Adjacent Channel Power Measurements and Troubleshooting

Bob Cutler

Hewlett-Packard Company
8600 Soper Hill Road
Everett, WA 98205
bobc@labrtc.lsid.hp.com

Abstract

The explosion in the number of digitally modulated carriers has generated a great deal of interest in power measurements, especially measurements relating to spectral occupancy. In this paper we will review the basic theory of spectrum measurements, including measurements on pulsed signals such as those found in TDMA systems. In particular, we will consider the implications of measurements that are both time and frequency selective. For example, we will discuss how to interpret a spectrum based measurement of adjacent channel power (ACP) given a finite, if not short, observation interval. Then, using new measurement techniques, we will identify the sources of excess ACP in two different systems: a continuous 32QAM system, and a pulsed PI/4 DQPSK system.

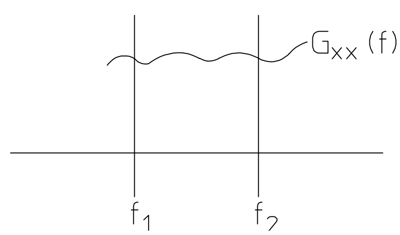
Introduction

There are almost as many ways to define adjacent channel power (ACP), as there are types of radio systems. Rather than try and describe each, this paper will take a more general approach to ACP measurements with the goal being a better understanding of how to use time-selective ACP measurements to isolate and identify transmitter problems.

The term *adjacent channel power* might lead one to believe that the goal of ACP measurements is to determine the amount of power that a transmitter puts into an adjacent (or alternate) frequency channel. The real goal is to quantify a transmitter's potential for interference. For this reason, the definition of "power" is somewhat variable from system to system. In one system, ACP might be defined as *the peak power at the output of a specified 30 kHz filter centered on the adjacent channel.* In another system ACP may have exactly the same definition except that instead of peak power, it might use the average power over some specified time interval. Both of these definitions incorporate the concept of time selectivity. In the first example, the signal is observed over a period of time and the peak power level recorded. In the second example, the measurement interval is specified exactly.

Frequency Selective Measurements

Before getting into measurements that are time selective, it's useful to review measurements that are frequency selective only. In these measurements, ACP is typically defined as the power in a channel obtained by integrating the power spectral density function $G_{xx}(f)$ over the bandwidth of the channel. As its name implies, power spectral density is a frequency domain



The PSD function Gxx(f) is defined as:

$$G_{xx}(f) = \lim_{T\to\infty} \frac{2}{T} E[X(f,T)]^2 \quad (1)$$

where:

$$X(f,T) = \int_{-\frac{T}{2}}^{\frac{T}{2}} x(t) e^{-j2\pi ft} dt \quad (2)$$

The power in the channel defined by f1,f2 is:

$$P = \int_{f1}^{f2} G_{xx}(f) df \quad (3)$$

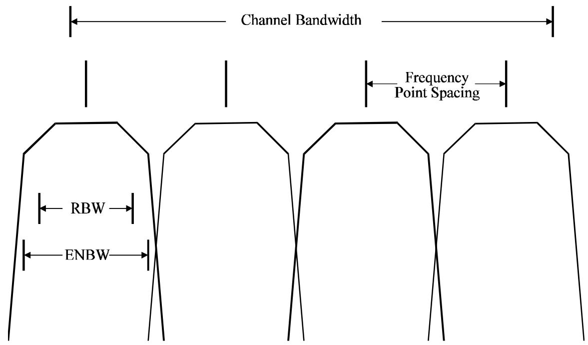


Figure 1. ***Relationship between frequency point spacing, RBW, ENBW and channel bandwidth.***

measure of a signal's power density. It's usually expressed in units of Watts/Hz or dBm/Hz.

