CROSSMODULATION - ITS SPECIFICATION AND SIGNIFICANCE

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ABSTRACT

Crossmodulation has historically been one of the basic parameters in the specification of CATV system performance, but it is now considered by many to be an insignificant factor. However, crossmodulation continues to be an issue with CATV operators and there exists some confusion in the industry as to its measurement, and hence as to the correlation of measurements. In general, there is no industry concensus regarding its significance and acceptable levels. This paper discusses its definition and measurement, and describes tests made to correlate measured distortion with observed impairment to a TV picture. The authors concluded the visibility threshold for crossmodulation interference to be approximately -31dB when measured in accordance with the NCTA definition.

INTRODUCTION

Crossmodulation is a familiar term in the CATV industry. Hybrid manufacturers and equipment suppliers specify crossmodulation performance. The Scientific-Atlanta system design group estimates that about half of its customers specify end-of-line crossmodulation performance, yet their experience indicates there is a lack of consistency in the specification and measurement of crossmodulation. More important, there is often a gross overspecification of system requirement due to lack of knowledge of the relationship between the specification and visual disturbance in a TV picture.

The first part of this paper reviews in a general way the specification and measurement of crossmodulation. The latter part discusses results of experiments to relate measured crossmodulation distortion to visibility of interference in a CATV system. A rationale is given to relate the NCTA measurement to a frequency spectrum measurement in an operating system carrying TV programming.

DEFINITION AND MEASUREMENT

Crossmodulation was originally defined by NCTA [1] as:

$$XM(dB) = 20 \log (a/b)$$

where

- a = peak-to-peak voltage of the undesired modulation envelope,
- b = peak voltage of the unmodulated video carrier.

The basic measurement procedure was also outlined in that document. Accordingly, all carriers except the channel under test are square-wave modulated at 15.75KHz and the amplitude modulation (a) impressed on the cw carrier under test is measured relative to that for a 100% modulated carrier. To achieve high sensitivity for this measurement and discrimination against composite triple beat (CTB) and other noise, crossmodulation is generally measured using a spectrum analyzer or field strength meter to linearly detect the envelope and a selective level meter tuned to 15.75KHz to measure the crossmodulation component. This procedure is still the one in use by hybrid amplifier manufacturers for specifying their devices and by Scientific Atlanta and, to our knowledge, other manufacturers for specifying equipment performance.

The NCTA method measures AM crossmodulation (amplitude modulation of the desired carrier) in agreement with the NCTA definition. However, crossmodulation can also exist as phase crossmodulation due to amplifier phase shifts and non-linearities. Also, at higher frequencies non-linear transistor junction capacities become significant contributors [2]. The development of hybrid amplifiers for 450-550MHz employed a new generation of transistor die that resulted in improved CTB and noise figure performance, but also resulted in less AM-to-PM conversion of crossmod at higher frequencies; the NCTA crossmod specification became worse than for its predecessors. To allay fears of the higher crossmod specification, tests were conducted at Scientific Atlanta with TRW engineers in 1982 with the 5000 series transistor-die hybrids [3]. It was demonstrated that in an HRC phase-locked system and at the lower channels where CTB is a minimum, performance seemed to be limited by CTB, not crossmod. Crossmodulation on channel 2 measured -32dB by the NCTA procedure; the composite triple beat plus second order beat (measured not phase locked) was -42dB, yet when crossmod was eliminated by the by-pass test [4], the visual distortion appeared about the same. This is not too different from results of the test described later.

Crossmodulation is also measured in the frequency domain by measuring the sideband level of the line-frequency (15.75KHz) sidebands. For 100% square-wave modulation the first order sidebands are 10dB below peak (unmodulated) carrier level. Thus, 10dB is added to the first sidebands to obtain the equivalent NCTA measurement. If crossmod exists as both AM and PM, upper and lower sideband levels will be different. In this case, 10dB is added to the average power of the two sidebands (relative to unmodulated carrier power) to obtain total crossmodulation ratio. The AM component can be measured as before; AM and PM crossmod are added on a power basis to obtain total crossmod.

