Agilent
4 Steps for Making Better Power Measurements

Application Note 64-4D

Agilent E4417A power meter

Agilent Technologies

Four steps for making better power measurements

Before you select a power meter and its associated sensors, make sure that you have taken the following four steps, each of which can influence the accuracy, economy, and technical match to your application:

1. Understand the characteristics of your signal under test and how they interact with the power sensing processes.
2. Understand power measurement uncertainties, and traceability to a primary power standard at a national laboratory, such as the U.S. National Institute of Standards and Technology (NIST).
3. Understand the characteristics and performance of available sensor technologies and operating features of various power meters.
4. Make the performance comparison and select the right product for your application.

Even a cursory analysis will reveal that present power sensor technologies have considerable overlap in capabilities. Yet, new system technologies, such as wireless modulation formats and their associated production test requirements, will often require some combined measurements such as time-gated peak parameters or computed data such as peak-to-average ratios. And you can be sure that all that data will be required at speeds that push the state-of-the-art.

Your analysis might also include considerations of the installed base of other sensors and power meters in your organization's inventory. And, it should consider the traceability chain of your organization's metrology lab to national standards.

This application note will provide you with a brief review of those four factors which influence the quality of your power measurements. It will also offer other suggested information sources with more technical details such as Agilent Application Note, AN 64-1C, "*Fundamentals of RF and Microwave Power Measurements*," publication number 5965-6630E.

Power — The fundamental RF and microwave measurement

Power measurement is the fundamental parameter for characterizing components and systems at RF and microwave frequencies. Above 30 to 100 MHz, where the parameters of voltage and current become inconvenient or more difficult to measure, microwave power becomes the parameter of choice. Power specifications are often the critical factor in the design, and ultimately the performance, of almost all RF and microwave equipment.

Power specifications are also central to the economic concept of equity in trade. This simply means that when a customer purchases a transmission product with specified power performance at a negotiated price, the delivered product must meet that specified power when installed and qualified at a distant location, perhaps in another country. Accuracy and traceability of your power instrumentation will help assure this measurement consistency.

STEP 1.
Understanding your signal under test

A world of signal formats

System technology trends in modern communications, radar and navigation signals have resulted in dramatically new modulation formats, some of which have become highly complex. The objective of this section is to briefly examine a range of typical formats to see how their spectrum characteristics interact with various power sensor technologies.

Wireless and cellular systems depend on digital I-Q (inphase-quadrature) modulations at high data rates and other spread-spectrum formats. Because the final transmitted signal combines multiple carriers, there are statistical processes working which can create extremely high peak power spikes, based on a concept called crest factor, described below and in the section entitled “digital and complex formats.”

Wireless systems also contain frequency-agile local oscillators which “hand-off” the vehicle’s signal as it moves from ground cell to cell and links up to each new base-station frequency. Sometimes the power perturbations, which occur during the frequency transition, need to be characterized.

Some radar and EW (countermeasures) transmitters have the traditional pulsed formats but many new systems also use spread spectrum or frequency-chirped and complex phase-coded pulse configurations, which reveal more precise data on the unknown target returns.

Navigation systems such as the Global Positioning System (GPS) use complex phase-shift-keyed (PSK) formats to yield precision radiolocation. Other navigation systems use pulsed formats for distance or coded target identification.

Some signals under test are comprised of multiple test tones and others contain high harmonic content. Still others are generated by frequency-agile synthesizers, which can simulate entire, full-channel communications traffic formats. These test signals are used to characterize the real-life performance of transmitters and receivers such as satellite transponder systems.

To test overload and rejection characteristics of a receiver, test signals are created to be a composite of out-of-channel interference signals. Anytime such multiple signals are present, composite carriers can add in random phase and create power “spikes.” Thus, an application analysis is crucial to understand these effects on the power sensor.

In the sensor technology section, much more detail is given to peak detection. But, the measuring principle is that an averaging sensor responds to the average value of any format as long as the signal peaks remain within the sensor’s square-law range. But driving ordinary diode sensors into their linear-detection ranges, even those with compensation techniques will cause errors. Peak and average diode detectors, specifically designed for peak excursions, generally do not have problems with any type of complex signal formats.

Pulsed formats

Some modern radars went to narrower pulses which permitted better separation resolution of multiple targets. Their rise/fall times were proportionately shortened as well, and the bandwidth of the radar receiver increased. Then came other technologies for pulsing with longer phase-coded formats, which allowed for determining things like the shape or size of a target. Multiple pulses and random pulse repetition times are design strategies needed for resistance to countermeasures jamming.

All of these different directions of pulse technologies mean that specifying a measurement power meter requires a clear knowledge of the key parameters which need to be characterized. For some test sequences, measurement of the numerous pulse power and time parameters performed by peak power analyzers may be needed. On others, only the pulse-top and average power will suffice.

Design and production test for pulsed systems often require measurements of both peak pulse power (pulse top) as well as average power for the transmitter and other system components. Thermal sensors inherently respond to total average power, as long as the peak power excursions do not exceed the peak ratings of the sensor. And given a pulsed waveform with fixed duty cycle (pulse width/total pulse period), its peak power can also be computed using the average power from a thermal sensor.

Diode-based sensors, and associated power meters, which are designed for peak detection are ideal when the pulse-top characterization is required, or when the pulse envelope must be profiled. These peak sensors feature wide-band amplification of the detected envelope, and permit digital signal processing (DSP) to measure and display the pulse shape and numerical parameters. Most modern radar and EW systems use complex and pseudo-random pulse-rate configurations for immunity to jamming, and thus can’t use simple computations with duty cycle. They require specific peak type sensors.

When measuring peak power, it is important to understand the specific test requirements for characterizing the pulse parameters of a system or component. For example, measuring the rise time or fall time of a radar pulse might be crucial for testing the power amplifier component. The reason is that short rise/fall times correlate with higher bandwidth of the transmitted pulse, and relate to its ability to resolve targets. Yet, in other production tests, perhaps on later subsystem tests, it may only be necessary to measure the pulse-top power of the pulse. By knowing the precise measurement specification required, a test engineer might use a simpler and less expensive power meter to determine that the subsystem is operating to its proper performance envelope.

Navigation systems such asm air-traffic control (ATC) or distance measuring transceivers (DME) also have non-traditional pulse configurations, such as pulse pairs or triplets. In that case, peak detecting power meter/sensor combinations such as the Agilent E4416/17A meters and E9320A sensors are indicated.

AM/FM formats

Not many systems are active these days that are pure AM or FM, other than commercial broadcast, and perhaps amateur radio or “shortwave” formats. Frequency modulation, since its carrier amplitudes are relatively constant, can be measured with simple averaging power sensors. Amplitude modulation signals, on the other hand, must be analyzed to assure that the peak modulation swings always remain below the limits of the sensor’s “square-law” range, since the modulation peaks result in a $(V_{\text{carrier}})^2$ effect on power.

Terrestrial communication

Terrestrial communication systems abound with design examples of the new digital phase modulation formats. Some early migrations of microwave terrestrial links from traditional FDM (frequency-division-multiplex), used 64QAM (quadrature-amplitude-modulation) formats.

Wireless and PCS

Later wireless technologies combined the digital formats with sophisticated carrier switching of transmit signals to permit time- shared information from thousands of mobile subscribers, who were arrayed around cellular geographical regions.

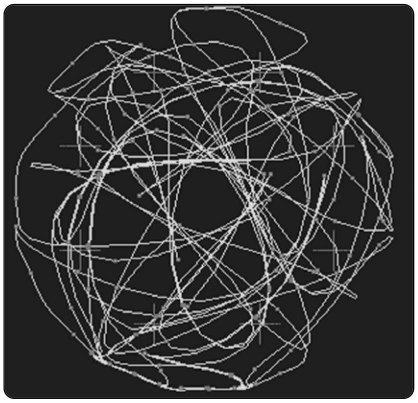


Figure 1. This 3π/8 shifted 8PSK digital modulation format is emerging for wideband data transmission on wireless channels, such as the EDGE technology.

