COMPOSITE SECOND ORDER: FACT OR FANTASY

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ABSTRACT

Distortion parameters have always been the limiting factor within a CATV system, but as the bandwidth has increased from 12 channels to 60 and 77 channels, the characteristics of the limiting distortions have changed. At the beginnings of CATV, cross modulation and noise limited the number of amplifiers an operator could run in a cascade. As the number of channels increased, cross modulation gave way to composite triple beat as the limiting factor, with noise still a prominent element. A strange thing has occurred however. As the number of channels increased further so did the importance of a distortion parameter that caused little if no concern before. This distortion parameter is called "second order" and in its discrete form still presents no problem to the CATV operator. But when this parameter is taken in its composite form, composite second order can compete with composite triple beat as the limiting factor for cascade length and feeder levels, especially in a 77 channel system.

This paper will re-investigate the causes of second order distortion. It will also provide insights into calculating which composite second order beats are present from discrete second order numbers. In addition, it will provide an analytical analysis of a trunk amplifier, bridging amplifier and line extender for composite second order and how this distortion can be a limiting factor within a cable system.

INTRODUCTION

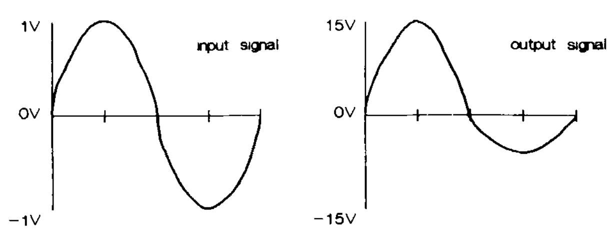
The CATV industry has seen a tremendous amount of change in the last 15-18 years. Systems that in the early 1970's carried 12 or so channels have now progressed to a point where today, 60 or even 77 channels are reaching consumers' homes. This represents approximately 5 times the number of channels that once were present. Along with this growth however, additional problems have presented themselves to the industry. This paper looks into one of these problem areas. It must be understood however, that the data used to calculate the amplifier models and the distortion numbers within this paper are in their worst case situations. In reality the effects of offset headends, modulated carriers and many other combinations can contribute improvements in the numbers presented.

CAUSES & EFFECTS OF SECOND ORDER BEATS

In a CATV system, amplifiers and cable are the medium used to transport TV signals from the point of origin to the viewer's home. If things were perfect, the amplifiers would provide <u>only</u> signal amplification and there would be no limit to the number of amplifiers that could be cascaded. However, in the real world there is no such thing as a perfect amplifier and they provide not only the desired signal increase or gain but they also introduce several unwanted elements commonly known as distortions.

Distortions can take many forms, but in this discussion, only the distortion parameter known as second order will be addressed. Second order distortion is created when the amplifying transistors are not biased in balance. This imbalance creates the non-linear transfer characteristic in the amplifier. This non-linear relationship results in the compression and expansion of the peaks of the sine waves of the amplifier output signal in relation to its input signal. This non-linear transfer characteristic can be expressed mathematically by eout = Xein + 1/2X (ein) 2 and is characterized by Figure 1.

FIGURE 1.
AMPLIFIER TRANSFER CHARACTERISTIC
$e_{out} = Xe_{in} + 1/2Xe_{in}^2$

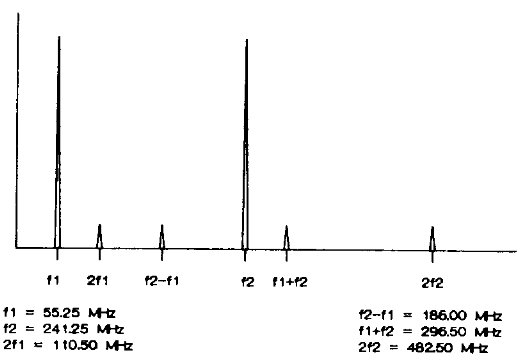


AMPLIFIER GAIN = 10 : X = 10

This diagram shows how the output signal is distorted with compression and expansion of the sine wave peaks when a 2.0 volt peak-to-peak input signal is inserted into an amplifier that exhibits the form of eout = Xein + 1/2X (ein) 2. This non-linear effect is known as a square law transfer characteristic.

