CHARACTERISTICS AND PERCEPTIBILITY OF CROSS MODULATION

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ABSTRACT

Results of a study to determine the measure and perceptibility of cross-modulation distortion in a CATV system are presented. Subjective tests evaluate the interference to a television picture or test pattern caused by one to 24 independent video-modulated carriers. Design of the test system enabled cross modulation to be measured and observed without being obscured by triple-beat distortions. Although cross modulation is not a predominant factor, it is of more concern in a phase-locked system because of suppression of triple-beat distortion.

Cross modulation can result in both AM and PM components. In distribution amplifiers, the PM component may be the larger of the two, particularly at the higher cha ıel frequencies, although generally only the AM component is measured. In these tests, the AM and PM distortion components are measured separately and the relative importance of each is shown.

INTRODUCTION

Cross modulation (crossmod) is a type of distortion that was particularly noticable in earlier CATV systems. It is characterized by the "windshield wiper" effect or interference appearing as frames or images slipping in the TV picture. As advances were made in amplifier performance and the number of channels increased from 12 to 62 or more at present, triple-beat distortion increased in relative importance. For cross modulation the distortion is closely proportional to the number of channels, whereas for triple-beat distortion, the effect increases rapidly as the number of channels increases. For wide-band systems, triple-beat distortion is the major contributor to the total distortion.

To extend the performance of newer wide-band systems phase locking came into being. This technique reduces triple-beat interference and enables system operating levels to be increased 4 - 5dB. Thus, with phase locking the relative importance of cross modulation is increased.

This paper presents results of experiments made to measure the amount of cross modulation that is just perceptable in a TV picture. Relatively little data has been found on the subjective measurement of cross modulation, partly because of the difficulty in separating other distortions from cross modulation and observing only cross modulation. The experiment described herein generates cross modulation by direct video modulation instead of by distortion in a cascade of amplifiers. This enables cross modulation to be controlled and observed without other impairments.

The following sections review the basic characteristics and measurement of cross modulation. The experiment is described and results are presented.

CROSS-MODULATION ANALYSIS

Amplifier distortion has been treated extensively in the literature, and distortion effects in CATV amplifiers are well understood. However, to aid in the discussions that follow a few of the basic equations and definitions are given in the following paragraphs. This simplistic treatment is presented to show the characteristics of cross modulation and distinguish it from other distortions, particularly those in which modulation sidebands occur because of modulation of carrier "beats".

If the amplifier nonlinearity is expressed by the first three terms in a power series [1], then

$$e_{out} = k_1 e_{in} + k_2 e_{in}^2 + k_3 e_{in}^3. \quad (1)$$

The coefficients k_1, k_2, and k_3 are the linear gain and second- and third-order distortion coefficients, and are real constants if we assume no phase or frequency-dependent distortion*. The input voltage is first assumed to consist of three sinusoidal voltages or carriers

$$e_{in} = A\cos W_a t + B\cos W_b t + C\cos W_c t. \quad (2)$$

The distortion produced at carrier frequency Wa is obtained by expanding (1) and collecting all terms containing Wa. Thus

$$e_{(W_a)} = (k_1 + 3/4\ k_3\ A^2)A\ \cos W_a t + 3/2\ k_3\ (B^2 + C^2)A\ \cos W_a t. \quad (3)$$

The first term contains a distortion term $3/4\ k_3 A^2$ which represents self-compression or self-expansion (depending on the sign of k_3). This term is identically the same whether or not other signals are present and can be neglected since certainly the system must amplify a single channel faithfully. The term $3/2\ k_3(B^2 + C^2)A\cos W_a t$ is the cross modulation component. This shows that for CW carriers the carrier at W_a is compressed or expanded by carriers at W_b and W_c regardless of their frequency. Thus, cross modulation is inherently different in origin from distortion caused by "beats" or mixing of carriers.

Only the linear and cross modulation terms are given in (3). A complete third-order expansion would give the following terms: (1) a dc term, (2) a linear term (desired component), (3) cross modulation terms, and (4) harmonics and "beat-frequency" terms (sum and difference frequencies including $2W_a \pm W_b$, $W_a \pm W_b \pm W_c$, etc.). This latter group is the major cause of distortion or interference to the TV picture. Carrier systems that are not phase locked are limited by carrier beats, primarily composite triple beat, at higher operating levels. In phase-locked HRC systems all video-carrier beats are coherent with the picture carriers, and in this case interference is caused by the modulation present on each beat. This effect may be called "beat modulation", and is different in origin but similar in appearance to cross modulation.