An advantage of the spectrum analysis method is that it can be employed to examine crossmodulation on an operating CATV system (if the carrier for the channel under test can be temporarily unmodulated). Another possible advantage of this method is that in an HRC phase-locked system it will show sidebands (which in effect are the same as crossmod sidebands) due to modulation of carrier beats. The carrier for the channel under test may be turned off for this test eliminating crossmodulation as the source of unwanted sidebands. Crossmodulation by the sideband method is outlined in the Hewlett-Packard "Cable Television Systems Measurement Handbook" [5]. This is also basically the procedure established by Canadian Broadcast Procedure 23 for evaluation and proof of performance of CATV systems [6]. Naturally, results of these measurements will be quite different from those made by the NCTA procedure since it is based on 100% square-wave modulation of all carriers. The next section discusses how these two measurements relate to each other and to visible distortion in a TV picture.

CROSSMODULATION INTERFERENCE TEST

The relationship of crossmodulation distortion and its effects on a TV picture in a high-capacity CATV system are difficult to quantify partly because of the difficulty in isolating crossmodulation from CTB and other distortions. Experiments for this have been devised, however, and the results of one are reported in this section. Figure 1 shows the set-up used to measure the level of crossmodulation for subjective levels of interference to TV pictures or test patterns. In this experiment 28 independent video sources, (including three scrambled channels) modulated a HRC phase-locked headend system. The

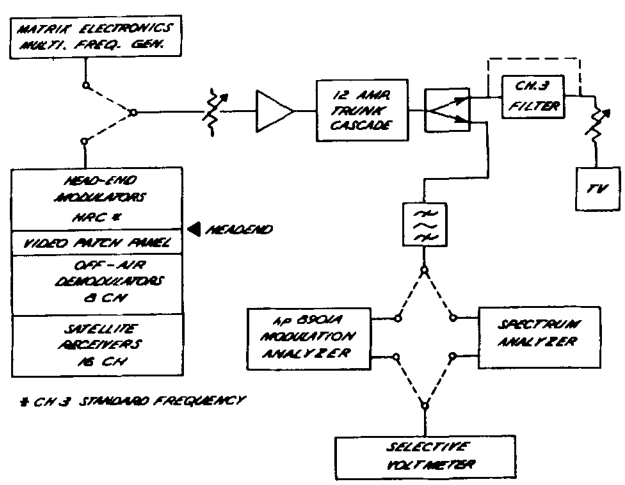

Figure 1. Crossmodulation Test Set-Up

system was loaded to 33Ø MHz; there were 42 channels in all, 14 of which were duplicated. The headend output was connected to a cascade of 12 55ØMHz push-pull hybrid trunk amplifiers. The output of the cascade was viewed on a Mitsubishi TV receiver and the corresponding levels of distortion were measured.

The procedure used to observe crossmodulation without the destructive effects of CTB was to offset the channel being observed, channel 3, to the standard frequency and then to turn off the channel above it. Since for HRC all carrier beats including second-order beats are at multiples of 6 MHz, these beats are at the band edges of channel 3 and thus do not interfere significantly with the signal being observed. At system levels high enough to produce visible crossmodulation, beats between sound carriers and picture carriers became quite significant; therefore all sound carriers were turned off. The spectrum within the video bandwidth was relatively clean. There were some spurious signals, probably due to luminance - chrominance carrier beats, but those were more than 6ØdB below the video carrier. The TV picture was clean except when levels were elevated further to produce high distortion in the picture.

In this experiment TV programs and test patterns were observed and the operating level that produced barely perceptible crossmodulation was determined. Crossmodulation was most noticeable on a flat field approximately 7.5-2Ø IRE, so data was taken for that condition. Results are summarized below:

SYSTEM PERFORMANCE FOR BARELY PERCEPTIBLE CROSSMODULATION. 42 CHANNEL LOADING

SIGNAL LEVEL (dBmv)	CTB (dB)	CROSSMOD (dB)		
		AM	PM	TOTAL
49.5	-39	-31	-4Ø.5	-3Ø.5

Data was measured by driving the cascade from a Matrix multi-carrier generator (standard frequency plan). Crossmodulation was measured with a Hewlett-Packard 89Ø1A Modulation Analyzer calibrated for agreement with the NCTA definition. Crossmodulation was also measured by measuring the 15KHz sideband levels and by using a spectrum analyzer and wave analyzer to measure the AM component as in the NCTA procedure. Results agreed within 1 or 2dB.

