REQUIRED SYSTEM TRIPLE BEAT PERFORMANCE

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A curve showing the triple beat level required in a system for high quality performance versus the number of triple beats per channel is given in this paper. The curve is the result of subjective tests conducted at EiE in which the threshold of perceptibility of the third order intermodulation (triple beat) is observed on a TV receiver. The paper discusses the development of the curve and substantiates it by probability theory.

A table is also given which lists from 1 to 30 channels and the number of triple beats that would be generated from these channels on the worst channel. This gives the system designer the necessary triple beat performance required to design a multichannel system.

GLOSSARY

Beats - Sum and difference frequencies produced from the product of two or more frequencies.

Coherent Headend - A headend in which an identical frequency spacing exists between the various picture carriers of the various channels.

Intermodulation - In a nonlinear transducer element, the production of frequencies corresponding to the sums and differences of the fundamentals and harmonics of two or more frequencies transmitted through the transducer.

Carrier to Intermodulation Ratio - The ratio between the carrier level and the level of the Intermodulation.

Intermodulation Distortion - The impaired fidelity resulting from the production of new frequencies that are the sum and the differences between frequencies contained in the applied waveform.

Intermodulation Products - The frequencies produced by Intermodulation.

Third Order Intermodulation - Intermodulation resulting from the cubic, X^3, characteristics of a nonlinear transducer element. Includes two-frequency beat ($2f_1 \pm f_2$) and triple beat ($f_1+f_2 \pm f_3$), and third harmonic (3f).

Third Order Spurious Signals - Unwanted signals resulting from the cubic, X^3, characteristic of a nonlinear transducer element. Third Order Intermodulation.

Triple Beat - Sum and difference frequencies produced from the product of three frequencies. Third Order Intermodulation resulting from three frequencies, $f_1+f_2 \pm f_3$.

Equivalent Triple Beat - The total number of triple beats plus one-fourth the total number of two-frequency beats.

Individual Triple Beat - One of many triple beats produced from the product of three frequencies.

Threshold of Perceptibility - The level at which an effect (i.e., Intermodulation Distortion) is first observed on a TV receiver.

Introduction

Third Order Intermodulation products (triple beat) have been much discussed (and cussed) over the past couple of years in the CATV industry. Most manufacturers now include third order intermodulation (triple beat) in their specifications, many CATV operators are considering their effects in proposal requests and some manufacturers are offering coherent headends to reduce the effects of all intermodulation distortion. Up to now the industry has depended on educated guesses with regard to the visibility of third order intermodulation products (triple beats) in a TV channel. This paper presents the results of subjective tests conducted at EiE which allows the system designer to accurately determine triple beat specifications that will provide the protection needed to avoid picture impairment.

Number of Spurious Beats

A computer run (Reference b) has been made giving the exact number of beats on each channel. Table 1 summarizes the worst case for various number of channels. The computer run (Reference b) showed that the center channel in a group of channels will be the worst case for the number of spurious beats. The two types of third order spurious signals given in the table are the signals resulting from two carriers ($2f_1 \pm f_2$ type) and the signals resulting from three carriers or triple beat ($f_1 + f_2 \pm f_3$ type). The spurious signals resulting from the two carriers are one-fourth (-6 dB) the level the spurious signals resulting from the three carriers (Reference a). The effective or equivalent total number of triple beats would therefore be the sum of this number of triple beats plus the sum of one-fourth the number of two channel beats.

Intermodulation Threshold

A limited amount of subjective testing has been done in determining the threshold of perceptibility of third order intermodulation distortion, and the data that is presented in this paper is based on experiments performed at EiE. A block diagram of the test setup is shown in Appendix A. Channel 10 was chosen for the subjective viewing since there was no "off air" signal in the area to interfere with the test and it is the center channel in the high band. Channel 10 was modulated with staircase modulation (grey scale) and other channels were unmodulated. The unmodulated carriers are a worst case condition for viewing third order intermodulation distortion, but it provides for more consistent results just as synchronous modulation does for cross modulation testing. The unmodulated carriers would represent the synchronous tip power in the worst case condition where all channels were synchronously modulated. If the carriers were modulated there would be an improvement in the threshold, but the amount of improvement would depend upon the characteristics of the modulation. The threshold given in Figure 1, therefore, provides some safety factor for an actual system just as synchronous cross modulation does. The threshold of perceptibility is not necessarily an acceptable level that the average viewer would tolerate, but is the worst case condition. Also, no attempt was made to space the channels so that the spurious signals fall within the null points around the carriers. The interferring effects of intermodulation on the television screen are reduced when the spurious signals are offset at frequency intervals about the carriers at approximately the half-line scanning frequency, or 8 kHz. The channels and frequencies used in the test are given in Appendix B.