*A more rigorous treatment is obtained by a Volterra series expansion [2]. With the power series expansion it is assumed that the output signal depends only on the input signal at the same instant of time. The volterra series expansion treats the case of frequency-dependent nonlinear characteristics. Similar results are obtained for cross modulation except for changes in magnitude and phase of the distortion components.

The above equations are given for CW (unmodulated) carriers, but also apply for modulated carriers. The carrier amplitudes A, B, and C can be video-modulated amplitudes $A(t)$, $B(t)$, and $C(t)$. Rewriting equation (3), cross modulation distortion is

$$XMOD = 3/2\ k_3(B^2_{(t)} + C^2_{(t)})A_{(t)}\cos W_a t \quad (4)$$

Since cross modulation is porportional to the amplitude of the interfered carrier $A(t)$ cross modulation will be larger in the darker areas of the TV picture. Note also that crossmod is proportional to the amplitude squared $(B^2(t)$ or $C^2(t))$ of the interfering signals.

The above discussion relates to amplitude cross modulation (amplitude modulation of the desired carrier). Cross modulation can also appear as phase cross modulation. Due to amplifier phase shifts and nonlinearities, amplitude modulation is converted to phase cross modulation. In addition, at higher frequencies the nonlinear transistor junction capacities become significant contributors to phase crossmod [3]. The presence of both amplitude and phase cross modulation has caused some confusion in the measurement, specification, and subjective effects of cross modulation [4].

Phase modulation of the TV signal becomes visible since phase crossmod results in frequency modulation, and FM is slope detected by the Nyquist filter in the TV receiver [4]. Since the instantaneous frequency is proportional to the derivative of phase, light-dark and dark-light transistions in interferring TV pictures (particularly leading and trailing edges of sync bars) produce large frequency deviations and will be seen as lines of interference. Components above the Nyquist slope (more than 600 KHz above the picture carrier) are detected equally whether phase or amplitude modulated.

CROSS-MODULATION MEASUREMENT

Cross modulation can be measured by different techniques and under various conditions. Equipment manufacturers and system designers measure and specify cross modulation by the familar "NCTA method". NCTA Standard 002-0267 "CATV Amplifier Distortion Characteristics" [5] defines and specifies this measurement. In this procedure all carriers except the one in question are square-wave modulated at the horizontal line rate. The level of modulation impressed on the observed carrier is then measured, usually by tuning a spectrum analyzer to the carrier, turning the IF sweep off, and measuring the linearly-detected envelope with a waveform analyzer tuned to 15.75KHz.

Cross modulation is also measured by measuring sideband levels with a spectrum analyzer [6]. This technique is useful for observing interference, but results will correlate with the NCTA measurement for only amplitude modulation and if beats do not obscure the 15KHz cross modulation sidebands. Since for 100% square-wave modulation the first sidebands are 10dB below the peak level, the NCTA measurement is 10dB greater than the 15KHz sideband level. Note however, readings can be effected by second- and third-order carrier beats. For example, if the carrier being observed is turned off, a cluster of beats (if the carriers are not phase locked) will be seen centered at the carrier frequency. If all carriers are modulated, clusters of sidebands due to modulation of individual beats will also be observed. These beats add noise to the carrier being measured (the carrier is not modulated by the beats), but the noise is rejected by narrow-band filtering if a wave analyzer or synchnouous demodulator is used in the NCTA procedure.