Figure 2 is the spectrum that resulted when all channels were 1ØØ% synchronously modulated as in the NCTA procedure; Figure 3 is for the system loaded with TV channels. With video modulation the sidebands varied around -65dB with large fluctuations due to the random nature of the video signals. Figure 3 was recorded with the spectrum analyzer operating in the peak hold mode for 1 minute to capture transients peaks. Recordings made this way were more consistant and easier to compare.

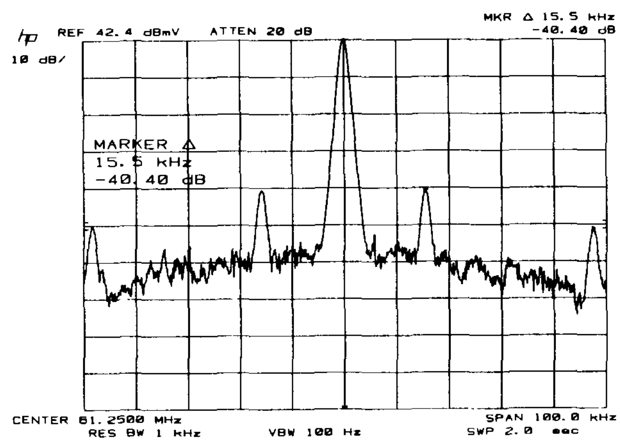

Figure 2. Crossmodulation Spectrum, Square Wave Modulation

As noted, there was a large difference in sideband levels between synchronous square-wave modulation and video modulation - a reduction from -4Ø dB to an average of approximately -65 dB or a peak of about -58 dB. This large reduction is caused by (1) a single TV channel interferes less than if it were 1ØØ% square-wave modulated at or near the line frequency, and (2) TV signals are generally uncorrelated, and uncorrelated signals add on a power