The PSD function is defined as the Fourier transform of the autocorrelation function. In practice it's measured using narrow filters -- usually the RBW filters of a spectrum or vector signal analyzer. Figure 1 shows how these filters are used to sample the power spectrum. As the filters are usually wider than 1 Hz, the PSD must be computed by dividing the power in the filter by the filter's equivalent noise bandwidth (ENBW). For example, if the power in a 30 kHz RBW filter with an ENBW of 33.84 kHz is -20 dBm, then the PSD at the center frequency of the filter is -20 - 10log(33840) = -65.3 dBm/Hz. This calculation is based on the assumption that the PSD is constant over the bandwidth of the filter. Usually this is true. However, if a signal is periodic, or contains periodic components (as shown in figure 2), then the spectrum will contain discrete spectral lines and the assumption will be invalid.

Figure 1 illustrates several important points. First, the ENBW of a filter describes the bandwidth of a rectangular filter that has the same power response. So, unless a filter is rectangular, its RBW and its ENBW are likely to be different. Second, the frequency point spacing is independent of the filter width. In other words, the filters may be heavily overlapped, or they may not overlap at all. Third, the start and stop frequencies for the channel may not line up with the edges of the filters. When this occurs, the first and last PSD estimates can be affected by energy outside of the channel bandwidth. Obviously, this is more likely to occur with wider filters, or filters with poor shape factors.

Since the PSD is a continuous function and we've measured the function at discrete points, we must use integration techniques designed to work with sampled data, e.g. trapezoidal integration. However, if we assume that the PSD is more or less constant between samples, then we can approximate the integral and compute the total power by summing the powers at each frequency point divided by the ENBW and then multiplied by the span over which that value applies. The span over which each value applies is usually the frequency point spacing (except for the points at the upper and lower edges of the band).

Time Selective ACP Measurements

In theory, it's necessary to observe a signal over an infinite amount of time to determine its power spectral density function. Since infinitely long observation intervals aren't practical, signals are usually observed over shorter periods of time with a corresponding loss in frequency resolution. In general, shortening the observation interval does not degrade the estimate of the PSD provided the signal appears to be stationary (in a statistical sense) within the period of observation. For pulsed signals, this would imply an observation interval that includes many pulses (i.e. many frames of a TDMA signal). If the observation interval is decreased further, beyond the point where the signal no longer appears stationary within the observation interval, then the measurement is said to be time-selective.

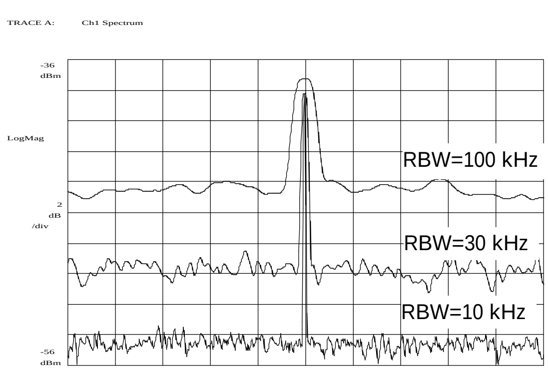


Figure 2. ***Spectrum measurements of a sine wave plus noise at three different RBW settings. The amplitude of the periodic component is constant.***

For continuous signals, that is signals that aren't pulsed, ACP measurements may provide a good indication of a transmitter's potential for causing interference even if the measurements aren't time selective. However, most receivers have finite memories. In other words, they respond to how energy is distributed in time as well as frequency. For example, if a transmitter that is interfering with a receiver on an adjacent channel is turned off, then the receiver will no longer suffer from the effects of the interference. While this is an extreme example, it does lead us to consider definitions of PSD that incorporate finite, if not short observation intervals. In fact we might conclude that the length of observation should be based, not on the characteristics of the transmitter, but on the characteristics of the receiver.

To gain further insight into time-selective measurements let's use a Fourier transform to look at several signals and their spectrums as computed over different observation intervals.

