MATCHING REPEATER AMPLIFIER PERFORMANCE CHARACTERISTICS TO CABLE SYSTEM LEVEL REQUIREMENTS

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INTRODUCTION

A cable television system provides a transmission path from a single signal processing center (traditionally referred to as head end) to multiple subscriber television receivers (Figure 1). The advent of transmission requirements from any point in the cable system back to the signal processing center results in a system with inputs from multiple locations in the cable system converging to a single output from the cable distribution system back to the head end.

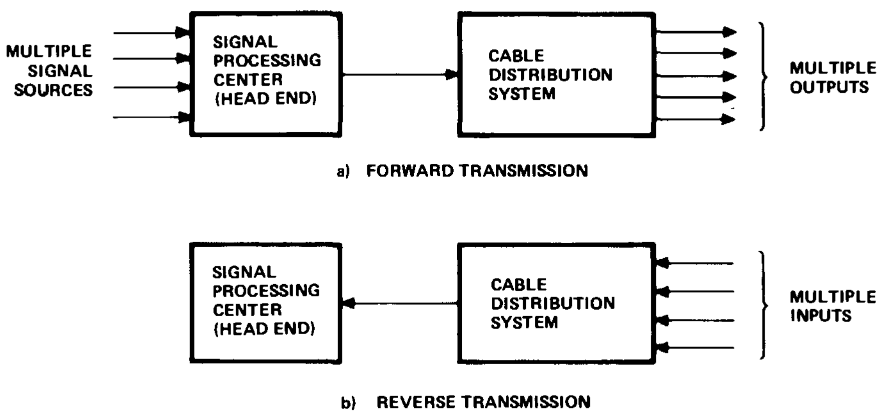


FIGURE 1

Numerous articles have been written on parameters and performance requirements of the cable distribution system. This paper will focus on the television signal level from cable distribution system input (head end output) to its output, the TV receiver input terminal.

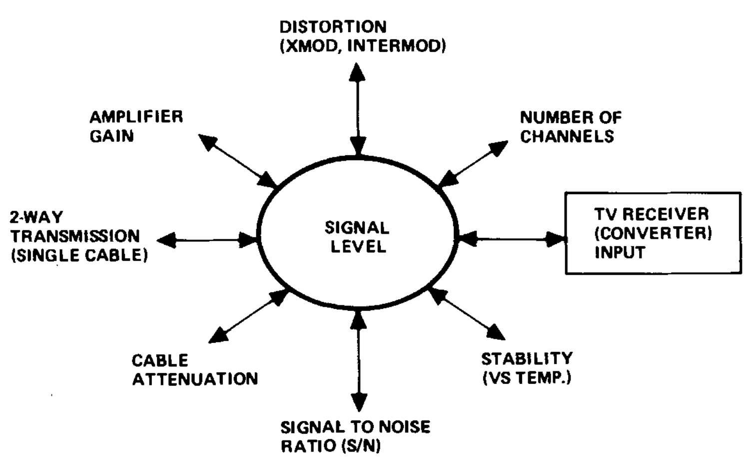
Knowledge of the signal level requirements in the cable distribution system guides the equipment designer to a hardware design which economically matches system requirements and likewise guides the system designer in selection of system components required to meet his system design objectives. Signal level, as the independent variable, determines many component (amplifier, cable, and directional taps) and system design decisions.

After considering the cable system signal level requirements, a coefficient system similar to that described by Carson (Reference 9) is used to exemplify sources of system performance limitations. The coefficient system is useful in weighting the performance of repeater amplifiers which have different operating characteristics.

Signal Level As Related to Equipment/System Parameters

A cable distribution system must deliver television signals to each subscriber's television receiver which produce acceptable pictures. Insight into cable equipment and system design results when the signal transmitted through the cable distribution system is distinguished by both level and quality. Signal level and quality specifications which are necessary to produce an acceptable picture are described in detail in such references as (4), (5), (6), and (7). The purpose of this paper is to show how certain cable amplifier performance characteristics are defined as a result of the television receiver input level requirements, and to relate the signal level to various signal quality performance factors.

A summary of parameters shown in Figure 2 may be viewed as defining cable system signal levels and/or as cable system signal levels defining cable system parameters. The value of these viewpoints will become apparent later.



