SECOND ORDER BEATS ON CATV SYSTEMS

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With the advent of hybrid technology and the increased prevalence of 35 channel testing, an updated view of second order intermodulation behavior is needed. This paper is a report of studies made on a "latest generation" of hybrid amplifiers showing levels of distortion in the hybrid module, single station, and a cascade. Conclusions are drawn on a method of testing, and it will be shown that the commonly accepted cascade derate factors are invalid.

It has been observed for some time in testing cascades for second-order performance in the lab and on proof of performances that the second order beat levels are not predictable at any given location. At some points in the system, a beat level is considerably less than it was in the previous station. In fact, as every station is probed, nulls are seen to occur in a number of locations as shown in Figures 1 and 2. Notice that complete nulling does not necessarily occur and that there is very little pattern or order to the curve.

The data in Figure 1 was taken on a twenty station cascade of discrete push-pull amplifiers. Notice the wide excursion of the beat in Channel 3. The peaks and valleys seem to have no relation to the peaks and valleys of the beats in Channels J and T. There are four stations at which the beat level exceeds the 10 log N curve, but at no station does it approach the visible level above -60 dB.

The data in Figure 2 was taken on a twenty amplifier cascade of hybrid amplifiers. The excursions are similar but again no pattern is evident. In order to try to explain this situation, an investigation of theory and hardware was undertaken. A number of papers have been presented in past years showing how intermodulation distortion is generated in an amplifier. Briefly, an amplifier was described as having a transfer function similar to a Taylor power series expansion, that is,

$$V_o = A_o + A_1 V_i + A_2 V_i^2 + A_3 V_i^3 + \_\_\_\_$$

This is sufficient for our discussion here, although other papers (1) (2) have shown that a Voltera series is more accurate. If the input signal, V_i, to an amplifier consists of two carriers

$$V_i = V_1 \sin \omega_1 t + V_2 \sin \omega_2 t$$

the second order term at the output, $A_2 V_i^2$, yields

$$A_2 V_i^2 = A_2 (V_i \sin \omega_1 t + V_2 \sin \omega_2 t)^2$$
$$= A_2 V_1^2 \sin^2 \omega_1 t + A_2 V_2^2 \sin^2 \omega_2 t$$
$$+ 2 A_2 V_1 V_2 \sin \omega_1 t \sin \omega_2 t$$

The first two terms are the second harmonic, respectively, of ω_1 and ω_2. It is the last term which accounts for the second order beats. For simplicity, assume unity amplitude, and in the absence of phase-locked headends, assume a phase difference. Then,

$$2 \sin \omega_1 t \sin (\omega_2 t + \beta)$$
$$= \cos (\omega_1 t - \omega_2 t - \beta)$$
$$- \cos (\omega_1 t + \omega_2 t + \beta)$$

The first cosine term represents the difference beat, f1 - f2, and the second cosine term represents the sum beat, f1 + f2.

If all of these carriers are inserted in a second identical amplifier, two more beats, f1 ± f2, will be generated and the original beats will be amplified. In two CATV stations where unity

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(1) A. Prochazka, "Cascading of Distortion in CATV Trunk Line", IEEE Transactions on Broadcasting, Vol. BC20, No. 2, pp 25-31, June 1974

(2) S. Narayanan, "Application of Voltera Series to Intermodulation Distortion Analysis of Transistor Feedback Amplifiers", IEEE Transactions on Circuit Theory, Vol. CT17, No. 4, pp 518-527, November 1970.