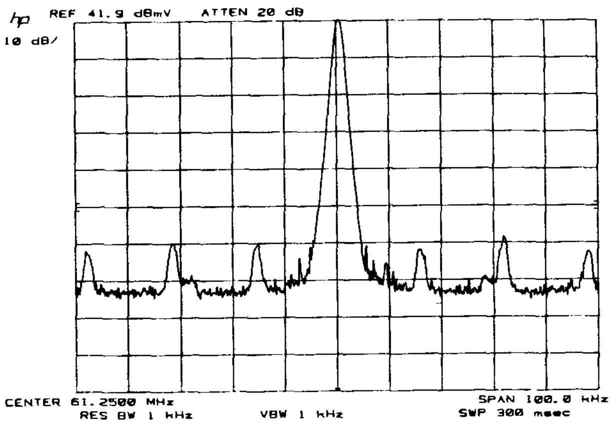

Figure 3. Crossmodulation Spectrum, Video Modulation

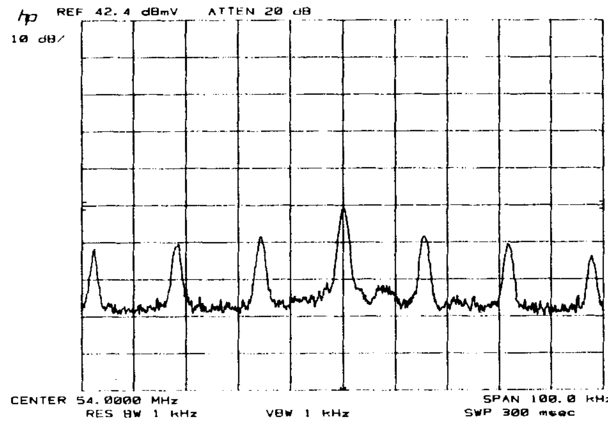

Figure 4. Beat Modulation Spectrum, HRC Phase Locked

basis, whereas for synchronous modulation the crossmodulation components add on a voltage basis. If we assume for simplicity that all carriers are equal amplitude and amplifier distortion is third-order and independent of frequency, synchronous crossmodulation will be proportional to the number of channels. For random TV modulation, crossmodulation will be proportional to the square root of the number of channels. Thus, the difference is proportional to $\sqrt{N}$ (N is the number of interfering channels), which in our case is 42, or 16 dB. This $\sqrt{N}$ relationship was born out in earlier experiments in which crossmodulation was simulated and its effect measured for 1-24 independent program sources. (A review of Figure 3B of [7] shows the departure from $\sqrt{N}$ to be less than about 2dB for 2-24 channels).

In order to correlate results obtained using square wave modulation of a carrier with results obtained with interfering video carriers, it was necessary to correlate the power at the major spectral points of the square wave modulated signal with the corresponding energy in the modulated video signal. Since interference is determined by the square of the amplitude of the interfering carrier, an experiment was devised to compare a squared (baseband) video signal with a squared baseband square wave. In the experiment baseband video and baseband square waves were squared using a four-quadrant multiplier IC and the energy in a 1 KHz bandwidth at line frequency was measured. It was found that the average level of the video signal so processed was 1ØdB below the corresponding level using a square wave. Thus, this factor (1ØdB) plus the 16dB reduction for N form an explanation, although certainly not a rigorous one, for the large difference in sideband level that was experienced with video modulation.

Fig. 4 shows the spectral interference at channel 2 with the carrier off. All other channels are TV modulated (HRC phase locked) and operating levels are the same as before. Non-linear distortion creates carrier beats (CTB, composite second order beats, harmonics, etc.) and these are phasor summed at carrier frequencies with each beat modulated by carriers that produced it. The composite beat has a carrier coherent with the desired video carrier and modulation of the beats produce 15.75 KHz line-frequency sidebands. The result appears the same as crossmodulation except that in this case the sidebands are present without the carrier for the channel under test, and by definition these can not be due to crossmodulation. These sidebands are evident in Figure 4. In Figure 4 as in Figure 3 the recording was made with the spectrum analyzer operating in the peak hold mode for 1 minute. The sidebands are very nearly the same in both cases, suggesting the expected interference would be the same. Actually, there was noticeably a slight difference; interference to channel 2 (beat modulation) was a little more pronounced than the interference observed in channel 3 (crossmodulation)*. Thus, even at the lowest channel where CTB is lowest, beat modulation produces more interference than crossmodulation; CTB will dominate even more at higher channels.

The sideband level reported here we believe to be essentially in agreement with that reported by Paul K Wong [8] and Canadian Broadcast Procedure 23, Issue 2 (BP 23) [6]. Mr. Wong states that crossmodulation will be just visible to most people when the ratio of the first-order sidebands of the interference to the unmodulated carrier is greater than -58dB, and that other established results using defined viewing conditions and a large variety of observers indicated that the threshold can be 3dB worse, i.e. -61dB. BP 23 specifies that qualification of crossmod specifications be conducted by measuring sideband levels at the subscriber terminal. Visibility threshold is given as 58dB below peak video.

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* Because of the random phase of the video carriers, the resulting beat modulation should be equally distributed between AM and PM, and the subjective interference will be less by nearly 3dB than that for AM crossmodulation only. In [7] we concluded phase crossmodulation was less damaging to a TV picture by approximately 9dB.

CONCLUSION

Based on the tests described in this paper it was found that the visibility threshold for crossmodulation is at or near -31dB as measured in accordance with the original NCTA definition. With other system operating environments, viewing conditions, and subjects, results will vary. For CATV system design it may be prudent to allow some margin in specifying crossmodulation distortion, but findings herein indicate that in current useage crossmodulation is considerably over specified.

REFERENCES

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