EFFECTS OF NONUNIFORM COAXIAL CABLE ON CATV SIGNAL QUALITY

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Variations in impedance of transmission lines are known to cause degradation of propagated signal quality. Abrupt changes in impedance can cause discrete ghosting to appear in television signals while random combinations of many small impedance changes generally contribute to the overall noise level of transmitted signals. Variations of impedance along the length of a line which recur periodically, seriously disturb only transmitted signals located in a relatively narrow band of frequencies.

The effects of echoes and noise on television picture quality have been reported in the literature over the past 20 years.[1,2,3,4] Cable impedance irregularities have been studied and mathematical relationships between discrete impedance variations and transmission properties have been published during this period.[5,6,7,8,9,10]

Direct relationships between cable impedance irregularities and actual television picture quality are quite complex since different, specific types of irregularities can result in seemingly unrelated forms of picture degradation. Echoes caused by signal reflection from a particular point along a cable can be calculated readily if the reflection coefficient and propagation characteristics of the cable are known. Experiments dealing with ghosting of this type and the effects on CATV systems were reported by Shekel.[11] Effects of randomly related echoes were studied by Ashcroft et al.[12] The direct influence of cable periodicities on picture quality does not appear to be well publicized in the literature and, indeed, may not be well known.

Presented in this paper are results of observations of a monochrome television picture transmitted over coaxial cables disturbed by impedance periodicities. Systematic impedance variations were introduced at controlled levels during the cable manufacturing process. The resonance frequency of the periodicity selected was approximately 83 MHz, a convenient frequency for use with the selected test apparatus. "Equivalent" echo ratings were assigned to the various observed conditions. Similar comparisons were made on signals transmitted through resonant networks. Application of results to CATV system requirements is discussed.

Theoretical return loss and attenuation discontinuity relationships predicted by Fuchs and Peltier[13] are experimentally confirmed as an interesting corollary to this work.

Preparation of Experimental Periodic Cables

A 15.1-inch diameter (47.8-inch circumference) sheave was trued and balanced and equipped with adjustable unbalancing weights. The sheave was installed in the coaxial cable extrusion line, wrapping the bare inner conductor around the sheave at a location prior to entering the extruder crosshead. Introduction of unbalance caused a nearly sinusoidal core diameter variation. A solid polyethylene dielectric and braided outer conductor were employed to enhance the possibility of verifying calculated impedance deviations in terms of cable dimensional variations. Expected values were calculated in accordance with Fuchs' and Peltier's predictions[14] (see Appendix). The braid assured that the core contour was "tracked" by the outer conductor. Diameter and capacitance variations were recorded during extrusion.

Six controlled periodicity levels were produced with a 0.146-inch diameter coax core (nominal $Z_o = 75$ *ohms*). In order to emphasize effects from these periodicities, return loss levels as poor as 9 dB with $\Delta\alpha/\alpha$ discontinuities of 25% were produced. Nominal sections of 40-dB loss at 83 MHz were fabricated (approximately 1300-foot lengths). For comparison to a cable with a different attenuation constant, a similar 40-dB length of 0.285-inch core diameter cable was prepared with a 30% attenuation discontinuity at 82 MHz.

As may be noted in Figures 1 and 2, experimental results agree remarkably well with calculated values for both return loss and concomitant attenuation discontinuities.

Test Method

Equipment connections are shown in Figure 3. All observations were based on viewing a 12x16-inch raster from a distance of 48 inches (in near total darkness). Experience gained through attempts to characterize the picture impairment led to use of three different viewing subjects: (1) a conventional monochrome test pattern, (2) a picture consisting of three vertical lines of approximately 1/8, 3/16, and 1/4 inch as measured on the viewing screen (about 4, 6, and 8 picture elements duration) spaced equidistantly across the field, and (3) a portrait subject providing good detail and serving as a basis for subjective echo ratings.

Two methods of assigning ratings were attempted, both intended to arrive at a number value that could be related to prior work of Mertz, Fowler and Christopher (see references 1 and 2). All comparisons were made by alternately switching the signal through an equal loss path containing a controlled positive echo delayed 3 *μs* from the main signal. Echo ratings are normally referred to a 10-*μs* (or greater) delayed ghost,[15] but results obtained using the 3-*μs* delay should differ by no more than one or two decibels.

