CROSS-MODULATION IN HRC SYSTEMS

G. G. LUETTGENAU

TRW SEMICONDUCTORS
14520 Aviation Boulevard
Lawndale, California 90260

Abstract

The nature and origin of AM and PM cross-modulation is discussed. A typical cascode amplifier is examined.

A 400 MHz CATV Hybrid is thoroughly characterized with respect to various forms of third-order distortion. It is shown that phase cross-modulation is a major factor at high frequencies.

Because of the pseudo-single-side-band nature of TV transmission, PM distortion becomes visible. Predictions for the shape and magnitude of visual manifestations are made. A practical experiment is described.

Cross-modulation in 52 channel HRC systems is investigated using a computer model. Significant improvements are predicted.

Cross-modulation in CATV Amplifiers

Historically, cross-modulation is the oldest form of third-order distortion recognized in CATV Systems. The concept was taken from the AM radio field, and was redefined by the NCTA. It causes the typical wind-shield wiper effect, which is easily recognizeable.

As the channel loading increased over the years, another form of third-order distortion became apparent. Soon the horizontal streaks of the composite triple-beat phenomenon dominated.

This led to a situation, where the main linearity criterion was CTB, with good cross-mod performance being taken for granted. Indeed, the cross-modulation of typical amplifiers is much lower than the theoretical predictions made in the early literature(1). This welcome characteristic was described and explained by Meyer et al (2). It is, in principle,due to the fact that phase-shifts in feedback amplifiers tend to convert amplitude cross-modulation to phase cross-modulation. Since X-mod is, by NCTA definition, measured with an AM detecting instrument, substantial improvements were often registered. It is possible for all AM X-mod to vanish, provided the open-loop gain of the amplifier is large and there is a 90^{o} phase difference between the open-loop gain and trasmission angle of the feedback network. In CATV amplifiers, as a first approximation, the transistor gain has an appreciable lagging angle (at high frequencies), whereas the feedback network is essentially resistive and does not turn the phase.

It has been suggested that broadband AM to PM conversion can be achieved by proper circuit design (3). In practice circuit considerations for gain flatness and good match may limit the freedom of the designer.

The Sources of X-Mod

Nearly all CATV amplifiers presently in use employ the push-pull cascode configuration. The push-pull feature has no influence on third-order behavior. The cascode arrangement, a common-emitter stage driving a common-base stage, contains two main sources of cross-modulation.

The base-emitter junction of the C-E stage is the major origin of AM X-mod. The amount of distortion is a function of resistor values in the base and emitter legs, the beta of the transistor, and the emitter current. F_t or other high frequency parameters do not enter significantly. This results in the fact that all amplifiers having like gain and current consumption have about the same X-mod performance on channel 2.

As the frequency rises, the common-emitter stage will exhibit an increasing phase lag, depending upon the cut-off frequency of the device. This phase-shift contributes to the gradual conversion of AM to PM cross-modulation. In 400 MHz amplifiers a 6-10dB reduction in AM X-mod between channel 2 and H14 is not uncommon.

It would be quite wrong, however, to assume that merely a phase shift of the cross-modulation sidebands occurs and that the absolute spurious power remains to be the same.

At high frequencies the non-linear junction capacitors become significant contributors to 3rd order distortion. Of these the output capacitance of the common-base stage has the greatest influence. The junction capacitances are responsible for the increase in triple-beat at high frequencies. Their effect on cross-modulation is the addition of significant phase X-mod in addition to the converted AM portion.

While phase cross-modulation in the past has received little attention, the visibility and possible performance limitations were pointed out by Gumm (4). In order to determine the quantities involved, the following set-up was assembled.

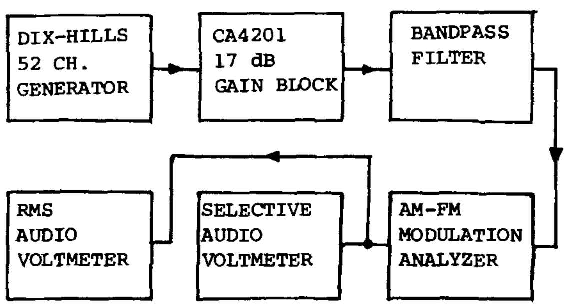

Figure 1. Test Set-up

The amplifier under test was loaded with 52 channels, flat, at 46dBmV. AM cross-modulation sidebands were measured using the AM detector and selective audio voltmeter. PM sidebands were calculated from measured FM deviation(IF bandwidth 400 kHz, audio roll-off 75 kHz). Triple-beat was read on the RMS audio voltmeter (IF bandwidth 20 kHz, audio roll-off 15kC). Figure 2 shows the power in each one of the AM and PM cross-modulation sidebands. To obtain NCTA composite X-mod, subtract 10dB from AM sideband values. It is evident that over much of the frequency range the power in the phase X-mod sidebands dominates. An interpretation of the visual effects will follow.