TEST SYSTEM

The subjective measurement of cross modulation perceptibility is difficult because of the presence of other distortions. A method of observing picture degradation in the presence of composite-triple-beat noise and with or without cross modulation has been reported [7]. This method allows crossmod to be eliminated from the observed distortion, and thus one can ascertain whether crossmod is a significant contributor to the total distortion in a particular system. However, crossmod cannot be observed with complete freedom from other distortions since they are generated by the same amplifier nonlinearities. Therefore, a method of simulating crossmod was devised and implemented. Furthermore, with this method cross modulation can be generated by either AM or PM (or some of each). The procedure is simply to add some interfering modulation to a normal video-modulated carrier and observe the result in the TV picture. Independent video sources are used to create the interference and the measurement is then related to crossmod as measured by the NCTA procedure. Note that for the simulation to be an accurate representation, equation (4) requires that the distortion be porportional to (1) the amplitude of the interfered carrier $A(_t)$, and (2) the amplitude squared of each interferring video source ($B^2(_t)$, etc.). The method for accomplishing this is illustrated in Figures 1 and 2.

The video picture or test pattern to be observed is connected to the video IF modulator of a Scientific-Atlanta 6350 Television Modulator. The video interfering signals are coupled to individual circuits which dc restore and square each signal. The outputs of the squaring circuits are then summed and ac coupled to the modulation input of an IC modulator. The RF input to the modulator is a sample of the video-modulated IF. The output of the modulator is the form

$$A(_t)\ [B^2(_t) + C^2(_t) + \ldots N^2(_t)]\cos W_{if}t,$$

which is the proper representation for cross - modulation distortion produced by N channels. This signal is attenuated, phase shifted by the line stretcher, and combined with the video-modulated signal to be observed. The line stretcher is used to adjust the phase of the cross modulation relative to the undistorted IF so as to produce AM or PM cross modulation. For amplitude crossmod, the relative phase is 180° in order to produce signal compression.

The IF modulated signal is then processed by the vestigal sideband filter and upconverted to channel 4. The composite signal is then viewed on a TV receiver. The amount of cross modulation is attenuated and the measured cross modulation is correlated with observer reactions.

