Measuring Power Levels In Modern Communications Systems

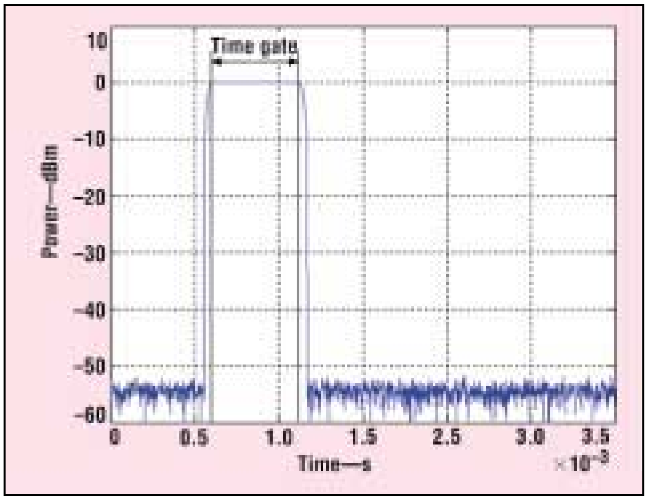
A choice of video bandwidths and time-gating capabilities can increase the accuracy and effectiveness of power measurements on modern wireless-communications systems.

Alan B. Anderson
Development Engineer
Agilent Technologies, Electronic
Products and Solutions Group-
Queensferry, SQF5TF, West Lothian
EH30 9TG, Scotland; e-mail:
alan_anderson3@agilent.com,
Internet: http://www.agilent.com.

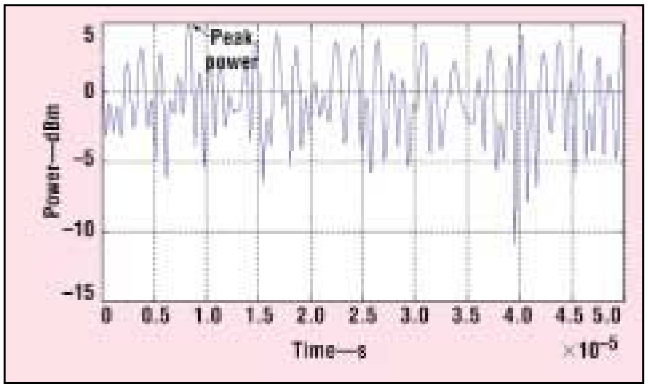
POWER-MEASUREMENT needs can vary greatly among different communications systems. Distinctions can be made, for example, between the power-measurement requirements of the two prevalent second-generation (2G) wireless formats, time-division-multiple-access (TDMA) and code-division-multiple-access (CDMA) systems. But as the industry moves toward third-generation (3G) wireless-communications systems, and TDMA and CDMA systems merge, the power-measurement needs of these new systems will also merge. The capability to make the required measurements is a key factor in choosing a power-measurement system, but this must also be supported by the capability to make measurements in a fast, repeatable, and accurate manner. This article will explore the types of power measurements required by these emerging systems and highlight the contributions to measurement accuracy that can be made by a properly designed test system.

Signals in TDMA-based systems involve bursts of modulated RF signals within an allotted time slot. Systems using the TDMA format include the Global System for Mobile Communications (GSM), the North American Digital Cellular (NADC) system, and the Bluetooth personal-connectivity system. The main requirement for power measurements of this type of signal is the capability to measure the average power within the burst, or in gated sections within the burst (Fig. 1).

Traditionally, power measurements of TDMA signals were achieved by performing an average power measurement of the periodic signal and then calculating the power in the whole burst using the duty



1. Burst average power is illustrated here.

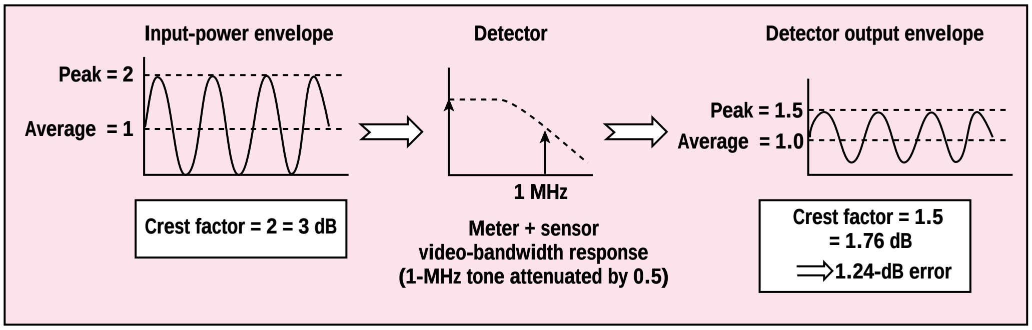


2. This figure shows CDMA power envelope.

cycle. However, this pulse-power measurement is reliant on the assumption of a perfectly pulsed RF signal. It is not very accurate, because it does not take into account the slope of the rise and fall time and variations in the pulse period. Secondary power-measurement requirements for TDMA may include measurements of the maximum RF power in a burst, or the power at different sections of the burst. Neither of these measurements can be achieved using the traditional method.