Method I

An echo-free picture of the test pattern is viewed while adjusting the television monitor local oscillator frequency. After this adjustment, the vertical line pattern is selected. The test cable and the path with the controlled 3-μs echo are alternately switched while adjusting the controlled echo to the same apparent intensity as the echo caused by the test cable. (Preliminary tests with known signal levels, indicated it possible to alternately view and discern intensity differences of 1 to 3 dB, depending on the gray level.) The delay caused by the test cable is estimated by measurement of the echo displacement as observed on the monitor screen. From the intensity and delay, an equivalent echo rating for long delays is computed by reference to Figure 4 (taken from Mertz's Figure 7, reference 2). It is not likely that the slope of the tolerance-delay curve remains constant at all echo intensities, but data published for 2-μs and 12-μs delays[16] suggest that it may be constant over a range of echo levels judged *just perceptible* to *definitely objectionable* (a range of about 20 dB). For levels around *just perceptible* the bias, if any, should disappear since Figure 4 is based on this tolerance level.

Method II

After completing the set of observations in Method I, a portrait subject is viewed and an echo rating assigned by alternating between the test cable and the path with the 3-μs delayed echo—while adjusting the echo level to produce what is judged an equally objectionable deterioration of quality.

Presumably the results of Method II would be equivalent to those calculated from the data of Method I. However, Method II is wholly subjective and variances with previously established norms may be caused by differences in subject matter as well as viewer opinion.

Method I utilizes features not so subjective, but the geometric forms used may not be translatable to an equivalent level for a viewed picture such as that used in Method II. Mertz[17] showed results obtained by Doba using a picture of small solid rectangles compared with the "normal" tolerance curve. Apparently, the echo threshold level for this type of subject is lower (more sensitive) for long delays. However, at about 3-μs delay, nearly equal sensitivity is indicated. The 3-μs reference delay was selected in an attempt to minimize discrepancies between Methods I and II which might arise because of subject differences.

Qualitative Effects of Cable Periodicities

It was determined that the camera/monitor system could be tuned through a picture carrier frequency range of 80 to 90 MHz with no apparent visual degradation. It seemed reasonable then to consider varying the operating frequency through the band containing the cable discontinuity. This is illustrated in Figure 5 where the cable discontinuity is shown just above the sound carrier. The cable discontinuities studied all exhibited a "bandwidth" of less than a megahertz.

Except for the severity of ghosting, all levels of cable discontinuity exhibited similar characteristics as the frequency was shifted. It is well to note here neither sound carrier nor color subcarrier were present and effects on them would obviously have to be treated as separate cases.

As the discontinuity frequency "moves" into the upper sideband region of the composite television signal, loss of high frequency resolution is evident from inspection of the test pattern. The impairment appears quite evident as the discontinuity center frequency becomes appreciably less than 2 MHz above the picture carrier. As the discontinuity frequency approaches about 1.25 MHz above picture carrier, a distinct ghost appears, delayed by perhaps one picture element (approximately 0.1 μs). As the picture carrier is approached, the echo level and delay both increase, becoming most intense about 0.6 MHz above the carrier. When the discontinuity is at or slightly below the picture carrier, the echo becomes *differentiated*[18] and the degradation of the picture improves noticeably. Below the picture carrier the ghosting becomes negative and the intensity increases until the frequency is about 0.4 MHz below the picture carrier. Negative ghost intensity diminishes rapidly, becoming indiscernible less than 1 MHz below the carrier. With certain qualifications, the peak severity of the negative ghosting is about the same as that observed with peak positive ghosting.

The actual frequency location (with respect to picture carrier) of the various characteristic distortions is undoubtedly related to both television channel bandwidth and the discontinuity bandwidth. Still, it is believed that this same general manifestation would be observed as any discontinuity "drifted" through the television band.

Two additional comments relating to practical aspects of the picture quality: (1) It was observed that positive ghosting (with short-time delay) tended to enhance the contrast of portrait subjects and undoubtedly swayed subjective evaluations of picture quality to the point that trade-offs were made between sharpness of detail and contrast boost. (2) The negative ghosting could be practically eliminated from the monitor by slight downward tuning adjustments without suffering noticeable compromise in picture quality. When observing small discontinuities ($\Delta\alpha$ about 4 dB or less), the negative ghosting was so slight in amplitude and delay, the effect could not be measured as an echo. In fact, compared with a higher loss section or normal cable, the picture could be "matched" to a lower level input signal. Retuning was not permitted for the data reported in the following section.

