CHARACTERIZATION OF PEAK FACTOR EFFECTS IN HFC SYSTEMS USING PHASE CONTROLLED CARRIERS

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Abstract

Traditional methods used to characterize multi-carrier distortion products are insufficient for the needs of emerging HFC systems. Noncoherent (free-running) oscillators, which have generally been used to test CTB and CSO products, do not provide the means to characterize performance of HFC system components under various conditions of peak power factor. Since HFC systems are particularly sensitive to distortions and signal clipping resulting from intermittently high peak factors, the ability to control the peak factor of the multi-carrier test signal is crucial.

New test methodology is described that allows the characterization of system components using a multi-carrier signal with precisely controllable peak factor.

BACKGROUND

CATV transmission systems generate thousands of intermodulation distortion products as a result of the multitude of signals that impinge on amplifiers and other nonlinear system components. These distortion products are typically known as composite second order (CSO) and composite triple beat (CTB) products reflecting second and third order distortions respectively.

The level of distortion products generated when a multi-carrier signal passes through a nonlinear component is primarily a function of the power envelope of the multi-carrier signal, rather than a function of the signal's average power level. This is most easily understood by observing the power envelope of a multi-tone signal under different conditions of carrier phasing. A multi-carrier CW signal is represented as:

$$v(t) = \sum_{i=1}^{N} \cos[\, \omega(\mathrm{i}) * t + \theta(i)]$$

The power envelope of a combined 16-carrier signal is shown in figure 1(a) with all phase terms equal to zero. In figure 1(b), the phase terms are randomly distributed. In figure 1(c), the phase terms are adjusted to produce maximum destructive interference. All three waveforms have identical average power levels and would appear identical on a spectrum analyzer, but the peak power factor (peak power to average power ratio) of these waveforms ranges from 15 dB in figure 1(a) to as low as 5.6 dB in figure 1(c). It would be expected that an amplifier will generate higher distortion products when driven from the signal in figure 1(a) than when driven from the signal in figure 1(b) because the amplifier is driven to higher levels of saturation. Similarly, the amplifier will generate even lower distortion product levels when driven from the signal in figure 1(c). As will be shown, CTB products do vary considerably in amplitude in response to varying conditions of carrier phase.

Amplitude vs. time of 16-carrier signal

Fig. 1(a): Carrier phases set to zero

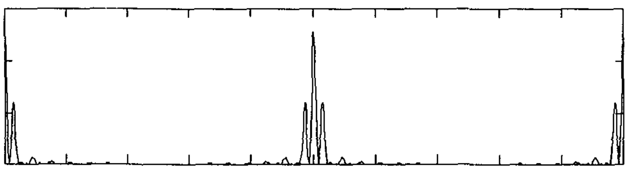
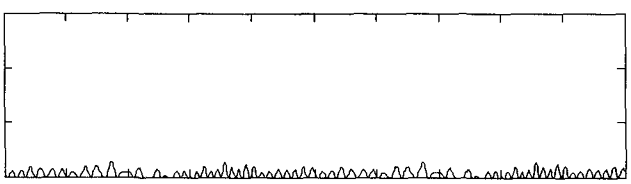


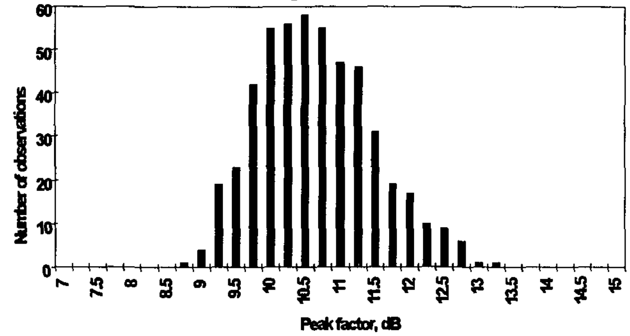
Fig. 1(b): Carrier phases randomly distributed

Fig. 1(c): Carrier phases set for minimal peak factor



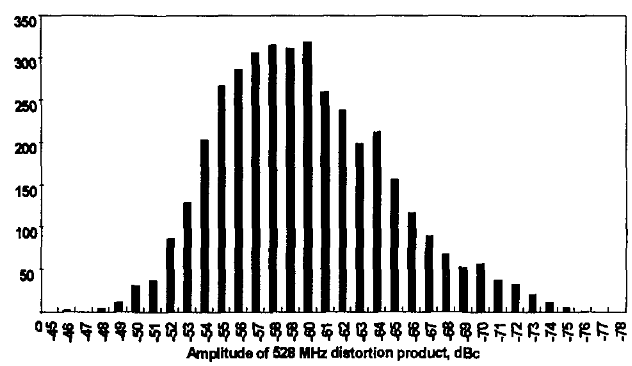
When examined over long time periods, the peak factor of a noncoherent head end varies continuously and is randomly distributed. Coherent head ends also have randomly distributed phases which drift slowly with time. Depending on the phases of the carriers, peak factor of an 83-tone signal can range from a minimum of about 3 dB up to a maximum of 22.2 dB if all carriers have zero phase.[1] The actual peak factor distribution of an 83-tone signal with random phases is shown in figure 2. Within a reasonable certainty, observed peak factors will randomly fall between 8.5 dB and 13.5 dB.

Fig. 2: Histogram of peak factor distribution, 83 carriers, random phases



CTB and CSO product amplitudes vary considerably in response to variations in the peak factor of the multi-carrier drive signal. Figure 3 shows a histogram of 3800 measurements of a 528 MHz distortion product generated when a HRC frequency spectrum was used to drive two standard broadband CATV amplifiers. The measured distortion product varied over nearly a 40 dB range.