Plotted on Figure 3 is the RMS triple beat voltage and the effective RMS voltage of the combined cross-modulation sidebands. Both are of similar magnitude and show similar frequency behavior. The

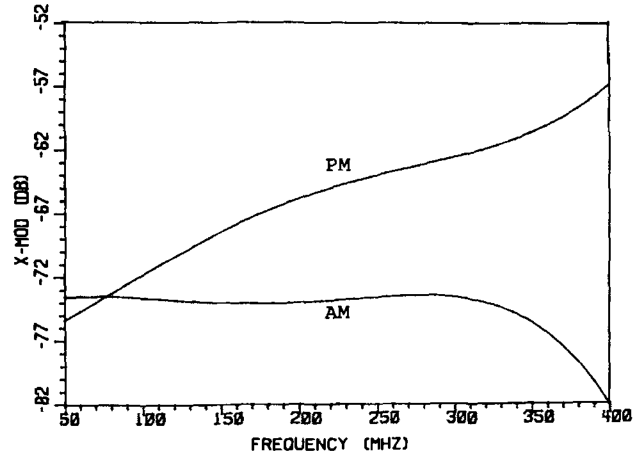

Figure 2. X-mod Sideband Power

triple-beat number shown here is the true RMS value. A spectrum analyzer, used in the logarithmic mode, will indicate a better value. Arnold has shown (5) that the difference between the true RMS value and the spectrum analyzer reading, which is often quoted, is approximately 3dB.

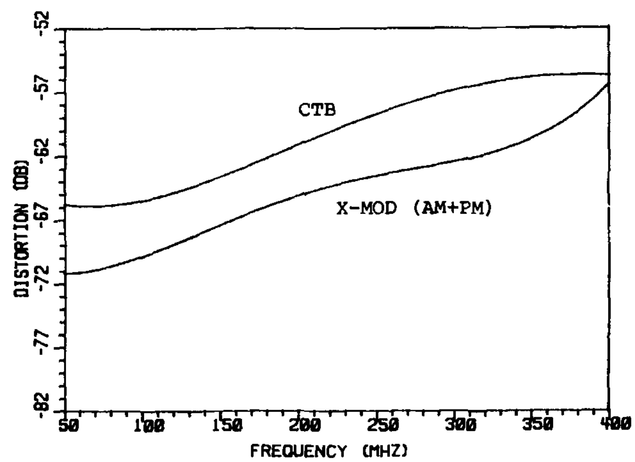

Figure 3. X-mod and CTB

Visual Effects of PM X-Mod

PM cross-modulation becomes visible on a TV screen because TV transmission uses a pseudo single-side band system. Consider Figure 4. The picture carrier is positioned on the halfway point of the Nyquist-slope. Phase modulation of the picture carrier may be expressed in equivalent frequency deviation, which in turn is slope-detected. Thus, PM X-mod sidebands can be expressed as equivalent AM modulation sidebands. For the condition shown in Figure 4 the equivalent AM is

$$AM\ (dB) = PM\ (dB) + 20 * \log\left(\frac{f}{600\ kHz}\right) \quad (1)$$

For f_{mod} = 15.75 kHz, the equivalent AM sidebands will be 31.62 below the PM value.

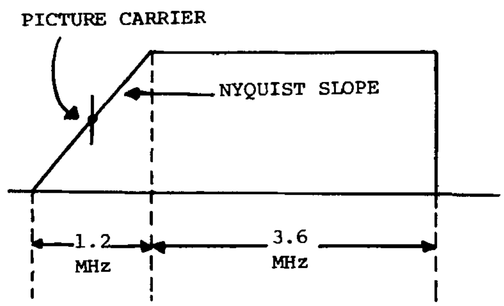

Figure 4. Idealized TV Bandwidth

If the modulation of the interfering carrier(s) is a square wave, a set of PM sidebands will be generated. For a symmetrical modulation envelope, these will be the odd harmonics, decreasing in amplitude inversely proportional to frequency. The equivalent AM sidebands will, however, be all of equal amplitude, because of the term f in Equation 1.