Discussion of Experimental Results

Three of the six 0.146-inch coaxials with attenuation discontinuities ($\Delta\alpha$) of 2, 7, and 11 dB and one 0.285-inch coaxial with $\Delta\alpha$ of 13.5 dB were selected for detailed study. Equal intensity levels are shown in Figure 6. Delay of the echo at peak intensity levels appeared to be approximately 0.4 μs, ranging from about 0.3 μs for the 2-dB discontinuity to about 0.6 μs for the 11-dB discontinuity. It may also be significant that the peak intensity of the larger $\Delta\alpha$ occurred at a frequency nearest the picture carrier.

Figure 7 shows the intensity levels of Figure 6 redrawn to *equivalent echo rating*, allowing for time delay weighting in accordance with the slope of Figure 4. According to Figure 7 an echo rating of -40 dB would be practically achieved at a 2-dB $\Delta\alpha$ level. The subjective tests (composite results of four observers) of Figure 8 show reasonable agreement near poorest points, particularly for the larger $\Delta\alpha$ levels and indicate better than -40 dB echo rating for $\Delta\alpha$ = 2 dB and $\Delta\alpha$ = 3.5 dB. At small $\Delta\alpha$ levels, positive echoes appeared to enhance picture contrast while negative echoes simply reduced contrast and echoes as such could not be discerned.

A parallel resonant circuit was used to simulate the cable discontinuity. Results were comparable to those obtained with the test cables with regard to general characterization of the discontinuity. By switching in additional circuit loss at each frequency studied, it was varified that the $\Delta\alpha$ effects were independent of total circuit loss. Echo intensity appeared more severe than for a cable with equal $\Delta\alpha$, but this may be a consequence of the greater phase shift exhibited by the network. Phase shift determinations showed approximately 140-degree phase shift over the bandwidth displayed by the network (approximately 2 MHz). The 10-dB $\Delta\alpha$ test cable exhibited no more than 40-degree phase shift over the same frequency range.

These results imply that the effects of the cable periodicities can be interpreted in terms of amplitude and phase deviations and that compensation with lumped (inverse) networks might be feasible as a practical corrective measure in a system. This aspect was not explored in the work presently being reported.

Application to CATV Systems

A published echo rating objective for long-distance television networks is -40 dB.[19] This objective is an all-inclusive performance figure and includes corrections of equalization techniques that might be applied. If the previous results shown for a $\Delta\alpha$ of 2 or 3 dB are accepted as a CATV system objective, the following return loss levels could be permitted (assuming the discontinuity persisted over the *entire* cable system):

Loss at Highest Operating Frequency	*Permissible Return Loss for Periodicities*
100 - 150 *dB*	20 *dB*
200 - 300	23
400 - 600	26
800 - 1200	29

In practical cases, it is not likely that a single discontinuity would persist for cable systems of more than a few hundred decibel loss. The most critical region would be at the highest operating frequency, the total loss diminishing at the lower frequency bands. The return loss required at 50 MHz relative to 200 MHz would be relaxed about 3 dB. Trunk and distribution sections would likely exhibit different sets of characteristic discontinuities since the cable size is usually different, particularly if the trunk is long. Actually, variations between consecutively manufactured lengths of the same type of cable result in noticeable dispersion of discontinuities.

A discontinuity occurring at one frequency (or a limited number of frequencies) known to be peculiar to a specific cable design might be compensated with networks designed for use with that design.

It may be noted that previous studies relating to discrete discontinuities indicate critical return loss requirements (applicable only for that type of discontinuity) occurring at the low-frequency end of the operating range. Return loss requirements are thus limited at high and low frequencies because of different considerations. If results of prior work are accepted without further interpretation, return loss limits because of discrete echoes are generally more critical than limits applicable to periodicities.

It is also interesting to consider that reflections and delay times comparable to those treated in this study can be produced within the confines of a CATV subscriber's tap/drop coax/balun/TV system. Perhaps observations of "soft" pictures observed on CATV systems such as reported by Taylor[20] should be examined with this in mind.