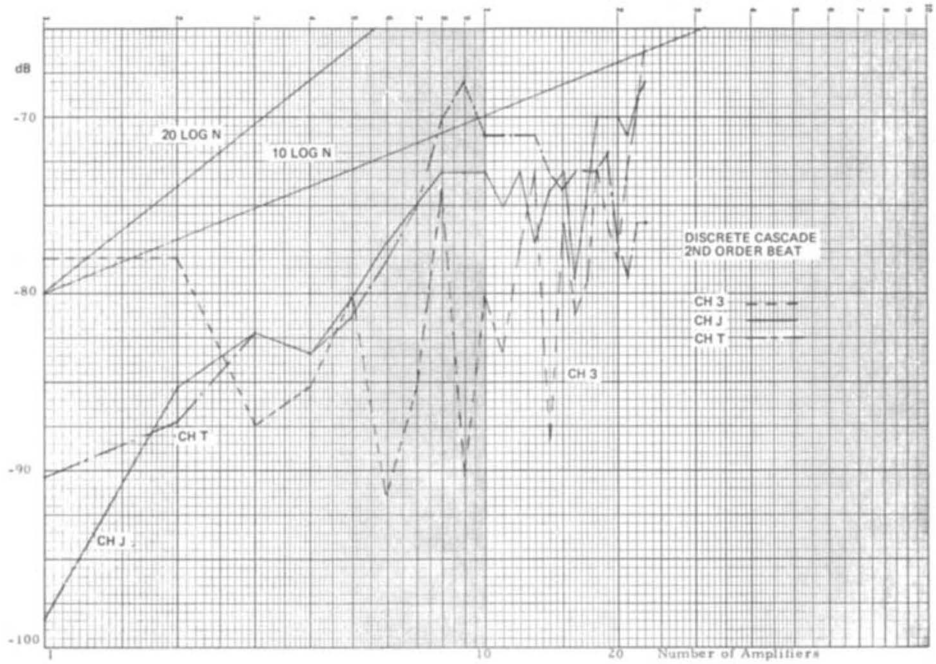


FIGURE 1

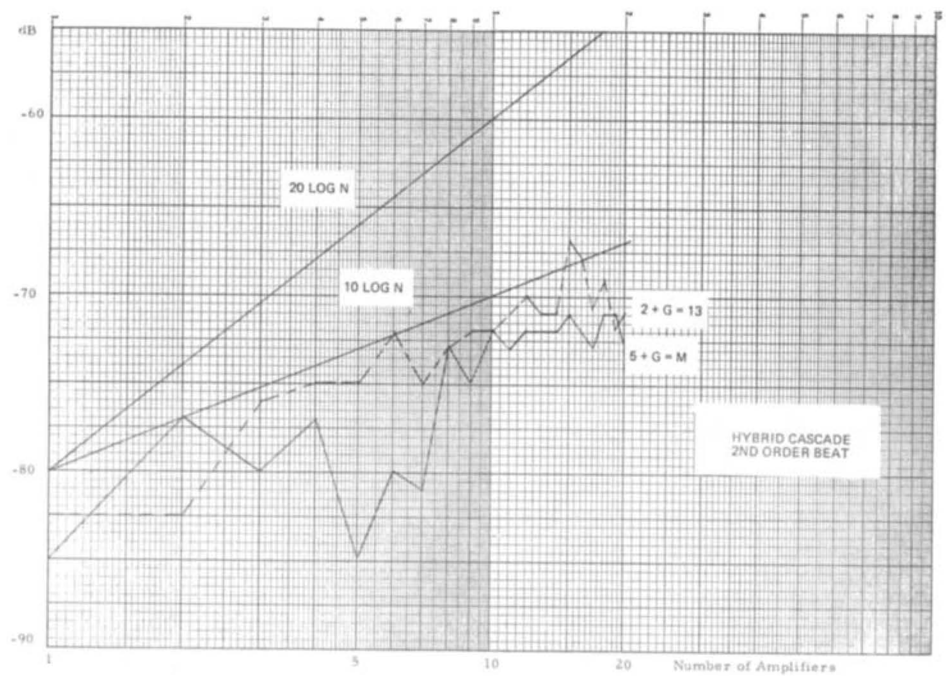


FIGURE 2

gain occurs due to cable losses, the output of the second amplifier will have two beats at exactly f1 - f2 and two beats at exactly f1 + f2. For example, if Channel 2 and Channel G are inserted, one of the beat frequencies will be at

$$157.25 + 55.25 = 212.50 \text{ MHz}$$

The output of the second station will contain two carriers at 212.50 MHz at the same level. These two carriers will add together and the resultant amplitude will be a function of the phase difference between them. That relation is:

$$\cos \omega_r + \cos (\omega_r + \beta_r)$$
$$= \cos (\omega_r - \frac{\beta_r}{2}) + \cos (\omega_r + \frac{\beta_r}{2})$$
$$= (2 \cos \frac{\beta_r}{2}) \cos \omega_r$$

The first term, $2 \cos \frac{\beta r}{2}$ is the magnitude of the resultant frequency, ω_r, as shown in Figure 3.