TDMA (time division multiple access) is the technology for time-sharing of the same base station channel. Encoded voice data and new high-data-rate wireless links are modulated unto the transmitted carrier in the phase plane. These create “constellations” of bit symbol locations such as shown in the 3π/8 shifted-8PSK configuration of Figure 1. This particular modulation format is used in the EDGE (Enhanced Data Rates for GSM Evolution) systems which will offer high-data-rate transfer over mobile wireless channels. By packing 3 bits per symbol, it increases data information rates, but thereby increases amplitude swings up to 16+ dB, making amplifier saturation more likely.

Each TDMA wireless subscriber’s share of time might allow a useful data burst of 524.6 µS, during which it is crucial for the power amplifier to remain below its saturation region. Driving the output stage into non-linear amplification causes the outermost phase states to compress, thereby increasing bit errors and lowering system reliability.

Another competitive wireless modulation technology is called code division multiple access (CDMA), such as used in IS-95 wireless systems. CDMA encodes multiple data streams onto a single carrier using a pseudo-random code, with a resulting transmitted power spectrum that exhibits almost white-noise-like characteristics.

But, just like white noise, the average power of the transmitted signal is only one of the important parameters. Because of the statistical way that multiple carrier signal voltages can add randomly, instantaneous peak voltages can approach ratios of 10 to 30 times the rms voltage, depending on formats and filtering. This ratio, calculated with voltage parameters, is commonly called **crest factor**, and is functionally similar to a peak-to-average power ratio that is measured by Agilent peak and average power meters.[1]

System designers accommodate this crest-factor effect by “backing off” the power amplifiers from their maximum peak ratings to assure that signal peak power operation is always within their linear range.

---

[1] Accepted definition of crest factor (pulsed carrier): The ratio of the pulse peak (voltage) amplitude to the root-mean-square (voltage) amplitude.

Intermodulation tests

Two-tone (or three-tone) test signals are often used for characterizing amplifiers for linearity of their amplification. Amplifying two pure input signals of $f_1$and f_2 results in intermodulation signals at the output, of the form $2f_1 - f_2$, $2f_2 - f_1$, $f_1 \times f_2$, and many more.

Measuring power of such tones needs analysis because the two carrier's phases add or cancel randomly versus time. In a two-tone example, of V_1 and V_2, each with equal power P, the constructive addition of tones results in a peak carrier of 2V that is a peak power of 4P. An average-responding sensor would indicate 2P but a peak-responding sensor would indicate 4P.

Noise loading tests

Noise loading tests of microwave amplifiers involve full-channel signals, simulated with a white noise input, except for a single notched-out (slot-filter) carrier. If there is non-linear amplification, the amount of intermodulation power in the notch at the output, measures the performance of the amplifier.

There are also many examples of simple CW signal testing. Metrology laboratories would be a typical application, such as power sensor calibrators that are driven by CW test signals. Many component tests use simple unmodulated signals for test procedures.

These above examples are intended to illustrate that detailed knowledge of your unknown signal and its spectrum and modulation content is crucial to your selection of the best power sensor. In some cases, CW and averaging sensors serve commendably. But others require precise characterization of the peak power performance to yield peak-to-average power ratios or time-gated parameters, and assure conformity to specified industry standards.

Step 2.

Understanding measurement uncertainties and traceability to national standards

The primary standard for an RF or microwave power measurement is a set of national power standards maintained by the U.S. National Institute of Standards and Technology (NIST) in Boulder, Colorado, USA. Many other countries also maintain national power references, and regularly perform comparisons with other standards laboratories in sophisticated measurement assurance processes. These highly-sophisticated power standards are called microcalorimeters (Figure 2) and are the basic reference for measurement services in coax and waveguide, with transfer techniques capable of achieving uncertainties of 0.42% at 18 GHz.

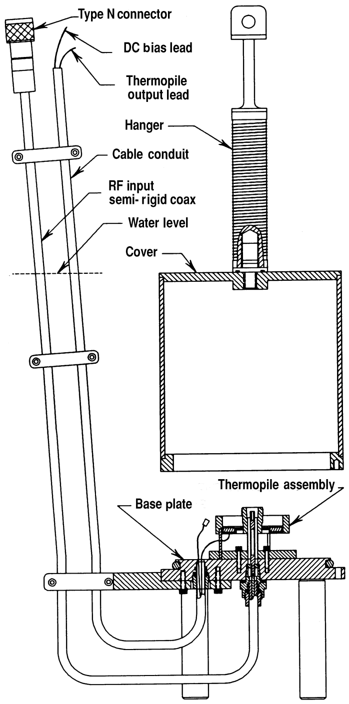


Figure 2. Schematic cross-section of the NIST coaxial microcalorimeter at Boulder, Colorado, U.S.A.

NIST and other country standards agencies offer fee-based measurement services for transferring such standards to customer primary labs. [1] [see reference literature] They include comprehensive documentation of the procedures with fee schedules and application notes which provide detailed technical descriptions of the theory and practice of their measurement processes.

Agilent power instrumentation and sensor calibrations are traceable to those NIST standards, and to certain other national standards. Agilent performs its sensor production tests using automatic network analyzers for improved accuracy, by taking into account the complex reflection coefficients of each individual sensor. The sensors are furnished with calibration charts that include reflection coefficient as well as calibration factor data. With this individualized test data, the user can reduce measurement uncertainties introduced by that sensor-to-source mismatch.

Measurement uncertainty standards

In recent years, the world's metrology and quality community has actively implemented a new process for calculating and reporting the uncertainties of measurement. The process is based on a standard promulgated by the International Standards Organization, Geneva, Switzerland, *ISO Guide to the Expression of Uncertainty in Measurement*, often referred to as the GUM. [2] [see reference literature]

The NCSL International (previously National Conference of Standards Laboratories), Boulder, Colorado, cooperating with the American National Standards Institute, adopted the ISO document as a U.S. National Standard, and introduced it in the USA as an industry document, ANSI/NCSL Z540-2-1996, *U.S. Guide to the Expression of Uncertainty in Measurement.* [3] [see reference literature]

Both of the uncertainty standards operate within a larger metrology context, specified by ISO Guide 25, *General Requirements for the Competence of Testing and Calibration Laboratories*. This document was adapted to a U.S. version with the identical title, ANSI/NCSL Z540-1-1994.

Over the last several years, the ISO has replaced ISO Guide 25 with ISO/IEC 17025, and promulgated it internationally. In the U.S., the ANSI/NCSLI Standards Writing Committee has recognized the advantage of a worldwide standard and adopted the ISO/IEC 17025 document as a U.S. National Standard in cooperation with the American Society of Testing Materials (ASTM) and the American Society of Quality (ASQ). To meet the needs of users who rely on the older ANSI/NCSL Z-540-1-1994 standard, it has been officially extended for five years.

Because of its international scope of operations, Agilent Technologies has moved quickly to adopt ISO/IEC 17025 in lieu of its previous commitment to ANSI/NCSL Z-540-1. As a result, most of Agilent's production and support operations are moving to offer optional product specific test data reports compliant to 17025. Option 1A7 will assure compliance with 17025 for new products shipped from the factory and Agilent will provide for support re-calibrations to the same 17025-compliant processes, data and testing.

The new processes provide more rigor and standardization to the combining of all the uncertainties of power parameters from the mismatch at measurement and calibration time to the traceability of the 50 MHz reference source. An extended explanation of the uncertainty calculation process is detailed in Chapter 7 of Agilent Application Note 64-1C *Fundamentals of RF and Microwave Power Measurements*, literature number 5965-6630E. In that example, twelve different uncertainty elements are combined.