Assume that the modulating square-wave has a rise-time of 140ns between peaks. This is the fastest possible value in a 4.2 MHz video bandwidth system. It can be shown that such a square-wave must contain all odd harmonics up to harmonic number 265. These can be accommodated within the available bandwidth. The first 20 odd sets of phase-sidebands will fall onto the Nyquist slope and contribute equally to the resulting conversion into AM. Of the higher-order sidebands, only the upper ones will contribute. Their influence will be inversely proportional to frequency. Calculation of the total peak equivalent AM modulation is straightforward, but is best done on a computer. For the conditions described (15,750 kHz square-wave modulation, rise-time 140ns), the peak value of the combined equivalent AM sidebands is:
AM peak (dB) = PM (dB) -31.62 + 35.11dB. PM (dB) is the value of one of the first set of PM sidebands. The width of the peak exursion is quite narrow, the "6dB time-width" is 0.212 nsec, that is =0.4% of a horizontal scanning line. For a practical example let us take the measured data from Figure 2. The AM X-mod sidebands at channel M14 were -81.6dB. This translates into -71.6dB NCTA X-mod. The PM sidebands in the same channel were -57.21dB. Using Equation 1 we may calculate a p-p cross-modulation of -41.67dB for this case. The results are illustrated in Figure 5.

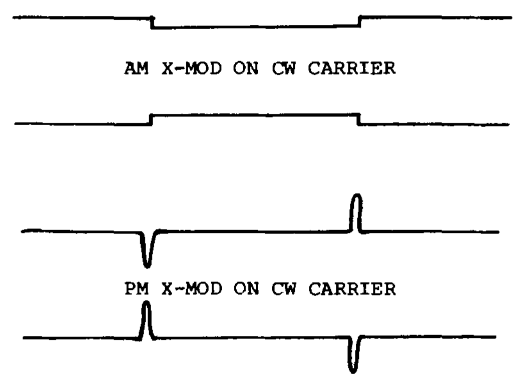

Figure 5. AM and PM X-mod on TV

On the screen we will first see a white, then a black narrow vertical line at the edges of the modulating square-wave.

In practice modulation voltages with longer rise-times than 140 ns will be encountered. If the rise-time is more than 0.833 μs, all associated PM sidebands will fall on the Nyquist slope. In this case the resulting AM cross-modulation is easily calculated:

$$\Delta\omega = \frac{d\phi}{dt}$$

where

$\Delta\omega = \Delta f * 2\pi$ = frequency deviation

$d\phi$ = peak phase deviation

$$= 2 * 10\ \mathrm{Exp}\left(\frac{dB}{20}\right) * \pi/4$$

where

dB = dB value of first set of phase sidebands

dt = rise-time

For example, for PM sidebands of -60dB and a rise-time of 833 ns, the frequency deviation is 300 Hz. The p-p equivalent AM cross-mod is

$$20 * \log\left(\frac{4 * 300}{600\ 000}\right) = 54dB$$

TV Screen Test

In order to observe the visual effects of PM cross-mod the test set-up shown under Figure 6 was assembled.

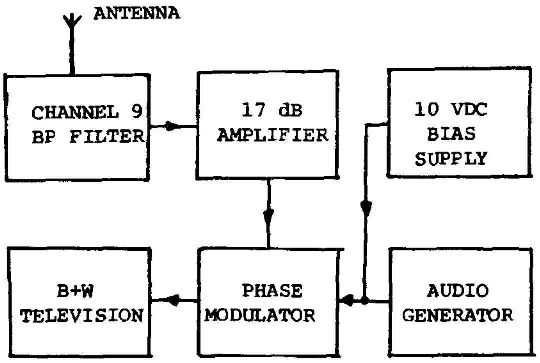

Figure 6. Phase Modulation of TV Signal

The phase modulator was a WB-Engineering RF bridge, the capacitance diode a TRW PC117 (47 pF at 4 volts). When terminated properly, 0.04 radians peak phase deviation were produced at 187.25 MHz by 1 volt RMS audio superimposed on a fixed bias of 10 volts dc. There was no discernible AM. The frequency of 187.25 was chosen because channel 9 was the best channel at the test location. A modulation frequency of 100 kHz was selected. Vertical black and white stripes became visible at a modulation voltage of .25V. These had the same appearance as sinusoidal AM cross-mod. At this point the PM sidebands can be calculated to be:

$$\text{PM (dB)} = 20 * \log (.25 * 0.04/2) = -46\text{dB}$$

The equivalent AM sidebands are:

$$\text{AM (dB)} = -46+20*\log \left(\frac{100 \text{ kHz}}{600 \text{ kHz}}\right) = -61.6\text{dB}$$

Trained observers are said to be able to detect cross-modulation due to -60dB sidebands. The apparent discrepancy of 1.6dB could easily be caused by a slightly non-standard Nyquist slope of the B&W TV set used or by other minor imperfections of the test set-up. In either case it is shown that phase cross-modulation of the magnitude observed in CATV amplifiers can produce visible distortions.