For phase angles less than 120°, the magnitude will increase, and for phase angles greater than 120°, the magnitude will decrease. At 180°, complete cancellation occurs.

For unequal amplitudes,

$$V_1 \cos \omega_r + V_2 \cos (\omega_r + \beta)$$
$$= \sqrt{V_1^2 + V_2^2 + 2V_1V_2 \cos \beta} \cos \omega_r$$
$$= 2 \cos \frac{\beta}{2} \cos \omega_r \quad \text{when } V_1 = V_2 = 1$$

This equation is plotted in Figure 4 and shows the resultant magnitude with unequal carriers. Complete cancellation cannot occur under this condition.

To understand how phase differences occur in a system, some of the components starting with the cable were characterized. The phase constant of coaxial cable is given by:

$$\beta_c = \omega \sqrt{LC}$$
$$\simeq \omega \, CZ \text{ where } Z = \sqrt{\frac{L}{C}}$$

for foamed polyethylene with $Z = 75\Omega$, $C = 17 \text{pf/ft}$

$$\beta_c = 0.459f \text{ degrees/ft where f is in MHz}$$

A modern hybrid linear amplifier has a phase constant of

$$B_a \approx 2f \text{ where f is in MHz}$$

and an AGC variation of $\Delta B_a = \pm 10^{\circ}$.

