Accurate RF Power Measurements of Second and Third Generation Wireless Communication Signals

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In this seminar, we will be discussing different methods used for measuring power of modulated communication systems. While some of our examples will deal with cellular & PCS wireless systems, many of the principals we will discuss will apply to any modulated communication system.

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•Accurate power measurements are important for maintaining a high quality connection in a communication system. With the rapid growth of wireless systems, system providers are challenged to provide a quality signal with maximum coverage.
•In a wireless system, the phone needs to be calibrated to provide the power necessary to reach the base station. On the other hand, in order to conserve battery life, the power transmitted should not be more than what is needed. The handset must therefore have very accurate linearity in order to tune the output power for an optimum connection.
• Also, the base station and handset must not exceed the max allowable power transmitted according to standards and FCC regulations. Assuring that the transmitted power does not exceed the allowable limit, which is traced to a known standard, is a primary concern.
•This brings us to the question, why use power meters? Power meters provide the most accurate method of measuring RF power. They have excellent linearity which assures that the power measured over a wide dynamic range is accurate. Also, a power meter is the best way to assure that the power measured is traceable to a government standard, in our case that is the National Institute of Standards and Technology, or NIST.
•Previously, power meters were designed using thermal sensing devices. While these devices are accurate, they are also slow. They were primarily designed to measure unmodulated signals and have been adapted to provide limited power information of modulated signals.
Giga-tronics uses diode sensors to provide the fastest accurate measurements possible. What we will be discussing is how Giga-tronics uses diode sensors to improve the speed of the measurement and still maintain the accuracy necessary.

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•Let's first define what we mean by RF power. Notice that power is defined as work over a period of time. One watt is 1 joule per second. In other words, what we are primarily interested in is average power rather than instantaneous power. We obtain average power by integrating the product of voltage and current over time. In this seminar, I will be using the term power to mean average power.
• Another term used to describe power is Peak Power. The term Peak power is used to describe the average power at a specific time. In other words, if the signal is being modulated, then the average power is constantly changing. If we sample the average power at a particular point in time, then we are measuring the peak power of the power envelope. We will discuss this in more detail when we talk about modulation measurements.

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Sensors used by power meters can be classified into two categories; thermal sensors and diode sensors. Thermal sensors use either a thermocouple or a thermistor to measure the RF power. Both use the properties of heat to integrate the RF power over time. Due to the nature of thermal characteristics, thermal sensors provide a slow response to changes in power, such as when you have a modulated condition.

Diode sensors rectify the RF energy to a dc voltage. The advantage of this method is that they are able to track very rapid changes in power if the sensor is designed properly. We will discuss the difference between tracking the average power of a modulated signal and the peak power. For optimum performance, a diode sensor must have enough video bandwidth to track the peak envelope of the modulated signal.

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When considering power measurement accuracy, or more correctly, measurement uncertainty, a number of factors must be taken into account. The 8 factors listed here are the more significant ones. Mismatch uncertainty due to the interaction between the sensor and source is usually the most dominant. Then, factors such as instrumentation linearity, calibrator uncertainty and calibrator/sensor mismatch should be included. Finally, if the measurement takes place within the last 15 dB of dynamic range, zero and noise will become a major contributor to measurement uncertainty.

Notice that these terms will change whenever there is a change in frequency, testport match, or power level. So in order to determine total measurement uncertainty, a complete analysis of each of these terms is required whenever power or frequency is changed. Giga-tronics has a paper that discusses how to calculate each of these terms manually. In addition, we have developed an Accuracy Audit program which takes the measurement information and automatically converts the information into an uncertainty number. The program is a stand alone executable and is available on CD. If you would like a copy of the paper or the program, send us an email either directly to me or through our web site, and we will send you a CD with the materials.

During this seminar, I will spend time discussing application concerns when measuring modulated signals rather than show how to calculate the individual uncertainties.

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Here we have three classes of signals identified; Constant wave, or CW, where the amplitude is constant over time, Modulated Signals and Digital Modulation. Digital communication signals use a combination of phase and amplitude modulation to code the carrier and have a more complex nature.

Before talking about modulated measurements, let’s first review how power meters measure CW signals.

