Digital Sampling Power Analyzer for GSM and CDMA

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The digital modulation methods employed for cellular telephone and other wireless communications present a challenge for making accurate peak power measurements. Although there are many different implementations, the two basic types of modulation systems in use are time division multiple access (TDMA), and code division multiple access (CDMA).

Of the many TDMA systems, GSM (Global System for Mobile communication) is in widespread use in Europe and Asia and will soon appear in the USA. The RF envelope is in the form of 542.8 µsec pulses which are located within a 576.9 µsec timeslot, each containing 147 bits of information. The power-versus time relationship for each pulse is controlled within narrow limits for both turn-on and turn-off. This is necessary to prevent interference between adjacent time slots which are assigned to different transmitters. A GSM transmitter has only 28 µsec to ramp up to full power, a 70dB dynamic range, while remaining within a specified power/time profile. The profile defines limits for overshoot and rise-time as well as fall-time. A peak power video bandwidth of at least 1 MHz is required to assure compliance with the profile.

CW Power Measurement

The average power of an unmodulated RF carrier can be measured accurately by a CW type power meter with a thermoelectric or diode detector. The thermoelectric detector offers good accuracy over a dynamic range of about 50dB. The diode detector can provide a much larger dynamic range, about 90dB. The average power of a modulated RF carrier which has a constant envelope amplitude, e.g. FM, can also be measured accurately using these techniques.

For modulated RF carriers with non-constant envelope amplitude, e.g. pulse modulation, the thermoelectric detector will still respond accurately to the average power of the signal. The long time constant associated with thermal effects prevents this type of detector from following the envelope at the modulation rate, and therefore, is unable to provide any measure of instantaneous power.

The conventional CW type diode detector will also respond accurately, provided that it is used at low power in its square-law response region. This usually corresponds to a power at the diode of no more than -20 dBm or 10 µW. Higher input power is accommodated by placing an attenuator between the input signal and the diode. In a CW type detector the diode is loaded by a fairly large capacitance which filters the noise and improves sensitivity. The resulting time constant is long compared with modulation frequencies and prevents the detector from following the instantaneous value of the envelope.

Pulse Power Measurement

Pulse power is determined traditionally by adjusting the average power reading of a CW type power detector for the duty cycle of a modulating pulse. In this way, a peak power measurement of moderate accuracy can be obtained from an average power value, provided certain conditions are met. First, the modulation must consist of constant amplitude rectangular pulses of known duty cycle (on/off ratio). Second, the linear power range of the detector must not be exceeded by the peak power applied. This requirement is often overlooked, resulting in invalid readings or damage to the detector. The pulse power measurement technique is not suitable for digital modulation systems in which the duty cycle is not constant and pulse amplitude and shape varies.

Peak Power Measurement

What is needed for complex digital modulation is true instantaneous power measurement with a bandwidth of at least 1 MHz. The **Boonton** Model 4400A RF Peak Power Meter and Model 4500A RF Peak Power Meter / Analyzer provide the capability to measure peak power accurately with a dynamic range of as much as 60 dB and a demodulated video bandwidth as large as 35 MHz, with the Model 56518 Peak Power Sensor. Knowledge of the modulation method or modulating signal is not required for accurate average and peak power measurements.
In simplified form the Model 4400A/4500A peak power measuring system consists of the following: *See Fig. 1*

- A Peak Power Sensor containing a dual diode detector with wide RF bandwidth (up to 40 GHz) and a narrower video bandwidth (3 to 35 MHz), and a precision log amplifier compatible with the video bandwidth.
- A fast sample and hold amplifier, asynchronous with respect to the input signal.
- An analog to digital converter which operates at the sampling rate.
- A Digital Signal Processor (DSP) for processing the samples at high speed.
- A built-in, digitally controlled, 1 GHz precision CW power calibrator with internal pulse modulation.
- A host processor to control I/O interfaces and all sub-processes.
- A VGA processor for full color display of numerical and graphical data.

