PERFORMANCE OF A 400 MHz, 54 CHANNEL, CABLE TELEVISION DISTRIBUTION SYSTEM

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ABSTRACT

A summary of extensive tests of a 400 MHz, two-way sub-split distribution network is given. Data includes noise performance, frequency response, and distortion measurements. Subjective evaluations of the television picture quality are also given.

The distribution system consists of a 20 amplifier trunk cascade and a bridger, taps and line extender. Each station was fitted with standard equipment and accessories as would be encountered in a typical field installation. The entire distribution system was installed in an environmental chamber and tests were performed from -40°F to 140°F.

A complete TV headend system with 54 forward and four reverse channels fed the distribution network. Television signals were obtained off the air, from satellite video receivers and test generators. Tests were conducted for standard and harmonically-related-carrier (HRC) frequency assignments. Of particular interest is the comparison of performance when phase locked and non-phase locked.

INTRODUCTION

At Scientific-Atlanta, a 400 MHz headend and distribution system was constructed for engineering tests, evaluation, and customer demonstration. With this complex, tests can be conducted under controlled conditions and a variety of experiments can be performed that would be inconvenient or impractical in a field installation even before commissioning the system. A summary of the more important tests that were made is the subject of this paper. Tests of the headend are not addressed since it consists of standard equipment (except for hyper-band LO units) that have been operational at 300 MHz for a number of years. Likewise, performance of the 5-30 MHz sub-split reverse system is the same as for 300 MHz reverse systems and is not discussed herein. All 400 MHz distribution equipment employed for these tests was assembled with standard production run Scientific-Atlanta products.

System Description

Before discussing the performance of the distribution system, a brief description of the system complex is in order. In the headend, television programming originates from an earth station with 16 video channels and off the air with four VHF and four UHF channels. Each of these video channels is processed by two modulators to provide 48 TV channels. These are supplemented with teletext and test patterns for a total of 50 channels in the harmonically-related-carrier (HRC) frequency plan. Phase locked and non-phase locked operation is employed. In addition, a 54 channel Matrix Electronics Multiple Frequency Signal Generator (in the standard frequency plan) supplied carriers for CW distortion tests.

The trunk cascade consists of 20 trunk stations, each interconnected by 0.5 inch gas injected dielectric cable with 22dB loss at 400 MHz. Each trunk station includes a dual-pilot control and a sub-split reverse amplifier. The feeder, which consists of 8 taps (each separated by 1dB of cable), an in-line equalizer, and one line extender is driven from the bridger in the last trunk station. The entire trunk cascade and feeder system operates in an environmental chamber with capability of operation from -40°F to over 140°F.

The trunk amplifier is a conventional two-hybrid design. All fixed cable equalization (plug-in equalizers and pads) is at the input to the first hybrid. Automatic-gain-control (AGC) and automatic-slope-control (ASC) circuits are included in the interstage network between hybrid amplifiers. Provisions are included for plug-in interstage trim networks which may be used to make small corrections to the cascade response. Gain of the trunk amplifier is 22dB in the normal operating configuration. Normal operating level is 33dBmV at the high channel with 3dB cable-equivalent tilt.

The bridger and line extender operate at a level of 46dBmV at the high channel with 7dB tilt. The line extender includes a thermally-compensated slope and gain control designed to compensate for 10dB of cable loss and 8 taps, or an equivalent mixture of cable and tap loss.

AMPLIFIER SPECIFICATIONS

	Trunk Station	Trunk with Bridging Station	Line Extender
Typical Operating Gain	22dB	35dB	29dB (max.)
Noise Figure	11dB	14dB	12.5dB
Output Level	33dBmV 3dB Tilt	46dBmV 7dB Tilt	46dBmV 7dB Tilt
Composite Triple Beat (54 Channel)	-82dB	-59dB	-61dB
Cross Modulation (54 Channel)	-85dB	-61dB	-64dB
Second Order	-83dB	-64dB	-73dB

Amplifier Specifications

Abbreviated specifications for the trunk amplifier, bridger, and line extender are given below. These specifications apply for all equipment in its normal operating configuration at 68°F.

