A New Approach to Evaluating CATV System Triple Beat Performance

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As the number of channels carried by a CATV system increases much past twelve, the predominant distortion limiting performance changes from Cross Modulation to Triple Beat products. The mathematics of Triple Beat build-up and its characteristics are briefly reviewed for background. Experimental data on triple beat measurements using various techniques is then presented to illustrate the problems and limitations of current test methods as related to practical system design and operation. Based on further experimental work, a new approach to evaluating CATV system triple beat performance will be discussed, which yields a test technique whose results may be directly correlated to visible degradation of the received picture.

Triple Beat distortion in CATV systems is not something new, but rather has been with us all along. It was just not recognized as such and was generally referred to as "busy background". The recent emphasis on triple beat performance in the industry is due to the increase in the number of channels carried by modern systems, since as the number of channels carried by a CATV system increases much past twelve, the predominant distortion limiting performance changes from cross modulation to triple beat products.

Mathematically, the beats are caused by third order distortion in an amplifier, and are of the form $F_1 \pm F_2 \pm F_3$ and $2F_1 \pm F_2$ where F_1, F_2 and F_3 are discrete frequencies. Cross modulation is a special case of third order distortion where the modulation from one carrier is transferred to another carrier.

It has, therefore, been suggested from time to time that the individual triple beat level, relative to the desired carrier, be established as a more fundamental criterion of amplifier and/or system performance. The question is, what criteria should govern? If we relate to the 51 dB NCTA cross modulation visibility threshold, the corresponding triple beat threshold is given by:

$$(\text{Triple Beat})_{\text{Threshold for X-Mod}} = [\,51 + 20 \log (N-1)\,]\ \text{dB} \qquad (1)$$

where N is the number of channels.

This relationship will generally over-estimate the triple beat requirement since the measured NCTA cross modulation is rarely as bad as one would predict based on a measured triple beat and a simplified theoretical relation between triple beat and cross modulation. [1]

Another approach is based on Arnold's observation [2] that the threshold for picture degradation due to triple beat is given for $B > 50$, by $53 + 10 \log B$, where B is the number of beats falling in the "worst" channel. We will shortly show that $B = 0.034N^{2.6}$ is a fair approximation for the standard channel selections. Thus,

$$(\text{Triple Beat})_{\text{Threshold for Triple Beat Noise with CW Carriers}} = [\,38 + 26 \log N\,]\text{dB}\ (N > 15) \qquad (2)$$

(1) "The Decibel Relationship Between Amplifier Distortion Products" - K. E. Simons, Proc. IEEE, 58, P 1077 (July 1970).

(2) "Required System Triple Beat Performance" - B. Arnold, Dec. 1972.

Yet a third equation is found in the Netherland PTT CATV System Technical Requirements. This states that:

$$(\text{Intermodulation})_{\text{Level below carrier}} \leq [45 + 25 \log N] \text{ dB} \quad (3)$$

Figure 1 is a plot comparing equations (1) through (3). Note that in order to correctly predict the cross-over between triple beat and cross modulation visibility threshold, equation (1) would have to be dropped 4 to 5 dB. It appears that equation (3) is too severe a criterion although it does have nearly the same slope as equation (2).

Returning to the relationship between number of beats and number of channels, consider the case where the channels are spaced at regular 6 MHz intervals without any gaps. Figure 2 shows that the number of beats is then approximately proportional to N to the 2.2 power ($N^{2.2}$). However, if the standard 12, 21, and 35 channel configurations including channels 5 and 6 are considered, there are fewer beats for a given number of channels(3), and the number of beats is approximately proportional to N to the 2.6 power ($N^{2.6}$). One would expect that as the number of channels becomes very large the 2.6 power curve will asymtotically approach the "no-gap" case wiping out the effects of channel 5 and 6 and the FM band.

For any specific channeling plan, of course, the exact number of beats can be determined on a computer. We have run such a program for a thirty channel system, channels 2-13 and A-R, with three pilot carriers, the results of which are shown in Table 1. For all practical purposes, the results are typical of a 33 channel system. From the Table, it may be seen that the maximum number of beats occurs in a broad

(3) " Third Order Distortion Buildup in a Multi-Channel Cascade" - R. Bell and P. Rebeles, Presented at 1973 NCTA.