Readers who are embarking on calculating measurement uncertainties, should recognize that the above-mentioned documents may seem simple enough in concept, and they are. But in the characterization of more complex instrumentation the written specification uncertainties can often depend on multiple control settings and interacting signal conditions. Impedance bridges, for example, measure in complex number format. Network and spectrum analyzers have multi-layered specifications. Considerable attention is being expended to define and characterize these extensions of the basic GUM.

Generally, power measurement uncertainties are relatively straightforward. The dominant measurement uncertainties include sensor calibration factor uncertainty and the mismatch between the source under test and the sensor. For the E-series sensors, Agilent provides temperature-banded calibration factor uncertainties. The two temperature bands are 25 ±10°C and 0 to 55°C. These temperature ranges reflect a normal working environment (plus a guard band) and the full specified operating temperature range.

The smaller calibration factor uncertainties over 25 ±10°C are therefore more realistic for R&D and manufacturing environments, and ultimately provide a lower overall measurement uncertainty. Other E-series power sensor specifications that provide temperature-banded data are linearity and SWR.

Since the reflection coefficient of the test source is usually beyond the control of the user, it is desirable to choose power sensors with the lowest specified reflection coefficient. Agilent sensors are conservatively specified, and the actual reflection coefficient data for each sensor is furnished with the sensor. If, for example, in the sensor specific Calibration Report, the reflection coefficient (ρ) value was 0.01for a E9321A power sensor (at 1 GHz), then the SWR would be 1.02 (Return Loss –40 dB). This value could be used in the source/sensor mismatch calculation, refer to Chapter 7 *Measurement Uncertainty* in Application Note Fundamentals of RF and Microwave Power Measurements, literature number 5965-6630E. This SWR value would be in contrast to the warranted maximum SWR specification of 1.12 (at <=0 dBm, for 1 GHz) contained in the *E4416A/E4417A EPM-P Series Power Meters and E-Series E9320 Peak and Average Power Sensor*, Data Sheet, literature number 5980-1469E, and like the temperature-banded calibration factor data, provide a lower overall measurement uncertainty.

STEP 3.
Understanding Agilent sensor technologies and power meter features

In general, power sensors are designed to match user signal formats and modulation types. Similarly, power meters are designed to match the user's measurement data requirements. Sensor technology has developed over the years to better meet the advancing needs of users. The thrust has been to increase sensitivity and dynamic range, while improving the speed, accuracy and reliability demanded by the fast-paced industry.

Power sensors are of two general types:

1. Heat-based
2. Diode-detector based

Heat-based sensors such as thermistors and thermocouples depend on the process of absorbing all (except for tiny inefficiencies and reflections) of the RF and microwave signal energy, and sensing the resulting heat rise. Since the heat effect integrates all the signal power, such sensors are totally independent of the waveforms and spectrum content of the signal. Thus, they respond to the true average power of the signal, whether pulsed, CW, AM/FM, or other complex modulation, and including spiked power effects such as crest factor.

Diode-based sensors depend on the rectifying characteristics of their non-linear microwave detection curve. Their ability to detect and measure power down to -70 dBm recommends them for ultra-low signal detection applications such as at the front end of RF or microwave systems. They are also ideal for wide-dynamic-range measurements. And they provide much faster response times, making them important for pulsed and high-data-rate applications.

While basic diode sensors operate in their “square-law” range from –70 to –20 dBm, Agilent has extended the diode technology into three other areas, extended-range CW sensors, two-path-diode-stack sensors for higher power, and peak and average sensors, which provide powerful pulse-power characterization. All will be described below.

Thermocouple technology

Agilent thermocouple sensors use a heat-based design with –30 dBm sensitivity and the high-stability offered by a chopped-signal amplification path for the tiny DC signal generated by the thermal element. Agilent's silicon-web technology (circa 1974), which absorbs the RF/microwave heat and drives the silicon/metal thermocouple element, provided a major advance in improved impedance match. See Figure 3. This resulted in lower mismatch uncertainties and better measurement confidence. The chip also features a rugged termination design that withstands reasonable signal overloads.

Typical modern thermocouple sensors achieve wide frequency coverage with coaxial inputs, but some are configured in waveguide up to 50 GHz. With their dynamic power range of –30 to +20 dBm, they measure convenient ranges of industry-common system power.

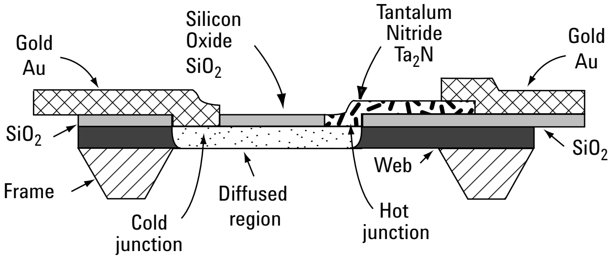


Figure 3. Cross section of Agilent thermocouple chip. Power dissipated in the tantalum-nitride resistor heats the hot junction.

Thermocouple sensor accuracies depend on a precise 50 MHz reference power calibrator, which is resident in each power meter. Used in conjunction with an associated calibration factor, the meter/ sensor combination then accurately transfers traceable power references to all frequencies of the sensor bandwidth.

Agilent has also extended the +20 dBm upper power range of several families of coaxial thermocouple sensors by including internal attenuators for 3-watt and 25-watt maximum inputs up to 18 GHz. Conveniently, the attenuator performance is included in the calibration factor data for better total accuracy.

The Agilent 8480A/B/H family of sensors typify this powerful thermocouple technology. Thermocouple sensors are recommended for all systems with CW, pulsed or complex modulations, because when the signal format lies within their dynamic range, you can be assured that the sensor is responding to total aggregate (average) power.

For some tests, however, such as a “mute” test on wireless power amplifiers (–55 dBm), their limited sensitivity requires a second sensor to be used, increasing test times in some applications. In addition, measurements at the low-end of the specified range of thermocouple sensors (typically –25 to –30 dBm) sometimes require time-averaging to produce an accurate, stable reading.

Diode technology

Diodes convert RF/microwave to DC (or video in pulsed applications) by means of their rectification properties, which arise from their non-linear current-voltage characteristic. Figure 4 shows a typical diode detection response curve starting near their noise level of –70 dBm and extending up to +20 dBm.

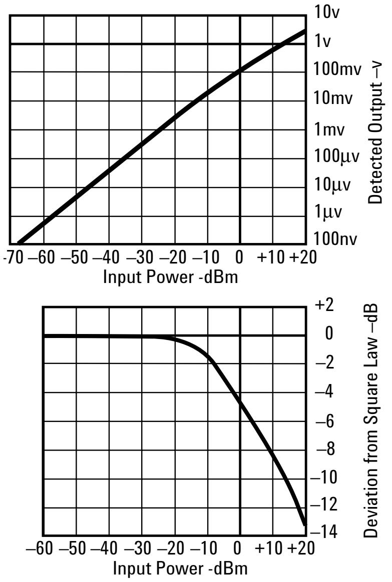


Figure 4. The diode detection characteristic is square law from the noise level up to –20 dBm, followed by a transition region and then a linear range to +20 dBm. The lower graph shows deviation from “square-law.”

In the lower “square-law”' region the diode's detected output voltage is linearly proportional to the input power (V_{out} proportional to V_{in}^2) and so responds linearly to power. Above –20 dBm, the diode's transfer characteristic transitions toward a linear detection function (V_{out} proportional to V_{in}) , and the square-law relationship is no longer valid.

Traditionally, diode power sensors have been specified to measure power over the –70 to –20 dBm range, making them the preferred sensor type for applications that require high sensitivity measurements. In applications that require fast measurement speed, diode sensors are chosen over thermocouple types because of their quicker response to changes of input power.