Trunk tilt was chosen to provide constant carrier-to-noise ratio. Since all fixed equalization precedes the first hybrid amplifier (the trunk amplifier response is essentially flat with no equalization added), a tilt of 3dB is required to overcome the higher noise figure and circuit loss at 400 MHz. The bridger and line extender operate with 7 dB tilt to overcome feeder cable and tap losses.

Calculated Performance

From the above unit specifications, performance of the distribution system can be calculated by noise-power addition of uncorrelated components and voltage addition of distortion components which maintain the same phase relationship in each amplifier. Since the preponderance of third-order distortion terms (Fa+Fb-Fc, and 2Fa-Fb) add in phase in a linear-phase cascade,[1] composite-triple-beat and cross-modulation components are added on a voltage basis. Second-order distortion is accumulated on a power basis. With these assumptions, the computed system performance is given below.

TABLE 1

CALCULATED SYSTEM PERFORMANCE

	TRUNK CASCADE ONLY				TRUNK CASCADE + BRIDGER STATION				TRUNK CASC + BRIDGER + 1 LINE-X CASCADE			
CSC	C/N	X/M	2ND	CT/B	C/N	X/M	2ND	CT/B	C/N	X/M	2ND	CT/B
1	59.0	-85.0	-83.0	-82.0	56.0	-61.0	-64.0	-59.0	53.2	-56.4	-63.5	-53.9
2	56.0	-79.0	-80.0	-76.0	54.2	-60.5	-63.9	-58.4	52.2	-56.0	-63.4	-53.6
3	54.2	-75.5	-78.2	-72.5	53.0	-60.0	-63.9	-57.8	51.4	-55.7	-63.4	-53.3
4	53.0	-73.0	-77.0	-70.0	52.0	-59.5	-63.8	-57.3	50.7	-55.4	-63.3	-53.0
5	52.0	-71.0	-76.0	-68.0	51.2	-59.0	-63.8	-56.8	50.1	-55.2	-63.3	-52.6
6	51.2	-69.4	-75.2	-66.4	50.6	-58.6	-63.7	-56.4	49.6	-54.9	-63.2	-52.4
7	50.5	-68.1	-74.5	-65.1	50.0	-58.2	-63.7	-55.9	49.1	-54.6	-63.2	-52.1
8	50.0	-66.9	-74.0	-63.9	49.5	-57.8	-63.6	-55.5	48.7	-54.4	-63.2	-51.8
9	49.5	-65.9	-73.5	-62.9	49.0	-57.5	-63.6	-55.1	48.3	-54.1	-63.1	-51.5
10	49.0	-65.0	-73.0	-62.0	48.6	-57.1	-63.5	-54.7	47.9	-53.9	-63.1	-51.3
11	48.6	-64.2	-72.6	-61.2	48.2	-56.8	-63.5	-54.4	47.6	-53.6	-63.0	-51.0
12	48.2	-63.4	-72.2	-60.4	47.9	-56.4	-63.4	-54.0	47.3	-53.4	-63.0	-50.8
13	47.9	-62.7	-71.9	-59.7	47.5	-56.1	-63.4	-53.7	47.0	-53.2	-62.9	-50.6
14	47.5	-62.1	-71.5	-59.1	47.2	-55.8	-63.3	-53.3	46.8	-52.9	-62.9	-50.3
15	47.2	-61.5	-71.2	-58.5	47.0	-55.5	-63.3	-53.0	46.5	-52.7	-62.9	-50.1
16	47.0	-60.9	-71.0	-57.9	46.7	-55.2	-63.2	-52.7	46.3	-52.5	-62.8	-49.9
17	46.7	-60.4	-70.7	-57.4	46.4	-54.9	-63.2	-52.4	46.0	-52.3	-62.8	-49.7
18	46.4	-59.9	-70.4	-56.9	46.2	-54.7	-63.2	-52.1	45.8	-52.1	-62.7	-49.5
19	46.2	-59.4	-70.2	-56.4	46.0	-54.4	-63.1	-51.9	45.6	-51.9	-62.7	-49.3
20	46.0	-59.0	-70.0	-56.0	45.8	-54.2	-63.1	-51.6	45.4	-51.7	-62.6	-49.1