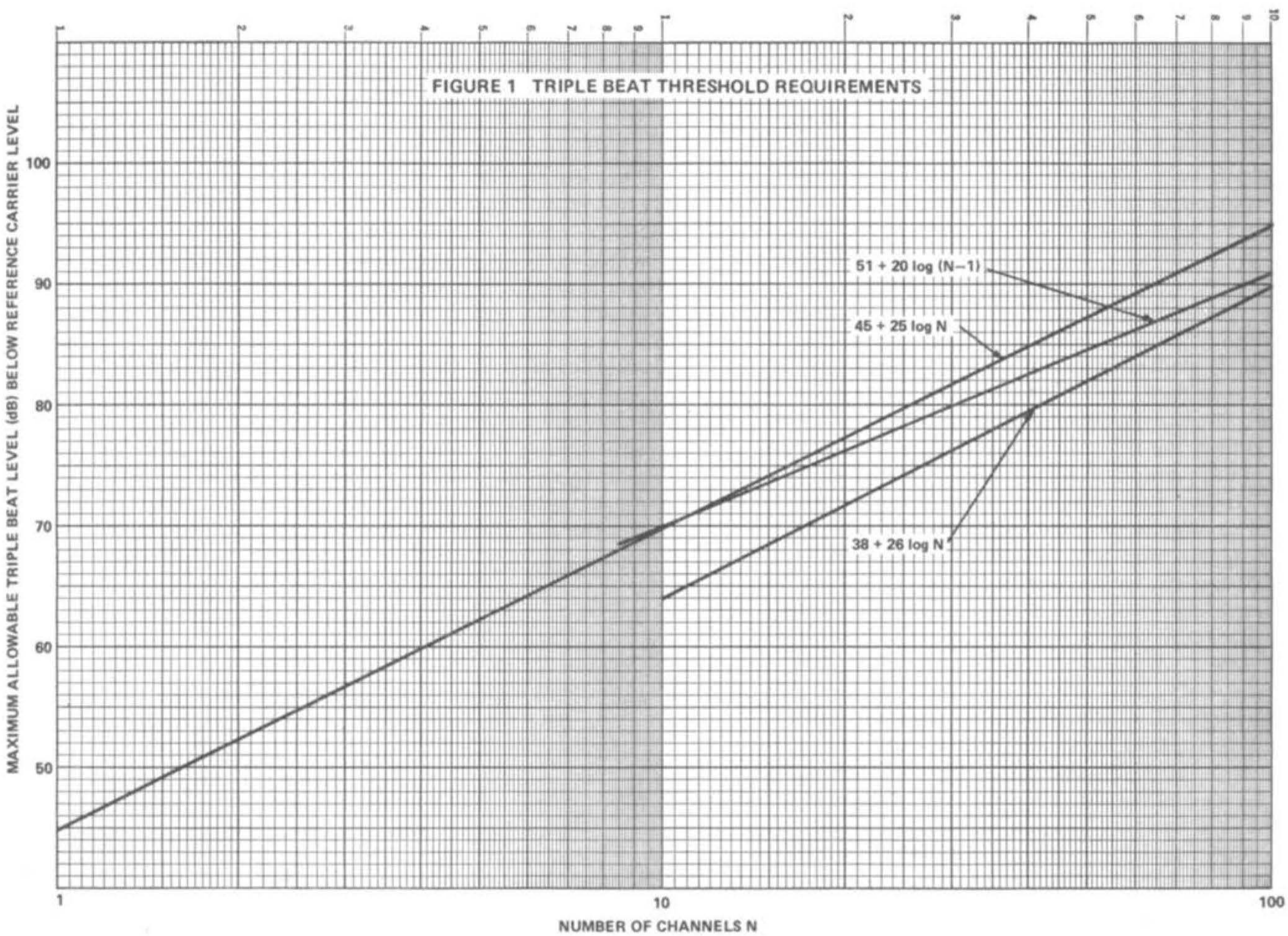