Diode sensors (Agilent’s 8480D-family) average the effects of complex and multiple signals within their square-law range from –70 to –20 dBm, with the proviso that no peak energy can exceed the –20 dBm level. This limits their use considerably for pulsed power measurement. The diode elements have also been designed into waveguide sensors, with coverage from 26.5 to 110 GHz (8486-series).

Extended dynamic-range diode sensors

Agilent diode sensor technology now permits measuring continuous wave (CW) power over an extended dynamic range from –70 to +20 dBm, up to a frequency range of 33 GHz. Their 90-dB range makes them ideal for wide-dynamic range applications such as high-attenuation component measurements. When these sensors are used with the EPM series power meters, they offer a fast measurement speed mode – up to 200 readings/second with the single channel E4418B meter.

These E4412/13A sensors employ a combination sensor-meter architecture, whereby the calibration factor is measured and stored in an EEPROM within each individual sensor, and downloaded into the meter. Since the correction factors are derived from a CW source, they do not provide an accurate average power reading for modulated signals, such as CDMA, when the signal peaks rise above the diode’s square law region.

Two-path-diode-stack sensors

When power testing from –70 dBm up to +20 dBm is necessary, as has become increasingly the case, the traditional approach has been to use a diode sensor to cover the low range, and a thermocouple sensor for the high end. In a high-volume manufacturing environment, this dual measurement configuration consumes too much test time, especially if optimum accuracy must be maintained.

The ideal averaging sensor would combine the accuracy and linearity of a thermal sensor with the wide dynamic range of the extended diode approach. Agilent's E-series sensors based on a patented dual-path, diode-attenuator-diode topology, have the advantage of always maintaining one of the two sets of sensing diodes within their square law region and therefore responding correctly to complex modulation formats.

The E-series E9300 power sensors are implemented as a Modified Barrier Integrated Diode (MBID). The MBID is comprised of a two-diode-stack pair for the low power path, a resistive attenuator and a five-diode-stack pair for the high power path, as shown in Figure 5. Only one path is active at a time, and switching between paths is fast, automatic and transparent to the user, effectively producing an 80 dB dynamic range over –60 to +44 dBm, depending on the sensor model.

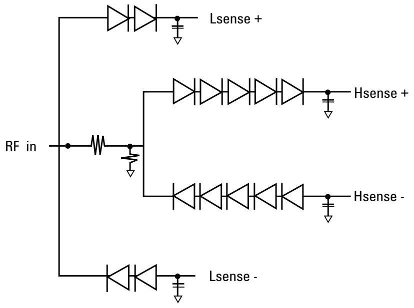


Figure 5. Simplified block diagram of the two-path-diode-stack topology.

This innovative approach has the important application advantage of making the sensor capable of handling higher power levels without damage, than simple diode sensors. This is particularly useful with W-CDMA signals, which exhibit high peak-to-average ratios.

These MBID sensors have a maximum average power specification of +25 dBm and +33 dBm peak (<10 µS duration). This means that the full 80 dB dynamic range can be used to measure signals that simultaneously have both high peak power and high average power.

The new sensor technology facilitates an inherently broadband average power measurement technique, limited by none of the bandwidth or dynamic range trade-off considerations found in sampled techniques. These sensors are an ideal fit for users who need the flexibility to make wideband average power measurements.

The E9300 family of sensors cover the 6 and 18 GHz bands as shown in the product listings of Table 5, page 18. Optional coverage for the 6 GHz sensors extend to 18 GHz (Opt. H18 and H19), and for the 18 GHz products to 24 GHz (Option H24 and H25).

Together with the new E-series E9300 power sensors, the companion Agilent EPM power meters (E4418B/19B) are capable of accurately measuring the average power of modulated signals over a wide dynamic range, regardless of signal bandwidth.

Peak and average power sensors

The Agilent E9320 peak and average sensors presently cover the 50 MHz to 6/18 GHz frequency ranges and -65 to + 20 dBm power range. They are optimized for comprehensive measurements on pulsed envelopes and signals with complex modulation. When teamed with the new Agilent EPM-P series power meters (E4416A/17A), the combination can handle test signal envelopes with up to 5 MHz video[1] bandwidth.

Of particular utility for production testing, the meters' 20 Msamples/second continuous sample rate permits fast measurement speed, via the GPIB, of up to 1,000 corrected readings per second, ideal for use in automatic test system applications.

Agilent peak and average sensor/ meters feature two-mode operation, **normal** for most average and peak measurements (with or without time gating), and **average only** for average power measurements on low level or CW-only signals. Both modes use the same micro-circuit diode-sensor element.

---

[1] Note that the 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.

The Agilent E9320 sensor family (using the EPM-P meter) can provide highly accurate and useful data for parameters such as pulse top or average power on pulses as narrow as 300 nS. While not specifically intended for narrow pulse characterization, its 5 MHz bandwidth amplifiers can deliver the measurements of Table 1. This capability is described further in the power meter section, page 14.

The signal processing is provided by two amplification paths, each optimized to their different data requirements. The amplification is distributed, with some in the sensor unit and more in the meter. In the **average-only mode**, amplification and chopping parameters are much the same as in previous Agilent diode sensors, with typical dynamic power range of –65 to +20 dBm.

Bandwidth considerations

In the normal mode, the separate-path pulse amplifier provides maximum bandwidths of 300 kHz, 1.5 MHz or 5 MHz, defined by the sensor model number. This allows the user to match the test signal's modulation bandwidth to the sophisticated instrument data processing. For example, the three maximum bandwidth choices match up with these typical wireless system requirements:

300 kHz	TDMA, GSM
1.5 MHz	CDMA, IS-95
5 MHz	W-CDMA, cdma2000

To further optimize the system's dynamic range, the video bandwidth can be user-selected inside the meter amplifier to high, medium, and low, as detailed in Table 2. Thus, when users need to measure the power of multiple signal types, within a single sensor, by considering the dynamic range of the bandwidth settings shown, they can determine if they require only one sensor or need multiple sensors for their application(s).

When instrumenting for peak power measurements, it is crucial to analyze the effect of the instrumentation video bandwidths on the accuracy of the resulting data. Agilent E4416/17A meters have been optimized to avoid degrading key specifications like linearity, mismatch, dynamic range and temperature stability. For further information on this matter, see the following article, "Power Measurements for the Communications Market." [4] [see reference literature]

Measurement accuracy is enhanced without compromise, since the sensors store their three-dimensional calibration data in an EEPROM, resident in each sensor. The data is unique to each sensor and consists of cal factor vs. frequency versus power input versus temperature. Upon power-up, or when the sensor is connected, these calibration factors are downloaded into the EPM-P series power meters.

Thermistor technology

Agilent maintains a line of coaxial and waveguide thermistor sensors and one thermistor power meter. Thermistor sensors are heat-based, and exploit a balanced-bridge architecture using the DC substitution method. Thus, they are ideally suited for metrology-type applications such as transferring a reference power level from the primary standards of a national laboratory, or for an industry intercomparison process called a Round Robin.

The Agilent 432A power meter and associated 478/86 sensors and their role in traceability processes is fully detailed in Chapter 3 of Application Note 64-1C, *Fundamentals of RF and Microwave Power Measurements*, literature number 5965-6630E. Custom versions of the thermistor sensors, which feature selected low reflection coefficients, are available for the lower uncertainties they provide to reference power transfer applications.

Table 1. E9320-series sensors can measure pulse parameters.