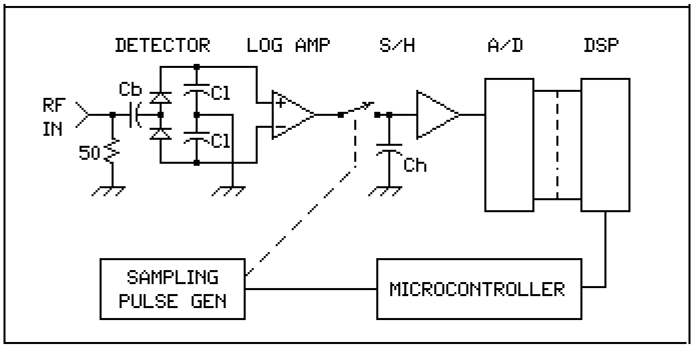

Figure 1. Simplified view of peak power measurement system.

Precision Digitally Controlled Calibrator.

In order to eliminate the error associated with diode non-linearity, a calibration table is created for each sensor which stores the response to a series of precision power levels covering the effective dynamic range along with additional data. This is accomplished automatically by a precision, digitally controlled, 1 GHz RF power source and control program. The resulting calibration table is extended by interpolation to create a power entry for all possible A/D converter values. This allows the DSP to calculate the instantaneous power of each individual sample of the RF envelope. Average power is calculated by summing the instantaneous power values. The non-linear relationship between instantaneous RF power level and diode output is resolved before any averaging is done, thus, the result is correct for an arbitrary waveform. It is this characteristic which separates this method of power measurement from the conventional average power method in which the output of the detector is averaged before A/D conversion.

Random power samples in time can be processed by the DSP to provide results in any form needed by an application. This includes peak power versus time, peak power relative to a trigger event, average power over various time intervals, peak to average ratio, maximum peak power in a time interval, etc. It does not matter that the samples are disordered in time. For a stationary signal, the sum of the random samples over arbitrary, equal length time intervals is the same, provided there is no periodic relationship between the sampling rate and the modulating signal. In addition, there must be a sufficient quantity of samples taken to ensure adequate coverage. The advantage of a high sampling rate is the ease of accumulating a large number of sample points for each reading.

If the detected signal is stationary or quasi-stationary in time, the waveform of the RF envelope can be re-constructed from the random samples. In conventional pulse or linear amplitude modulation, the RF carrier envelope and thus the detected signal correspond closely to the modulating signal waveform. In TDMA systems, the exact shape of the pulsed RF envelope is critical for optimum performance. The **Boonton** Model 4400A is particularly suited to applications in which peak power versus time is the primary concern.

Statistical Methods Using the Model 4500A

Digital modulation methods in which amplitude and phase modulation are combined in a multi-level arrangement to represent a group of bit values from one or more data streams, and multiple carrier spread spectrum systems, such as CDMA, do not have simple envelope waveforms which can be directly related to modulation parameters. Traditional parameters such as modulation depth and modulation index are not meaningful because the peak to average power ratio of the modulated carrier is a complex function of the data stream content, rather than the amplitude of the modulating signal. The resulting noise-like character of these signals suggests a statistical approach to analysis. The **Boonton** Model 4500A RF Peak Power Meter / Analyzer is designed to extract the statistical properties of these signals in addition to the time related properties discussed above.