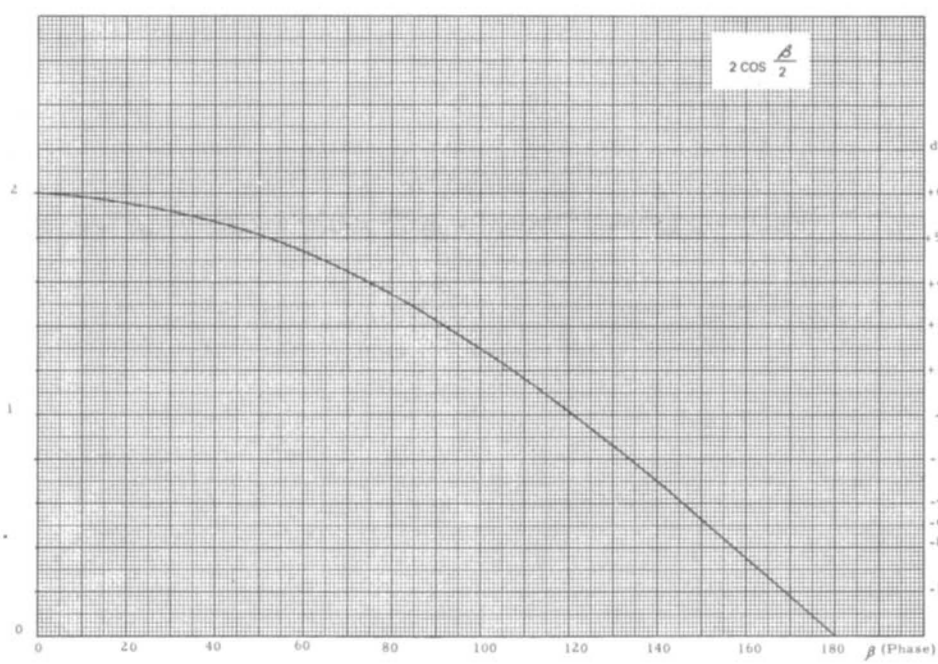


FIGURE 3

BEAT COMBINING CURVE

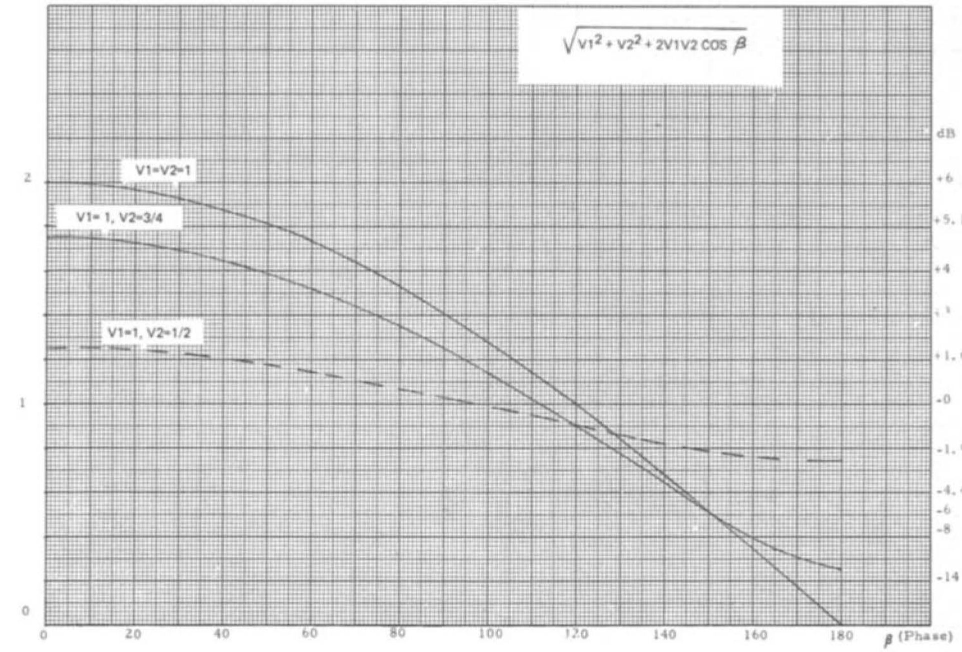


FIGURE 4
BEAT COMBINING CURVE

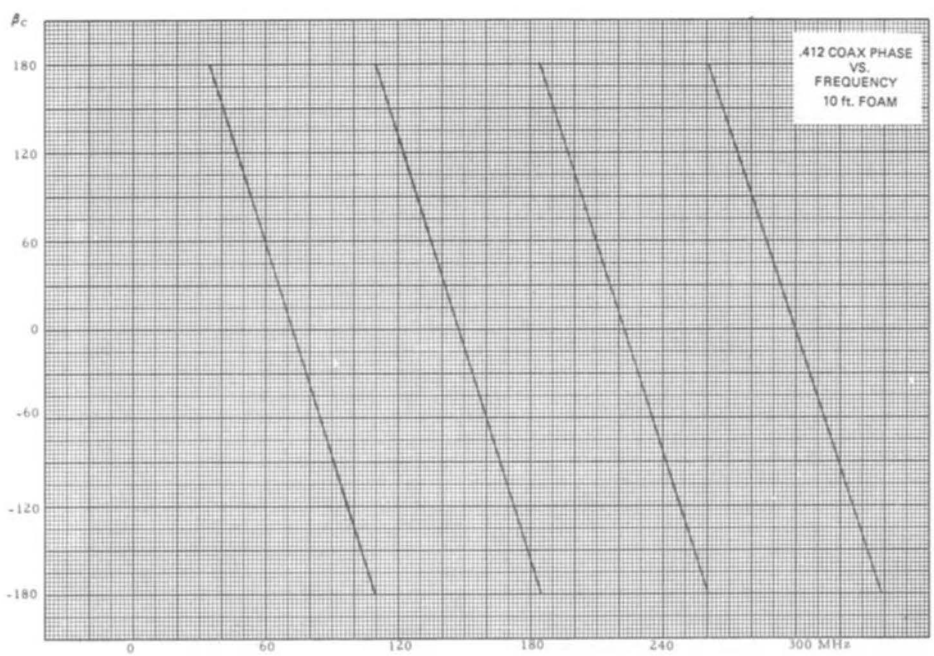


FIGURE 5