Figure 1

Figure 1 is a plot of two curves, Curve 1 being the required system level of an individual triple beat as a function of the total number of beats per channel. The measured points on Curve 1 were found by observing the threshold of perceptibility on a TV receiver of the total third order intermodulation on one channel and then measuring the level of an individual triple beat with the spectrum analyzer.

Curve 2 is a plot of the actual threshold level of perceptibility of the total third order intermodulation per channel as a function of the total number of equivalent triple beats per channel. Curve 2 is derived from Curve 1 by summing levels of the third order intermodulation products that fall on one channel using the formula:

$$V_{rms} = \left[\Sigma v_i^2\right]^{1/2}$$

(see Reference c). Curve 2 is given for reference since it is very difficult to measure the summation of the third order intermodulation products in a system due to the level of system noise. The bandwidth cannot be reduced enough to eliminate the system noise and still sum the intermodulation products; therefore, Curve 1 or the individual triple beat should be used when specifying or measuring third order performance in a system.

The unusual shape of Curve 1 in Figure 1, requires some explanation. When one spurious signal was beating with the viewed channel, the threshold of perceptibility was a carrier to intermodulation ratio of 60 dB. This value agrees with most of the testing that has been done in the past with a single beat frequency. Increasing the number of random spurious signals to two, the worst case threshold increases to 66 dB due to the periodic summing of the peaks of the two spurious signals. As the number of spurious signals is doubled, the theoretical threshold level would increase 6 dB due to the periodic summing of the peaks of the spurious signals, but subjective viewing has shown that the periodic summing of more than two spurious signals becomes quite random. The curve makes a sharp transition after two spurious signals and crosses over to another line which is a power addition (10 log N) of the spurious signals.

The shape of the curve in Figure 1 is substantiated by Probability Theory. The central-limit theorem (Reference d,e) in probability states that as the number of independent random variables approaches infinity, the density approaches the normal density curve (gaussian distribution) which is the density for white noise. This would explain why after a large number of random signals (which the triple beats are) the signals add on a power basis or the same as random noise.

Several authors (Reference d,e) of Probability Theory have pointed out that since the central-limit theorem involves a limit of infinity, one might feel that the number of random variables must be large before an approximation of the normal distribution can be made.

However, the convergence for many of the ordinary density functions is surprisingly fast. In fact, the normal distribution curve is closely approximated by just 3 random variables and 4 random variables is an "extremely good" (Reference d) approximation. This explains the sharp transition in Figure 1 after just 2 spurious signals.

Since the large number of spurious signals are all clustered about the signal carrier within $\pm$20 kHz, the effect is narrow band random noise as compared to wideband (4 MHz) random noise. Extrapolating the 10 log N slope of the curve in Figure 1 back to the vertical axis, one finds that the threshold for narrow band random noise would be 53 dB. In order to compare directly the visual effects of noises having different power spectra a weighting factor (Reference f) must be used. The weighting factor of a specific noise spectrum is obtained by integrating the noise spectrum multiplied by the weighting function, over the video bandwidth to be considered. The weighting factor from narrow band flat noise to wideband flat noise is -6.1 dB. Therefore, the random noise threshold in Figure 1 would be approximately 47 dB for wideband (4 MHz) random noise.

Intermodulation Reduction

Some of the methods that can be used to reduce the third order intermodulation distortion in a system were discussed in the earlier paper (Reference a), and will be mentioned again for clarity. Device manufacturers are constantly being urged to develop more linear transistors in order to reduce intermodulation distortion. Until more linear transistors are developed, the power will have to be limited to maintain good quality pictures. The power can be reduced by operating the amplifier with a tilted output, that is, the low channels operating at progressively lower levels than the higher channels to equalize for the cable attenuation.

Another obvious method to reduce the power is to reduce the output level of all amplifiers, but in order to maintain the signal-to-noise ratio, the spacing must be reduced an equal amount. Figure 1 shows that there is an approximate 8 dB degradation in the threshold level when changing from standard 12 channels to 30 channels, which means that for 30 channels the output level of each amplifier should be reduced 4 dB for equal performance to a standard 12 channel system.