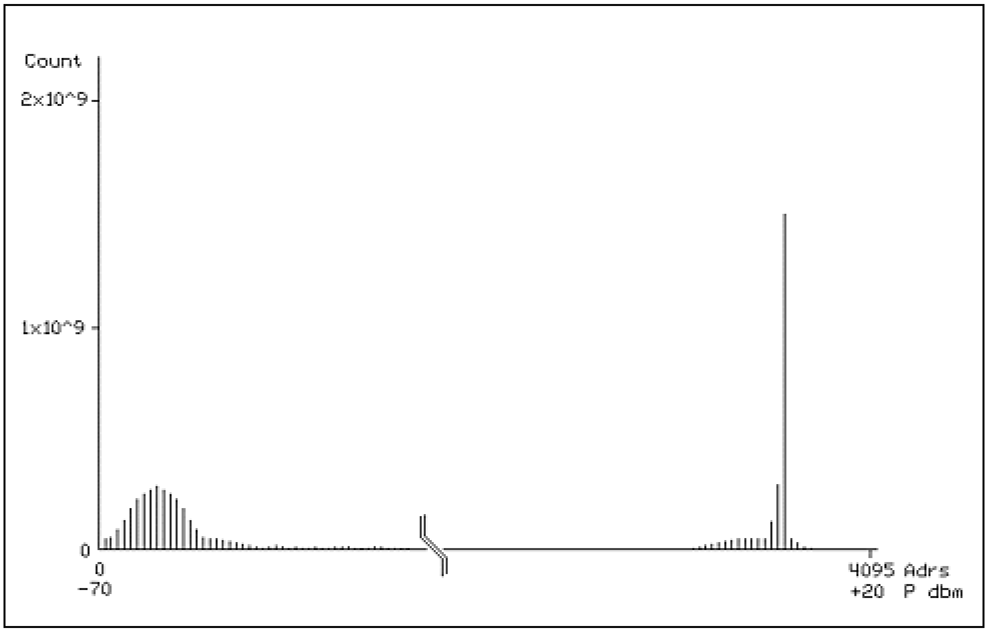

Figure 2. Sample Count Array in memory.

Since the power of the individual random samples is known, they can be sorted and counted by power level. For a 12-bit A/D converter system there are 4096 possible power levels. If a memory array of this size is established, each address corresponds to one of the possible power levels. With the array initially cleared to zeroes, the value of each sample taken is interpreted as an offset address into the array, and the count stored at that location is incremented by one. As this process is repeated millions of times, the array contents approaches N times the probability function for the signal, where N is the total count of the entire array. The count at any address divided by N is equal to the probability of occurrence of the power level represented by that address. *See Fig. 2*

The measurement process must keep track of the total number of samples taken in order to scale the results properly and to estimate the statistical uncertainty, which is inversely proportional to the square root of the number of samples. A high degree of confidence is assured by a very large number of samples and a long running time. A word size of 31-bits will account for at least 2.1 billion (2.1 x 10^9) samples without overflowing any counter. Even at 500,000 samples per second, the running time will be at least 4,200 seconds or 1.17 hours before any possible overflow can occur. The measurement could be allowed to run indefinitely with a suitable decimation process, but not without loss of some information. Unfortunately, ordinary right shifting of the data results in the loss of the small counts which are typically the most important ones. As a result, the measurement is automatically stopped before any overflow occurs. Well-defined modulation processes may show convergent results after only a few million samples are collected. Running times of only a few seconds may be completely adequate for these applications.

It is convenient for analytical reasons to organize statistical data into one of several standard forms. The **Boonton** Model 4500A displays the data both numerically and graphically on a color VGA CRT. The following symbols are used throughout the formulas:

Y is a discrete random variable with a range equal to all possible sampled values of carrier power.

y is a specific power value contained in Y.

PDF. The probability distribution function of Y. The PDF is the percentage of time that the power is equal to a specific value, y. The percentage ranges from 0 to 100%, and the power extends over the entire dynamic range of the system.

PDF expressed as a percentage is:

PDF = $P(y) = 100 * P[Y=y]$ where y ranges over all values in Y, $0 \le P(y) \le 100\%$

As samples are continuously taken, the sample space is rescaled to 100%. This conforms to the requirement that all P(y) add up to 100%.

$\sum P(y) = 100\%$ where y ranges over all values in Y

The PDF is useful for analyzing the nature of modulating signals. Sustained power levels such as the flat tops of pulses or steps show up as lines. Random noise produces a gaussian shaped curve.

CDF. The cumulative distribution function of Y. The CDF is the probability that the power is less than or equal to a specific value, y. The CDF is non-decreasing in y, that is, the graph of CDF versus y cannot have negative slope. The maximum power sample taken will lie at 100%.

CDF expressed as a percentage is:

CDF = $Q(y) = 100 * P[Y \le y]$ where y ranges over all values in Y, $0 \le Q(y) \le 100\%$

$Q(y_{max}) = 100\%$, and also, just as for PDF above, $P(y) = 100\%$

CCDF. It is often more convenient to use the complementary CDF, or CCDF, or 1-CDF, sometimes called the "upper tail area". The CCDF is the probability that the power is greater than a specific power value. CCDF is non-increasing in y and the maximum power sample lies at 0%.