COAX PHASE VS FREQUENCY

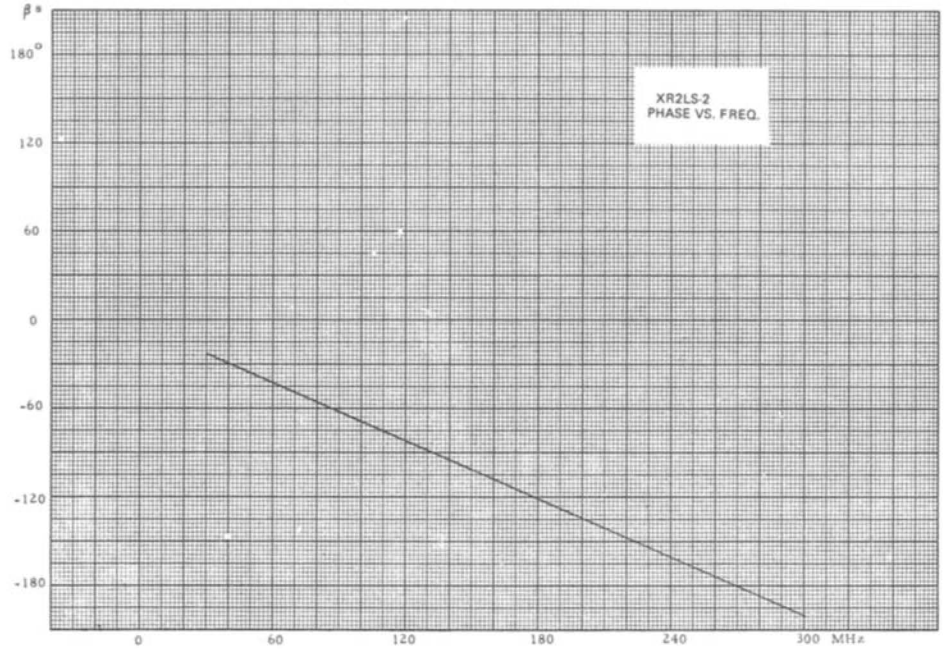


FIGURE 6

LINE SPLITTER PHASE VS FREQUENCY

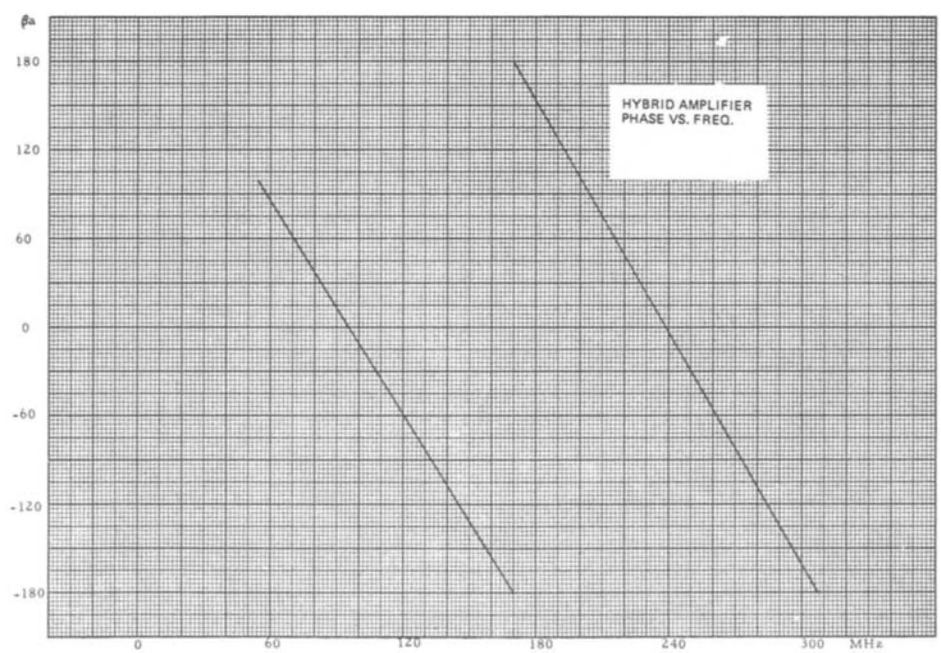
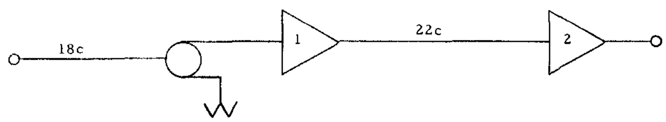


