the input power but is also sensitive to those changes regarding temperature and RF frequency.

To enable the sampling power meter to measure power with a diode sensor, each sample of the diode output volt-

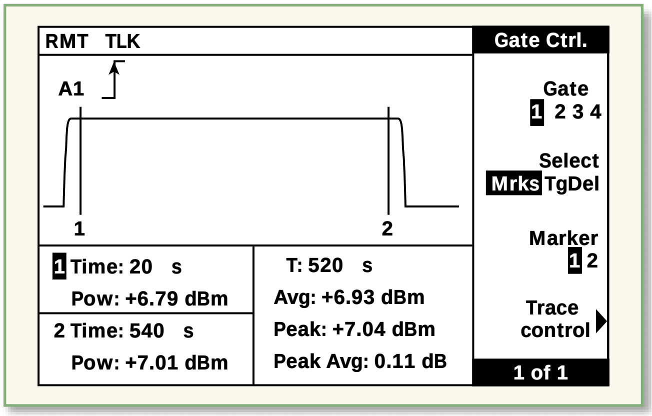


8. This is a diode signal as it appears at the ADC input, but measured with an oscilloscope (a). The same signal is measured with a sampling power meter (b).

age must be converted to power. This is achieved by sensor characterization during its manufacture. Each sensor is subjected to known power inputs and the output voltage is saved. This provides the power-to-voltage conversion characteristic of the particular sensor. Within the sampling power meter, this characteristic is converted to a voltage-to-power conversion law and applied to each input sample.

As mentioned earlier, the diode's

power-to-voltage conversion characteristic is highly dependent on frequency and temperature. Sensor characterization against these variables is also carried out during manufacture, and the voltage-to-power conversion law is modified when either of these variables changes. A thermistor that is mounted on the diode microcircuit, or (with less effectiveness) on the sensor body, senses temperature and the user must enter the frequency of the RF input. Compared with continuous-wave (CW) sensors, high-bandwidth peak-power sensors are particularly sensitive to changes in frequency. Thus, entering the RF frequency is very important.



9. This shows the marker setup for GSM burst-power measurement using the Agilent EPM-P.

In addition to compensating for the diode characteristics, it is also necessary to provide a frame of reference for the measurements. The corrections for the diode characteristics are intended to ensure a linear response to power, but this linear characteristic is not referred to any absolute value. To perform this, the meter normally employs a "zero & cal" procedure. "Zeroing" involves measuring any residual offset when no power is applied (the "zero" power), and subtracting this offset from any subsequent measurement. "Cal" measures the effective gain with a known power (usually 0 dBm at 50 MHz), thus providing the meter with a second reference point for the linearized characteristics and supporting absolute-power measurements.

Using sampling power meters with logarithmic scaling highlights a further distinction between these instruments and an oscilloscope. Dynamic range, when perceived in logarithmic terms, reveals the limitation of the acquisition system. A high-precision analog-to-digital converter (ADC) can compensate, but this alone cannot fully meet the requirements of some digital communications formats. For example, the Global System for Mobile Communications (GSM) standard calls for a ratio of burst on-to-off power of 55 dB. This would equate to 110 dB of voltage range for a truly linear sensor. Luckily, the diode's nonlinearity is advantageous here since it reduces the voltage range. However, the required range is beyond the range available from off-the-shelf ADC devices.

Some form of range switching must be provided to achieve the required dynamic range. Measuring the on-to-off ratio implies that this switching must be performed very quickly. The Agilent EPM-P power meter and E9320 peak-power sensor family offer four ranges—two ranges in the meter and two in the sensor. Sensor-range switching takes a few microseconds, while the meter ranging is indiscernible to the user. **Figure 8** shows this capability and the contrast in dynamic range compared to an oscilloscope.

Due to the power meter's nature as a sensitive measurement instrument, noise must be limited at every opportunity. This implies that the bandwidth be restricted to the minimum required to support the measurement. Nyquist sampling can be used to limit the bandwidth to the minimum required, but an anti-alias filter must be used before the sampler to prevent aliasing. Neither of these are strictly necessary in all circumstances, but not following Nyquist forces some other assumptions on the signal. To achieve good time-domain response, one must restrict the passband flatness available from an analog filter. Good time-domain response is needed to avoid overshoot on fast-rising edges. However, continuous signals with bandwidth less than the anti-alias filter will suffer degraded peak measurement due to the filter's passband droop.

Digital-signal-processing (DSP) techniques can be used to compensate for the droop. They can also be used to reduce the measurement bandwidth to cover the input signal and, thus, provide some additional noise-reduction benefit. This can be switched off when fast pulses are being measured. Compensation filters are generated by measuring the frequency response of the anti-alias filter, calculating the complementary response to this, and combining that with a filter designed to restrict the bandwidth.

Continuous sampling has advantages in the amount of noise bandwidth for a particular measurement bandwidth. It has another advantage that is useful for examining modern digital-modulation formats. Since the measured signal can be reconstructed perfectly, it is possible to examine modulation artifacts from random data signals. An example of this may be residual amplitude modulation (AM) in constant-AM schemes such as Gaussian minimum-shift keying (GMSK). If examined with a random sampler, it would be impossible to tell random data from noise, whereas with continuous sampling it is easy to distinguish between the two. Random sampling relies on repetition of the signal to build up a picture of the signal, but data signals do not repeat. So each new capture has no relation to the last and, hence, appears to be noise. On-off events and the signal before and

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Table 7: Sampling power-meter measurements

MEASUREMENT		UNITS	DESCRIPTION
Triggered	Average	Watts/dBm	The average power of the waveform displayed on the screen
	Peak		The peak power of the waveform displayed on the screen
	Pulse top		The power at the top of the pulse signal (the most likely voltage at the pulse top)
	Overshoot	Percent	
	Peak-to-average ratio	Percent/dB	
	Rise time	Seconds	The time it takes for a signal to rise from 10 to 90 percent of the pulse height
	Fall time		The time it takes for a signal to fall from 90 to 10 percent of the pulse height
	Period		The time required for one full repetition of the waveform
	Frequency	Hertz	The frequency of the signal (the reciprocal of period)
	Duty cycle	Percent	The ratio of high-to-low-pulse intervals for a pulsed waveform
Non-triggered	Average	Watts/dBm	The average of the RF power at the sensor input
	Peak		The peak of the RF power at the sensor input
	Peak-to-average ratio	Percent/dB	
Gated	Average	Watts/dBm	The average power of the waveform during a time interval defined by the measurement gate
	Peak		The peak power of the waveform during a time interval defined by the measurement gate
	Peak-to-average ratio	Percent/dB	The peak-to-average ratio of the waveform during time interval defined by the measurement gate
Combination	Gates	Watts/dBm/ percent/dB	Add/subtract/multiply/divide combination of gated measurements from two different gates
	Channels		Add/subtract/multiply/divide combination of measurements from two different channels