CABLE SYSTEM SIGNAL LEVEL-CABLE SYSTEM PERFORMANCE PARAMETERS

FIGURE 2

For example, the television receiver or converter must be given multi-channel input signal levels within a given range, assuming acceptable signal quality, to produce an acceptable picture. Distributing a signal level above the minimum value required by the TV receiver or converter unnecessarily increases system cost. Some excellent work has been done (4), (5) in determining the range of levels which should be provided by the cable system to the TV receiver input.

Another example of the importance of selecting system signal levels relates to the system distortion and S/N parameters. The original source of the majority of noise and distortion in CATV equipment is the amplifying device, the transistor. Recent advances in microelectronic circuit technology (1), (2), (11) can allow efficient circuit designs to realize low noise and low distortion performance which are basically device limited. An example of a broadband microelectronic circuit currently used by Anaconda Electronics in production repeater station amplifiers is shown in Figure 3.

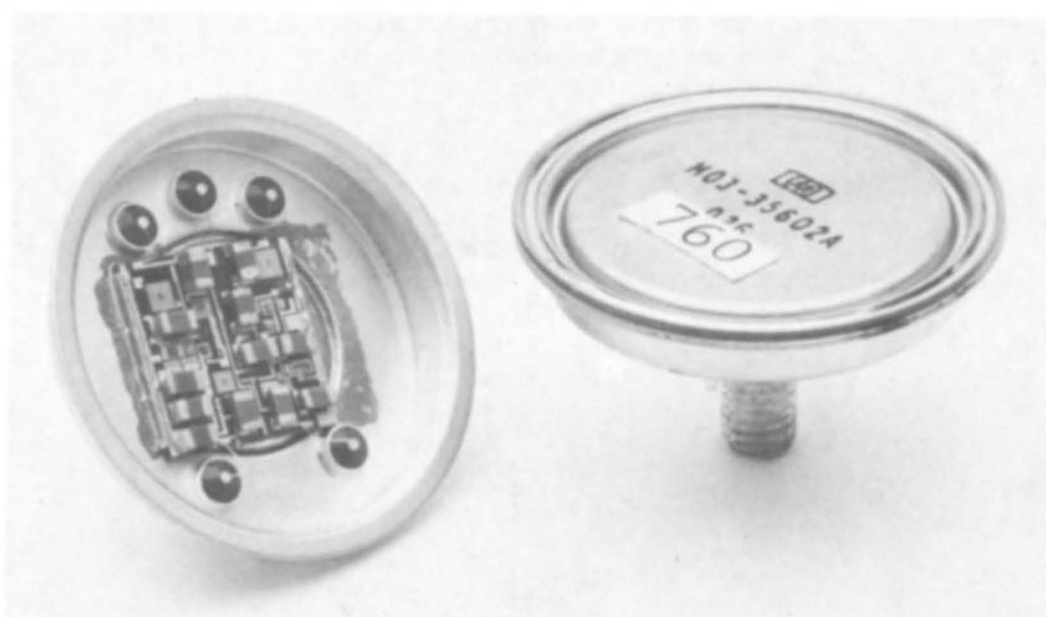


FIGURE 3

Trunk system signal levels may therefore be chosen to operate within the amplifier constraints of noise and distortion so that system design may be optimized. Alternatively, signal levels may be selected to provide added performance margin if system length is not a performance limiting factor.

Judicious apportionment of noise and distortion between trunk and feeder systems can be accomplished not only by choice of equipment but also by selection of system signal levels. This system design approach can result in a reduced system cost.

CABLE DISTRIBUTION SYSTEM

The cable distribution system provides the means of distributing head end signals to multiple subscriber locations in an area. The signal delivered to the subscriber's receiver terminals must be of such a level and quality as to produce acceptable pictures.

Definition of what signal characteristics produce acceptable pictures are covered in detail in (4), (5), (14). To design the most economical and efficient cable distribution equipment, the designer must consider in depth the requirements of the subscriber receiver equipment.