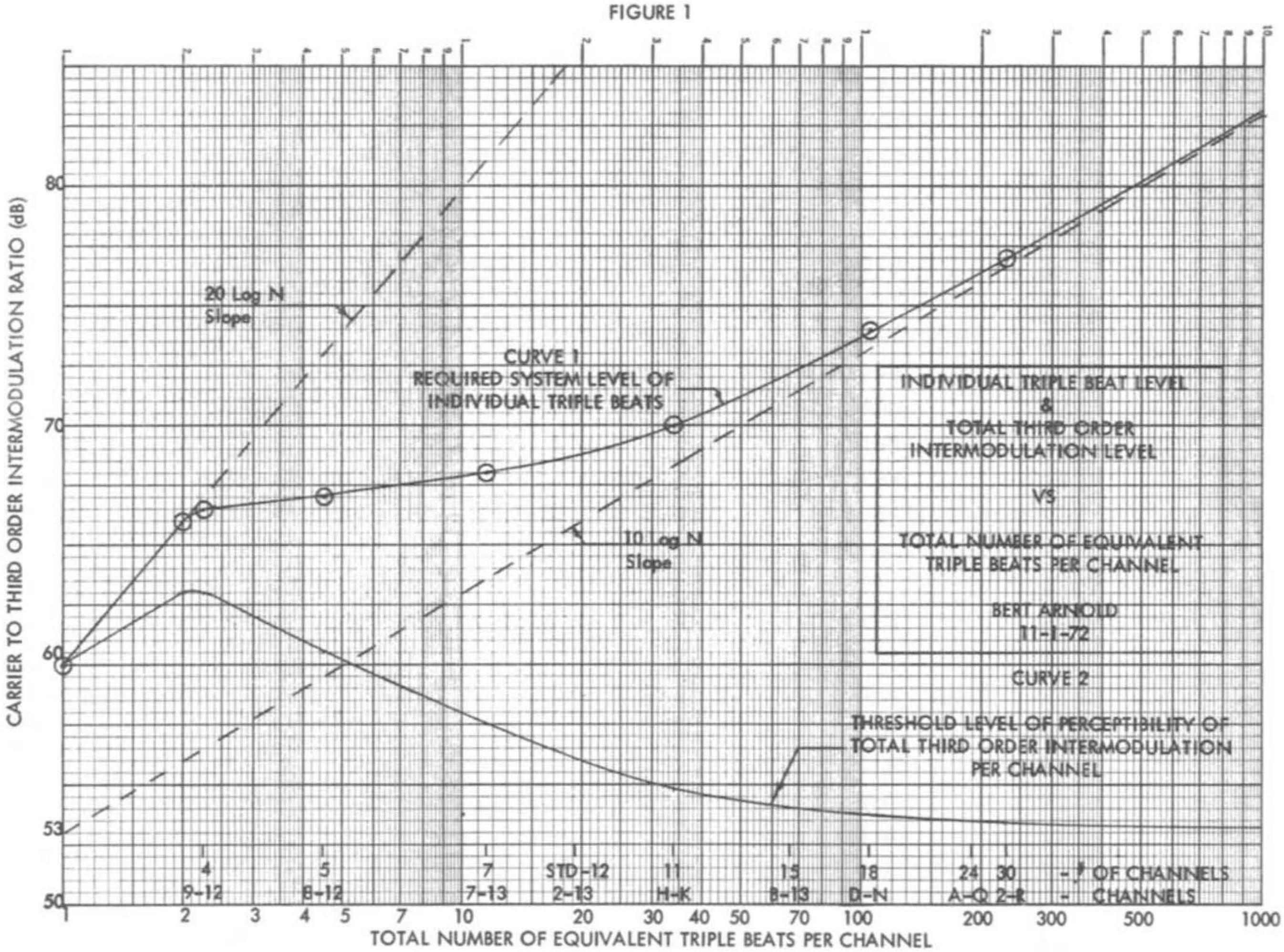
The beat between the third order products and the signal carrier could be eliminated by utilizing a coherent headend, but this would not eliminate the side bands resulting from the modulation of the spurious signals. The improvement in picture quality in a system with a coherent headend will depend upon the relative threshold of intermodulation and cross modulation distortion. A problem with the coherent headend would be in the case where it was desired to phase lock to two or more "off air" channels (VHF broadcast) in a high signal level area, only one channel could be used. The most practical way to deal with the intermodulation problem is to consider it when designing a system to insure that the picture quality is not degraded by the intermodulation.