Consider an unmodulated carrier. It's spectrum contains a pair of impulse functions, one at the carrier frequency, and one at the negative of the carrier frequency (which we'll ignore). If the previously unmodulated carrier is modulated with a single pulse, then the spectrum takes the shape of a sinc function (sin(x)/x) centered at the carrier frequency (as shown in figure 3). We can easily predict this spectrum by observing that the multiplication of the sine wave by a RECT function in the time domain corresponds to the convolution of an impulse (at the carrier frequency) and a sinc function in the frequency domain.

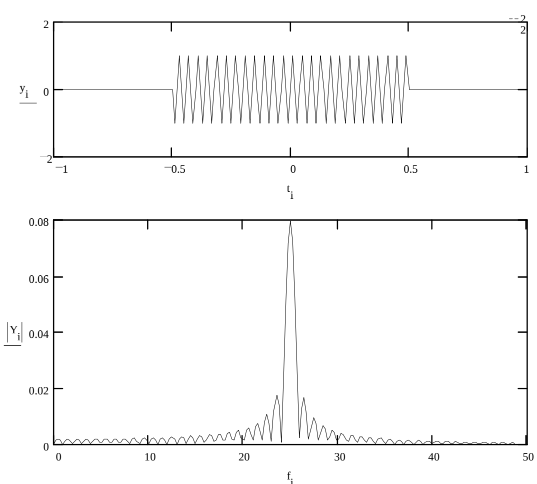


Figure 3. ***A sine wave multiplied by a RECT function has a spectrum that is a sinc function convolved with a dirac delta***

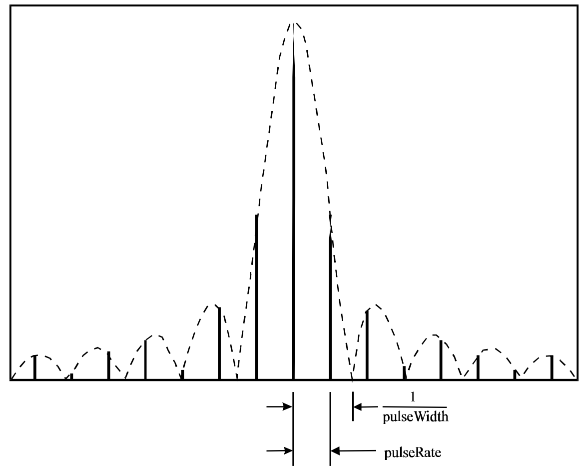


Figure 4. ***Spectrum sine wave multiplied by a train of RECT functions***

If instead of a single pulse, the carrier is modulated with a pulse train, then the spectrum will be comprised of impulse functions. The overall shape of the spectrum will remain unchanged provided the pulse width remains unchanged. The spacing of the impulses, or spectral lines, is determined by the pulse repetition rate.

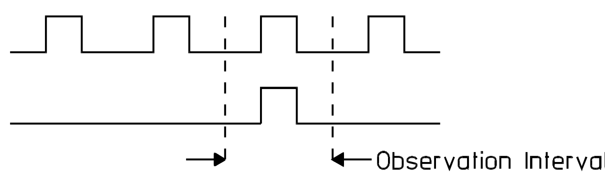


Figure 5. ***With a short observation interval, the PSD for the pulse train and single pulse can be identical.***

The single pulse and pulse train examples illustrate two important concepts. First, the single pulse example can be thought of as a time-selective measurement of the pulse train. In other words, by limiting the observation interval to a single pulse in the pulse train, we get a different spectrum than would be obtained by observing the signal over hundreds of pulses. Second, the pulse train has a spectrum with discrete spectral lines because the signal is periodic. Digitally modulated carriers normally transmit data that is random, however if the data contains a synchronization word that repeats periodically, then the spectrum will contain discrete spectral lines.