For CDMA applications, the main requirement is to measure the average power of a modulated signal. Further signal characterizing is achieved using either a peak-to-average ratio or peak-power measurements (Fig. 2). CDMA signals are intended to appear as random, "noise-like" signals, and a succinct measurement such as the crest factor can be used to give an immediate indication of whether a system is performing to specification.

Time-gated average power, peak power, and peak-to-average-ratio measurements of TDMA and CDMA signals are the core test requirements of a power-measurement system for today's wireless standards. As these wireless standards evolve, the capability to make peak, peak-to-average ratio, and average measurements on a single burst is required. This supports the fuller characterization of signals such as the time-division-duplex (TDD) signals used in wideband CDMA (WCDMA) and in EDGE systems, which have amplitude-varying modulation formats within an RF burst.



3. The effect of insufficient video bandwidth can be seen here.

Underpinning the requirement for additional measurement capability is the need to make the previously mentioned measurements in a fast, accurate, and repeatable manner. This depends on a combination of traditional power-meter and sensor specifications such as VSWR/mismatch, linearity, and instrumentation accuracy. The impact these make on measurement accuracy and repeatability is covered in Ref. 1. In addition, new specifications relating to peak and burst measurements become necessary. Specifications that were not previously apparent from data sheets of peak and average power meters, can still have a bearing on the accuracy of the expected results.

The following is an example of one error that arises with peak measurements. For the case of a signal comprising two RF tones separated by 1 MHz and of equal amplitude, the power envelope is a 1-MHz sine wave superimposed on the average power. The average power is equal to the sum of the power in each tone, and the peak power is twice this average, so the sine wave varies between zero and twice the average. The signal has a 3-dB peak-to-average ratio. When a diode-power sensor measures this signal, a DC component corresponding to the average power and a component at 1 MHz corresponding to the sine-wave variation in power envelope is generated. Any video bandwidth roll-off will directly effect the peak measurement and leave the average measurement unaffected (Fig. 3). If the video bandwidth of the power-measurement equipment is quoted as having a 3-dB bandwidth of 1 MHz, the sine-wave tone is attenuated to half the amplitude it should be. So, although this might be sufficient to measure average power, a 1.24-dB error will be present in peak-to-average ratio measurement. (Note that video bandwidth represents the ability of the power sensor and meter to follow the power envelope of the input signal. The power envelope of the input signal is, in some cases, determined by the signal's modulation bandwidth and, hence, video bandwidth is sometimes referred to as modulation bandwidth.)

Errors in peak-power measurements can be significant. Visibility of these errors needs to be apparent in the power-measurement system's specifications. A general statement of a megahertz value is insufficient for specifying the video bandwidth without defining its tolerance or variation.

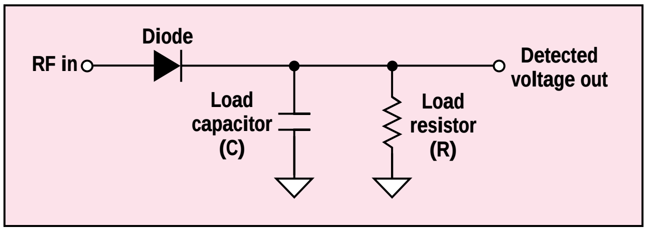
The effect of measurement noise can also impact the accuracy of a peak measurement. As a peak-power measurement is by definition a single occurrence, the measurement cannot benefit from additional averaging to reduce noise. For average-power measurements, averaging repeated measurements can reduce the variation of a measurement due to noise and allow

Digital control of video bandwidths

	DSP video-bandwidth setting		
Sensor	**Low**	**Medium**	**High**
E9321A/E9325A	30 kHz	100 kHz	300 kHz
E9322A/E9326A	100 kHz	300 kHz	1.5 MHz
E9323A/E9327A	300 kHz	1.5 MHz	5 MHz

lower powers to be measured. So it needs to be recognized that the specified minimum measurement power for a peak measurement is typically 15 dB above that achieved for time-gated average measurements.

To make time-gated power measurements on TDMA-type pulses, the measurement system must have sufficient rise and fall times to ensure that the gated section being measured is actually the signal and not a latent effect of a slow rising or falling edge caused by insufficient measurement-response times. If overshoot is to be characterized, the power-sensor rise-and-fall time specifications must be fast enough to follow the rising and falling edges of the signal under test. It is generally recommended that the power sensor have a rise time of approximately one-eighth of the expected signal's rise time to obtain accurate results. This will minimize the error introduced by the sensor and meter responses. However, if only the burst average power is being measured, a rise time similar to that of the signal can be used. Although the rising edge of the burst will delay the quickness of the measured pulse rise time, the start of the time-gated measurement can be delayed to account for this. In this manner, accurate burst-average-power measurements can be made.