TABLE 1

THIRD ORDER SPURIOUS

NO. OF CHANNELS	CHANNELS	CENTER CHANNEL	MAX.NO.ON CENTER CHANNEL $2f_1 \pm f_2$	$f_1 + f_2 \pm f_3$	TOTAL EQUIVALENT TRIPLE BEAT
0	0	0	0	0	0
1	13	13	0	0	0
2	12-13	13	0	0	0
3	11-13	12	0	1	1
4	10-13	12	1	2	2.25
5	9-13	11	2	4	4.5
6	8-13	11	2	7	7.5
7	7-13	10	2	11	11.5
8	I-13	10	3	15	15.75
9	H-13	9	4	20	21
10	G-13	9	4	26	27
11	F-13	8	5	33	34.25
12	E-13	8	5	40	41.25
12 STD	2-13	10	2	19	19.5
13	D-13	7	6	47	48.5
14	C-13	7	6	56	57.5
15	B-13	7	7	65	66.75
16	A-13	I	7	77	78.75
17	A-J	I	8	88	90
18	A-K	I	8	100	102
19	A-L	I	9	112	114.25
20	A-M	7	9	125	127.25
21	A-N	7	10	139	141.25
22	A-O	8	10	157	158.25
23	A-P	8	11	170	172.75
24	A-Q	9	11	187	189.75
25	A-R	9	11	204	206.75
26	6-R	10	12	204	207
27	5-R	10	12	206	209
28	4-R	9	12	212	215
29	3-R	9	12	219	222
30	2-R	8	13	226	229.25

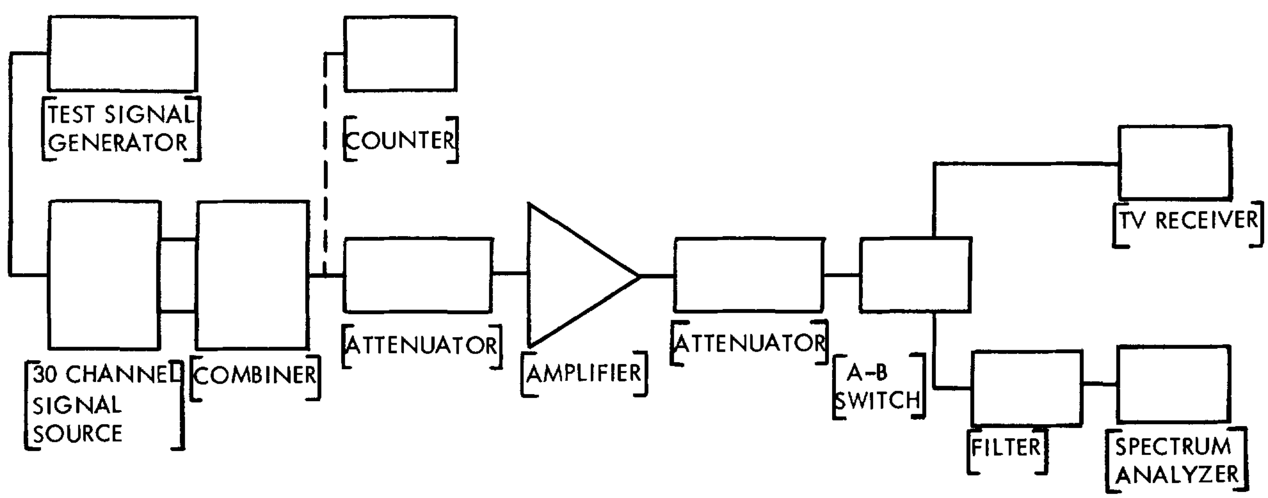
FIGURE 1


CARRIER TO THIRD ORDER INTERMODULATION RATIO (dB)
20 Log N
Slope
CURVE 1
REQUIRED SYSTEM LEVEL OF
INDIVIDUAL TRIPLE BEATS
10 Log N
Slope
INDIVIDUAL TRIPLE BEAT LEVEL
&
TOTAL THIRD ORDER
INTERMODULATION LEVEL
VS
TOTAL NUMBER OF EQUIVALENT
TRIPLE BEATS PER CHANNEL
BERT ARNOLD
11-1-72
CURVE 2
THRESHOLD LEVEL OF PERCEPTIBILITY OF
TOTAL THIRD ORDER INTERMODULATION
PER CHANNEL
4 9-12
5 8-12
7 7-13
STD-12 2-13
11 H-K
15 B-13
18 D-N
24 A-Q
30 2-R
- # OF CHANNELS
- CHANNELS
TOTAL NUMBER OF EQUIVALENT TRIPLE BEATS PER CHANNEL