This last signal is designed to show how dramatically different the spectrum can appear when the observation interval used to compute the PSD is changed. In figure 6, the spectrum computed using the entire burst has a null at the carrier frequency. If we limit the observation interval to either the first half or the last half of the burst, we will compute a spectrum that has a shape similar to that shown in figure 3. So, for the same signal, we can make two different measurements -- one that shows energy at the carrier frequency, and one that doesn't.

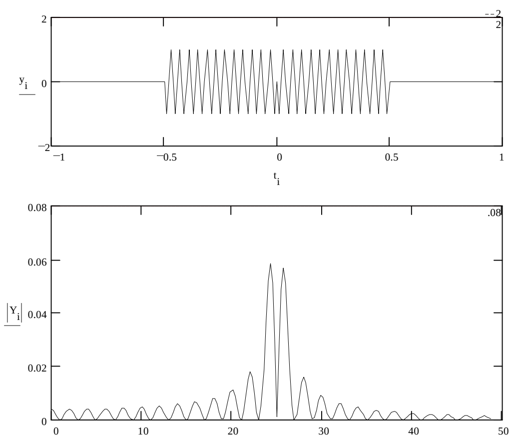


Figure 6. ***Sine wave multiplied by a RECT function that changes polarity at t=0***

Practical Time-Selective ACP Measurements

One of the most common time-selective measurements uses a technique called gating. Gated measurements provide a way of limiting the observation interval to specific portions of the time waveform. This technique can be used with both spectrum analyzers and vector signal analyzers. Figure 7 illustrates how gating is used to isolate the spectrum due to the digital modulation from the spectrum that includes the effects of both the digital modulation and the pulse modulation. In this example the on-off transitions of the pulse modulation clearly increase the amount of energy in the adjacent channels.

While this measurement suggests that the on-off transitions are a problem, it's not clear if the

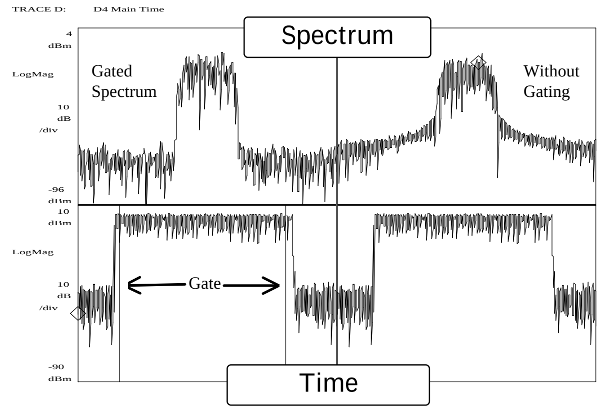


Figure 7. ***Gating is used to observe the spectrum without the effects of the on-off transitions.***

problem is with the rising edge, the falling edge, or both. This information can be easily obtained by simply changing the position of the gate, and perhaps its length, so that gate includes only one of the edges.

Not all ACP measurements are based on measuring, and then integrating, the power spectral density function. An alternative approach defines ACP in terms of the power at the output of a filter that has approximately the same bandwidth as the channel. Three of these filters are shown operating in parallel in figure 8. One filter is centered on the assigned channel and two filters are centered on the upper and lower adjacent channels. The input waveform is a pulse modulated carrier. The output of the detectors give an indication of the instantaneous power in each of their respective channels. Obviously, the results obtained are going to depend heavily on the impulse response of each filter.

Normally, a spectrum analyzer is used to make this type of ACP measurement. The analyzer is configured for zero-span operation with the RBW

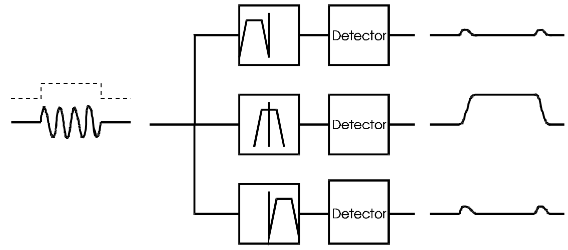


Figure 8. ***Filters and detectors are used to determine the instantaneous power in the assigned and adjacent channels.***

filter acting as the channel filter. Since the spectrum analyzer can only measure a single frequency at a time, each channel must be measured separately. For certain types of ACP problems this may be an acceptable limitation. However, there are many instances where it's desirable to observe the behavior of the assigned channel and the adjacent channels simultaneously. For example, a modulation error may cause the instantaneous power to exceed its designed limits for certain combinations of transmitted symbols. This type of problem will be transitory so it's unlikely that it will appear in both the assigned channel and adjacent channel measurements.