CCDF expressed as a percentage is:

$\text{CCDF} = 1-Q(y) = 100*P[\ Y>y\ ]$ where y ranges over all values in Y

$0 \leq 1-Q(y) \leq 100\%,\ 1-Q(y_{max}) = 0\%$

In a non-statistical peak power measurement the peak-to-average ratio is the parameter which describes the headroom required in linear amplifiers to prevent clipping or compressing the modulated carrier. The meaning of this ratio is easy to visualize in the case of simple modulation in which there is close correspondence between the modulating waveform and the carrier envelope. When this correspondence is not present, the peak-to-average ratio alone does not provide adequate information. It is necessary to know what fraction of time the power is above (or below) particular levels. For example, some digital modulation schemes produce narrow and relatively infrequent power peaks which can be compressed with minimal effect. The peak-to-average ratio alone would not reveal anything about the fractional time occurrence of the peaks, but the CDF or CCDF clearly show this information. *See Fig. 3*

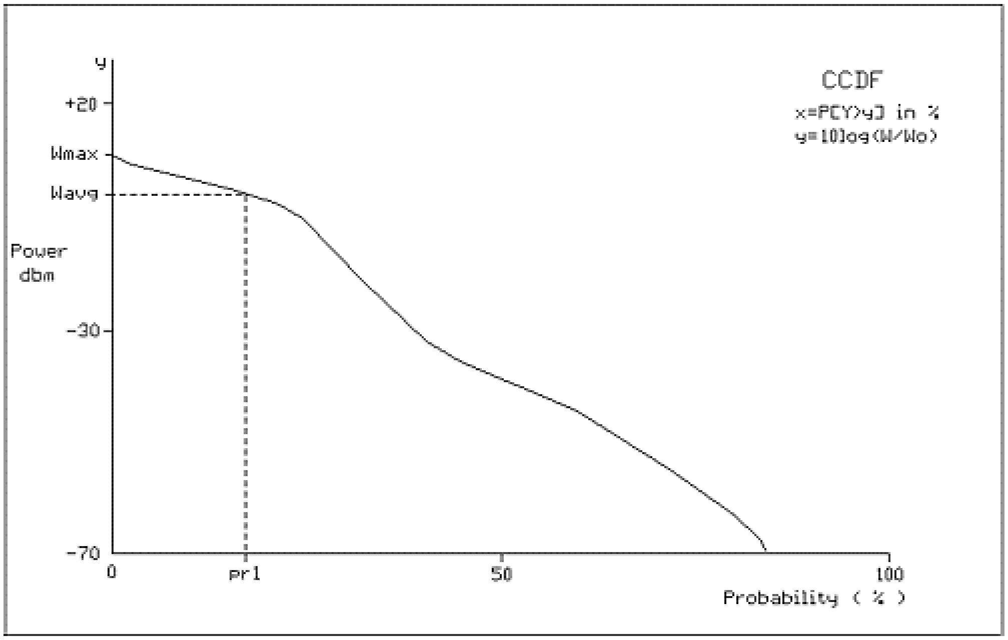

Figure 3. A CCDF with expanded time axis.

Note that the CCDF plot in Figure 3 has probability in percent on the X-axis and instantaneous envelope power in dBm on the Y-axis. The usual practice in texts on statistics is to show probability on the Y-axis. This change is made so that power always appears on the Y-axis in all instrument display modes. Keep in mind that power is the independent variable. The probability scale in Figure 3 has been expanded to better show the region around zero. Assume this plot represents a full length run of one hour plus with $2\text{x}10^9$ samples counted. On the Y-axis at probability 0% is the maximum peak power which occurred during the entire run. Or, there is zero probability that a power level higher than W_{max} occurred during the run. At probability = 1% is the power level W_{clp} which was exceeded only 1% of the time during the entire run.

Note that this analysis does not depend upon any particular test signal, nor upon synchronization with the modulating signal and there is no time base involved. In fact, the analysis can be done using actual communication system signals. Normal operation is not disturbed by the need to inject special test signals. This type of analysis is particularly suited to the situation in which the bit error rate (BER) or some other error rate measure is correlated with the percentage of time that the signal is corrupted. If known short intervals of clipping are tolerable, the CCDF can be used to determine optimum transmitter power output. The CCDF is also used to evaluate various modulation schemes to determine the demands that will be made on linear amplifiers and transmitters and the sensitivity to non-linear behavior.

The **Boonton** Model 4500A provides the CCDF as well as the CDF and PDF graphs along with power and pulse parameters for a comprehensive analysis of pulse or spread spectrum digital modulation.

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