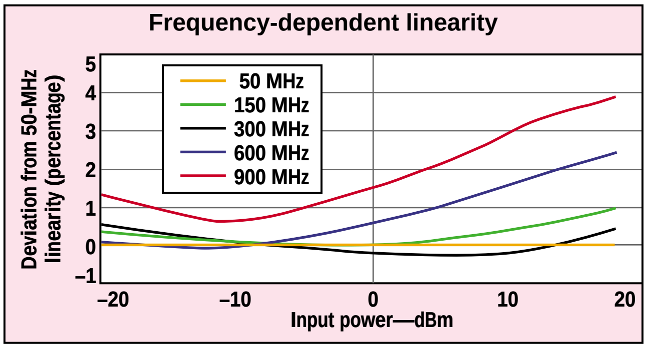


4. This is a basic RF-power detection circuit.

Confusion sometimes arises from the video-bandwidth definition of a sensor and its capability to perform accurate pulse profiling. If a pulsed signal has a pulse-repetition rate of X Hz, then it will also have significant signal components at odd-harmonics of the X Hz (3X, 5X, etc.). Therefore, if a sensor only had a video bandwidth of X MHz, these additional harmonics would not be accurately measured, resulting in an inaccurate pulse profile. So when accurate pulse profiling is required, it is best to follow the one-eighth rise-time rule.

The causes of peak-measurement errors are inherent in the diode-detection method of power measurement, yet by careful design they can be reduced to acceptable levels. Thermistors and thermocouplers are accurate for average power measurements, but for accurately following a fast-changing power envelope, diode detection is the most suitable approach.

To introduce the causes of these errors, a brief overview of the diode-detection process is outlined, allowing the cause of these errors to then be

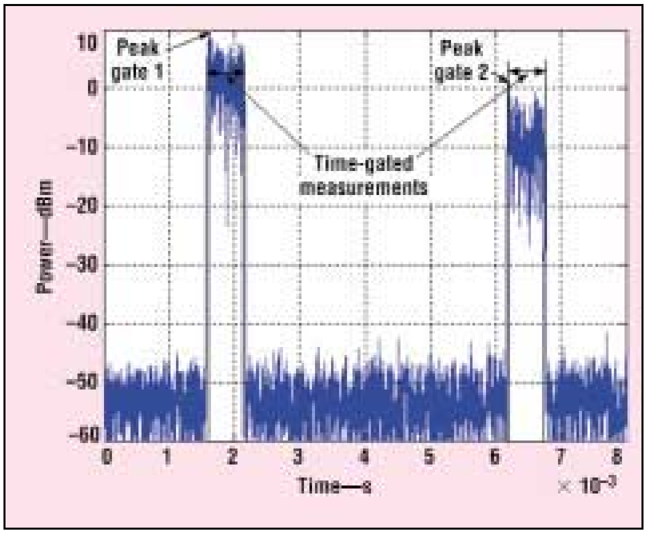


5. The frequency-dependent linearity of a wide video-bandwith sensor at spot frequencies from 50 to 900 MHz is depicted here.

highlighted. At RF, the diode conducts for approximately half of a cycle, shorting the RF to ground through the load-capacitor C (Fig. 4). As the signal passes through the non-linear diode, the RF signal is mixed down to baseband and generates a voltage across the load-resistor R. The voltage generated is proportional to the input power as the diode has a V^2 (square law) response ($P = V^{2/R}$) at low power levels (below −20 dBm). For a signal with a fast-changing power envelope, the baseband signal changes at the same rate as the signal power. To have the capability to make peak measurements, sufficient video bandwidth is required to allow this change to be followed through.

The filtering effects of R, C, and video-resistance of the diode in the first instance dictate the video bandwidth. For the types of diode used in power detection, the value of the video-resistance can vary from 200 Ω to 4 kΩ over power and temperature, leaving the video bandwidth susceptible to power and temperature changes and, therefore, introducing errors.

The two components in the measuring system, R and C, have conflicting demands placed upon them as they have a large impact on the performance of the power sensor. For example, for maximum sensitivity and dynamic range, R should be large, and for maximum RF-frequency range, C should also be large. However, for maximum flatness and stability of the video bandwidth, C and R should both be small. In addition there are optimum values of R and C for linearity, temperature stability and mismatch.