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We will first consider how thermal sensors measure CW power and then compare that to a diode sensor.

As mentioned previously, thermal sensors depend on the relationship between heat and power to determine the power level of the signal. The thermal sensor will therefore rise to the level of the power detected and eventually settle to the final reading.

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When measuring CW power with a diode sensor, the sensor samples the power at a given interval which is determined by the meter. The meter stores each of these samples in a bucket, averages all of the samples in the bucket and provides a measurement reading.

Averaging is the process of accumulating a number of buckets, averaging the readings and providing a single answer of all averaged buckets. So, if we were to set up the meter for an average of one, the meter would provide a reading from each bucket.

When we talk about measurement speed, we are referring to how fast the meter can provide measurements over the GPIB bus. Measurement speed therefore is determined by the speed of processing of measurements by the microprocessor.

We can also see that the number of samples included in each measurement is determined by the sample rate. In Giga-tronics meters all of the samples are included in a measurement. If the measurement speed decreases due to operating conditions, then the number of samples accumulated will increase. No samples are lost.

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Let's review the operating characteristics of diode sensors. Dynamic range is a key feature for power meters. As mentioned during the introduction, the handset must be characterized over a wide dynamic range in order to optimize system efficiency. A thermal sensor will have a dynamic range of 40 to 50 dB.

A diode sensor starts out with a linear dynamic range of 50 dB, from -70 dBm to around -20dBm. This is known as the square-law region of the sensor. It is also called the linear region since there is a linear relationship between the power in and the voltage out. Between -20 dBm and +20 dBm the diode sensor will operate, but it is not inherently linear. Giga-tronics achieves a 90 dB dynamic range by characterizing the non-linear properties of the sensor during the front panel calibration. By storing the non-linear characteristics in the meter and recalling the correction data during measurements, the meter is able to provide a very linear dynamic range from -70 to +20 dBm.

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This diagram explains further how Giga-tronics achieves a 90 dB dynamic range which is NIST traceable. We use a Wheatstone bridge which contains a thermistor as the reference. The thermistor is also called a bolometer and is a device whose measurement properties can be measured by NIST. A Wheatstone bridge with a thermistor is the method used by all power meters to establish a traceable 0 dBm reference for calibrating power sensors. What we have done in the Giga-tronics meters is included a patented process which incorporates stepped attenuators into the loop. Doing this allows us to step the power level from -30 to +20 dBm in 1 dB steps. This provides a very linear power sweep which is our reference for calibrating the sensor throughout the non-linear range and gives us a 90 dB dynamic range capability.

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Let's return to a CW measurement except this time we will measure a low level signal that is close to the noise floor of the meter. Notice that we no longer have a constant level power. Average power in this case is the mean of the power variations over time. We obtain the average power by accumulating a number of readings and using the average function of the meter. Both the thermal and diode sensors will settle to the average power. The diode sensor has the potential to settle much faster with a fast sample rate. A fast sample rate provides a large number of readings very quickly allowing the meter to average the measurements and settle to the reading. Notice that one of the characteristics of noise is the normal distribution around the mean.

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We will now start to evaluate modulation measurements by first examining a two tone, AM modulated signal. Notice that we are skipping FM modulation measurements. Frequency modulation implies that only the frequency, or phase, of the signal is changing. The amplitude of a FM modulated signal does not vary. It therefore can be treated as a CW signal. During modulation measurements, our primary concern is the variation of the amplitude of the signal. Notice that an AM modulated signal varies power level over time and that the average power is the mean of the power variations. Peak power is a term used to describe the power level of the modulated waveform at a specific point in time. We obtain the average power by averaging the peak power envelope. This is somewhat similar to the previous condition where we were measuring a CW signal with noise. The difference is that the modulation pattern is not normally distributed. Let's look further at the process of measuring power of an AM modulated signal.

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We will first consider how a thermal sensor measures a modulated signal. We see that when measuring modulated signals using a thermal sensor, we must wait for the sensor to settle to the average power level of the modulated waveform. This can often take multiple cycles of the modulation cycle.

A diode sensor samples the pattern and begins to provide an average of the samples accumulated. Notice that if the sample rate is fast enough, it is possible to obtain the average reading after one cycle of modulation.