In attempting to assess the total cable contribution to transmission nonuniformity, it would appear that a *trunk* cable with a maximum VSWR of 1.10 relative to 75 ohms (26-dB return loss) over the entire operating frequency range would ensure that the cable did not significantly degrade picture quality in runs extending to losses of 500 (perhaps 1000) dB. *Distribution* cable requirements might be relaxed somewhat since lengthy cascading is not common, but use of the same requirement (26 dB) would be desirable simply to give more margin for the trunk cable tolerance. It may be noted that 20-dB return loss periodicities in drop cable would not produce noticeable effects on picture quality, but discrete discontinuities, both in the cable and terminating devices, could easily negate all of the effort spent in delivering a flawless signal up to that point.

Acknowledgments

The authors wish to acknowledge the contributions of Mr. Paul Wilson in preparing the cable test samples and to Mr. Wilson and Mr. John Micol for their painstaking efforts in compiling test data used for this study.

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APPENDIX

Fuchs and Peltier[21] derived mathematical expressions relating return loss (VSWR) and attenuation to sinusoidal impedance irregularities occurring periodically along the cable length.

At resonance (when $\beta_o h = \pi$), the following relations apply

$$\alpha \doteq \alpha_o \sqrt{1 + u^2}$$

$$\overline{VSWR} \doteq u + \sqrt{1 + u^2}$$

$$\text{where:} \quad u = \frac{\pi}{4\alpha_o h} \quad \frac{\Delta Z}{Z_o}$$

[provided higher order terms of $\frac{\Delta Z}{Z_o}$ *can be neglected]*

α = *attenuation at resonant frequency (Nepers)*

α_o = *normal attenuation constant in the absence of the periodicity*

β_o = *normal phase constant*

h = *period of sinusoidal variation*

Z_o = *normal characteristic impedance*

$\Delta Z = Z_{max} - Z_{min}$ *difference between maximum and minimum local impedance*

For core diameter variations,

$$\Delta D = D_{max} - D_{min}$$

$$Z = \frac{60}{\sqrt{\varepsilon}} \log_e \frac{D}{d}$$

$$\Delta Z = \frac{60}{\sqrt{\varepsilon}} \log_e \frac{D_{max}}{d} - \frac{60}{\sqrt{\varepsilon}} \log_e \frac{D_{min}}{d}$$

$$\Delta Z \doteq \frac{60}{\sqrt{\varepsilon}} \log_e \frac{D_{max}}{D_{min}}$$

$$\Delta Z \doteq \frac{60}{\sqrt{\varepsilon}} \frac{\Delta D}{D} \qquad \text{when} \quad \Delta D \ll D$$

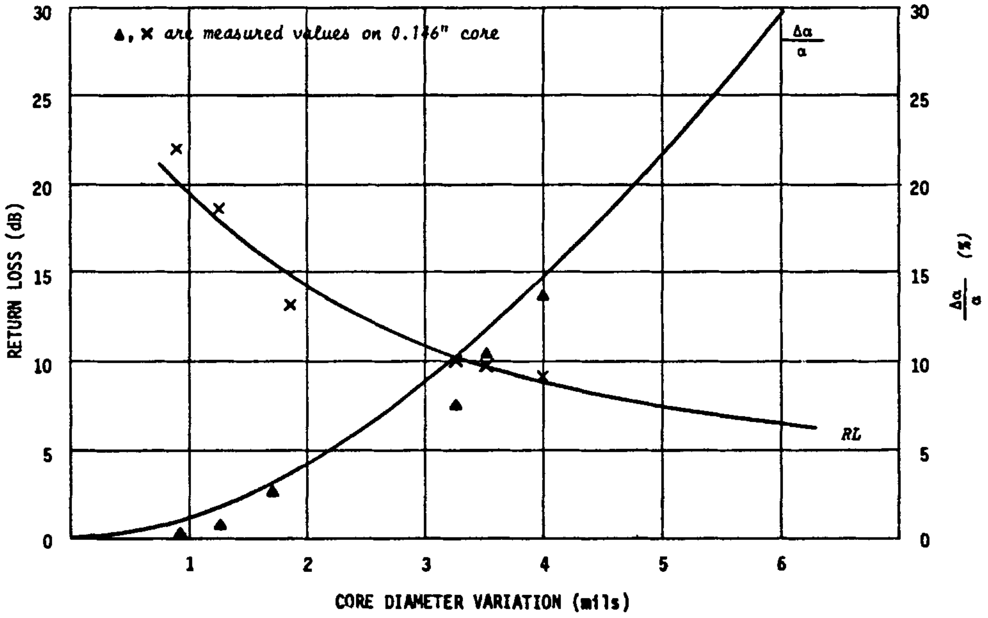

▲, × are measured values on 0.146" core
RETURN LOSS (dB)
30
25
20
15
10
5
0
1
2
3
4
5
6
CORE DIAMETER VARIATION (mils)
$\frac{\Delta\alpha}{\alpha}$ (%)
$\frac{\Delta\alpha}{\alpha}$
RL