A vector signal analyzer (VSA) can be used to simultaneously view the outputs of hundreds or thousands of parallel filters. By adjusting the bandwidths of the filters, tradeoffs can be made between frequency resolution and time resolution. For example, better frequency resolution may show that excess ACP is due to a spurious signal that couldn't be resolved using the wider channel filter.

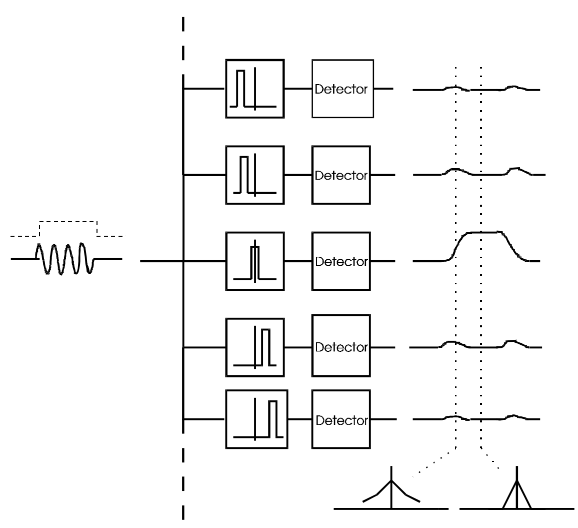


Figure 9. ***Narrower filters provide better frequency resolution at the expense of time resolution. Spectrums can be constructed from the parallel detector outputs.***

The parallel filter, demodulation and display capabilities of the HP 89400 Vector Signal Analyzer will be now used to characterize ACP problems in two digitally modulated signals.

Troubleshooting a 32 QAM Continuous Carrier Signal

Figure 10 contains two spectrum measurements which have been overlaid, one on top of the other. Band power markers have been used to compute the power between the markers for the assigned channel and the upper adjacent channel. The adjacent channel power ratio (ACPR) has been computed for both spectrums. In both cases the measurements were not time selective.

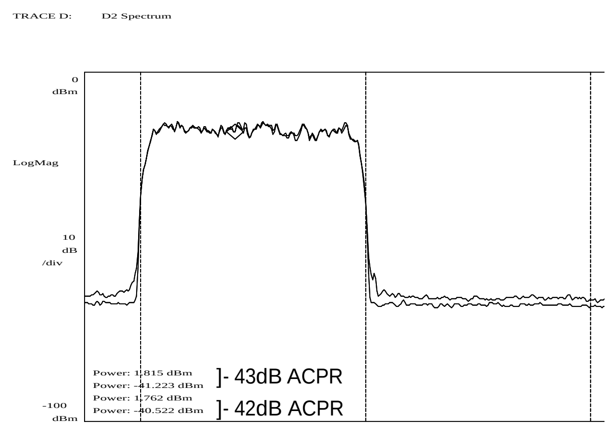


Figure 10. ***A problem introduces a 1 dB degradation in the ACPR for a 32 QAM signal. This measurement provides little insight into the nature, or seriousness of the problem.***

Without time selectivity, this ACP measurement gives little insight into the nature of problem, and may even understate the potential for interference from the impaired signal. We don't know if the problem's due to distortion in the power amplifier, improper filtering of the baseband signals, a defective component, or a coding error in the modulator software. In fact, with only 1 dB of degradation, we might conclude that there isn't a problem.