This square law characteristic, when present in amplifiers with two input signals, will present beats within the spectrum as the phase relationship of the two input signals changes with time. These beats will be evident at 2 times f1 (1st frequency); 2 times f2 (2nd frequency); f1 + f2 (1st frequency + 2nd frequency) and f2 - f1 (2nd frequency - 1st frequency). Figure 2 shows this relationship of beats for an amplifier with f1 = 55.25MHz (Channel 2 - IRC headend) and f2 = 241.25MHz (channel N - IRC headend).

FIGURE 2.
SECOND ORDER BEAT SPECTRUM

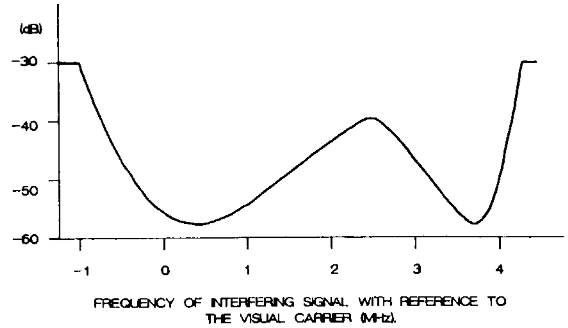


As can be seen in Figure 2, beats fall at 2f1 = 110.50MHz; 2f2 = 482.50MHz; f1 + f2 = 296.50MHz and f2 - f1 = 186.00MHz

The beat relationship depicted in Figure 2 holds true for whatever input signals are inserted into amplifiers that exhibit the square law transfer characteristic. Such beats can affect the picture quality of TV signals if the amplitude of the second order beat product is great enough.

Second order is evident to viewers as a herring-bone pattern that appears to be floating across the picture. The viewability of this phenomenon is highly subjective, and ranges of susceptibility have been as great as 9dB. Recommendations for the levels of discrete second order interference are -60dBc by the NCTA and Figure 3 shows the permissible limits for interfering signals in relation to visual carriers.

FIGURE 3.
RELATIVE SENSITIVITY OF A VISUAL CARRIER TO INTERFERING SIGNALS.

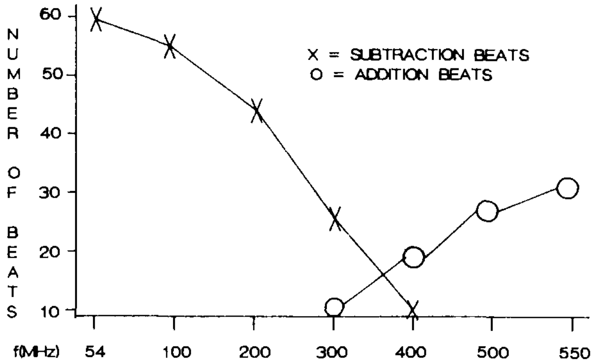


As can be seen by Figure 3 only the signals that fall at a frequency of fref +1.25MHz (fref = reference frequency) will present possible interference problems. The level of interference to visual carriers must be greater at this point than that of fref - 1.25MHz. If the beat products taken from Figure 2 are applied to the graph of Figure 3, then the only beats that could possibly present problems are those at 110.50MHz; 296.50MHz and 482.50MHz. For this reason beats that are generated as a subtraction (f2 -f1) are not considered as problems to the CATV operator. Even beats that fall into the fref + 1.25MHz category present no problems to systems with a small number of channels present. But now consideration will be given to the second order beats in systems that carry 77 channel loading.

COMPOSITE SECOND ORDER NUMBERS

Composite Second Order occurs when many combinations of signals beat together. The once unimportant discrete second order beat, when summed with many other discrete second order beats falling on the same frequency (due to other channel pairs), results in a composite second order distortion which may have a level large enough to interfere with the visual carrier. This presents problems since amplifier manufacturers and CATV equipment manufacturers at present only specify what Discrete Second Order (DSO) numbers should be-not those of Composite Second Order (CSO). Composite second order numbers can be calculated however, by the equation CSO = DSO + 10 log X, where X = number of beats on fref + 1.25. The unknown now is the number of beats that make up X. In a 550MHz system (77 channel) there are 29 beats that fall on 548.50MHz, the relationship of the number of beats to frequency can be seen in Figure 4.

FIGURE 4.
NUMBER OF COMPOSITE SECOND ORDER BEATS IN A 77 CHANNEL SYSTEM



As can be seen, the maximum number of CSO addition beats falls at 548.5MHz. Experiments have been performed on 10 samples each of a 550MHz 19dB gain push/pull hybrid; a 550MHz 19dB gain parallel hybrid and a 550MHz 24dB gain feedforward amplifier to determine how accurate the equation CSO = DSO + 10 log (X) is. The average of each group of amplifiers is given in Tables 1 thru 3.