Fig. 3: Histogram of measured distortion product at 528 MHz



This result correlates with a common observation: when distortion products resulting from a noncoherent drive signal are observed on a spectrum analyzer, the amplitudes fluctuate randomly over a considerable range. In order to make a measurement, the convention is to use a narrow video bandwidth (typically < 300 Hz) in order to resolve the "average" distortion product level.[2] This method does not therefore resolve the worst peak level that may occur in the multi-carrier drive signal.

While analog CATV systems may be merely degraded by the presence of distortion products, HFC systems employing both analog and digital transmission can be entirely corrupted by peak clipping to the point where BER thresholds are exceeded. HFC systems are more sensitive than analog systems in this respect because a "hard" failure may occur.

Proper characterization of HFC components is essential to insure adequate system performance. When measuring distortion, traditional CSO and CTB measurements do not adequately address the problem of instantaneous peak power spikes. Therefore, the multi-carrier drive signal used for distortion measurements must provide not only the full signal bandwidth, it must provide controlled level of peak power factor.

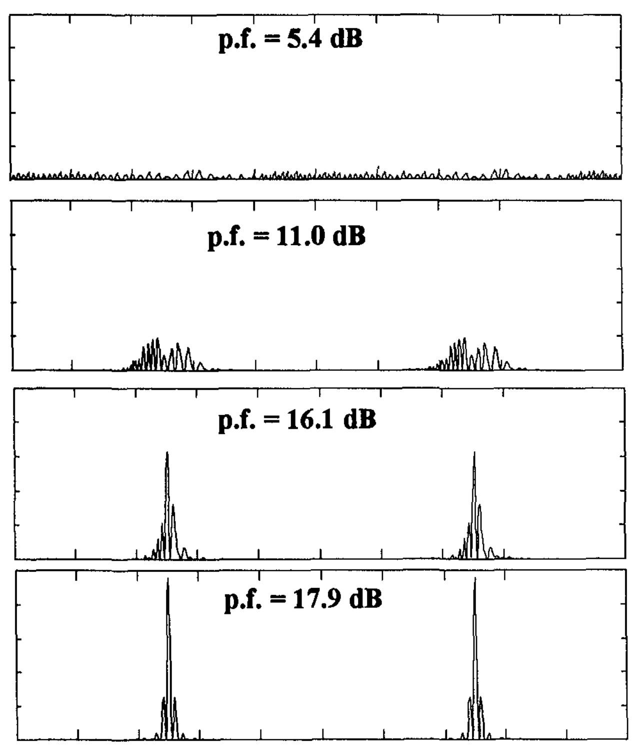
CARRIER PHASE CONTROL

A multi-carrier generator has been developed by RDL which has programmable carrier phase capability. By programming the carrier phases, peak factors can be established over a continuous range from 3 dB minimum up to the maximum theoretical peak factor of 10*log(2*N), where N is the number of carriers. Coherent (phase locked) carriers provide a stable, repeatable drive waveform which is statistically stationary over time.

The selection of carrier phases to provide a particular desired peak factor may be approached in a number of ways. There are infinitely many combinations of carrier phase which will produce a given peak factor. For example, random combinations of phase could be attempted until the desired peak factor is attained. This method is undesirable, however, because it would only produce peak factors over a limited range. Furthermore, the cumulative distribution function (cdf) of peak power level vs. time can take on many forms for a given peak factor, and the cdf of the signal also plays a role in determining the distortion spectrum.

To provide a methodical approach to controlling peak factor, RDL has developed algorithms which can be used to vary the peak factor directly, over its full theoretical range, while maintaining a relatively symmetric signal and consistent cdf. An example of the range of programmable peak factors is shown in figure 4.

Fig. 4: Examples of the range of programmable peak factors for an 83-tone signal.



The proper peak factor to be used for testing HFC components is determined by the system performance requirements. A suggested starting point would be to set the peak factor to a level near the upper tail of the peak factor distribution curve for the given number of carriers. For example, in the 83-carrier spectrum, the likely range of observed peak factors is 8.5 dB to 13.5 dB. Testing with a consistent 13.5 dB peak factor would represent the worst case condition that is likely to be observed. From that point, the peak factor can be adjusted to provide the optimal tradeoff between false rejections, improper acceptances, manufacturing yields, and required levels of system data reliability.

Another benefit of testing with controlled peak factors is measurement repeatability. Once the optimal peak factor and carrier phase combination is established, the same condition can be repeated on numerous multi-carrier signal generators so that results can be better correlated between vendor and customer.

HFC TEST METHODOLOGY

In addition to the traditional CSO and CTB measurements, dynamic operability tests are suggested for HFC components. These tests may take the form of BER testing or observation of waveforms with a high frequency sampling oscilloscope to observe signal clipping.

Dynamic measurements such as these are not practical using noncoherent carriers because there is no repeatable "trigger point" where the peak power spikes can be observed. Using coherent, phase controlled carriers insures that a specific peak power level is repeated at every waveform cycle. The waveform cycle for a CATV spectrum with 6 MHz spacing is $(6 \times 10^6)^{-1}$ or 166 nanoseconds.

Using multi-carrier signals with controlled peak factor, these tests can provide much insight into the effects of peak factor on HFC systems, and can provide more repeatable, meaningful, and accurate characterization of critical system components.

References

1. Schick, Darryl, "Source Tests Next Generation CATV Systems," *Microwaves&RF*, January 1996, Cover story.

2. National Cable Television Association, "NCTA Recommended Practices for Measurements on Cable Television Systems," Second Edition, 1983, I.B. page 4.