Key pulse parameter	**EPM-P/E9320 specifications**
Rise time	200 nS
Fall time	200 nS
Minimum pulse width	300 nS
Pulse repetition rate	2 MHz
Pulse repetition interval	500 nS

Table 2. E9320 sensor bandwidth versus peak power dynamic range (normal mode)

Sensor model	**Modulation bandwidth / Max. dynamic range**			
6 GHz/18 GHz	**High**	**Medium**	**Low**	**Off**
E9321A/E9325A	300 kHz / –42 dBm to +20 dBm	100 kHz /–43 dBm to +20 dBm	30 kHz / –45 dBm to +20 dBm	–40 dBm to +20 dBm
E9322A/E9326A	1.5 MHz / –37 dBm to +20 dBm	300 kHz /–38 dBm to +20 dBm	100 kHz /–39 dBm to +20 dBm	–36 dBm to +20 dBm
E9323A/E9327A	5 MHz / –32 dBm to +20 dBm	1.5 MHz /–34 dBm to +20 dBm	300 kHz /-36 dBm to +20 dBm	–32 dBm to +20 dBm

Agilent power meters

Agilent offers power meters in four basic families. (See Table 3.)

1. The E4416/17A series for peak and average applications. They have the highest functionality and most versatile measurement capability. Moreover, they are backward compatible with all Agilent thermocouple and diode power sensors.
2. The E4418/19B series for averaging power measurements. They offer full capabilities for average power applications, thus utilizing all but the E9320-series peak/ average sensors.
3. The E1416A (VXI) system power meter is compatible with the 8480 series sensors.
4. The 432A/478/486 thermistor family, which is preferred for metrology applications such as reference power transfer.

Figure 6. E4417A power meter configured to show a trace display (upper window) and a dual numeric display (lower window).

Peak and average meters (EPM-P series)

The E4416/17A peak and average power meters (EPM-P series) are Agilent's most powerful measurement tools for pulsed and complex modulation formats. In combination with the E9320 sensors, they feature a user-friendly interface and powerful display controls. (See Figure 6.)

Hardkeys control the most-frequently used functions such as sensor calibration and triggering, while softkey menus simplify configuring the meter for detailed measurement sequences. A save/ recall menu stores up to 10 instrument configurations for easy switching of test processes. And, in its GPIB programming mode, it can output up to 1,000 corrected readings per second.

A large LCD display partitions up to 4-line formats to help interpret and compare measurement results, or presents large character readouts to permit viewing from a distance. For example, the 4 lines could be configured to display average power in dBm and mW, peak power and peak-to-average ratio. The user can also set up a trace display as shown in Figure 6.

The powerful DSP (digital signal processing) mathematical processing permits the meter to measure burst-average and peak power, to compute peak-to-average ratios, and display other time-gated pulse power profiles on the power meter's large LCD screen. They can also measure and display other complex wide-band modulation formats whose envelopes contain high frequency components up to 5 MHz.

For time-gated measurements, the EPM-P series meters excel in versatility. The power meters measure peak and average powers at user-designated time-gates and gate widths along a test waveform. Figure 7 (page 14) shows another typical time-gated power measurement on a GSM signal. Gate 2 provides the burst average power over the "useful" GSM time period and Gate 1 indicates the peak power over the complete timeslot. Thus, a peak-to-average ratio measurement can be obtained by subtracting Gate 1 - Gate 2 (in dB).

This peak-to-average measurement made as shown, was using two different gate times and should not be confused with the peak-to-average ratio measurement in a single gate. A pulse droop

Table 3. Agilent's family of power meters

Agilent model	Name	Remarks
Peak and average power meters EPM-P series		
E4416A	Single-channel	Digital, programmable, peak and average measurements, uses E9320 series sensors. Innovative time-gated pulse-power measurements. 20 Msamples/sec.
E4417A	Dual-channel	Two-channel version of E4416A, plus measures and computes parameters between the two sensors.
Averaging power meters EPM series		
E4418B	Single-channel	Digital, programmable, uses E-series and 8480 series sensors, reads EEPROM-stored sensor calibration factors of E-series sensors.
E4419B	Dual-channel	Two-channel version of E4418B, plus measures and computes parameters between the two sensors.
System power meter		
E1416A	VXI power meter	Has functional performance features of previous model 437B; uses all 8480-series sensors
Thermistor power meter		
432A	Thermistor power meter	DC-substitution, balanced-bridge technology, ideal for reference power transfers

measurement can be obtained from the subtraction of the two powers, Gate 3 - Gate 4. With the 4-line numeric display, all 3 of these measurements can be simultaneously display on the LCD screen, along with the peak power from Gate 1.

All EPM-P power meters now feature a firmware enhancement for a graphical trace setup and analysis screen. Figure 8 shows this new feature with real-time marker measurements on the meter's trace display. Markers 1 and 2 show the instantaneous power and time relative to a selected trigger event. On the right side are computational parameters of Δ time, Δ average, Δ peak and Δpeak-to-average power ratios between markers 1 and 2. A trace-zooming capability is also available for more resolution on observations and settings.

VEE analysis package

Perhaps even more important to product development and verification engineers is a powerful analyzer software package which places the EPM-P meter totally in control of the PC or laptop. This EPM-P VEE software package is available free of charge. It operates via the GPIB, and provides the statistical, power, frequency, and time measurements that are required for CDMA and TDMA signal formats. The CD-ROM package includes a VEE installation program.

The statistical package includes the ability to capture:

1. Cumulative Distribution Function (CDF)
2. Complementary CDF (CCDF or 1-CDF)
3. Probability Density Function (PDF)

These are crucial diagnostic parameters for system signals like CDMA formats. Figure 9 shows a typical distribution function display. Analyzing such power distribution computations can reveal how a power amplifier may be distorting a broadband signal that it is transmitting. Or a baseband DSP signal designer can completely specify the power distribution characteristics to the associated RF subsystem designers.

Finally, the analysis package includes a powerful pulse characterization routine. It computes and displays the following power parameters: pulse top, pulse base, distal, mesial, proximal, peak, average, peak/average ratio, burst average, and duty cycle. It does the same for these time and frequency parameters: rise time, fall time, pulse repetition frequency (PRF), pulse repetition interval (PRI), pulse width and off time. All of these pulsed power parameters were originally defined with the 1990 introduction of the Agilent 8990A peak power analyzer.

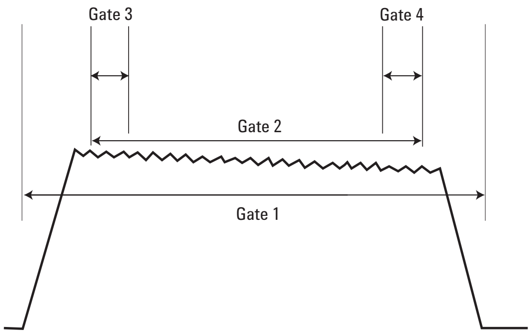
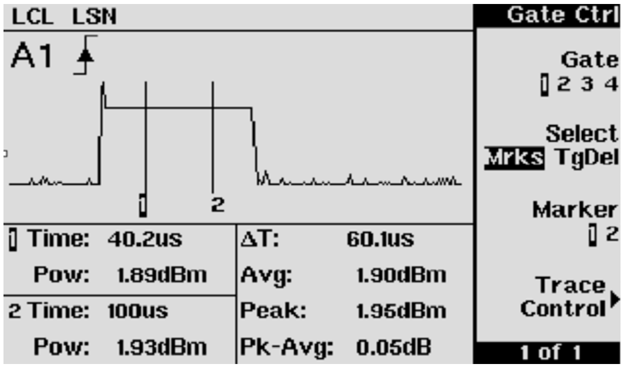
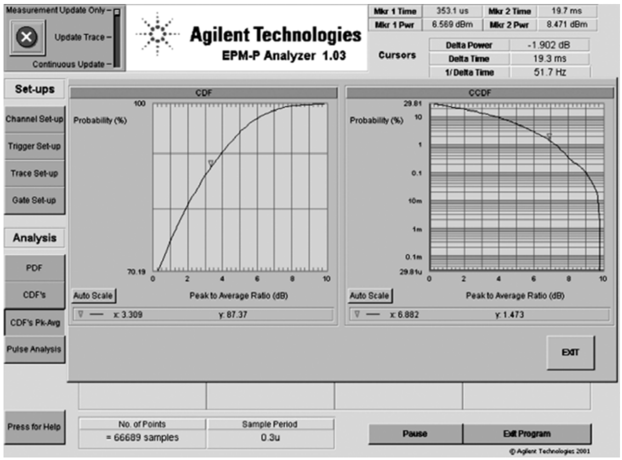


Figure 7. On this GSM pulse, powerful data configuration routines during four gate times, provide the feeds for the display.