<u>TABLE 1:</u> 550MHz 19dB Push/Pull Amplifier

Discrete Second Order Spec =
-66dB at +50dBmV
Calculated Composite Second Order Spec =
CSO = DSO + 10 log X where X = 29
= -66 + 10 log 29
= -66 + 14.6
= -51.4

	Average Measured DSO	Average Measured CSO
Freq. 548.50MHz	67.0	51.6

<u>TABLE 2:</u> 550MHz 19dB Parallel Hybrid Amp.

Discrete Second Order Spec =
-65dB at +50dBmV
Calculated Composite Second Order Spec =
CSO = DSO + 10 log X where X = 29
= -65 + 10 log 29
= -65 + 14.6
= 50.4

	Average Measured DSO	Average Measured CSO
Freq 548.50MHz	70.0	58.0

<u>TABLE 3:</u> 550MHz 24dB Feedforward Amplifier

Discrete Second Order Spec =
-80dB at +50dBmV

Calculated Composite Second Order Spec =
CSO = DSO + 10 log X where X = 29
= -80 + 10 log 29
= -80 + 14.6
= 65.4

	Average Measured DSO	Average Measured CSO
Freq 548.50MHz	85.0	71.0

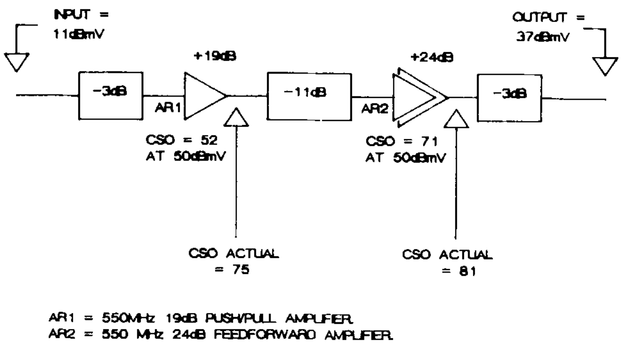
As can be seen from the data, all three amplifiers exhibited better DSO performance than specified: the push/pull by +1dB, the parallel hybrid by +5dB, and the feedforward by +5dB. However the relationship that needs to be looked at is that of the discrete second order beat to that of the CSO beat. In the case of the push/pull and feedforward amplifiers, the 10 log X with X = 29 holds very close to being true (difference = .6dB in both cases). Only in the case of the parallel hybrid amplifier did this relationship break down. These amplifiers showed only a 12dB degradation instead of the 14.6dB that was calculated.

Explanations to this might come from the fact that just as transistors within amplifiers are not biased in balance, the two separate amplifier sections that make up a parallel hybrid amplifier may not be balanced and the square law transfer characteristic of the gain block might be out of phase. Now that the relationships of DSO to CSO has been established, an analysis can be made as to how this affects trunks, bridgers and line extenders used in a CATV system.

AMPLIFIER ANALYSIS

As mentioned previously, amplifiers are used to transport TV signals from one point to another. The most common of these are called trunk amplifiers. These units are built to better distortion specifications than bridgers and line extenders due to the fact that several (most cases up to 20) may be cascaded together to transport these signals. When distribution of signals is required to neighborhoods, units known as bridging amplifiers and line extenders are used. These units, while not exhibiting as good of distortion performance, operate at higher levels than trunk amplifiers. In order to see the effects of CSO on a CATV system, models of these amplifiers will be made using the average CSO numbers from Tables 1 thru 3. In the case of the trunk amplifier a push/pull hybrid will be used together with the feedforward block. The bridging amplifier and line extenders will both be parallel hybrid units meaning that the push/pull hybrid will be used as the input with the parallel hybrid device used as the output. Levels for the units will be +11dBmV input; 37dBmV output for the trunk; and the outputs for the bridger and line extenders will be +46dBmV.