APPENDIX A

TEST SET-UP FOR TRIPLE BEAT MEASUREMENT

EQUIPMENT:	MANUFACTURER:	MODEL:
30 MODULATORS	EiE	CTMI
1 NTSC TEST SIGNAL GENERATOR	Tektronix	R140
1 COUNTER	Eldorado	1450
2 COMBINERS	EiE	151125-1
2 ATTENUATORS	Texscan	SA-78
1 TEST AMPLIFIER (HYBRID MODULE)	TRW	CA613
1 A-B SWITCHES	EiE	AB5-75
1 TV RECEIVER	RCA	XL-100
1 SET OF FILTERS	Hamlin	BPF10
1 SPECTRUM ANALYZER	H.P.	8554L/8552A



APPENDIX B

TEST CHANNEL FREQUENCIES

CHANNEL	FREQUENCY MHz	Δf khz
2	55.2515	+1.5
3	61.2469	-3.1
4	67.2449	-5.1
5	77.2480	-2.0
6	83.2493	-0.7
A	121.2469	-3.1
B	127.2492	-0.8
C	133.2423	-7.7
D	139.2461	-3.9
E	145.2504	+0.4
F	151.2496	-0.4
G	157.2504	+0.4
H	163.2503	+0.3
I	169.2493	-0.7
7	175.2407	-9.3
8	181.2450	-5.0
9	187.2421	-7.9
10	193.2452	-4.8
11	199.2500	0.0
12	205.2396	-10.4
13	211.2500	0.0
J	217.2497	-0.3
K	223.2476	-2.4
L	229.2454	-4.6
M	235.2428	-7.2
N	241.2464	-3.6
O	247.2517	+1.7
P	253.2520	+2.0
Q	259.2550	+5.0
R	265.2521	+2.1

APPENDIX C

DETERMINATION OF SYSTEM TRIPLE BEAT

FROM FIGURE 1

Example

Let's assume that an operator plans to operate his system with 24 channels, A-Q, on one cable. The determination of the system triple beat (carrier to triple beat ratio) is as follows:

In Table 1

The first column is labeled "Number of Channels." Find 24 channels in this column and read across to the last column labeled "Total Equivalent Triple Beat" to find the total number of equivalent triple beats that the center channel has.

From Table 1

24 channels = 189.75 spurious signals on the center channel 9.

In Figure 1

The Horizontal Axis is labeled "Total Number of Equivalent Triple Beats per Channel" and the Vertical Axis "Carrier to Third Order Intermodulation Ratio." Find the Horizontal Axis 189.75 spurious signals and the intersection with Curve 1. From the intersection of Curve 1, read across to the Vertical Axis for the triple beat required in a system.

From Figure 1

The system triple beat specification for 24 channels would be approximately 76 dB.

Note:

As mentioned in the text, this specification is for the threshold of perceptibility for unmodulated carriers. If the carriers were modulated there would be an improvement in the threshold, but the amount of improvement would depend upon the characteristics of the modulation. The unmodulated carriers are a worst case condition for viewing third order intermodulation distortion, but it provides for more consistent results just as synchronous modulation does for cross modulation testing. Many systems have been able to operate with a less than worst case triple beat specification mainly because of the modulation carriers, but there is no safety left for variations in system levels due to temperature changes, or aging.

APPENDIX D

DETERMINATION OF SYSTEM TRIPLE BEAT

FROM AMPLIFIER SPECIFICATIONS

Example

Assume a system cascade of 20 trunk amplifiers, one bridger and one distribution (line extender). The number of channels will be 30, Channel 2 through Channel R.

EiE Series 50 triple beat specifications are:

	Triple Beat	Output @300 MHz
Trunk	116 dB	30 dBmV
Bridger	82 dB	47 dBmV
Distribution	88 dB	44 dBmV

The degradation for a 20 amplifier cascade would be 26 dB.

20 Trunk = 116 - 26 = 90 dB

20 Trunk + Bridger = 90 dB + 82 dB = 79 dB

20 Trunk + Bridger + 1 Distribution =
79 dB + 88 dB = 76.5 dB

The system specification of 76.5 dB for practical purposes meets the required triple beat specification in Figure 1 of 77 dB.

If 2 distribution amplifiers are cascaded the levels can be reduced 2 dB to maintain the specification.

20 Trunk + Bridger + 2 Distribution
= 90 dB + 86 dB + 92 dB + 92 dB = 76.6 dB

Note: See note in Appendix C.

REFERENCES

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