1 Time: 40.2us
Pow: 1.89dBm
2 Time: 100us
Pow: 1.93dBm
ΔT: 60.1us
Avg: 1.90dBm
Peak: 1.95dBm
Pk-Avg: 0.05dB

Figure 8. This graphical display permits marker-selected power measurements, plus computations between the marker-identified data.



Mkr 1 Time 353.1 us
Mkr 2 Time 19.7 ms
Mkr 1 Pwr 6.569 dBm
Mkr 2 Pwr 8.471 dBm
Delta Power -1.902 dB
Delta Time 19.3 ms
1/ Delta Time 51.7 Hz
x: 3.309 y: 87.37
x: 6.882 y: 1.473
No. of Points = 66689 samples
Sample Period 0.3u

Figure 9. The Y-axis shows the percent time the signal power is at or above the power specified by the X-axis.

Basic computation power

By configuring the data obtained from the four gate periods, the E4416/17A meters can present computed data on their large LCD displays. For example, Figure 10 shows the data paths for the four independent gate periods. Each gate can accumulate three different parameters; average, peak, or peak-to-average ratio.

Each gate can then manipulate the selected parameter into two computed parameters (F-feeds) per measurement channel (maximum), such as F1 minus F2 or F1/F2, to be displayed in one of the four window partitions. This computational power is particularly valuable in TDMA scenarios such as GSM, GPRS, EDGE, and NADC where various simultaneous combinations of computed parameters are required.

This computational power is further enhanced in the E4417A dual-channel power meter, which can add data feeds from its second sensor into the user-configured display modes.

Averaging power meters (EPM series)

Average power meters respond to all signals, whether CW, complex modulation or pulsed. The main application criteria s whether the user needs to characterize the modulation or profile the envelope of those pulse parameters or simply requires a measurement of average power. In some cases of traditional pulsed signals, where the duty cycle is known and fixed, system peak powers may be computed from a knowledge of the duty-cycle value and an average power measurement.

The E4418/19B power meters and E-series sensor combination provides measurement speeds of up to 200 readings per second over the GPIB bus. The E-series sensors cover a 90 dB power range from –70 to +44 dBm, with frequency coverage to 26.5 GHz, sensor dependent. For CW, multi-tone and modulation applications, the E-series sensors can make measurements using only a single sensor rather than several of the 8480 series as before.

Agilent EPM series meters operate with the entire line of 8480 series thermocouple and diode sensors, to protect your equipment investment. Programming code, written for the previous 436A, 437B and 438A power meters, is also directly usable with the E4418B and E4419B power meters.

System power meter

Agilent offers the E1416A VXI power meter, for system applications in the industry-standard VXI configuration. The E1416A has the functional performance and operating features of the previous 437B power meter, except it has no front panel.

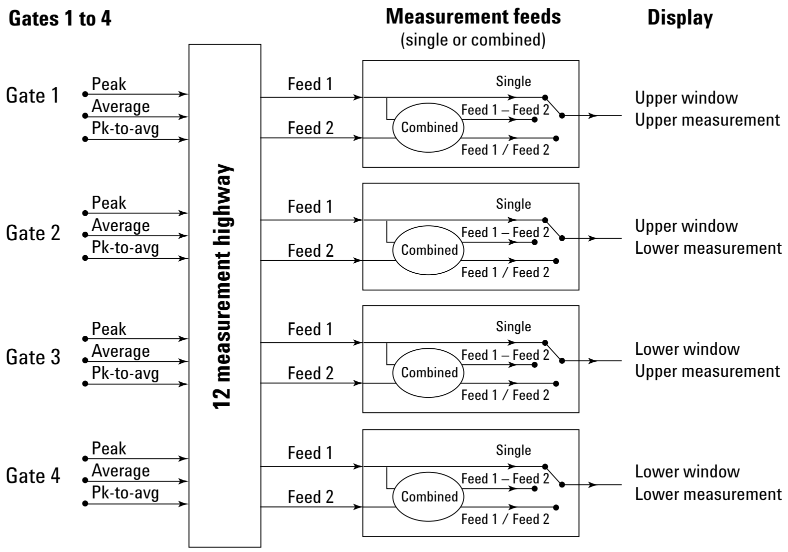


Figure 10. User-configured data manipulations are one big feature of the EPM-P series power meters.

STEP 4.

Making the performance comparison and selecting the best product for your application

By far, most power measurements are made with averaging power meters. Based on the previous comparison of sensor technology, and the selection guide for sensors (see below), the user can easily determine which sensor model meets the power and frequency range performance required. The compatibility Table 4 shows which meters operate with which sensors.

For averaging applications, the two EPM power meters are prime alternatives, since not only are they designed for the E-series CW and E9300 sensors, but they are also backwards-compatible with the entire line of 8480 thermocouple and diode sensors (but not thermistors). Considering the large installed base of Agilent sensors in most organizations, this makes the EPM meters far more versatile and cost effective. Further, many calibration laboratories are functional with test systems which are designed specifically to calibrate Agilent's long line of power sensors.

In spite of the popularity of averaging meters, the rapid growth of the wireless communications industry has driven measurement requirements into power characterizations of peak power, peak burst, peak-to-average ratio, burst average power, and other important parameters. Agilent's peak and average E4416/17A EPM-P meters are innovative solutions to the stringent needs of the industry. If you need peak power characterization in your lab or production line, the Agilent EPM-P meters are your choice. They are functionally the most versatile and computational of our power meter line.

In the benchtop or production line environment, selecting between single- and dual-channel capability gives the next sort. Agilent's meters have means of sensing the specified power range of the individual sensor attached, and thus assure the correct power readout. This feature also disables the readout if the user applies too much power and drives the meter outside the specified range, such as the standard 8480 series diode sensors which are limited to a top level of –20 dBm.

In terms of GPIB programming code, as well as complying to the Standard Commands for Programmable Instruments (SCPI), the E4418B power meter has been designed to be code-compatible with the previous 436A and 437B. The E4419B dual channel power meter is code-compatible with the previous 438A. This provides a substantial saving in new program- ming costs. Yet, the EPM series power meters offer flexibility, accuracy, and convenience for manual applications in the research lab.

For automated system use, the fast measurement speed, (EPM–200 readings per second, EPM-P—1,000 readings per second) make them ideal for programmed applications. Their digital-signal-processing (DSP) circuit architecture not only provides for powerful computation and averaging routines, but also results in the elimination of the standard range switch-time delays, thus speeding up the overall measurement speed.

Thermistor-based sensors and meter for metrology applications

Finally, Agilent offers a line of coaxial and waveguide thermistor sensors and a full DC-substitution power meter, the 432A, which serves metrology applications for the transfer of power standards.

Selection guides

Power measuring equipment for all applications

Power measuring equipment is a key part of Agilent's instrumentation line of RF and microwave measurement tools. Through the decades, the power-meter line has advanced with additions of the newest sensor technologies and the power of the microprocessor for more capable and flexible power meter products.

From the original drift-prone thermistor sensors of the 1950's, to low-SWR thermocouple sensors, Agilent has exploited the latest technologies to take the inaccuracies out of your power measurements. The latest sensor technologies that use planar-doped-barrier diodes in various configurations now offer the best in sensitivity and low drift for both average-power and peak-power measurements. And Agilent's newest power meters and E-series sensors give you new speed and accuracy for measurements over a dynamic range of –70 to +44 dBm, sensor dependent.

Table 4 presents a compatibility overview of the entire Agilent power measurement family, including meters and sensors.