CASE # 1
FEEDFORWARD TRUNK AMPLIFIER
BLOCK DIAGRAM



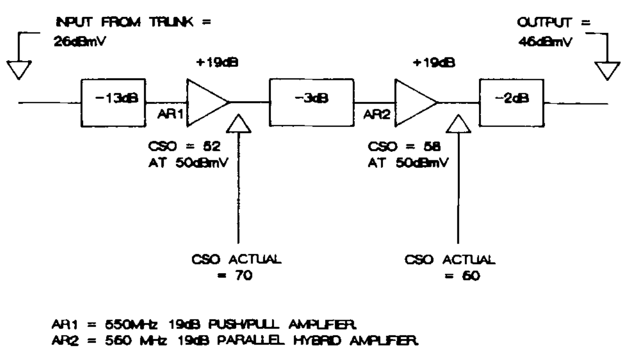
CASE 1:
CSO for unit =

$$10 \log (10^{\frac{x}{10}} + 10^{\frac{y}{10}})$$

$$= 10 \log (10^{\frac{-75}{10}} + 10^{\frac{-81}{10}})$$

= -74

CASE # 2
PARALLEL HYBRID BRIDGING AMPLIFIER
BLOCK DIAGRAM



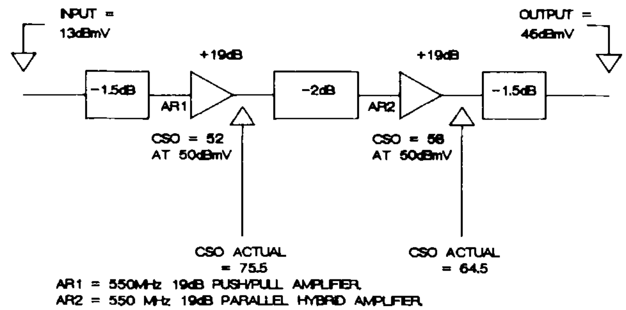
CASE 2:
CSO for unit =

$$10 \log (10^{\frac{x}{10}} + 10^{\frac{y}{10}})$$

$$= 10 \log (10^{\frac{-70}{10}} + 10^{\frac{-60}{10}})$$

= -59.5

CASE # 3
PARALLEL HYBRID LINE EXTENDER
BLOCK DIAGRAM



CASE 3:
CSO for unit =

$$10 \log (10^{\frac{x}{10}} + 10^{\frac{y}{10}})$$

$$= 10 \log (10^{\frac{75.5}{10}} + 10^{\frac{64.5}{10}})$$

= -64

A review of the preceding cases shows that in trunk amplifiers, the input hybrid is the limiting component in determining CSO, while in the bridging amplifier and line extender, the output device is the one that contributes the most to CSO.

SYSTEM ANALYSIS

Now that models have been generated for trunk, bridging and line extender amplifiers, the numbers derived from these models can be used to determine the consequences of CSO on the cable plant. If a typical system of 20 trunk amplifiers, a bridging amplifier at the 20th location, followed by 2 lines extenders is analyzed, the following CSO numbers can be calculated. From Cases 1-3:

Case 1 Trunk amplifier CSO = -74
Case 2 Bridging Amplifier CSO = -59.5
Case 3 Line Extenders CSO = -64

TABLE 4

Trunk contribution = -74 + 10 log 20
where 20 = number of identical amplifiers in cascade.
Trunk contribution = -61dB CSO
Bridging Amplifier Contribution =

Trunk Amplifier CSO Number + Bridging Amp CSO Number

therefore,

$$CSO = 10 \log \left(10^{\frac{-61}{10}} + 10^{\frac{-59.5}{10}}\right) = -57dB$$

Line Extender Contribution =

Trunk & Bridging Amp CSO Number + Line Extender 1 CSO Number

therefore,

$$CSO = 10 \log \left(10^{\frac{-57}{10}} + 10^{\frac{-64}{10}}\right) = -56dB$$

This is added to a second line extender whose CSO number is also -64 therefore,

$$CSO = 10 \log \left(10^{\frac{-56}{10}} + 10^{\frac{-64}{10}}\right) = -55dB$$

This -55dB CSO number represents the end of the line performance and is 5dB below what the NCTA recommends for DSO performance. When this -55dB CSO is compared to the minimally acceptable interference graph of Figure 3 it can be seen that CSO is right on the threshold on acceptability.

CONCLUSIONS:

While the data presented in this paper is that of an absolute worst case situation, (IRC headend - no offsets; CW carriers, no system tilts etc.) care and consideration must be given to CSO. No longer can operators afford the luxury of ignoring this phenomenon if 77 channel and larger systems are to be built. Additionally, both the amplifier and CATV equipment manufacturers must start specifying equipment with CSO numbers.

ACKNOWLEDGEMENTS:

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