FIGURE 7

HYBRID AMPLIFIER PHASE VS FREQUENCY



CHANNEL	INPUT	STATION 1	STATION 2	COMPOSITE
5	0°	+178°	-5°	
6	0°	+82	-67°	
5 + 6			-80 dB /+95°	
5 + 6		-80 dB /+130°	-80 dB /-106°	-80 dB /0°
5	0°	+178°	-5°	
M	0°	+50°	-80°	
M - 5			-80 dB /+173°	
M - 5		-80 dB /+178°	-80 dB /+38°	-83 dB /+105°

FIGURE 8

SYSTEM BEHAVIOR EXAMPLE

A two-way line splitter has

$$\beta_s \approx 0.67f \text{ where f is in MHz}$$

The phase measurements were made with a General Radio Model 1710 Network Analyzer and apply only to frequencies between 50 and 300 MHz.

A typical system span with 18 dB of cable and a two-way splitter would have:

$$\beta_t = \beta_c + \beta_s + \beta_a$$

$$= [(0.459)(1600') + 0.67 + 2]f$$

$$\approx 734f \text{ degrees}$$

With this information, several beats on a system can be followed. Assume two spans of cable, the first with 18 dB and a two-way splitter, and the second with 22 dB of cable as shown in Figure 8. Apply Channels 5 and 6. At the first station, a beat will be produced at

$$77.25 + 83.25 = 160.50 \text{ MHz}$$

Assume also that all beats are generated at -80 dB. At station two, Channels 5 and 6 will cause another beat at 160.5 MHz. This beat is -80 dB but shifted +95° from the beat at the first station due to the phase shifts of Channels 5 and 6. The first beat will be amplified by station two and its phase shifted to 106°. If these are added by Figure 4, the resultant is -80 dB / 0° . It would appear to a spectrum analyzer or field strength meter that the second station did not generate a beat. As a second example, apply Channels 5 and M to the input, and a beat will appear at M-5=158 MHz. At station one, the magnitude and phase is -80 dB / + 178°. At station two, this beat is shifted to +38°. The beat generated at station two is -80 dB / +105° or 3 dB lower than at station one. Similar analysis with other beat combinations shows various levels of addition and cancellation up to the full 6 dB addition.

If two pairs of carriers are selected such that their respective beats fall on the same frequency, the previous analysis can be used except that the two resultant beat frequencies may differ by up to 40 KHz. For example:

$$\text{Ch } 2 + \text{Ch } G = 55.25 + 157.25 = 212.50$$

$$\text{Ch } 4 + \text{Ch } E = 67.25 + 145.25 = 212.50$$

The original Channel 2, 4, E and G frequencies will vary slightly depending on crystal tolerances or on deliberate offsets such as local 10 KHz as required by the FCC. The 40 KHz difference amounts to 0.08% at Channel 2 and will have insignificant effect on the beat amplitudes. A small sideband may exist on the resultant beat, but will probably not be seen if the level of the beat is very low.