Cross-Modulation in HRC Systems

The advantages of HRC operation are well known. With few exceptions the industry agrees that the best investment towards better system quality lies in converting to HRC operation. The elimination of all triple-beats has a drastic visual effect. Some of the initial euphoria subsided when it was realized that the triple-beat power did not vanish completely but re-appeared as a form of cross-modulation, albeit at a much reduced level. Under HRC operating conditions the multitude of triple-beat components which otherwise constitute the CTB noise, become a single voltage vector which is added to the picture carrier affected. The magnitude of this vector is determined by the magnitude of all contributing carriers. If their amplitude varies, e.g., if they are modulated, so will the amplitude of the triple-beat vector. The effect is modulation transfer or cross-modulation. Switzer (6) showed early, that by controlling the phase of the contributing carriers, the individual TB components could be made to cancel each other with more or less perfection. Krick (7) described a computer optimization effort for 27 channels. With 52 or more channels now at play, "phase-phiddling" becomes a formidable task. In most HRC head-ends for high capacity systems little or no effort is made to obtain optimum phase conditions.

This situation was investigated by creating the following computer model: A black box with a non-linear transfer characteristic was assigned a first-order coefficient, M_1, of unity and a third-order modulation coefficient, M_3, of 8 E-5. Fifty-two harmonically related carriers of 46dBmV each were summed and passed through the system. A random number generator adjusted the phase of each signal to an arbitrary value. A Fourier analysis was performed on the output which yielded the value of third-order distortion products in each channel. By making many computer runs with different sets of carrier phases and by averaging the results, the probable behavior of the system could be determined. Figure 7 shows the probability with which a certain dB value of AM cross-modulation (in terms of NCTA definition) could be expected. Through mathematical manipulation the "classic" AM X-mod was eliminated so that the results shown are solely X-mod due to triple-beat components.

To put the results in perspective, we may calculate the composite triple-beat for a conventional system as described. 52 carriers on an HRC frequency plan generate 903 beats on 246 MHz. The composite triple-beat (worst channel) is then:

$$\text{CTB} = 20 * \log_{10} \text{ (A)}$$

$$A = 3/2*8\text{E-}5 \left(\sqrt{2}*10\text{Exp}\left(\frac{46-60}{20}\right)\right)^2 \sqrt{903}$$

CTB = -70.84dB.