In figure 9 we showed how spectrums could be constructed from the outputs of the detectors. Although two spectrums are shown, it should be obvious that more spectrums, representing more points in time, can be easily computed. The VSA can display hundreds of spectrums on a single

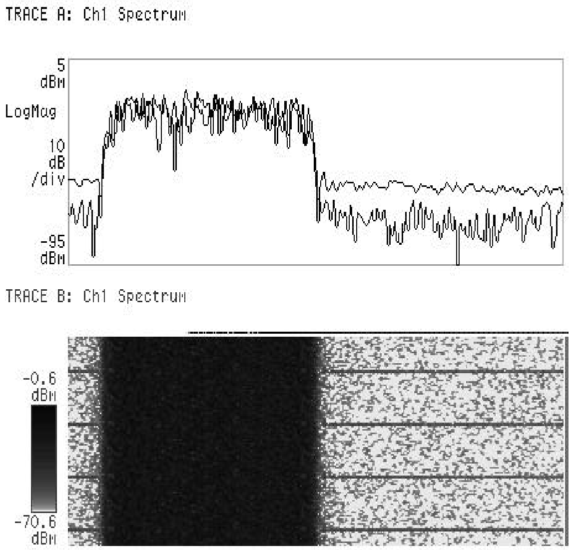


Figure 11. ***Two time selective measurements in the upper trace show a higher level of ACP than previously observed. The lower trace contains more than 100 spectrum measurements in a spectrogram. It shows that the excess ACP is periodic.***

display using a display type called a spectrogram. In a spectrogram, the amplitude of the spectrum is encoded into color or intensity so that each spectrum can be displayed in a single row of pixels. The spectrogram in the lower trace of figure 11 has an x-axis of frequency and a y-axis corresponding to time. As the legend on the left indicates, the amplitude scaling is from -0.6 dBm (dark) to -70.6 dBm (light).

Two separate time-selective measurements of the continuous 32 QAM signal, shown in the upper trace in figure 11, indicate that the excess ACP can be much worse than indicated by the measurement that wasn't time selective. The spectrogram clearly shows that the excess ACP occurs periodically. This rules out several distortion mechanisms, and problems such as improper filtering, and points to an algorithmic problem in the modulator. To isolate the problem further, the VSA's digital demodulator was used to check the quality of the modulation. The error vector magnitude (EVM), which is an indicator of overall quality looks good at 1.6%. However, the peak in the error vector plot in the lower left trace of figure 12 indicates that one symbol is slightly misplaced.

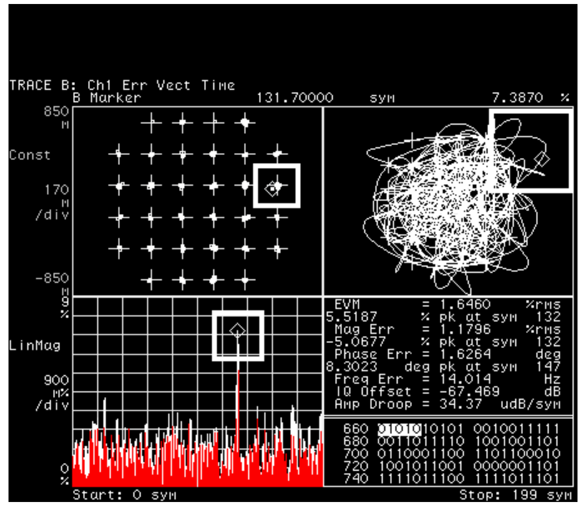


Figure 12. ***Digital demodulation of the 32 QAM signal uncovers a misplaced symbol in an otherwise clean signal.***

From the vector diagram in the upper right trace we see that the symbol with the largest error is associated with a large amplitude excursion. In fact, the error in this system caused the data going to the DAC to be improperly scaled This resulted in distortion on signals with large amplitudes. In the particular test pattern used, it happened that only one combination of symbols caused amplitudes large enough to exceed the maximum count on the DAC. The periodicity of the ACP was caused by the repetition of the binary test pattern.