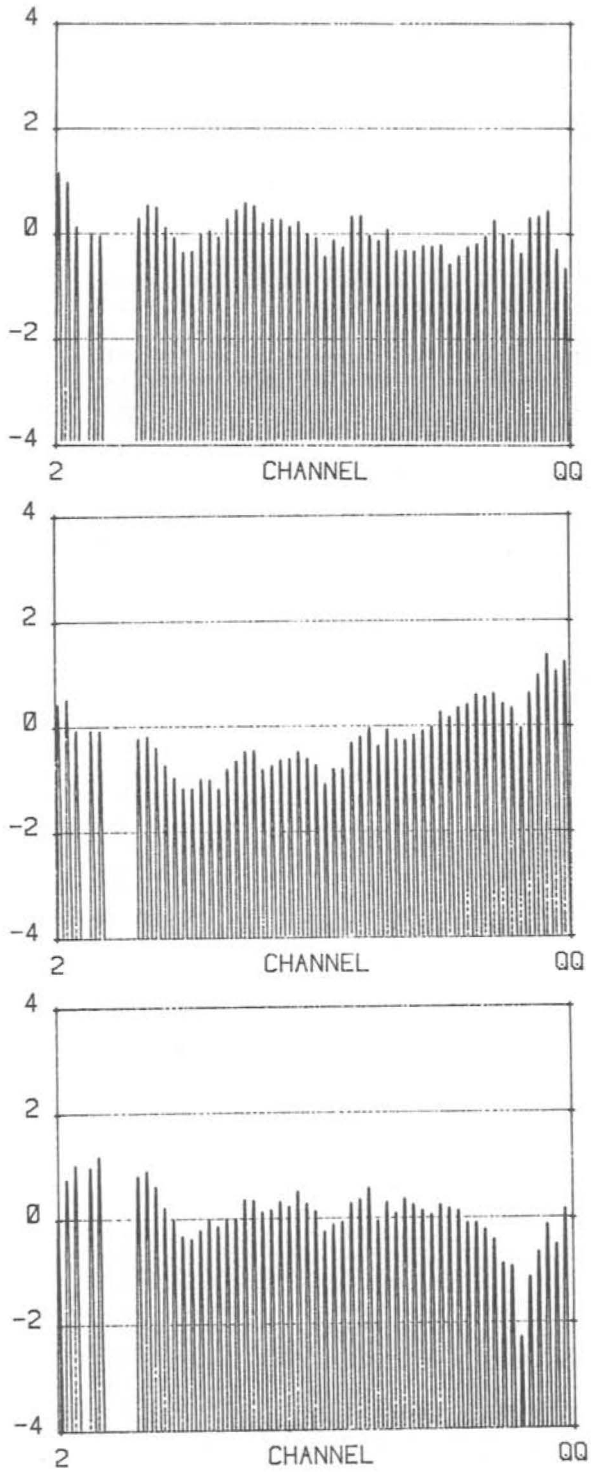

Figure 1. Trunk Response
Top: 140^{0}F Center: 68^{0}F
Bottom: -40^{0}F

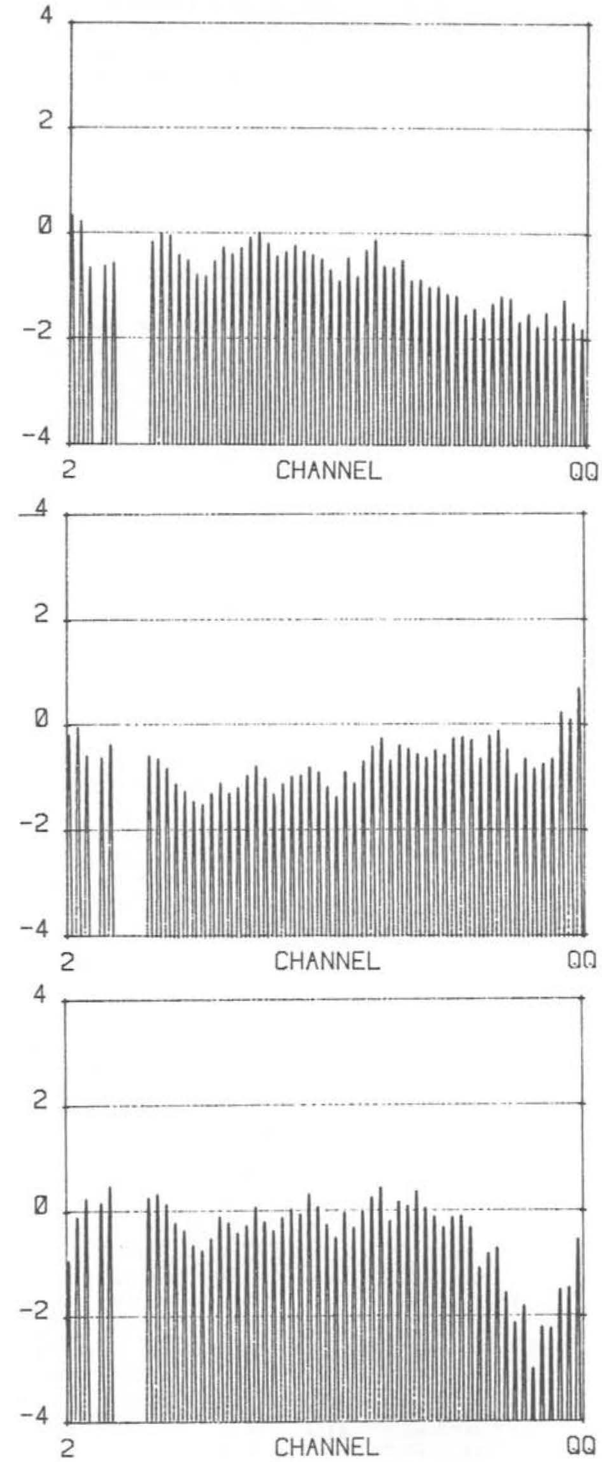

Figure 2. Bridger Response
Top: 140^{0}F Center: 68^{0}F
Bottom: -40^{0}F

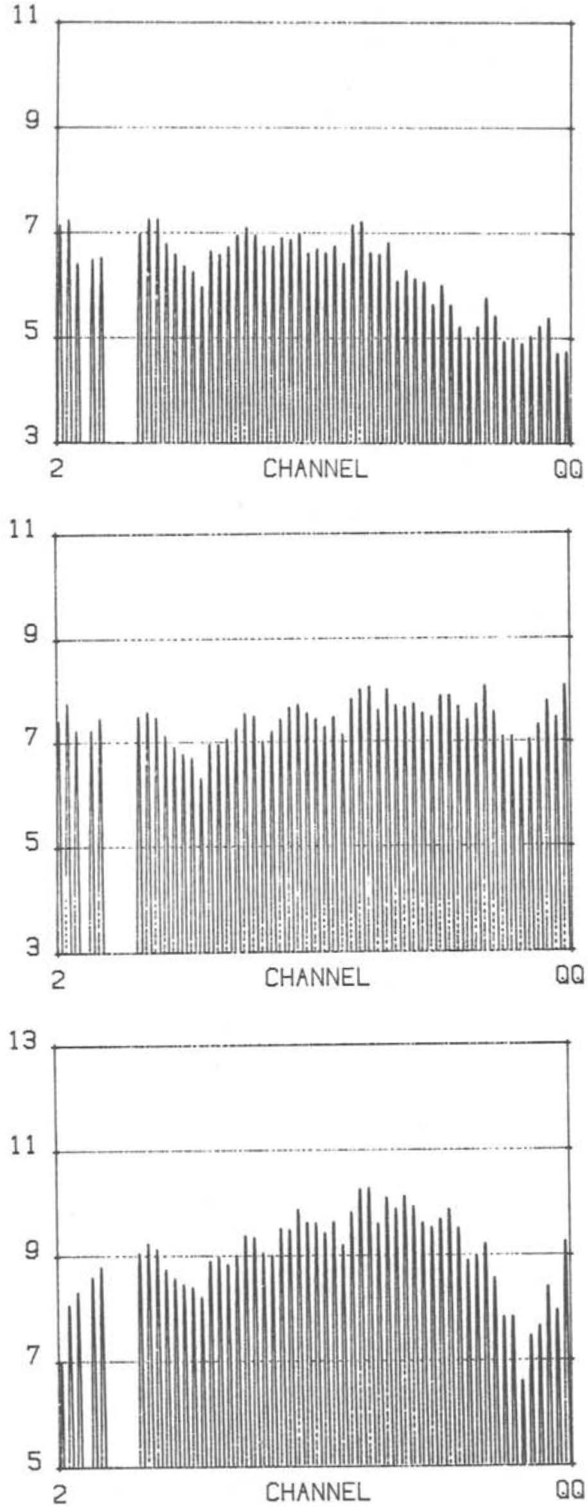

Figure 3. Tap Response
Top: 140°F Center: 68°F
Bottom: -40°F

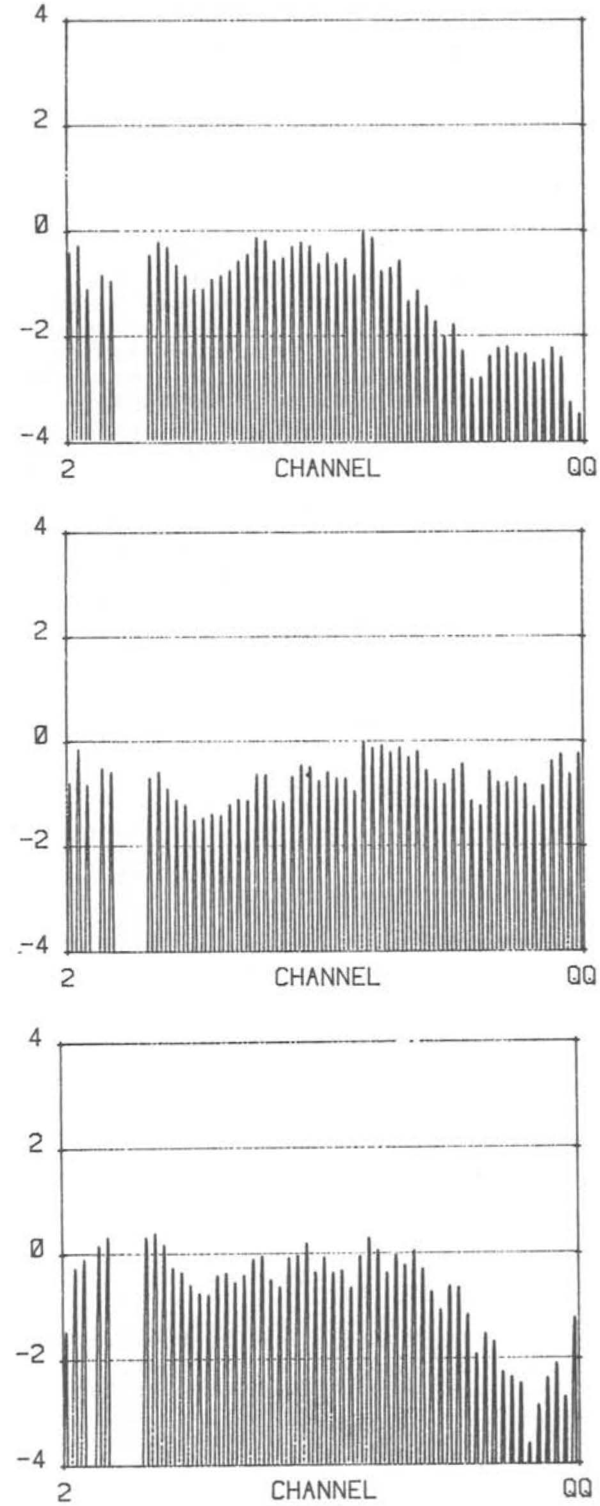

Figure 4. Line Extender Response
Top: 140°F Center: 68°F
Bottom: -40°F

MEASURED PERFORMANCE

Frequency Response

Plots of the trunk, bridger, tap and line extender are given in Figures 1-4 for temperatures of -40°F, 68°F and 140°F. These responses were recorded through a tilt correction network to remove the nominal system tilt. The 0dB reference on each scale represents