A test method that is instructive but very time consuming consists of viewing the composite beats with all cw carriers on the system simultaneously as is done with triple beats. This is done with a spectrum analyzer with storage mode capability. A narrow band filter in front of the spectrum analyzer is useful in order to prevent distortion in the analyzer. With a scan width of 0.5 MHz, the triple beat can be seen right at the carrier frequency and the composite second-order beats can be seen at 0.75 MHz and at 1.25 MHz above the picture carrier. On some channels, a second order pile-up will be seen at 0.75 MHz below the picture carrier. Figure 9 shows a typical plot of composite beat versus frequency, and Figure 10 shows composite beats in a cascade. Due to ever present noise, a narrow bandwidth and slow scan rate is necessary.

Table 1 shows the number of mathematical combinations of beats on a 35 channel system in each channel. Below Channel 10, the beats are primarily 0.75 MHz above the video carrier, and above Channel 10, the beats are + 1.25 MHz above the channel carrier. Due to their 2 MHz offset, Channels 5 and 6 contain a large number of in-band beats. Except for Channels 5 and 6, the maximum number of beats at the same frequency is eight in super band. The standard twelve channels have only two or three beats. If the spectrum analyzer scan width is made narrow enough, these beats can be separated on the display since they are at slightly different frequencies. The beat with the highest amplitude will be more premoninant in a visual test. The effect of viewing two such beats on a TV set is the grid or "screen-door" effect. Since this is a time consuming test, it is not necessarily recommended for proof of performance and maintenance tests.

The visual aspects of the beat frequency relative to the video carrier frequency have been known for some time. One of the more recent and well-illustrated curves for this is published by the Department of Communications in Ottowa, Canada.(3) The results show that the permissible level for a beat at 0.75 MHz above the carrier is -56 dB and a beat at 1.25 MHz above the carrier is -52 dB. The limit for a beat at 0.75 MHz below is -42 dB.

These levels agree very closely with work done at Bell Laboratories(4) in 1960 and separate tests performed by this author in 1968. Note

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(3) Technical Standards and Procedures for Cable Television (CATV) systems, Broadcast Procedure 23, Telecommunication Regulation Branch, Department of Communications, Ottowa, Canada, March 29, 1971.

(4) C. A. Collins, A. D. Williams, "Noise and Intermodulation Problems in Multi-Channel Closed Circuit Television Systems", AIEE Winter General Meeting, New York, N. Y., Jan. 29-Feb. 3, 1961.