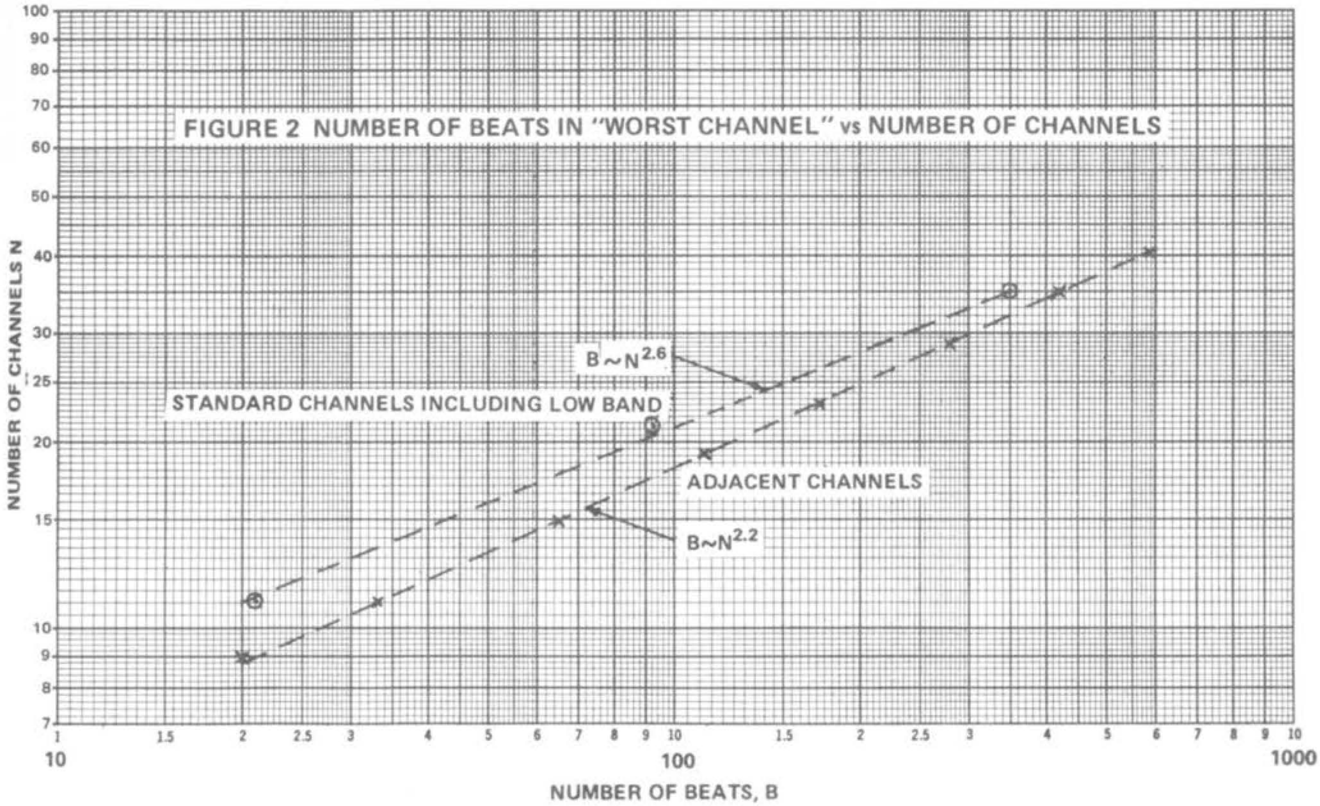