the nominal signal level. The scale for the tap output is the tap level in dBmV. Response of the trunk cascade within ± 1dB was achieved with five interstage trim networks, four of which are low-frequency peak networks that compensate primarily for diplex-filter cross-over loss, and one broad-band "dish" network (a mid-band dip with peaks at low and high ends). As seen in Figure 1, the response of the trunk cascade remains nearly constant from -40°F to 140°F. The line extender contains a thermal gain and slope network to compensate for approximately 4dB total change in high-frequency loss of the feeder network over the temperature range. The response of the total cascade to the line extender output is within 4dB peak-to-valley over the temperature range.

Carrier-to-Noise Ratio

Carrier-to-noise ratio is plotted in Figure 5. The results agree well with the predicted performance - approximately 1.5dB better than calculated at 68°F, and constant to within 1.5dB. The carrier-to-noise ratio decreases as temperature increases due to the increased cable loss and increase in noise temperature of the cable and lossy circuit elements. However, the main source of output noise are the hybrid amplifiers, and those devices operate at elevated temperature. The separation of the high-temperature and low-temperature curves of Figure 5 follows that expected from noise temperature calculations.

Composite-Triple-Beat

Composite-triple-beat is measured as the ratio of the average power of all beats at the carrier frequency to the carrier power with all carriers unmodulated. These triple-beat measurements were made in the standard frequency assignments (carriers not phase locked) and, therefore, do not include second-order beats. Plots of the composite-triple-beat are given in Figure 6. The cascade performance is well behaved and 2-3dB better than predicted by the amplifier specificatios. The plots also show very little change with temperature. Although the maximum number of beats occur on channel 0, that is not necessarily the worst channel. Hybrid "high-frequency effects"[2] produce a weighting factor that is higher at the higher frequencies.

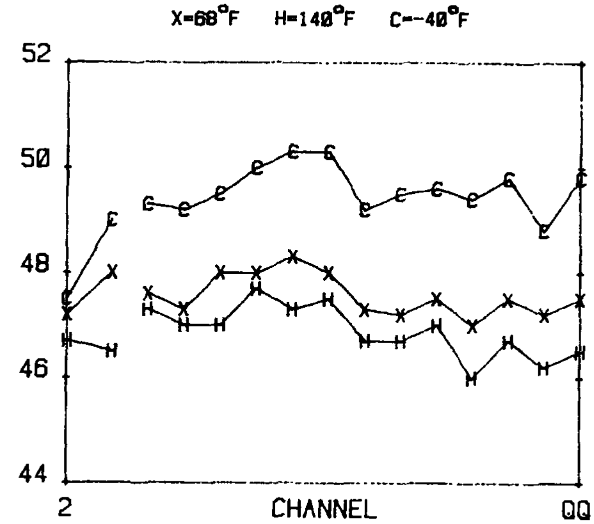

Figure 5. Carrier-To-Noise Ratio (dB)