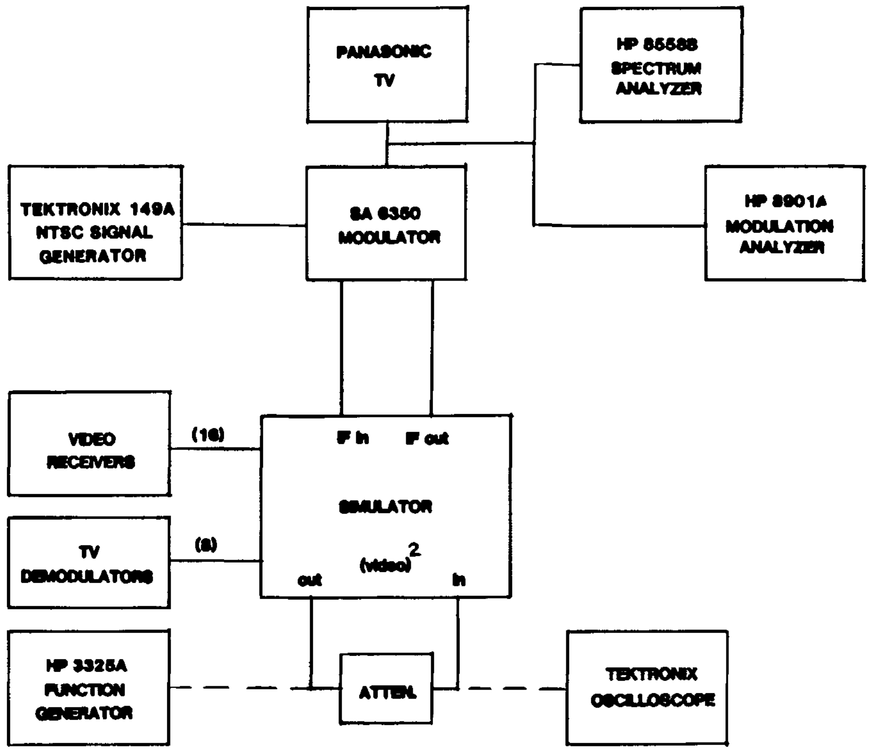

Figure 1. Cross-Modulation Test Set-Up

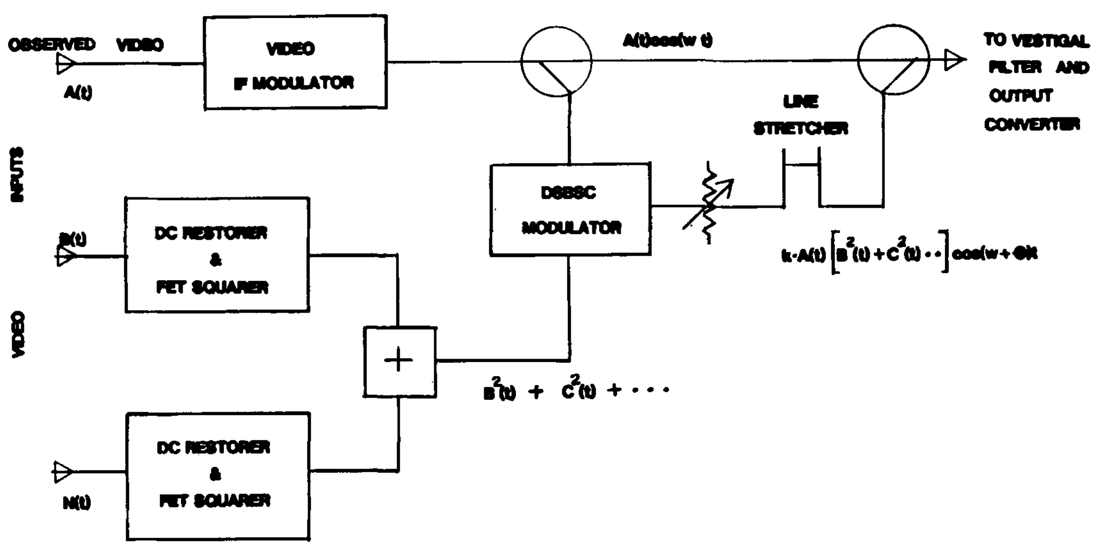

Figure 2. Cross-Modulation Simulator

TEST RESULTS

Cross modulation was measured for interference against a test pattern background. Observations were made when using TV programming material, but the large variations and movements in actual scenes made it difficult to determine the threshold for cross modulation visibility. Since cross modulation is most noticeable in a dark background, a gray flat field of 7.5 - 10 IRE was used in this experiment. The TV receiver was a Panasonic CT9051, and was viewed in dim lighting. The picture was clean - the carrier-to-noise ratio was greater than 55dB. These conditions lead to a measurement much more sensitive than would be obtained - if one could do so - under actual field conditions with live scenes and inherent noise and distortions.

Data is presented as a function of the number of video sources: 1, 2, 4, 6, 12, 18, and 24. These were independent sources; eight from local broadcast stations and sixteen from satellite receivers. For each measurement, the flat field was first viewed with strong interference, and then the cross modulation was reduced until it was barely visible. The measurements thus obtained were related to the NCTA measurement by substituting a 1V peak-to-peak 15.75 KHz square wave for each video source and measuring sideband levels on a spectrum analyzer. Adding 10dB to the 15KHz sideband levels gives the NCTA measurement.

The same procedure was used for both amplitude and phase cross modulation. Although the NCTA method is specifically for AM, it is meaningful to express phase cross modulation in the same terms by converting the measured PM to the equivalent AM. (For pure AM or low mod. index PM, as is the case here, one cannot distinguish between the two from a spectrum analyzer display). Thus, for phase cross modulation, the 15KHz sidebands were determined and 10dB added to give the equivalent NCTA number.

Results of the experiment are shown in Figure 3. For a single interfering channel the data averaged -50dB for AM and -43dB for PM. Cross modulation from a window test pattern averaged -51dB for AM and -44.5dB for PM. For 15.734KHz square-wave interference (equivalent to 100% modulation) the threshold was -59dB for AM and -52dB for PM. Thus, 100% square-wave modulation was more discernable by 7 - 8dB.

As the number of video sources increased the difference in amplitude between square-wave sources and the composite of the video waveforms increased. For a large number of video sources, the signals combine in a somewhat random manner resulting in substantially lower peak energy than for synchronous modulation. For 24 video sources, the measured cross modulation threshold averaged -35dB for AM and -26dB for PM. The difference between 100% synchronous square-wave modulation and video modulation is 24dB in AM cross modulation perceptibility.

