Agilent
EPM-P Series Power Meters Used in Radar and Pulse Applications

Application Note 1438

Introduction

The focus of this product note is the alternative ways that pulse and peak power measurements are made. The note looks at the measurement capability of the EPM-P series power meters and E9320 peak and average sensors for pulse measurements, along with the pulse analysis feature provided by the EPM-P Analyzer Software.

Pulse Power

Pulse power was traditionally determined by measuring the average power of the pulse and then dividing the measurement result by the pulse duty cycle value to obtain the pulse power reading, as shown:

$$\mathbf{P_p = P_{avg} \,/\, Duty\ Cycle}$$

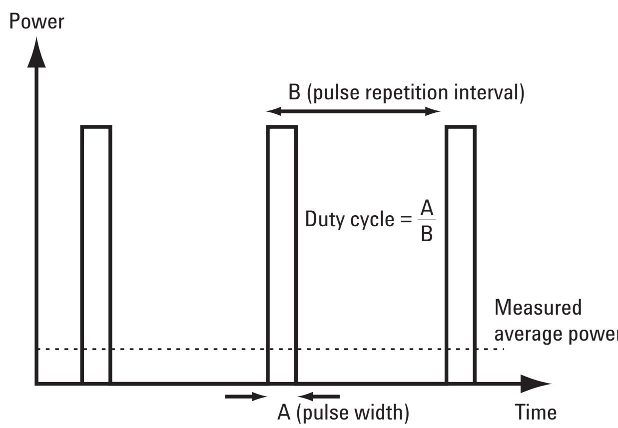


Figure 1: Pulse power measurement

The measurement result is a mathematical representation of the pulse power rather than an actual measurement and assumes constant peak power. The pulse power averages out any aberrations in the pulse, such as overshoot or ringing. For this reason it is called pulse power and not peak power or peak pulse power as is done in many radar references. In order to ensure accurate pulse power readings, the input signal must be a repetitive rectangular pulse of constant, known duty cycle. Other pulse shapes (such as triangle or Gaussian) will cause erroneous results. This technique is also not applicable for digital modulation systems, where the duty cycle is not constant, and when the pulse amplitude or shape is variable.

There are some advantages with using duty cycle to calculate the pulse power. The duty cycle technique provides the lowest cost solution, with average power meters and sensors being less expensive than peak and average power meters and sensors. They also have the ability to measure over a wide power and frequency range. Agilent 8480 and E9300 average power sensors have a power range –70 dBm (–60 dBm for E9300 sensors) to +44 dBm, and frequency range 9 kHz (100 kHz for 8480 series sensors) to 110 GHz (24 GHz for E9300 sensors).

Let us take a look at how the power meter duty cycle technique works using an Agilent EPM series power meter. In this example, shown in Figure 2, we are supplying a pulsed signal with a pulse width of 10 µs and a pulse period, or pulse repetition interval (PRI) of 40 µs. The pulse signal is set with a power level of approximately 0 dBm.