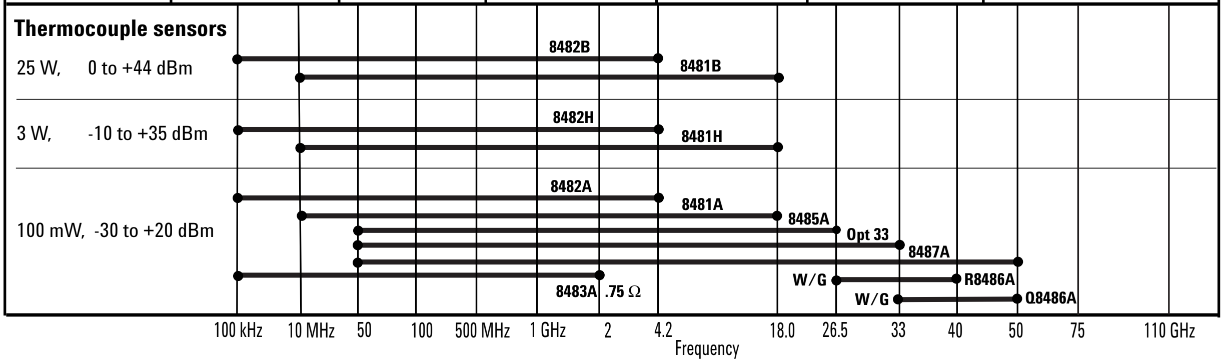
Table 4. Agilent power meter/sensor compatibility chart

	Agilent power meters			
Agilent power sensors	EPM-P series peak, average and time gating E4416A single Ch E4417A dual Ch	EPM series averaging E4418B single Ch E4419B dual Ch	System power meter	Thermistor power meter 432A
Thermocouple 8480A/B/ H-family R/Q8486A W/G (11 models)	●	●	●	
Diode 8480D-family 8486A/D-W/ G-family (7 models)	●	●	●	
Diode sensors with extended range E4412A/13A (2 models)	●	●		
Two-path-diode-stack E9300 family (7 models)	●	●		
Peak and average sensors E9320 family (6 models)	●			
Thermistor sensors 478 coaxial 486 waveguide (6 models)				●

Table 5. Agilent's family of power sensors

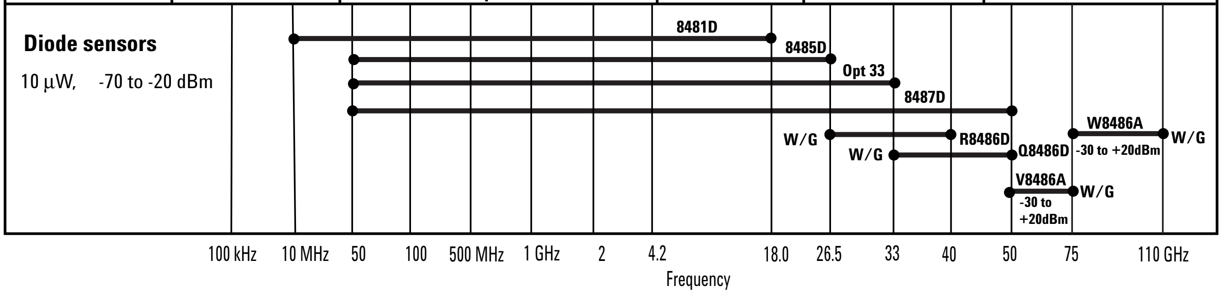
Thermocouple sensors

Sensor family	Technology	Max. dynamic range	Frequency range[1]	Power range[1]	Signal type	Max. measurement speed (rdgs/sec)
8480 series	Thermocouple	50 dB	100 kHz to 50 GHz	-30 to +44 dBm	All signal types, unlimited bandwidth	40 (x2 mode)



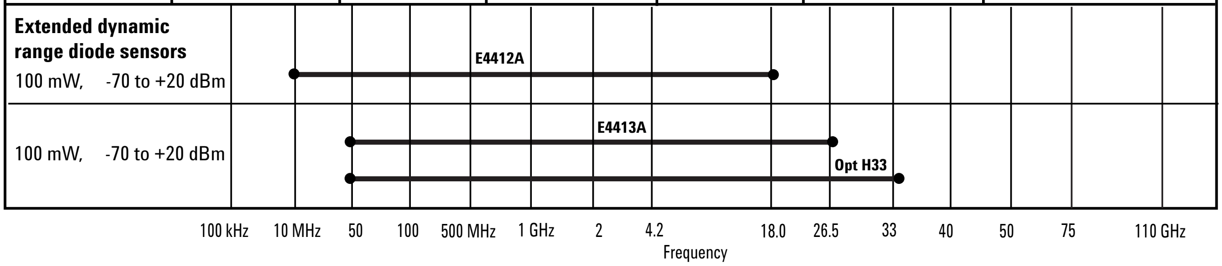
Diode sensors

Sensor family	Technology	Max. dynamic range	Frequency range[1]	Power range[1]	Signal type	Max. measurement speed (rdgs/sec)
8480 series	Diode	50 dB	10 MHz to 110 GHz	-70 to -20 dBm	All signal types, unlimited bandwidth	40 (x2 mode)



Extended range diode sensors

Sensor family	Technology	Max. dynamic range	Frequency range[1]	Power range[1]	Signal type	Max. measurement speed (rdgs/sec)
E-series: CW E4412A E4413A	Single diode pair	90 dB	10 MHz to 26.5 GHz	-70 to +20 dBm	CW only	200 (fast mode)