FIGURE 1 TRIPLE BEAT THRESHOLD REQUIREMENTS



area around channels 7 through 10, and further, that approximately 88% of them occur at the carrier frequency.

We now have some conflicting theoretical number for required triple beat performance and some idea of the number of beats in the "worst case" channel. The next question, of course, is how do these numbers correlate with the visual effects observed in a multi-channel system. Unfortunately, the answer is "a little bit, but not very much."

In order to understand this it is necessary to examine some of the factors associated with three carrier triple beat measurements.

First, there are no industry standards or procedures for this type of test. Thus, it is possible for different people to make these tests using different techniques and come up with completely different answers, which makes comparing specifications or system performance impossible. A good example of this is in calibration where there are currently three popular approaches.

(a) Use of a field strength meter or other receiver to feed an audio wave analyzer, using 100% square wave modulated signals such as NCTA cross modulation as a reference. This is a fairly convenient technique, but can yield errors up to 4 dB since the reference is a double sideband signal, whereas the beat appears as a single sideband. It also requires manually scanning the wave analyzer to locate the beat, which can be very frustrating.

(b) Insertion of another CW signal set a known amount below the carrier, usually 40 dB, and offset in frequency by a small amount to establish a reference on the audio wave analyzer. This is quite accurate but very time consuming. You still have to manually scan for the beat.

(c) Direct observation on a spectrum analyzer. Dynamic range is a problem here and it is difficult to observe close in beats. There is also a question of how much of the beat is generated in the test equipment.

TABLE I

THIRD ORDER BEAT PRODUCTS

Channels

2 through 13
A through R

Pilot Carriers

109.25
271.25
301.25

CHANNEL	$F_1 \pm F_2 \pm F_3$		$2F_1 \pm F_2$		TOTAL	
	At Carrier	In Channel	At Carrier	In Channel	At Carrier	In Channel
2	135	228	10	18	145	246
3	146	237	10	15	156	252
4	154	243	11	17	165	260
5	27	253	0	17	27	270
6	27	258	0	19	27	277
A	237	297	13	16	250	313
B	247	304	12	15	259	319
C	254	308	14	19	268	327
D	262	313	12	15	274	328
E	266	314	14	17	280	331
F	272	319	13	14	285	333
G	275	320	15	17	290	337
H	280	324	13	15	293	339
I	282	325	14	16	296	341
7	287	326	13	17	300	343
8	285	326	15	16	300	342
9	286	324	14	19	300	343
10	285	323	15	18	300	341
11	284	322	14	16	298	338
12	282	318	15	18	297	336
13	278	314	14	17	292	331
J	274	308	15	20	289	328
K	270	304	14	16	284	320
L	265	297	15	19	280	316
M	260	293	14	17	274	310
N	253	287	15	20	268	307
O	247	282	14	17	261	299
P	239	274	14	18	253	292
Q	231	265	14	19	245	284
R	220	256	14	18	234	274
TOTAL	7,110	8,862	380	515	7,490	9,377

A second factor is the choice of frequencies used to make the measurement. An amplifier's triple beat performance is not constant over its operating frequency range.

A third factor is that in normal system operation, signal tilt is employed. This greatly complicates the question of what is an acceptable triple beat level, as is illustrated in Table II.

The first column in Table II is a list of the specific triple beats measured in a typical 16-amplifier cascade. Note that with channels 2, 3 and 4 a difference product in the low VHF band was measured as well as a sum product in the high VHF band. Column 2 is the measured beat level for each group in dB down from the desired carrier. Column 3 is the measured beat level in dB down when each group was set for the tilt, but not the level, that it would have in normal operation. Here we can see that this cascade changes 2 for 1 in beat level with system level quite nicely, even though the levels are substantially above normal. Column 4 shows the calculated beat level which results when the system is derated on a 2 for 1 basis to normal operating levels. It was not possible to actually measure these due to the dynamic range limitation of the test equipment. Finally, column 5 shows the beat level calculated back to a single amplifier at normal levels.

By examining this Table we can see that what appeared to be reasonably consistent performance when everything was measured at a constant level, became a large spread in numbers when reduced to an operational mode. It also points out that the effective operational triple beat performance becomes worse with increasing frequency. This is to be expected since third order distortion does increase with increasing frequency in both discrete and hybrid amplifiers.

One final factor which becomes evident from Table II is that it is generally necessary to use elevated levels in order to get a measurable single beat. In the case of a single amplifier, this may be a substantial amount, driving the amplifier into a completely unrealistic operating mode and generating even higher order distortion products. The multiplying effect of a cascade permits more realistic operating levels, but not too many people can build long enough cascades for practical equipment evaluation.