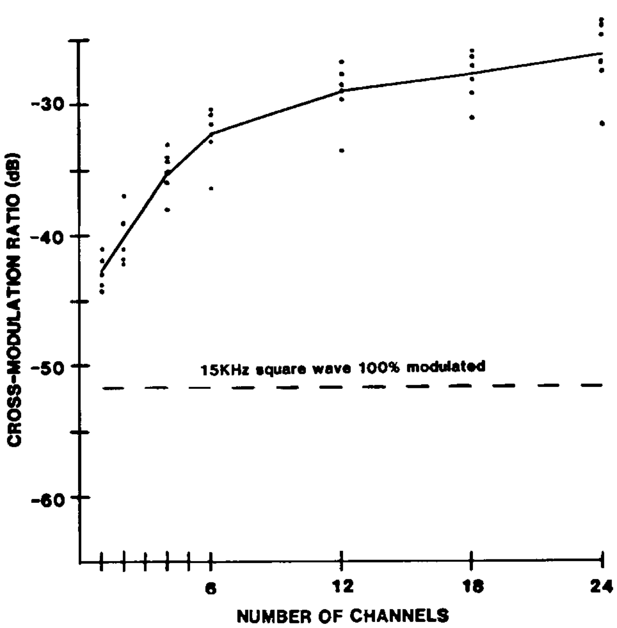

Figure 3A. Phase Modulation

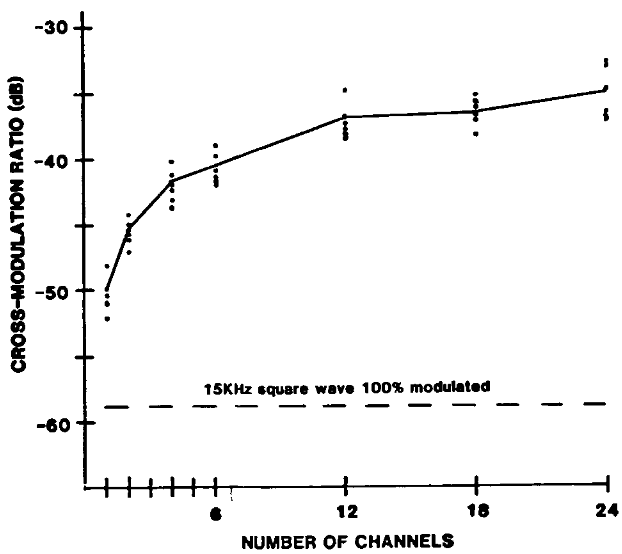

Figure 3B. Amplitude Modulation

Figure 3. Threshold of Cross-Modulation Visibility

The threshold level of cross modulation derived in this experiment is high compared to standards in general use in the CATV industry. From the trend of the data in Figure 3 we would expect a present-day channel loading of 52-62 channels to have a visibility threshold of about -32 to -34dB in a picture free of noise and other distortion. It is generally agreed that triple-beat distortion is just perceptible for a CTB ratio of -46 to -48dB* in systems not phase locked. For HRC phase-locked systems operating levels can be increased 4 - 5dB, resulting in a CTB threshold of approximately -38dB [9]. Thus, a cross modulation threshold of -33dB is 5dB higher than the CTB threshold. Amplifier cross modulation ratios are usually within a few dB of each other at their worst channels. For example, for the TRW CA5000 hybrid operating at 46dBmV, 6dB tilt, and 52 channel loading, the CTB is -67.6dB at 400 MHz and cross modulation (predominately AM) is -68.6dB at 54 MHz; CTB is higher by 1dB [10]. Since these are both third-order distortions the same difference should exist at higher operating levels: if the CTB ratio is increased to -38dB, cross modulation should be -39dB. From these numbers we conclude that triple-beat distortion in a phase-locked system is 6dB higher than cross modulation distortion.

The fact that triple-beat distortion is the predominant factor in phase-locked systems as well has been demonstrated and reported elsewhere [7]. We also reached the same conclusion in a similar experiment and also in other different tests. The objective of this paper was to quantify the measurement of AM and PM cross modulation distortion so its relative importance could be evaluated and compared by others and in other situations.

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*This is the ratio that is measured if video-modulated carriers that produce just visible distortion are replaced with CW carriers at the same peak level, and the CTB ratio measured by the NCTA method [8]. For CW beats the ratio usually quoted varies from -51 to -57dB.

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