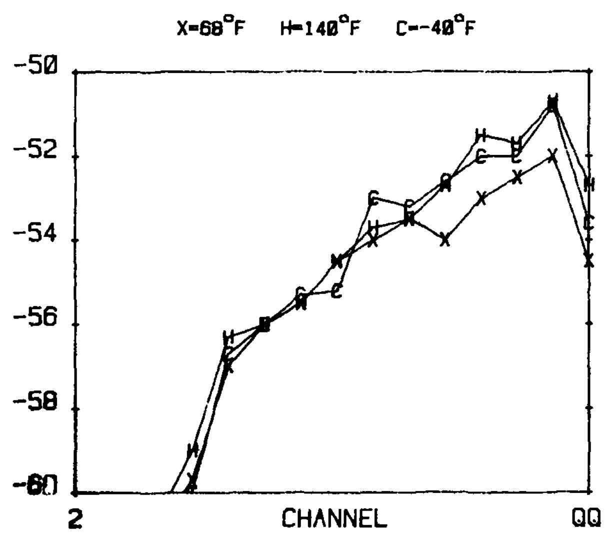

Figure 6. Composite Triple Beat (dB)

Cross-Modulation-Ratio

Cross-modulation-ratio is measured as the ratio of the modulation detected from an unmodulated carrier to the modulation detected in a 100% modulated carrier with all carriers modulated except the one in the channel being measured. Modulation of the triple-beat components also produces modulation noise on the carrier being measured, but when not phase locked, that noise was rejected by the narrow-band selective level meter employed for the test. Plots of the measured cross modulation are given in Figure 7.

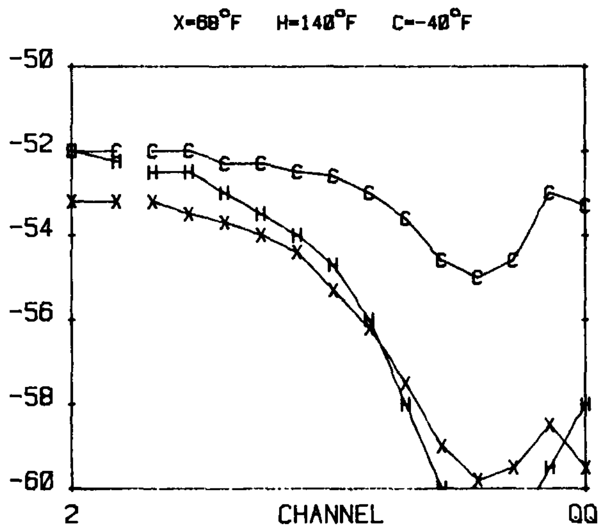

Figure 7. Cross-Modulation Ratio (dB)

Second-Order-Distortion

Second-order distortion causes the sum frequency of two carrier beats to fall 1.25 MHz above another carrier and the difference frequency to fall 1.25 MHz below a carrier in the standard frequency plan. The second-order single beats measured were quite low as seen from the data in the table below. Beats falling on channel QQ were -70dB or lower. In addition to single-beat measurements, composite second-order beat was measured with all carriers on, and this level also was low. The actual power in the channel 2 beat is somewhat higher than measured since the spectrum of the beats is spread and high analyzer resolution had to be used to resolve the beats from noise.