One of the requirements of the diode sensor is that it be able to track the power envelope. To do this, it must have enough amplitude, or video, bandwidth to track the envelope accurately. In other words, the sensor must have enough rise and fall time to track the waveform. If it does not, the sensor will provide up to a few tenths dB positive offset error.

Another important requirement for fast accurate measurements is the sampling method used. Notice that the sample rate can be below the modulation frequency. Since power is a scalar measurement, we do not need to obtain phase information in order to calculate the average power. Remember that the power measured is an integrated measurement which is phase independent. A consideration when undersampling is the potential for aliasing. In order to avoid aliasing, Giga-tronics power meters use asynchronous sampling. This technique minimizes aliasing and provides fast accurate power measurements.

There is the possibility of measuring higher modulation rate signals which are above the bandwidth of the sensor. It is possible to make these measurements using diode sensors by staying within the square-law region of the sensor. When making measurements this way the sensor will integrate the waveform and provide average power without having to track the actual power envelope. This is similar to a thermal sensor only much faster.

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Here we have a more complex modulated signal which might represent a real world signal. Notice there is a repetitive waveform characteristic to the signal. On the left, we are showing the average power of the signal as it is integrated over time. Due to the nature of the modulation, it takes a number of cycles before the reading settles to the average power of the waveform. This gives us an indication why we sometimes need to use a high averaging number in order for the reading to settle.

On the right we are setting the meter to read the signal for only one modulation cycle. This is similar to what we were seeing in a two-tone measurement. If we can set the meter to a time value, rather than an averaging number where there is limited control of measurement time, we can minimize the fractional N contributions of the signal and achieve a faster measurement.

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(No Notes.)

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The terms Peak sensors and Modulation sensors are commonly used to describe sensors that are designed to measure modulated power. Peak sensors in this case would refer to the fact that the sensor is able to track the peak power envelope. Giga-tronics uses the term Peak Pulse sensor to describe the sensors used to measure the peak pulse power of a pulse modulated signal. We use the term Modulation Sensors to describe sensors designed to perform complex modulated measurements.

To review what we have discussed regarding modulation sensors, a modulation sensor has a video bandwidth that allows the meter to track the power envelope and provide the average mean power of the modulation signal. Notice that an important consideration is that the sensor will operate this way in the non-linear as well as the square-law region. This means that the meter must take into account the non-linear characteristics of the sensor and correct for them as the samples are accumulated. Giga-tronics power meters do this in the DSP before sending the measurements to the host processor.

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Now let's take a look at pulse modulation. The average power of a pulse signal is similar to what we saw in a AM modulated signal. Average power in this case is the mean of the pulse waveform over many cycles. However, designers are interested in what the peak pulse power is when the power is on. If we only have a thermal or average-only sensor we need to estimate the top of the pulse by calculation using the duty cycle. If there is a slow rising and falling edge in the waveform, which is usually the case in wireless systems, then the estimate will not be accurate enough. What we need is a sensor with fast enough rise time, or bandwidth, to directly measure the top of the pulse.

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The Giga-tronics Peak Pulse Sensors provide a fast rise time to easily measure the pulse power. The measurement point is set relative to a trigger point and provides a direct reading of power at the specified time. This method eliminates the error due to duty cycle estimation. Peak pulse sensors with a rise time of 100 nsec are available with the 8540C and 8650A power meters.

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Now we are ready to discuss digital communication systems. This chart identifies the more popular wireless formats. The different systems can be classified into three categories, TDMA, GSM and CDMA. The different systems use different forms of digital modulation techniques. As we saw earlier, what is important in measuring modulated signals is to know the amplitude modulation rate and to verify that the sensor used has the bandwidth necessary to track the signal. In the case of TDMA and GSM, that would be the modulation rate of the vocoder. In the case of CDMA, the modulation rate is determined by the channel bandwidth. We will discuss this further in a bit.

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TDMA and CDMA systems use a form of QPSK modulation for coding the RF carrier. QPSK modulation shifts the phase of the carrier to different positions within the four IQ quadrants. Although QPSK is a phase shift technique, the process of transitioning from one quadrant to another results in a change in amplitude.