6. Gated-measurement capability makes it possible to focus on peak power levels.

So while it is possible to practically eliminate any significant error due to insufficient video bandwidth, this would have the effect of severely impacting other key specifications such as linearity, mismatch, dynamic range, and temperature stability. Conversely, optimizing for the other key power-sensor specifications and ignoring the error introduced in peak-power measurements is also undesirable.

Agilent Technologies (Palo Alto, CA) has taken the approach to introduce a range of sensors (the E9320 family of peak- and average-power sensors) with three video bandwidths of 300 kHz, 1.5 MHz, and 5 MHz. Each sensor type has been specifically optimized for maximum dynamic range and minimum errors for specific wireless standards:

- 300-kHz bandwidth for GSM and EDGE.
- 1.5-MHz bandwidth for IS-95 CDMA.
- 5.0-MHz bandwidth for WCDMA.

One instance where the conflicting demands on load-circuit components becomes apparent is when one considers the trade-off between the low-frequency RF range and wide video bandwidth. In order to remain sensitive at low frequencies (<100 MHz) high load resistance and capacitance are optimal. However, wide video bandwidth requires low values for these components. This leads to a compromise between variations in video bandwidth and the frequency dependence of sensor linearity. If the video bandwidth is not sufficiently flat, errors will be introduced in peak-power measurements. The wider the video bandwidth, the greater the variation in linearity. In traditional wide-dynamic range sensors with minimal video bandwidth, only a 50-MHz linearity calibration is required. Figure 5 shows how only one frequency-linearity correction at 50 MHz will lead to linearity errors for sensors with a wide video bandwidth.

To achieve a wide, flat video bandwidth without compromising linearity, a frequency-dependent linearity correction (FDLC) has been implemented in the E9320 sensors. These sensors are factory-calibrated at 50 MHz and at key frequency points up to 900 MHz in order to provide the correction data for the FDLC. This addresses the trade-off in linearity and video bandwidth, but it still leaves the bandwidth susceptible to power and temperature variations in the detection diode's resistance. To stabilize this, a fifth-order filter has been designed to replace the simple resistive-capacitive (RC) detection circuitry. This filter improves the accuracy of peak measurements and has the additional benefit of increasing the roll-off of the video bandwidth, helping to further reduce the frequency dependence of linearity.

The E9320 peak and average sensors operate with the new Agilent EPM-P-series power meters (E4416A single-channel and E4417A dual-channel). The EPM-P meters are also compatible with the entire range of 8480 and E-series sensors. Based on industry-standard E4418B/19B power meters, additional capability has been added for making power measurements on wireless standard signals.

Central to these enhanced capabilities is the time-gating feature. The EPM-P-series power meters' flexible time-gating means that peak, peak-to-average ratio and average measurements can be made on a single gate simultaneously, and with up to four gates and two channels available, this is a powerful capability (Fig. 6). The benefit of this can be seen when trying to characterize an EDGE or WCDMA (TDD) signal, where peak, peak-to-average, and average measurements on a single timeslot can be made simultaneously. In addition, multiple timeslots can be analyzed within the same frame, which is of particular use for general packet radio service (GPRS), for bursts of different amplitude.

Previous approaches have required many repetitive pulse measurements to extract this type of information, as they have used random repetitive sampling. This means that not all of the power envelope is captured in one go. The EPM-P power meters use a continuous sampling rate of 20 MSamples/s and are capable of performing this measurement in a single capture for signals with up to a 5-MHz modulation bandwidth.

The 20-MSamples/s continuous-sampling rate also provides the unique feature of digital-signal-processing (DSP) bandwidth correction and reduction. Although the E9320 sensors have video bandwidths targeted for specific communications formats, the DSP-bandwidth filters can reduce the video bandwidth to better suit the communications format and increase the dynamic range. These filters are designed to ensure a flat frequency response to minimize peak-power errors (see table).

When choosing a sensor to measure a particular wireless format, to achieve maximum dynamic range and the minimum uncertainty of a measurement, a sensor with the video bandwidth just larger that the modulation bandwidth of the format should be selected. However, by selecting a sensor that has sufficient video bandwidth for all wireless formats likely to be measured, one sensor is all that would be required. The variable DSP video-bandwidth settings can then be set to further optimize dynamic range if a reduced video bandwidth is appropriate.

For making power measurements on wireless standard signals, making the key measurements of peak, peak-to-average ratio, and average power measurements is a fundamental influence when choosing a power meter and power sensor (further information is in Ref. 2.) Also, through careful choice of a power sensor that has been targeted for the specific signal types, the accuracy and repeatability of the power measurements can be significantly improved. • •

References

1. Application Note 64-1, "Fundamentals of RF and Microwave Power Measurements," Agilent Technologies, Palo Alto, CA, Literature No. 5965-6630E.
2. Application Note 64-4, "4 Steps for Better Power Measurements," Agilent Technologies, Palo Alto, CA, Literature No. 5968-7150E.