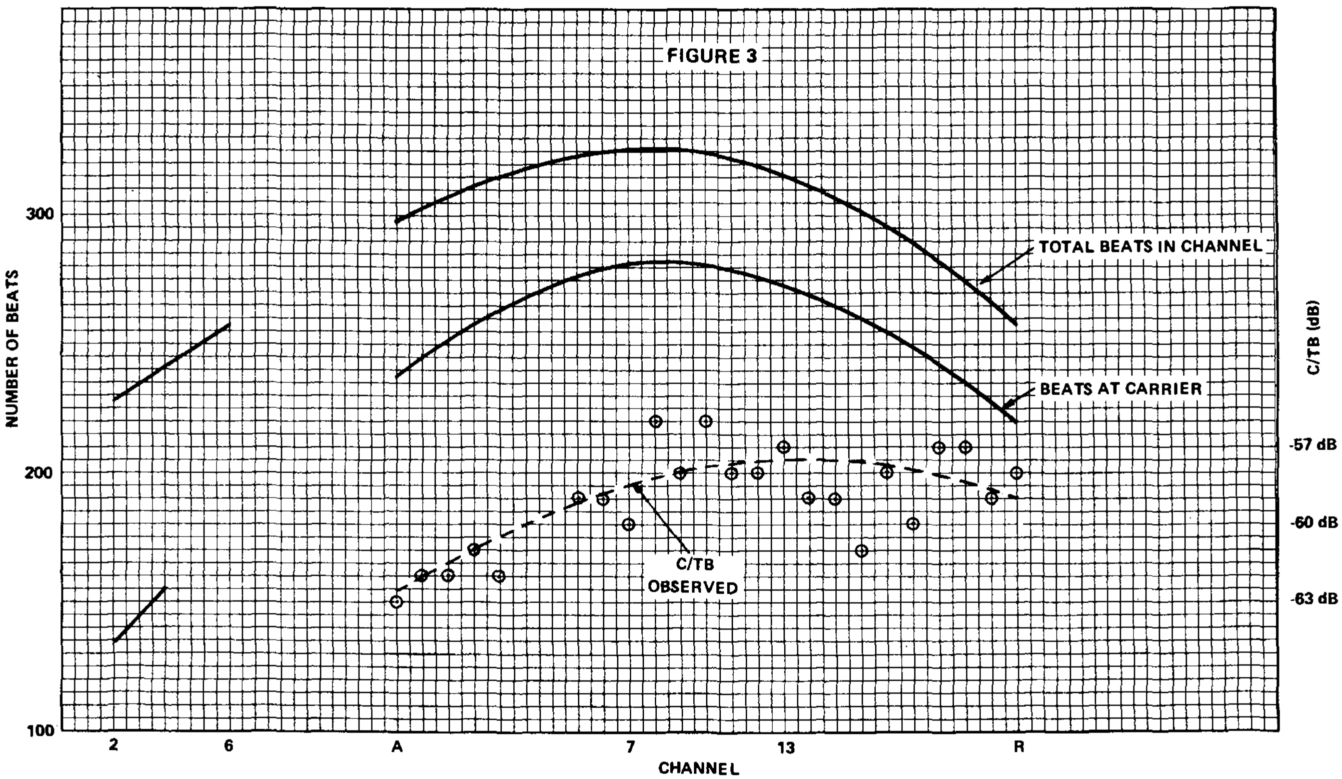
In view of the above factors, plus a lot more experimental data, we at Theta-Com concluded that three carrier triple beat numbers were for all practical purposes, of little value in system design, and that there had to be a better way to handle the problem. The approach we decided to take was very similar to that used in the early 1950's to establish the criteria for cross modulation performance. Namely, to set up an operating system, and, using a large number of observers, determine the visual threshold for triple beat, as well as the tolerance range. Then, using these conditions, devise a measurement technique which would accurately represent the visual effect.

You will recall that in Table I we saw that the number of beats varied from channel to channel and reached a maximum at approximately channels 7 through 10 for a 30 channel system. This data is shown again in Figure 3. From this we selected channel 7 for our test channel, since it is in the maximum beat area, would not require a converter ahead of the TV set, and was not a local channel.

TABLE II

MEASURED TRIPLE BEAT (16 Amplifier Cascade)

Channel	Output Levels @ +40 dBmV	Output Levels @ +40/43/45/47 dBmV	Derate to Normal Level	Single Amplifier
2 + 4-3 on 3	-60	-60	-90	-114
G + I-H on H	-58	-53	-83	-107
9 + 13-11 on 11	-56	-46	-76	-100
S + U-T on T	-54	-40	-70	-94
2 + 3 + 4 on 8	-65	-70 Below Ch. 8	-100 Below Ch. 8	-124 Below Ch. 8



A 32 amplifier cascade, with bridger and two line extenders was then set up for the test. Twenty-nine channels of off the air video from our headend were fed into the system, with channel 7 fed from a modulator with test patterns to obtain a clean, steady signal. A Sony Trinitron receiver/monitor was used as the TV set.