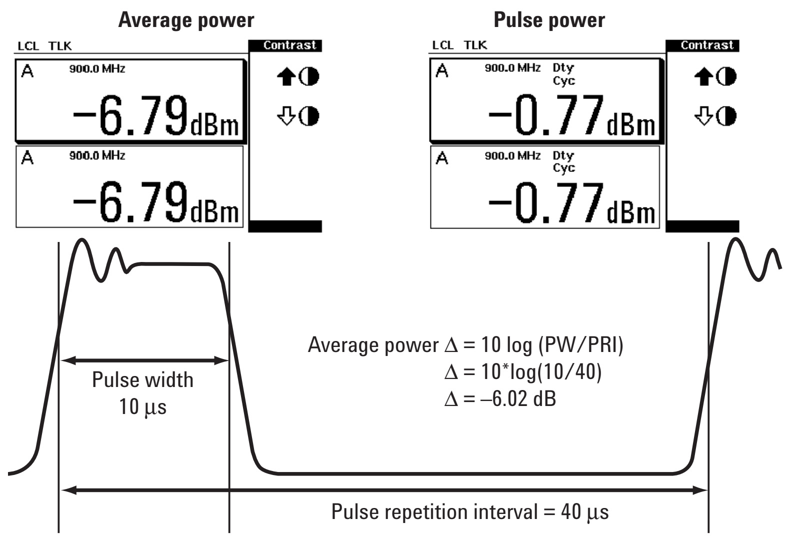


Figure 2: Measuring pulse power using duty cycle

Using a power meter to measure the average power of the signal, the result of –6.79 dBm is shown in the average power display. Since the duty cycle is known to be 10 µs divided by 40 µs, which is 25%, this value can be entered into the power meter. This generates a pulse power reading of –0.77 dBm. To understand what the power meter is doing, we can look at the duty cycle calculation. The equation:

Average Power Δ = 10 log (Pulse Width / PRI)

provides the difference between the average power and pulse power. This results in a calculated value where, for this example, the average power is 6.02 dB lower than the pulse power. The power meter makes this correction to show the pulse power using the entered duty cycle.

In a lot of cases, as shown in Figure 2, the pulse may not be purely rectangular since there is an associated rise and fall time, as well as overshoot and ringing on the signal. The combination of these effects, create an error in the calculated result.

Pulsed power measurements using the EPM-P series power meters

The evolution of highly sophisticated radar, electronic warfare and navigation systems, which is often based on complex pulsed and spread spectrum technologies, has led to more sophisticated instrumentation for characterizing pulsed RF power. The EPM-P series power meters go a long way to provide this necessary power measurement sophistication. Used in conjunction with the E9320A sensors, they provide the measurement and pulse profile display of time-gated peak, average and peak-to-average ratio power measurements.

The EPM-P power meters utilize a continuous sampling technique, and therefore can make measurements over a defined period rather than using a calculation. The EPM-P power meters have a 20 Msamples/s continuous sampling rate to allow accurate profiling of the signal being measured. In the design of a sampling power meter, the choice can be made between continuous sampling and random sampling, and for pulse measurements there are some clear advantages obtained by continuous sampling. For example, continuous sampling allows the signal to be captured if a single shot measurement is made. This is an advantage if the pulse you are trying to capture is not repetitive. Continuous sampling also allows for digital filtering architecture and bandwidth correction within the power meter. Digital filtering enhances the dynamic range of the meter/sensor combination, and bandwidth correction provides optimum accuracy for peak and statistical power measurements. In contrast, if random sampling is used, there is no guarantee that the peak signal will be captured. For repetitive signals the trace can be built up, however this happens over a number of traces and therefore takes longer to build the display.

In Figure 3 the same signal as used for the duty cycle example in Figure 2 is being measured.

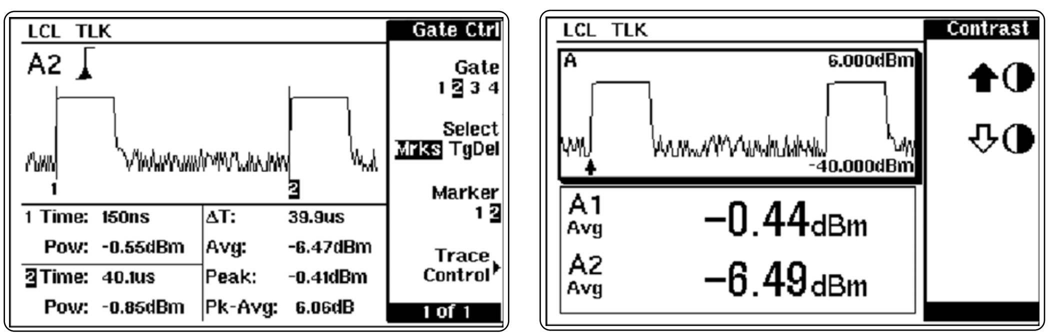


Figure 3: Pulse power measurements using the EPM-P power meters

From the EPM-P displays we can see the difference between the duty cycle method. The most obvious difference is the ability to see the pulse signal. The left side screen shot shows how the trace can be used to configure the measurements to be made. In this example two gates have been setup, the first gate over the pulse width of the signal, to measure the power within the pulse itself. The second gate, shown by markers 1 and 2 in the left side screen shot, measures the power across the full pulse repetition interval (PRI).