FIG. 1

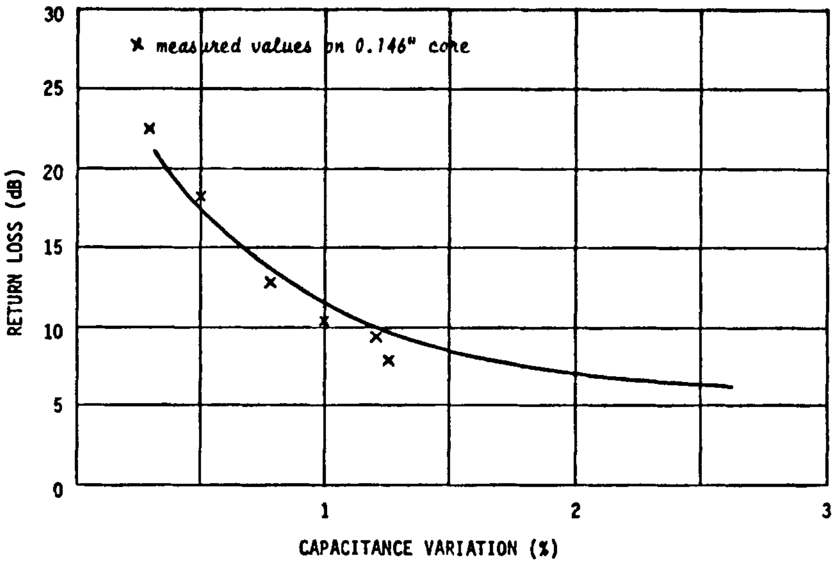

× measured values on 0.146" core
RETURN LOSS (dB)
30
25
20
15
10
5
0
1
2
3
CAPACITANCE VARIATION (%)