The procedure was then to observe the TV set and adjust the system levels as a group, until triple beat interference was just on the threshold of visibility. This was done with people who could be classed as trained observers (critical viewers), and average viewers.

A first cut measurement was then made by using a standard 600 KHz bandwidth signal strength meter to make a carrier to "Triple Beat Noise" ratio measurement by measuring the peak carrier level and then measuring the noise with channel 7 removed, but all other carriers on. The result, for trained observers, was a carrier to triple beat noise ratio of 46 dB. (The term carrier to triple beat noise ratio quickly degenerated to carrier to garbage, but that is not very technical). The carrier to thermal noise ratio, uncorrected, under the same conditions was 48 dB, so we were not very far above thermal noise, but it was measurable, and repeated very well.

This procedure was then repeated with a spectrum analyzer using various bandwidths, sweep rates and filters to obtain better noise discrimination. As would be expected, the threshold number varied quite a bit depending on the control settings selected, but again, for a given set of conditions, yielded consistent numbers with trained observers. It was also noted that all of the near carrier beats fell in the range of ± 20 KHz from the carrier, which is in line with the expected range of ± 40 KHz which could be expected from standard FCC channel assignments. Figure 4 shows the triple beat noise spectrum as displayed on a Hewlett-Packard 8554L/8552B spectrum analyzer with the following control settings:

Bandwidth	1 KHz
Sweep Width	10 KHz/Div.
Scan Time	0.1 Sec./Div.
Video Filter	Off
Scan Mode	Internal
Scan Trigger	Automatic
Storage Mode	

For contrast, Figure 5 shows the same measurement with 20 channel loading and Figure 6 with 12 channel loading.