The right side screen shot shows how the power meter’s display can be configured with the trace being shown in the upper window and the lower window being set for a dual numeric display. In the dual numeric display we have chosen to display the average power within the two gates (A1 and A2 average power). We can see from the results that the average power over the full PRI is 6.05 dB lower than the pulse itself. The measured value is therefore very close to the calculated 6.02 dB difference for the duty cycle method, which was for the ‘perfect’ pulse shape.

Keys to success in radar and pulse applications

For radar and pulse applications the ability to make a time-gated power measurement is very important. The time-gated measurements are performed using the EPM-P power meters extensive triggering capabilities, and includes the ability to have up to four independent measurements on either a single pulse or on multiple pulses. An example of this is shown in Figure 4 where four independent start delays and gate lengths are set from the trigger event for a single pulse.

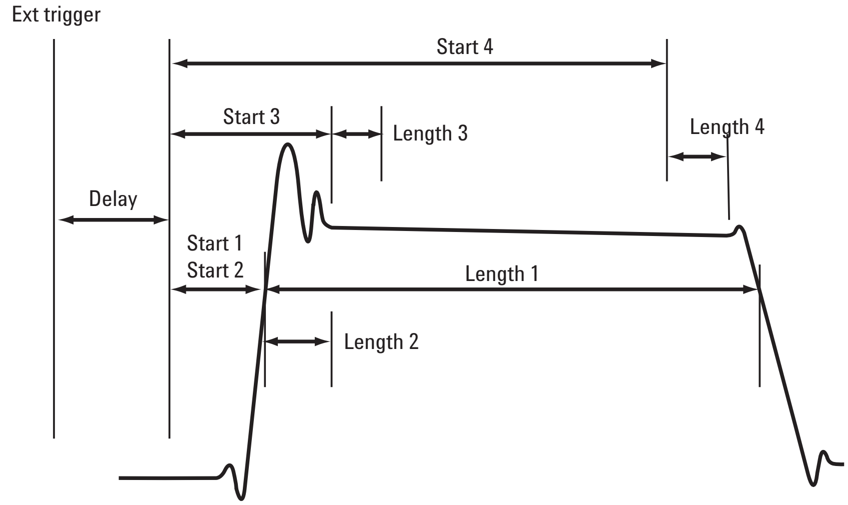


Figure 4: Versatile time-gating features of the EPM-P series power meters

Each of these four measurements can be set up to measure peak, average or peak-to-average ratio. This gives a powerful measurement setup, for example, users have the ability to make a peak measurement on the overshoot (peak power in Length 2), measure the average power over the pulse burst (average power in length 1), and measure the pulse droop, this being obtained from the subtraction of the two powers in Lengths 3 and 4.

Figure 5 shows the EPM-P power meter's capability to measure power on multiple pulses.

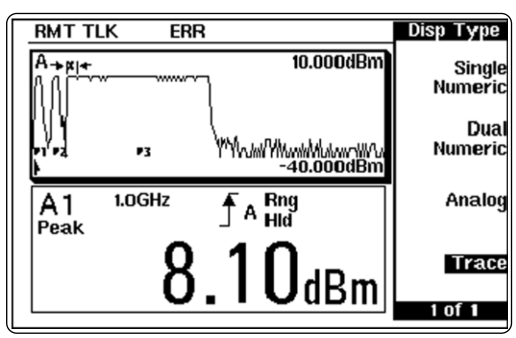


Figure 5: Power measurements on multiple pulses

Level triggering can be used to trigger on pulse P1. The Start and Length can be used to measure the peak power of P1, P2 and between the markers shown in P3 (Length X). Stable and reliable triggering is also essential for viewing the pulse profile, this is achieved using the power meters Trigger Holdoff feature. This feature disables the trigger for a user-defined period.

Understanding important pulse parameter specifications, as shown in Table 1, and how they relate to the signal under test, is also key to success in being able to measure radar and pulse signals.