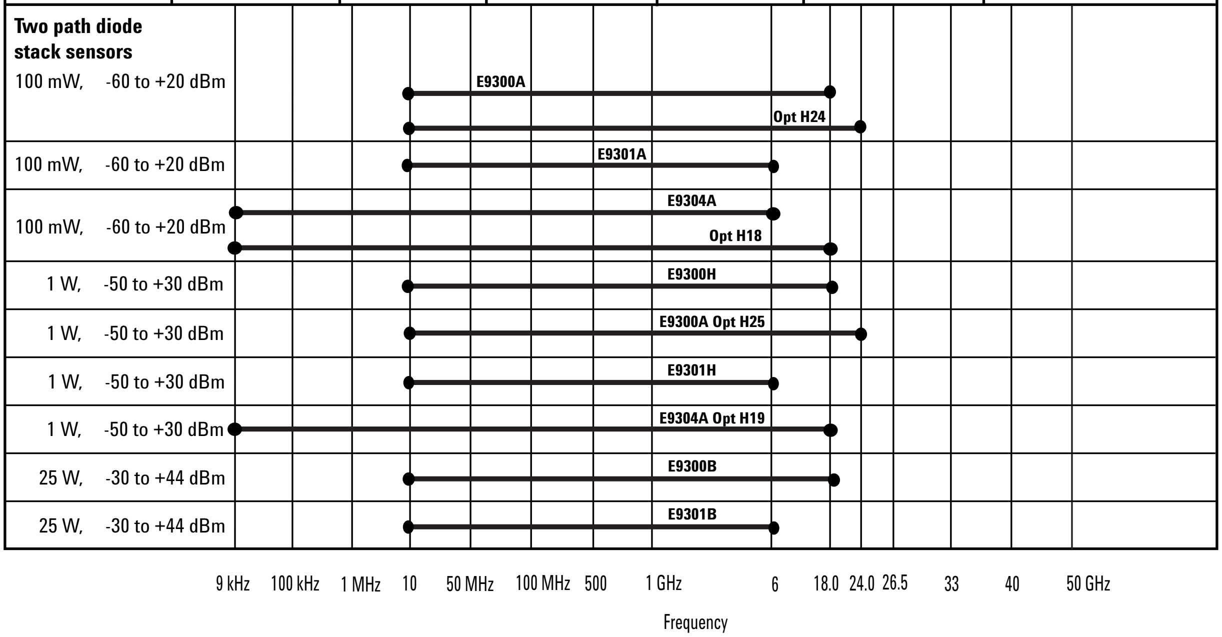


---

1. Sensor dependent

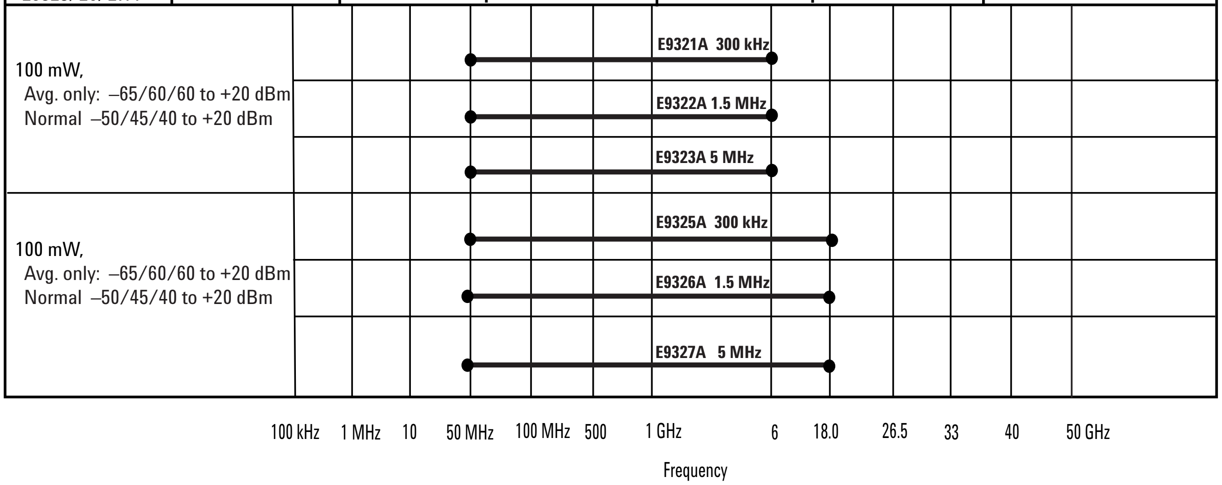
Two-path diode stack sensors

Sensor family	Technology	Max. dynamic range	Frequency range[1]	Power range[1]	Signal type	Max. measurement speed (rdgs/sec)
E-series: average power sensors E9300	Diode-attenuator-diode	80 dB	9 kHz to 18 GHz	-60 to +44 dBm	All signal types unlimited bandwidth	200 (fast mode)



Peak and average sensors

Sensor family	Technology	Max. dynamic range	Frequency range[1]	Power range[1]	Signal type	Max. measurement speed (rdgs/sec)
E9320-series[2] peak and average E9321/22/23A E9325/26/27A	Single diode pair, two-path	85 dB	50 MHz to 18 GHz	–65 to +20 dBm	CW, avg, peak	Up to 1000



---

1. Sensor dependent
2. Peak and average sensors must be used with an E9288A, B, or C sensor cable, and only operate with the E4416A/17A power meters

References

[1] *A Calibration Service for Coaxial Reference Standards for Microwave Power*, Claque F.R., NIST Technical Note 1374, NIST, 325 Broadway, Boulder, Colorado, USA. May, 1995

[2] *International Organization for Standardization*, Geneva Switzerland, ISBN 92-67-10188-9, 1995.

[3] *National Conference of Standards Laboratories*, Boulder, CO, ANSI/NCSL Z540-2-1996.

[4] Anderson, Alan, *Power Measurements for the Communications Market*, MW/RF Magazine, October, 2000.

For more information:

Choosing the Right Power Meter and Sensor, Product Note, literature number 5968-7150E.

Fundamentals of RF and Microwave Power Measurements, Application Note 64-1C, literature number 5965-6630E.

Related Agilent literature

EPM-P Power Meters and the E9320 Series Power Sensors, Technical Specification, literature number 5980-1469E.

EPM and EPM-P Series Power Meters and E-Series Power Sensors, Configuration Guide, literature number 5965-6381E.

EMP-P Series Single and Dual-Channel Power Meter-E9320 Family of Peak and Average Power Sensors, Product Overview, literature number 5980-1471E.

EPM Series Power Meters, E-Series and 8480 Series Power Sensors, Technical Specifications, literature number 5965-6382E

EPM Series Power Meters, Product Overview, literature number 5965-6380E

E9300 Power Sensors, Product Overview, literature number 5968-4960E

CD-ROM: EPM and EPM-P Series Power Meters, part number E4416-90032.
This CD-ROM contains the power meters and sensors Learnware (User's Guides, Programming Guides, Operating Guides and Service Manuals). The CD-ROM also contains technical specifications, data sheets, product overviews, configuration guide, application and product notes as well as power meter tutorials, analyzer software for the EPM-P power meters, IVI-COM drivers, IntuiLink toolbar for the EPM power meters and VXI Plug & Play drivers for the EPM power meters.

This versatile CD-ROM package is shipped free with every EPM and EPM-P power meter. Additional of the information is also available at: **www.agilent.com.**

Agilent Email Updates

www.agilent.com/find/emailupdates
Get the latest information on the products and applications you select.

Agilent Technologies' Test and Measurement Support, Services, and Assistance
Agilent Technologies aims to maximize the value you receive, while minimizing your risk and problems. We strive to ensure that you get the test and measurement capabilities you paid for and obtain the support you need. Our extensive support resources and services can help you choose the right Agilent products for your applications and apply them successfully. Every instrument and system we sell has a global warranty. Support is available for at least five years beyond the production life of the product. Two concepts underlie Agilent's overall support policy: "Our Promise" and "Your Advantage."

Our Promise
Our Promise means your Agilent test and measurement equipment will meet its advertised performance and functionality. When you are choosing new equipment, we will help you with product information, including realistic performance specifications and practical recommendations from experienced test engineers. When you use Agilent equipment, we can verify that it works properly, help with product operation, and provide basic measurement assistance for the use of specified capabilities, at no extra cost upon request. Many self-help tools are available.

Your Advantage
Your Advantage means that Agilent offers a wide range of additional expert test and measurement services, which you can purchase according to your unique technical and business needs. Solve problems efficiently and gain a competitive edge by contracting with us for calibration, extra-cost upgrades, out-of-warranty repairs, and onsite education and training, as well as design, system integration, project management, and other professional engineering services. Experienced Agilent engineers and technicians worldwide can help you maximize your productivity, optimize the return on investment of your Agilent instruments and systems, and obtain dependable measurement accuracy for the life of those products.

Agilent T&M Software and Connectivity
Agilent's Test and Measurement software and connectivity products, solutions and developer network allows you to take time out of connecting your instruments to your computer with tools based on PC standards, so you can focus on your tasks, not on your connections. Visit
www.agilent.com/find/connectivity
for more information.

By internet, phone, or fax, get assistance with all your test & measurement needs

Phone or Fax
United States:
(tel) 800 452 4844
Canada:
(tel) 877 894 4414
(fax) 905 282 6495
China:
(tel) 800 810 0189
(fax) 800 820 2816
Europe:
(tel) (31 20) 547 2323
(fax) (31 20) 547 2390
Japan:
(tel) (81) 426 56 7832
(fax) (81) 426 56 7840

Korea:
(tel) (82 2) 2004 5004
(fax) (82 2) 2004 5115
Latin America:
(tel) (305) 269 7500
(fax) (305) 269 7599
Taiwan:
(tel) 0800 047 866
(fax) 0800 286 331
Other Asia Pacific Countries:
(tel) (65) 6375 8100
(fax) (65) 6836 0252
Email:
tm_asia@agilent.com

Online Assistance:
www.agilent.com/find/assist

Printed in USA, March 11, 2003
5965-8167E

Agilent Technologies