SECOND ORDER DISTORTION

Channel Measured	Carriers On	Second-Order Distortion (dB) -40°F	68°F	140°F
2	HH, QQ	< -69	-66.5	-67
2	All	-69	-66	-65
QQ	2, HH	< -70	< -70	
QQ	10, 12	< -70	< -70	< -70
QQ	All	-62.5	-63	-60

VISUAL TESTS

Visual tests were performed to assess the quality of the TV picture for home viewing and to determine the upper margin of signal level in the trunk system at which distortion becomes perceptible. The set-top terminal and receiver could be switched between the headend output and output of the distribution system for direct comparison. Both television programming and test patterns were observed on a Sony Trinitron. At normal signal levels and under close scrutiny, the author found no significant degradation in picture quality due to distortion with the headend either phase locked or not. Some noise could be seen in the background under close scrutiny. No estimation of noise impairment was made since it was felt that the carrier-to-noise data reported previously would best measure the effect of noise.

Experiments were performed in which the signal level at the input to the trunk was elevated and correlated with the threshold of perception of impairments in the TV picture. Here, the judgment of perception was made by another trained observer. Results of this experiment are plotted in Figure 8. When non-phase locked, interference was first observed as what appeared to be composite triple beat, or dark horizontal streaking in the picture. The threshold level of Figure 8 has the general shape of the composite-triple-beat curve of Figure 6. The shapes of the curves are very similar as they should be for a composite-triple-beat limited system.

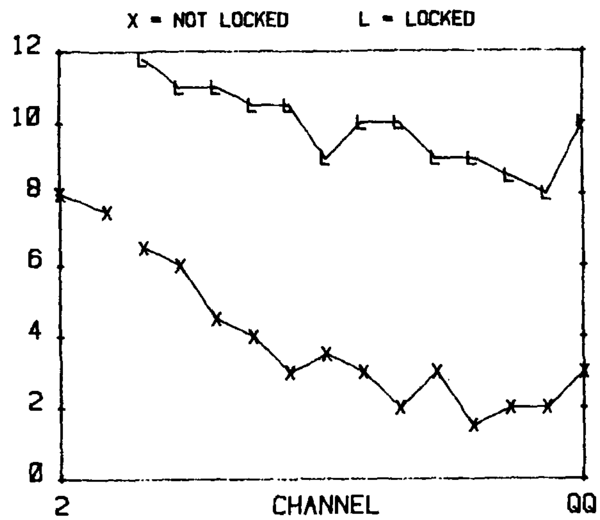

Figure 8. Elevated Level for CTB Threshold of Perception

For the phase locked mode, the signal level could be elevated considerably before distortion could be seen in the test pattern. Distortion first appeared as a hint of frames or sync bars slipping in the background, and occasionally a faint image could be seen. At about the same level, or slightly higher, horizontal streaking similar to triple-beat streaking in the non-phase locked mode could be seen. The threshold for which distortion of either type first appeared is plotted in Figure 8. The improvement by phase locking is clearly evident. The threshold date for Figure 8 was taken on a color bar test pattern.

REMARKS

The tests reported in this paper are evidence to the technical accomplishment of 400 MHz Cable TV. Now a number of similar systems are in operation in major cities and similar results are being experienced. The first 400 MHz system became operational June 30, 1980 in Orland Park, Illinois, and performance of the distribution system as reported to this author has been very good; results are comparable to data presented in this paper. Details on the performance of that system are given in a paper by Gerald Bahr[3] to be presented at the 1981 30th Annual National Cable Television Association Convention.

REFERENCES

1. Bell Telephone Laboratories Technical Staff, "Transmission Systems For Communications," Western Electric Company, Inc., 1971, pp. 320-325.

2. Luettgenau, G. et al, "400 MHz - A Challenge For The Hybrid Manufacturer," 29th Annual NCTA Convention Technical Papers, 1980, pp. 5-8.

3. Bahr, G. et al, "The Design, Construction, Cost, And Performance of the First 400 MHz Cable Television System," 30th Annual NCTA Convention Technical Papers, 1981.