Key Parameter	EPM-P / E9323A/7A Specification
Dynamic range	52 dB peak (80 dB average)
Frequency range	**E9323A:** 50 MHz to 6 GHz; **E9327A:** 50 MHz to 18 GHz
Rise time	200 ns
Fall time	200 ns
Minimum pulse width	300 ns
Pulse repetition frequency	2 MHz
Pulse repetition interval	500 ns
Pulse analysis	**Use EPM-P analyzer software**

Table 1: Pulse-related specifications

The dynamic range of 52 dB, in Table 1, is for peak power measurements, which cover –32 dBm to +20 dBm, with the maximum dynamic range for average power measurements being 80 dB, from –60 dBm to +20 dBm.

Key specification definitions are:

Rise time: The time difference between the 10% and 90% points of the pulse-top-amplitude.

Fall time: Same as rise time measured on the last transition.

Pulse width: The pulse duration measured at the 50% power level.

Pulse repetition interval (PRI): The interval between the pulse start time of the first pulse waveform and the pulse start time of the immediately following pulse waveform in a periodic pulse train.

Pulse repetition frequency: The reciprocal of the PRI.

EPM-P Analyzer Software

Figure 6 shows the features of the EPM-P analyzer software. The analyzer software operates via the GPIB in a PC or laptop environment and provides statistical, power, frequency and time measurements. The analyzer software is in full control of the meter, therefore all the meter functions and pre-defined setups are not relevant as the software overrides the meter. The analyzer software is an Agilent VEE run-time program, and is supplied as standard with all EPM-P power meters, free of charge, on a CD-ROM or can be downloaded from **www.agilent.com/find/powermeters**.

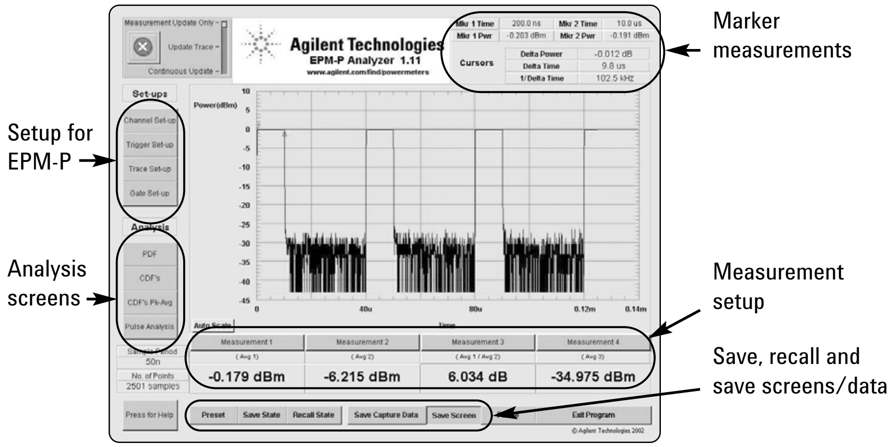


Figure 6: EPM-P analyzer software

We have seen how we would set up the power meter for a pulse measurement and will now look at the capabilities of the EPM-P analyzer software for making measurements. Figure 6 shows the main areas that need to be considered.

Setups for EPM-P: This software controls the power meter and is used to set up the Channel, Trigger and Gate Setups as shown through the front panel. The trace is required to be setup where the user sets the capture time.