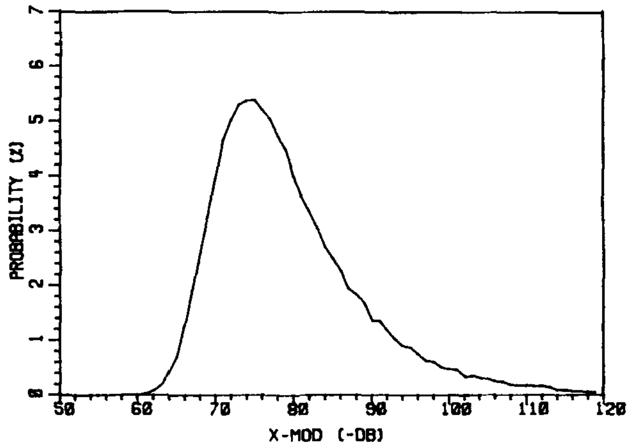

Figure 7. Probability of X-mod

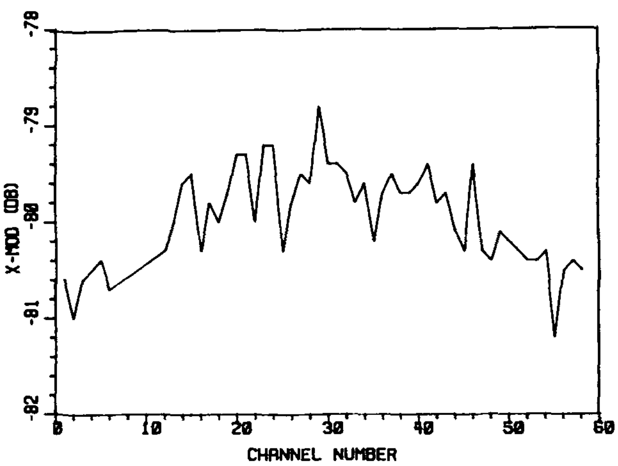

Figure 8. X-mod in TV Channels

Figure 8 shows the probable amount of apparent AM X-mod in each channel. Channel number 1 is 54 MHz, number 58 is 396 MHz. There are no carriers at 72, 90, 102, 108, 114, and 402 MHz. (Disregard portions pertaining to these frequencies on Figure 2, 3, 7, and 9). The typical X-mod is -79.5dB. One may conclude that in HRC systems CTB is converted to AM X-mod at a level 8.66dB below the CTB value. It may be mentioned at this point that the computer model also predicts phase cross-modulation with exactly the same distribution and sideband power as the AM components. This seems plausible because of the completely random nature of the signal phases.

The results shown are simple averages of 1000 computer runs. To demonstrate values obtained from individual runs, 3 sets of predictions are plotted in Figure 9. As seen here, there is always the chance of obtaining "bad" channels. In this case some phase correction may alleviate the problem or move it to a less critical channel.

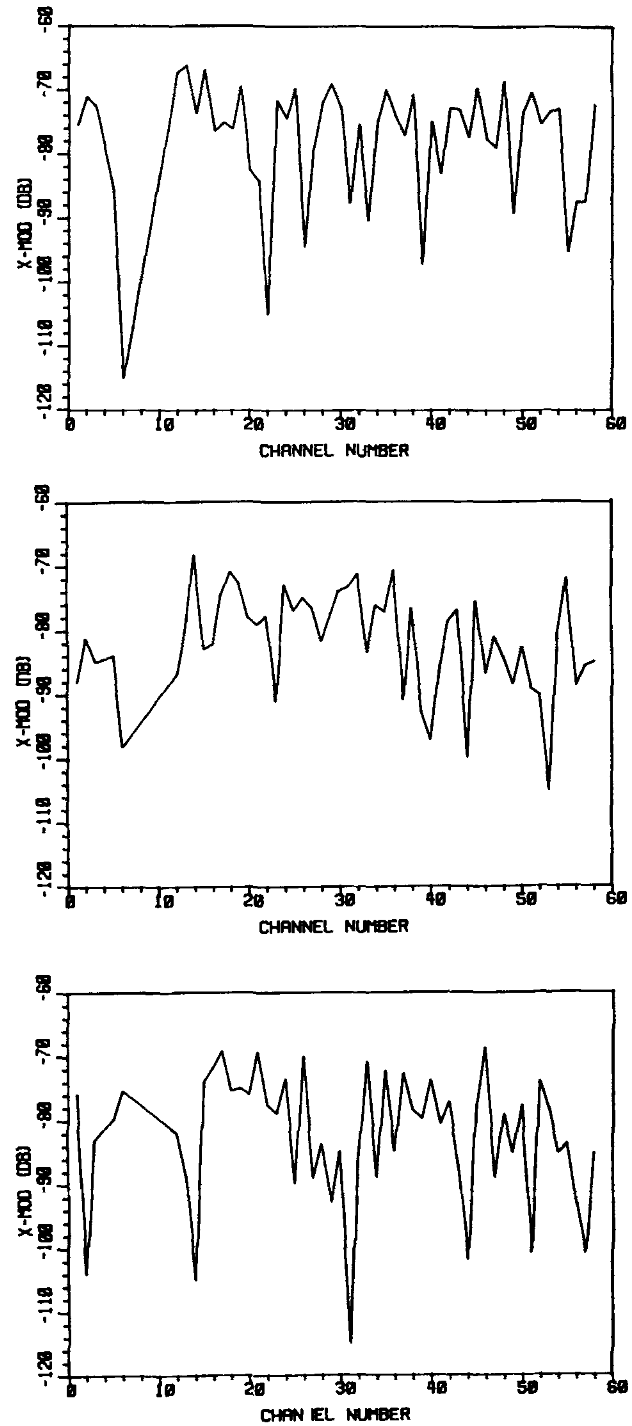

Figure 9. Three Computer Runs

Conclusions

I was shown that HRC operation results in an average AM X-mod 8.66dB below the CTB reading. Since X-mod becomes visible at about -48dB and CTB at -57dB, a total visual distortion reduction of 17.66dB is achieved. This improvement can only be utilized if the "classic" cross-modulation is negligibly small. HRC does not affect this type of distortion in any way. While, due to AM-PM conversion, the AM cross-modulation may indeed be small, the PM components may be so large as to become a limiting factor. More investigation in the light of HRC and 400 MHz operation seems appropriate.

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