All 30 channels were then examined with the

FIGURE 4

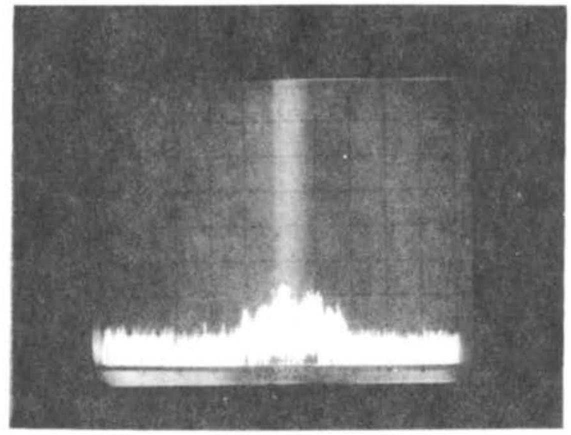


FIGURE 5

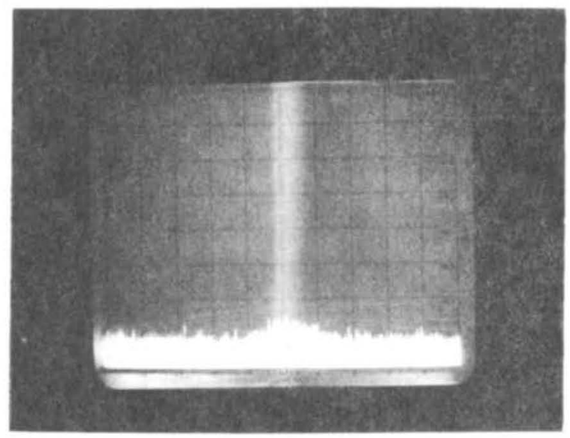


FIGURE 6

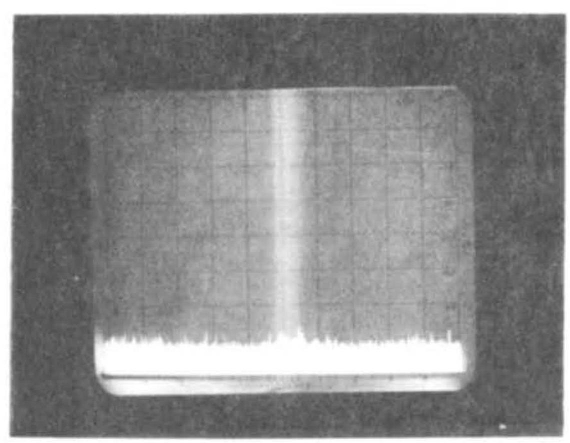


TABLE III

CARRIER TO TRIPLE BEAT NOISE RATIO

30 Channels

Channel	Condition 1		Condition 2	
	Beat (-dB)	Noise (-dB)	Beat (-dB)	Noise (-dB)
2	-	-67	-67	-69
3	-	-63	-63	-65
4	-	-64	-63	-67
5	-	-65	-68	-68
6	-	-65	-65	-68
A	-63	-67	-61	-70
B	-62	-67	-59	-70
C	-62	-67	-57	-69
D	-61	-66	-56	-68
E	-62	-66	-57	-70
F	-61	-66	-55	-70
G	-60	-66	-54	-68
H	-59	-64	-54	-67
I	-59	-65	-54	-67
7	-60	-66	-55	-69
8	-56	-65	-53	-68
9	-58	-64	-53	-66
10	-56	-64	-52	-66
11	-58	-64	-54	-66
12	-58	-63	-54	-64
13	-57	-63	-53	-65
J	-59	-64	-55	-68
K	-59	-64	-55	-67
L	-61	-66	-57	-69
M	-58	-64	-54	-66
N	-60	-64	-56	-67
O	-57	-62	-51	-64
P	-57	-61	-52	-63
Q	-59	-63	-55	-66
R	-58	-62	-54	-65

spectrum analyzer to determine if they followed the pattern predicted by the computer analysis. Two conditions were used. 1) with the system levels set for threshold on channel 7, and 2) with the system levels elevated 3 dB. These results are shown in Table III and also in Figure 3.

The plotted data shows some scatter, which may be due in large part to the visual integration required with the spectrum analyzer display. However, it does generally follow the predicted curve up to the maximum in the channel 7 to 10 region, but does not roll off as fast at higher frequencies as predicted by the computer data. Visual check of all channels also confirmed the plotted data as near as could be seen. The apparently poor values at channel 8 and 10 could not be confirmed visually, and may have been due to off the air pickup, as these are local channels.

During the observer portion of the visual tests for the threshold and tolerance, several interesting characteristics of triple beat were noted:

1. With a test pattern and a trained observer, the break between non-visible and visible beats is quite sharp, about 1 dB in signal level change.

2. With off air pictures and a trained observer, the threshold signal level is about 1 dB higher than the test pattern case, but still quite sharp.

3. With off air pictures and an average observer, the threshold signal level is about 2 dB higher in signal than for a trained observer.

4. Average viewers felt the picture was better (up to a point) with signal levels higher than a trained observer's threshold. This apparently is because these people are more tolerant of "busy background" than they are of thermal noise.

All of the above tests for threshold and measured beats were done with video modulated carriers. Since this is not practical for field testing, the use of CW carriers was investigated. Again, the procedure was to observe a test pattern on channel 7, but with 29 CW carriers on the other channels. The CW levels were then varied relative to the channel 7 level until the same visual effect was noted. The carrier to triple beat ratio was then measured with the signal strength meter and the spectrum analyzer with the result that the visual effect and measured numbers were the same when the CW carriers were 3 dB below normal carrier levels. Thus, this technique is practical for field use with relatively simple equipment, and is being used for proof-of-performance testing in several Theta-Com turnkey projects. The criteria for acceptance is a 46 dB carrier to triple beat noise ratio, with the measured carrier at normal level and the remaining CW carriers 3 dB lower in level, using a signal strength meter.

While the technique of measuring carrier to "triple beat noise" ratio with full channel loading shows great promise for determination of this important parameter, there is a great deal of work to be done before it can be considered as an industry standard. Such factors as measurement bandwidth, dynamic range, detector characteristics and readout, must all be investigated more and correlated with visual observations. Threshold limits with specific instrumentation must be determined and perhaps even special instrumentation designed.

In addition, the technique must be extended to measurement of individual pieces of equipment so that they can have meaningful specifications. And those specifications must have significance to the system designer so that he can predict final system performance.

In conclusion, we have found that:

1. Three carrier triple beat measurement has limited use in determining equipment and system performance.

2. A carrier to triple beat noise measurement can be related to actual system performance and further that the industry should proceed in this direction toward establishment of standards.