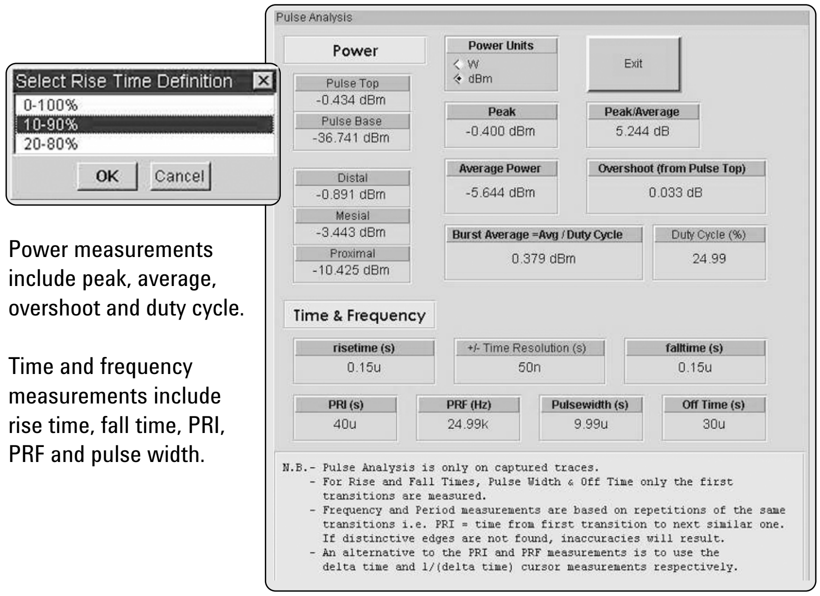
Analysis screens: After the power meter is configured, the trace is captured to allow for analysis of the captured trace data. There are various analysis screens covering statistical analysis such as Probability Density Function (PDF) and Complementary Cumulative Distribution Function (CCDF or 1-CDF) measurements and pulse analysis.

Marker measurements: When the trace is captured, the marker measurements can be used to provide time and power information, and the trace can also be zoomed in on to look closely at areas of interest.

Measurement setup: The display can show up to four real-time power measurements, which are configured in a similar manner to the power meter display, and allows time-gated average, peak, peak-to-average ratio measurements, as well as combination measurements to be displayed.

Save, recall and save screens/data: If the analyzer display is required for reports or import into other applications, the screen can be saved as a JPG or BMP file and the power and time data from the captured trace can also be saved in a CSV file. The analyzer software allows 10 states to be stored and recalled. This ensures easy set up of the analyzer software and allows repeatable measurements to be obtained. These states are saved in a separate file, and stored on the PC or a disc, ensuring users on different PCs are operating the same setups and therefore making the same measurements.

Selecting the Pulse Analysis screen will give the display as shown in Figure 7. A choice of rise time definition is presented with the most common definition being 10% to 90%.



Power measurements include peak, average, overshoot and duty cycle.

Time and frequency measurements include rise time, fall time, PRI, PRF and pulse width.

Figure 7: Pulse analysis screen

The pulse analysis computes the numerous power, time and frequency parameters shown in Figure 7. The notes at the bottom of the pulse analysis screen are informative about how the measurements are determined. The measurements made are on the captured trace data only, even if you have zoomed on the trace, all the captured data is used. The measurements are split into Power, and Time & Frequency information. The Power information includes the pulse top power, peak power, peak-to-average ratio, overshoot from the pulse top and the duty cycle. In the Time & Frequency measurements the rise and fall times, pulse width and off time are all calculated using the first measured transitions or pulse. If you are level triggering, it is good practice to add in a negative time delay in order to capture the complete first pulse rise time. If you want to analyze a secondary pulse, the trace captured would need to be made using a trigger delay to ensure the first pulse is not included in the data. Frequency and period measurements, such as PRI, are calculated on repetitions of the same transitions or pulse. If only one pulse is captured then no reading will be presented.

It can be noted that the time resolution is accurate to +/- 50 ns; this is due to the 20 Msamples/s sampling rate of the EPM-P power meters, since 1/(20 Msamples/s) is 50 ns.

The terms measured on the pulse analysis display are based on IEEE definitions[1]. Pulsed power is difficult to measure, as the waveform envelopes under test require many different parameters to characterize the power flow. In 1990 with the introduction of the 8990 peak power analyzer series, Agilent chose to extend the older IEEE definitions of video pulse characteristics into the RF and microwave domain. The standard was originally a video pulse standard, the ANSI/IEEE standard 194-1977. For measurements of pulse parameters such as rise time or overshoot to be meaningful, the points on the waveform that are used in the measurement must be defined unambiguously. To achieve this, all the time parameters are measured between specific amplitude points on the pulse, for example the mesial point, and all the amplitude points are referenced to the two levels named pulse top and pulse base.