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Here we see the result of QPSK modulation. The amplitude varies as the signal is modulated. Because of the nature of the modulation, the signal takes on a psudo-random quality that looks similar to noise. The rate of modulation depends on the vocoder or, in the case of CDMA systems, channel width.

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Time Division Multiple Access uses time division to multiplex multiple callers. In this system, up to 8 callers may occupy the same frequency. Each caller is assigned a specific time slot within the burst. The carrier is modulated using QPSK techniques.

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GSM systems use GMSK, or Gaussian Minimum Shift Keying, modulation. GMSK also uses a phase shift method to code the carrier in the four quadrants. However, instead of transitioning the carrier through or near the origin as in QPSK systems, GSM systems maintains a constant amplitude. The result is a burst signal with no amplitude modulation within the burst. As a result, the bandwidth of the sensor needs only be high enough to capture the rising edge of the burst in order to measure individual slots within the burst.

An exception to the constant amplitude method of GSM is the new EDGE system. EDGE uses an 8 PSK modulation which is a form of QPSK and results in amplitude modulation.

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If we go back to our example of a pulse modulated signal, except now we add QPSK modulation within the burst, the result is a complex modulated signal that can be very challenging to measure. Trying to estimate the power transmitted by using the duty cycle correction method is prone to more errors when measuring a QPSK modulated burst.

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Giga-tronics uses a proprietary mode for measuring burst signals which we call burst average power, or BAP mode. This mode is very useful for measuring pulse modulated signals which have amplitude modulation during the pulse 'on' time, as in the case of TDMA signals. In this mode, the meter recognizes the beginning and end of a burst of RF power and takes an average of the power during the burst. Automatic duty cycle correction synchronizes the meter to the pulse, thereby avoiding errors due to risetime and falltime. The RF level can vary over a wide range during the burst as long as it remains above the noise threshold.

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We will now look at CDMA systems. Code Division Multiple Access multiplexes users through the use of spread spectrum techniques. The system uses QPSK modulation and individual codes to identify callers. Without code correlation the signal from individuals looks like noise. The IS-95 standard uses a 1.23 MHz BPSK signal to spread the spectrum so that each caller occupies the entire 1.23 MHz channel bandwidth. Because of the BPSK signal, the maximum amplitude modulation rate the sensor sees is 1.23 MHz, which is also the bandwidth of the channel. Thus channel bandwidth of a CDMA system will tell you what the bandwidth of the sensor needs to be. For third generation CDMA systems, as the channel bandwidth goes up, the bandwidth of the sensor needs to increase in order to track the peak envelope and provide peak as well as average power measurements.

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Measuring the maximum peak power of a QPSK system is important because system designers need to know the maximum value the system sees during operation. System linearity must take into account the peak power excursions. A modulation sensor that tracks the peak envelope can provide measurements of the maximum peak power encountered.

Another important parameter is the peak to average power, or crest factor, of the system. Crest factor provides the worse case peak to average value. Both the 8540C and 8650A power meters provide the ability to measure crest factor.

While crest factor provides important analysis information, it does not always provide all the information needed to properly evaluate a signal. Here we have two examples of a signal with the same 12 dB crest factor. However, the power distribution and percent occurrence of the worse case condition are quite different. A crest factor measurement of 12 dB would not be enough to fully describe what is going on. In addition to crest factor we also need to evaluate the signal using histogram, CDF and CCDF functions.

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This is an example of the same signal plotted in a histogram graph. The histogram displays the power distribution as a percent of occurrence for each given power interval. With this plot, we can quickly determine how often the worse case peaks are transmitted by the system. With histogram information it is also possible to derive the CDF and CCDF graphs of the signal. The CDF graph displays the percentage of time the power is at or below an indicated power level. The CCDF provides information on how often the power is at or above the indicated power. The 8650A power meter provides the ability to graph the histogram, CDF and CCDF plots on the instrument screen.

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This is an example of a histogram plot displayed on the 8650A power meter. Remember that the key to providing information like this is that the sensor have the bandwidth to track the power of the modulated signal. Sensors that do not have this ability, even diode sensors which only operate as average power sensors, cannot obtain the information necessary to provide important statistical analysis data.

Notes Slide 30:

(No Notes.)