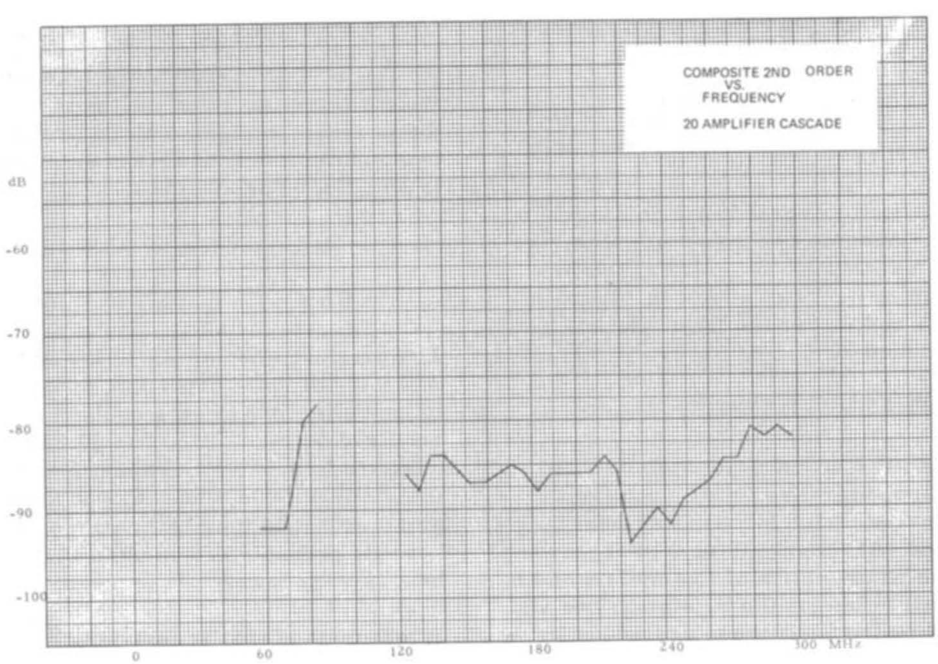

FIGURE 9

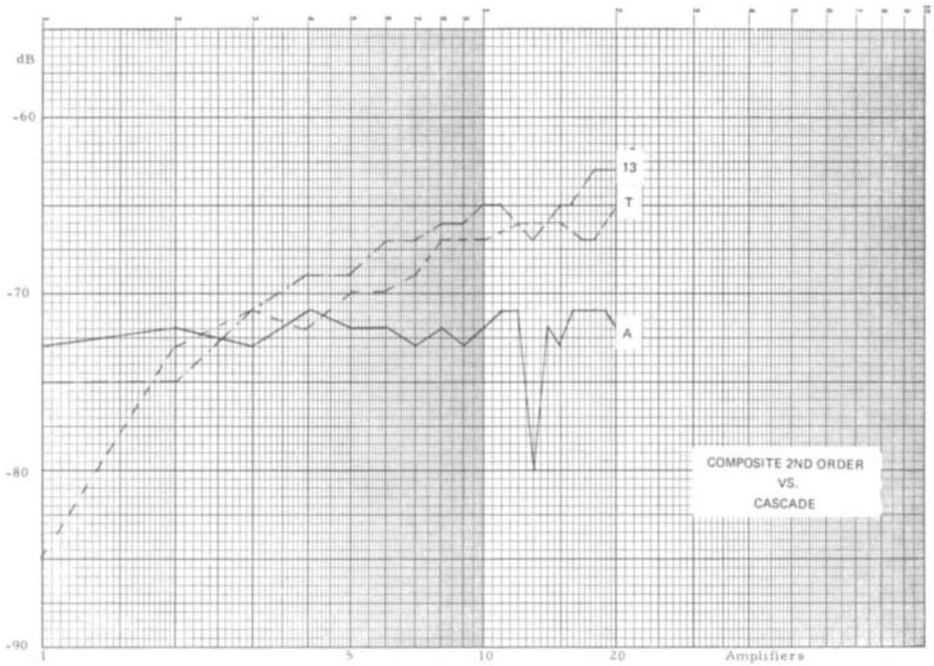

FIGURE 10

that the beat at 0. 75 MHz below the carrier is near the band edge. If a combination of test signals is chosen such that one of the beats is on a band edge, such as Channel 13 minus Channel 2 equal 156. 0 MHz, the resulting beat is a good indicator of the performance of the system, but by itself should not be used to reject a system since a real acceptable band edge level is -30 dB.

CONCLUSION:

One can see from Figures 1 and 2 that the cascade derating is not a simple logarithmic curve, and that predicting beat levels is virtually impossible. It appears that the only way to insure that system performance will meet a given specification is to specify a minimum acceptable level that applies to any point in the system. At Theta-Com, we prefer to specify a minimum second order beat in any channel of -60 dB at any point in the system. The contributing channel carriers for test purposes may or may not be specified.

TABLE 1

BEAT LOCATIONS PER CHANNEL

Ch.	-0.75	+0.75	+1.25	+2.75	+3.25 MHz
2		2			
3		2			
4		2			
5		22		2	
6		21		2	
A		2	2		
B		2	1		
C	1	2	1		
D	2	2			
E	2	2			
F	1	2			1
G		2			1
H		2	1		1
I		2	1		
7		2	2		
8		2	2		
9	1	2	2		
10	1	1	3		
11	1		3		
12	2		3		
13	2		3		
J	2	1	4		
K	2	1	3		
L	2		4		
M	2		4		
N	2		5		
O	2		5		
P	2		5		
Q	2		6		
R	2		6		
S	2		7		
T	2		8		
U	2		8		
V	2		8		
W	2		8		
Visual Limit	-42	-56	-52	-43	-53 dB