1. IEEE STD 194-1977, *IEEE Standard Pulse Terms and Definitions*, July 26, 1977.

Summary

In summary, the EPM series average power meters can be used for pulse power measurements when using the duty cycle technique, however the ability of the EPM-P series power meters to make peak, average, peak-to-average ratio power measurements in the time domain make a better solution for measuring the power of pulsed signals.

In the past, the now discontinued range of 899XA peak power analyzers were the instruments of choice for making pulse measurements. While the EPM-P power meters are not a direct replacement for the 899XA analyzers, they will provide a good fit in many radar and pulse applications, especially when combined with the EPM-P analyzer software.

Appendix A: Optimizing the EPM-P Power Meter Setup for Pulse Measurements

The first hardkey we will look at is the Channel key, which provides an ideal summary of the setup within the power meter. For pulse measurements the main items are:

Sensor Mode: The E9320 power sensors have two modes, Average Only and Normal. If peak measurements or time-gated measurements are being made then Normal mode should be selected. Average Only mode is suitable for measuring the average power of a signal up to –20 dBm, and for signals above –20 dBm this mode will give accurate results for CW signals only.

Range: This is an important setting for pulse measurements, especially when narrow pulses are being measured. If auto range is selected the sensor may switch range from lower to upper during a rising edge and from upper to lower on a falling edge. The time delay for this with video bandwidth set to off is 4 μs and this may impair the measurement. Setting the range to upper or lower removes this delay. If the pulse signal being measured is above –15 dBm then upper range should be selected, and if the maximum power being input, including any overshoot, is less than –5 dBm the lower range should be selected.

Frequency: Since the E9320A peak and average power sensors are fully corrected for calibration factors, and these corrections are stored in EEPROM, it is important to enter the frequency of the signal being measured to ensure optimum accuracy.

Video Bandwidth: There are four settings for the video bandwidth – High, Medium, Low and Off. High, Medium and Low refer to the modulating signal bandwidth and the filters used are designed to be very flat over the bandwidth. The Off setting provides approximately 3 dB roll-off at the maximum bandwidth and is recommended for pulse measurements since it removes any ringing effects caused by the sharp filters.

The High, Medium and Low settings allow for different bandwidths to be selected and the trade-off with bandwidth is dynamic range, the wider the video bandwidth, the smaller the dynamic range, as shown in Table 2.

High (5 MHz)	Medium (1.5 MHz)	Low (300 kHz)	Off (5 MHz)
–32 dBm to +20 dBm	–34 dBm to +20 dBm	–36 dBm to +20 dBm	–32 dBm to +20 dBm

Table 2: Video bandwidth versus peak power dynamic range for the E9323A/7A sensors

Step Detect: If step detect is set to On, this will reduce the settling time after a significant step in the measured power. In this case the filter re-initializes if a step increase or decrease is detected.

Trigger hardkey: To make use of the measurement gates for pulse measurements either single or continuous acquisition should be used. Under trigger settings the trigger can be either internal using the rising or falling edge, or an external trigger input or GPIB trigger can be used. The trigger mode can be chosen to be Auto level or Normal mode where a trigger level can be set. To ensure a stable reading is obtained, additional control features such as trigger holdoff, hysteresis and delay are provided.

Meas Setup hardkey: This hardkey allows you to configure the display to see the measurements that are important to you. For pulse measurements it is often useful to see the trace and this can be combined with either a single or dual numeric display. The numeric display allows you to select the input type for the gate (average, peak or peak-to-average ratio). If a dual channel meter is used, mathematical combinations A-B, B-A, A/B and B/A can be set up..

Meas Display hardkey: This is where you can select the display type between the trace display, single or dual numeric or an analog display. Analog display is useful for monitoring maximum or minimum power adjustments.

Related Agilent Literature

Agilent EPM Series Power Meters, Brochure, literature number 5965-6380E

Agilent EPM Series Power Meter E-Series and 8480 Series Power Sensors, Data Sheet, literature number 5965-6382E

Agilent E4416A/E4417A EPM-P Series Power Meters and E-Series E9320 Peak and Average Power Sensors, Data Sheet, literature number 5965-1469E

Agilent EPM-P Series Single and Dual-Channel Power Meters E9320 Family of Peak and Average Power Sensors, Product Overview, literature number 5980-1471E

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