FIG. 2

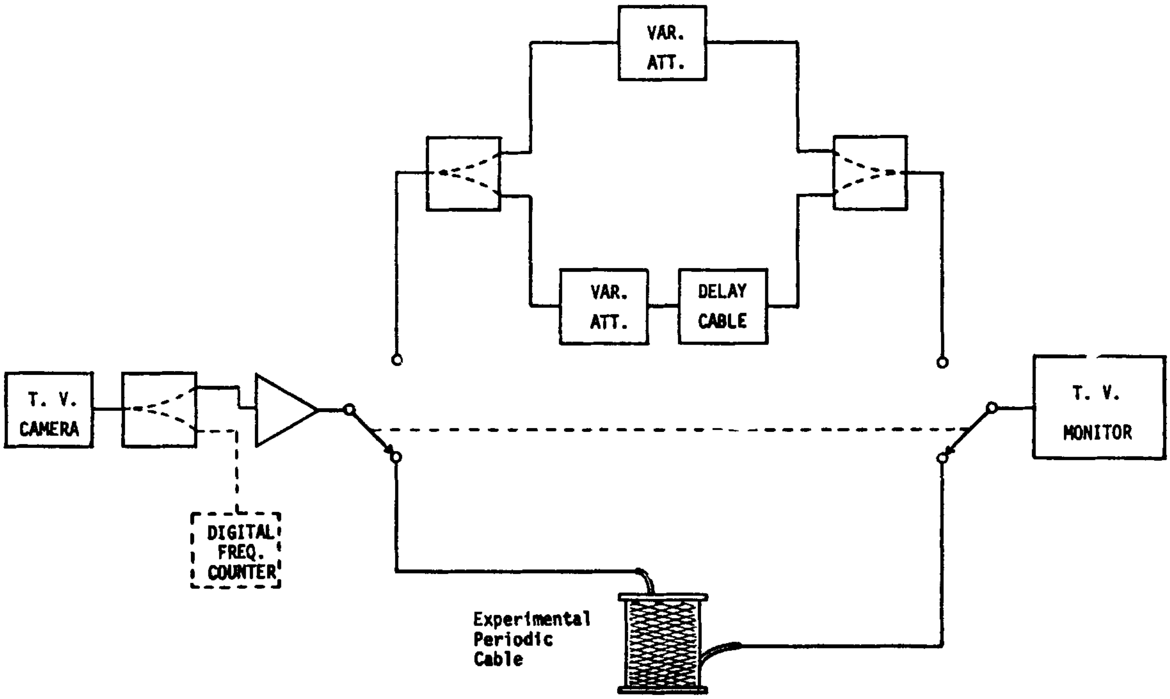

VAR. ATT.
VAR. ATT.
DELAY CABLE
T. V. CAMERA
DIGITAL FREQ. COUNTER
T. V. MONITOR
Experimental Periodic Cable