Troubleshooting a Pulsed PI/4 DQPSK Signal

In the gated measurement mentioned earlier in this paper, it was determined that the pulse modulation contributed to the signal's excessive ACP. It was also mentioned that the gate could be moved, and possibly shortened, so that only the rising or the falling edge appeared within the observation interval. This would be done to determine which transitions contributed to the ACP problem.

Using the Vector Signal Analyzer it's possible to incrementally move the gate through the pulse and observe the resulting spectrums. Because the gate is moved incrementally, each observation interval is heavily overlapped with the previous observation interval. Although described differently, this is the

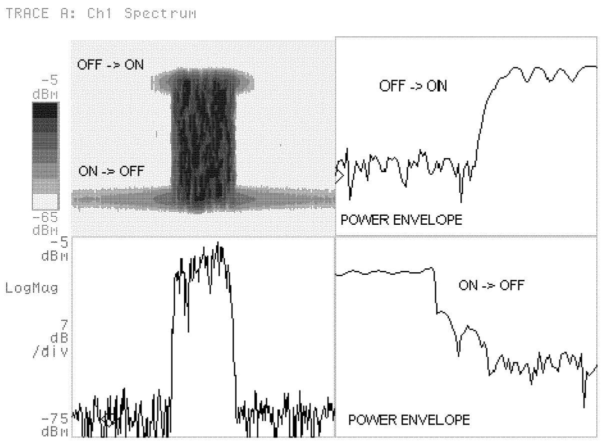


Figure 13. ***The spectrogram clearly shows how the faster ON to OFF transition affects ACP. The spectrogram and the lower left trace also show that the data modulation portion of the burst is clean.***

same *parallel filter* measurement technique that was used to evaluate the 32 QAM signal. The VSA's spectrogram capability will again be used to simultaneously view all of the results.

The measurement results shown in figure 13 clearly show what most power amp designers already know -- fast power transitions cause splatter. In this example, there was no attempt to control the on-to-off transition. The result is obvious. What may not be obvious is that the system could have had controlled transitions and still produced a spectrogram similar to the one shown. For example, a phase instability in the carrier caused by the power-on transition coupling into one of the local oscillators could have also caused excessive ACP.

Summary

There are many ways of making adjacent channel power measurements. While specific measurement techniques may be required for compliance testing, other techniques such as those presented here, can and should be used. These techniques are useful in the design lab and on the manufacturing floor. Not only do they provide better visibility into the nature of an ACP problem, but in many cases the measurements requires less time to perform.

The goal of ACP measurements is not to make a *textbook* power measurement, but rather to identify and prevent sources of interference in communication systems. For this reason, the definitions of *power* and *power spectral density* may vary from the norm. Even terms like *peak power* may not have the usual meaning.

All of the measurements in this paper were made using an HP 89440A Vector Signal Analyzer.

References

1. C. Rhodes, "Measuring Peak and Average Power of Digitally Modulated Advanced Televisions Systems", IEEE Transactions on Broadcasting, Vol. 38, No. 4, December 1992
2. "Frequency and Time Selective Power Measurements with the HP 89410A and 89440A", HP Product Note 89440A-1
3. H. Chen, "Time Selective Spectrum Analysis: A powerful tool for analyzing TDMA communication signals", Hewlett-Packard RF & Microwave Measurement Symposium, 1992
4. J. Gorin, "Make Adjacent Channel Power Measurements", Microwaves and RF, May 1992
5. "Innovations in Spectrum Analyzer Noise Measurements", Hewlett Packard, PN 5091-2316E
6. K. Johnson,"Use spectrum analyzers' selectivity to precisely measure random noise", EDN, March 2, 1992
7. B. Cutler, "Power Measurements on Digitally Modulated Signals", Hewlett-Packard Wireless Communications Symposium 1994