FIG. 3

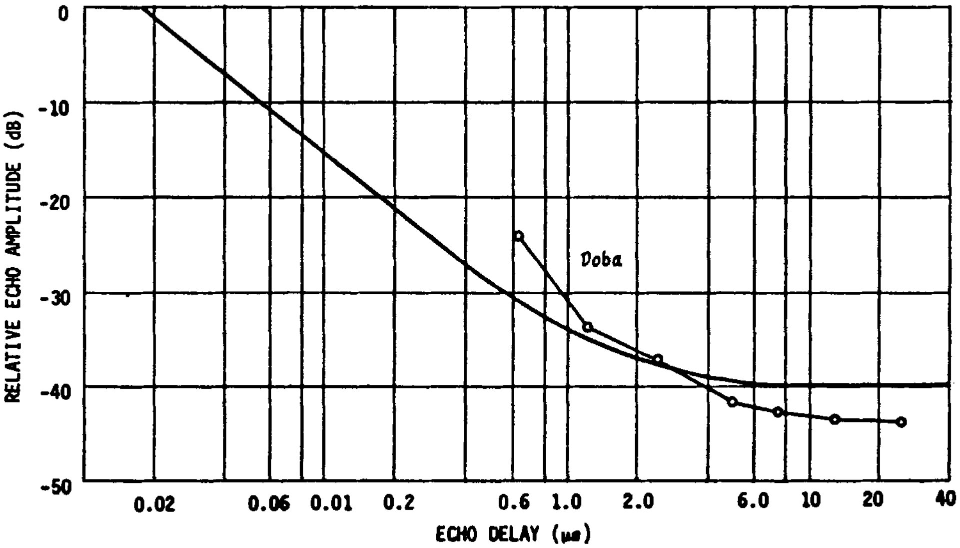

0
-10
-20
-30
-40
-50
RELATIVE ECHO AMPLITUDE (dB)
0.02
0.06
0.01
0.2
0.6
1.0
2.0
6.0
10
20
40
ECHO DELAY (μs)
Doba

FIG. 4

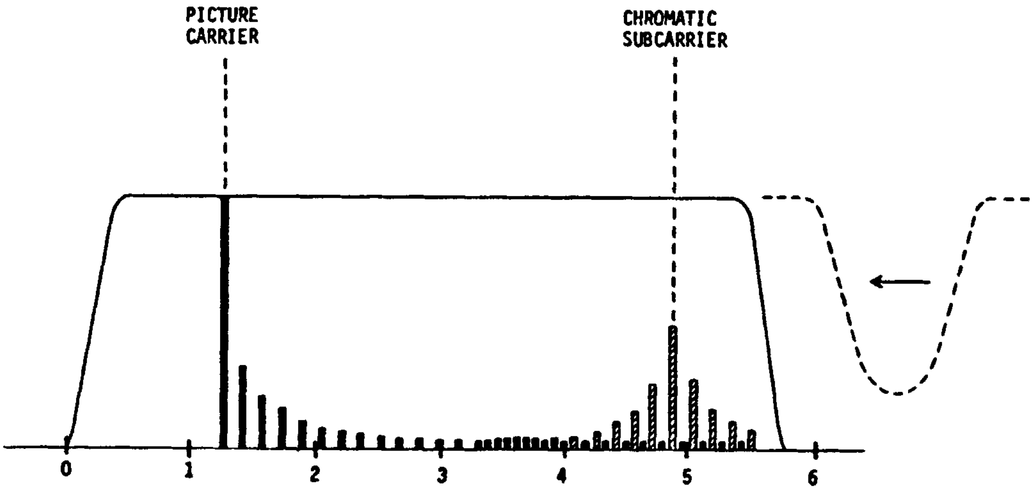

PICTURE CARRIER
CHROMATIC SUBCARRIER
0
1
2
3
4
5
6

FIG. 5

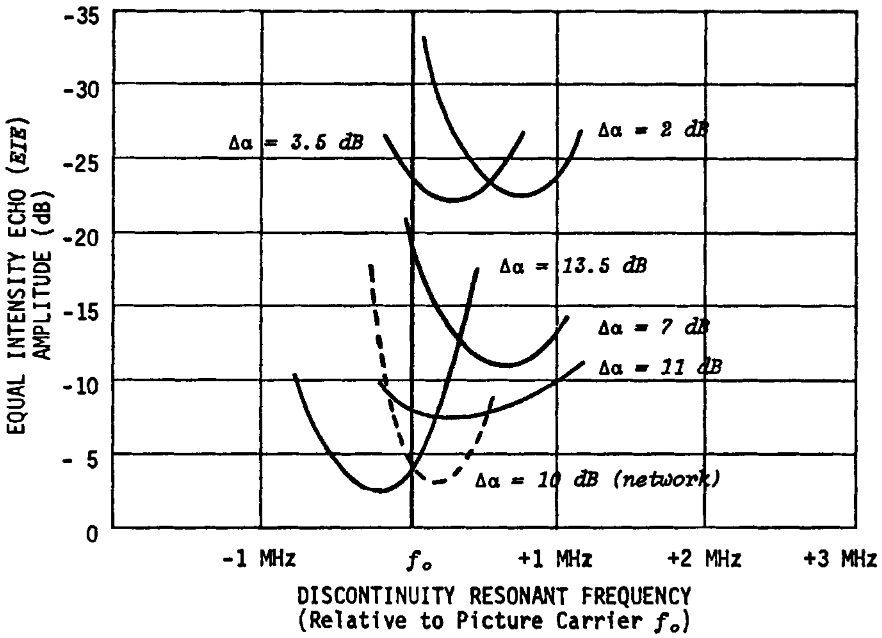

-35
-30
-25
-20
-15
-10
- 5
0
EQUAL INTENSITY ECHO (EIE) AMPLITUDE (dB)
Δα = 3.5 dB
Δα = 2 dB
Δα = 13.5 dB
Δα = 7 dB
Δα = 11 dB
Δα = 10 dB (network)
-1 MHz
f₀
+1 MHz
+2 MHz
+3 MHz
DISCONTINUITY RESONANT FREQUENCY
(Relative to Picture Carrier f₀)

FIG. 6

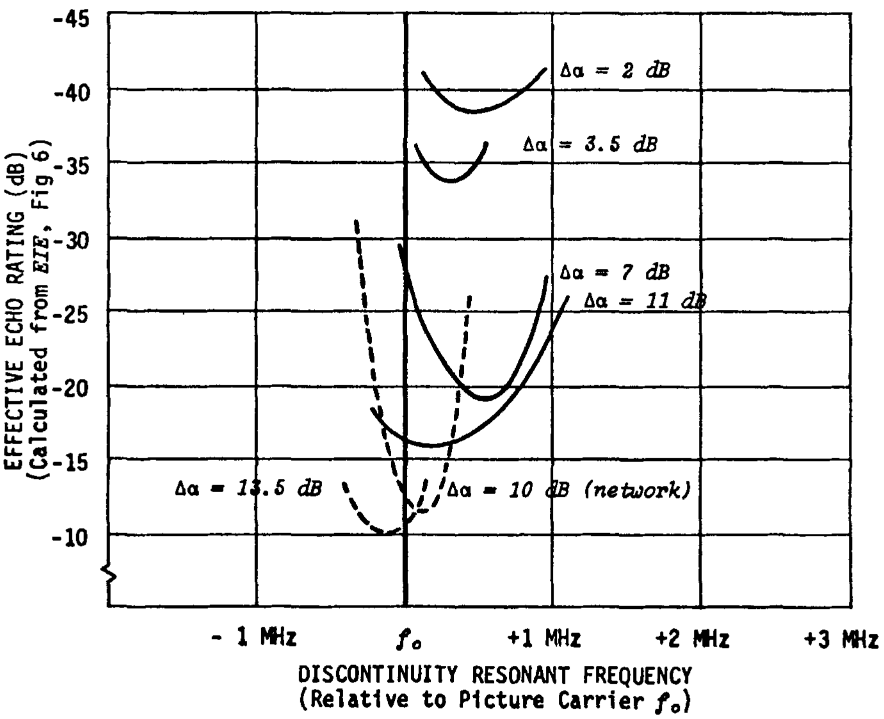
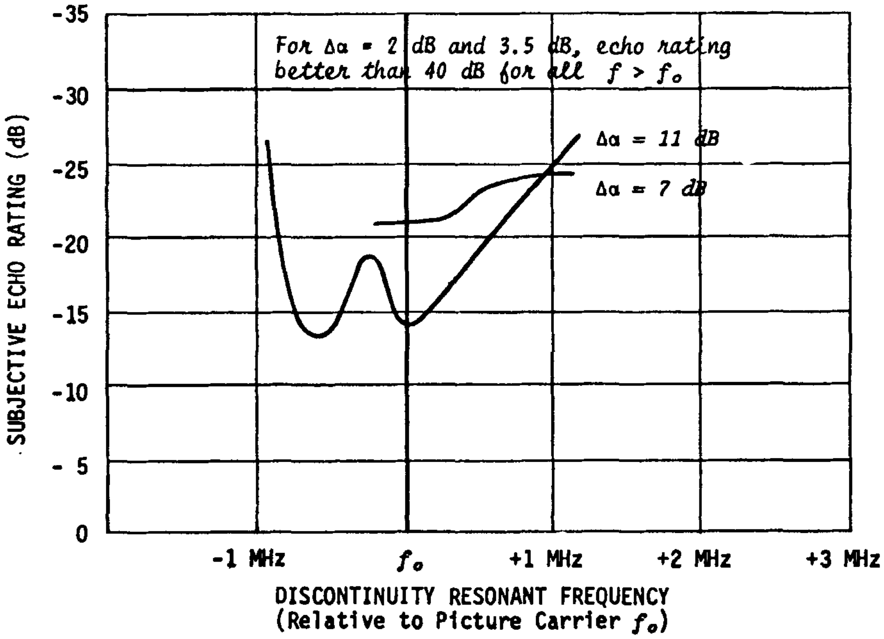


FIG. 7



For Δα = 2 dB and 3.5 dB, echo rating better than 40 dB for all $f > f_o$

FIG. 8

DISCUSSION

Mr. Walter Roberts: Any questions--yes?

Question: Not audible

Mr. Roberts: These would not be weighted in any manner. I think the term "weighting", so far as I know, was used to describe at one time the tolerance that you might have as far as the inherent loss of the cable is concerned. If you looked at a particular cable at say 50 megahertz, you'd have, let's say, 1 dB loss per 100--at 200 you might have 2 dB loss and the effects of a ghost trying to weight both the delay of the ghost and the fact that the signal would be attenuated on the way down to where this ghost might occur and on the way back and in the attempt to weight all these things, you can come up with a minimum value, a worse case, and this gets more tolerant as you go up in frequency. And it gets tolerant to the tune of, what is it, 3 dB per octave or something like that--so at one time we spoke of weighting the return loss to recognize the fact that you could be more tolerant at high frequencies----a ghost or a reflection that was the result of this discreet discontinuity, but if it didn't happen to be a result of that, we don't know if the weighting is valid or not. If you look at the effect we studied here now, the return loss that results from a periodicity not a discreet discontinuity, it goes the other way. Since, in a system that's a 1000 dB long in channel 13, for example, is only 500 dB long in channel 2 for the same return loss would not develop to the half the level for the same percent. So now the upper end becomes more critical. So when I start pondering over that, I say, well, let's forget about weighting--maybe we better just have a weight that we hope will be good enough to assure us of a uniform system at any frequency here and for whatever reason that discontinuity occurs. While we may kind of be experts and be able to make certain adjustments with bridges and say---now there's a periodicity or that's not and we can. It's not a practical matter to sit and make judgment on every stinking length of cable you looked at and decide what kind of discontinuity is for us and whether or not it was serious and so on and so forth. So I think if at all possible, it makes sense to have one number if it's practical and realistic and let that number absorb all these variations and if we're talking something in a 26 or so dB level, I think it's reasonable. If we're talking 32 or 34 from the present state of manufacturing art, I think you'd better be real careful about how you specify it and whether you're worried about one type more than the other and so on and so forth. It gets pretty sticky when you really get down to those levels. Any others?