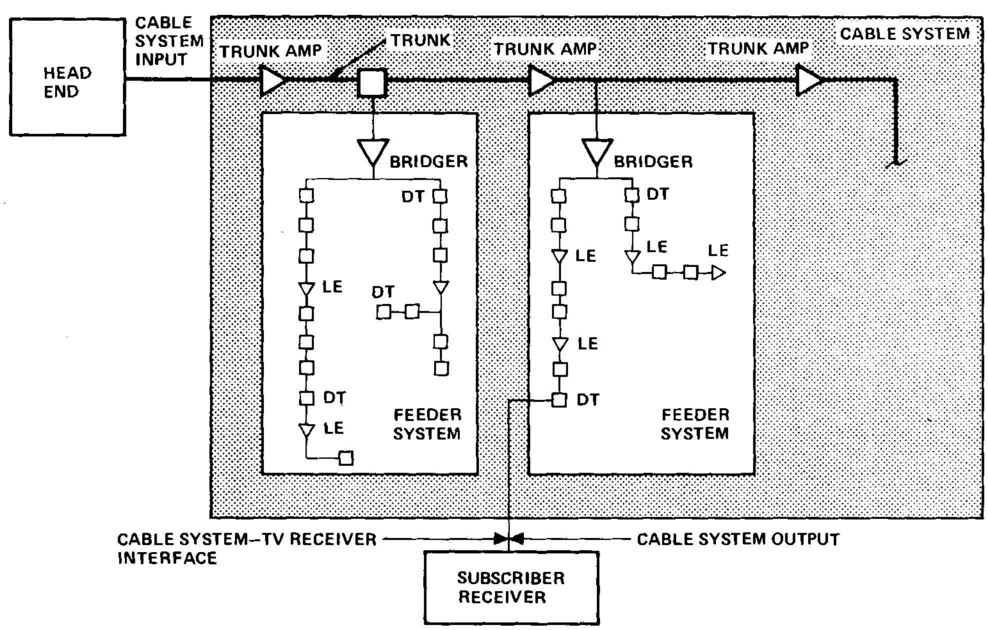


FIGURE 4

In Figure 4 is shown a representative block diagram of a cable distribution system. A trunk system is used for transmission of the signal from the head end to the areas in which the signal is to be distributed and does not directly feed signals to subscribers. A feeder system consists of equipment which is used to deliver signals from the trunk system to subscribers.

TRUNK SYSTEM

Trunk amplifiers are required at intervals along the trunk cable route to offset signal attenuation due to cable, power splitters, and intermediate bridging amplifier insertion losses. The amplifiers are spaced so that the signal level does not drop below the minimum value required to meet the system S/N objective nor exceed the maximum level consistent with the system distortion specification.

The laws of cascaded amplifier distortion and noise accummulation (6), (12), (15) provide guidelines for selecting levels on the trunk system needed to match trunk amplifier noise and distortion characteristics to the trunk system transmission objectives.

Some general principles applied to trunk system amplifiers which are helpful in meeting system noise and distortion objectives are listed below.

Automatic Gain Control (AGC) Amplifier

1. Should have the lowest noise figure and/or be short spaced to preserve the minimum S/N since its input level will tend to be the lowest in the system (with the possible exception of head end input).

2. Should be spaced at intervals such that its dynamic control range is not exceeded by that range dictated by cable attenuation variation from low to high temperature.

3. Should be spaced to maintain level variation to less than maximum value dictated by system S/N and distortion objectives in order to realize consistent year round service.

4. Should have distortion characteristic which does not change as a function of dynamic gain. The AGC amplifier should have consistent same crossmodulation, regardless of ambient temperature.

Manual Gain Control (MGC) Amplifier

1. S/N for MGC amplifier will vary as a function of temperature, but will always be greater than S/N of AGC amplifier (assuming amplifier with equal noise figure).

2. Distortion at cold temperature will be worst in the MGC trunk amplifier immediately preceding the AGC amplifier.

3. Open loop thermal compensation in the MGC will tend to minimize the amount of increased crossmodulation at low temperature.

Level Tilt in Cable Distribution System

The relationships between signal levels of each channel carried in the cable distribution system are established at the head end. The actual setting however, is determined by the design of the repeater amplifier and performance of other system components. It is essential that levels are set to match the characteristics of the repeater amplifier if the system S/N and distortion objectives are to be met in an optimum manner.

FEEDER SYSTEM

The amount of noise and distortion added to the television signals in the trunk system limit the amount of noise and distortion which may be introduced by the feeder system while meeting the system objectives. The minimum allowable signal level in the feeder system is established by the minimum level to be delivered to the subscriber receiver. Designing the feeder amplifiers (bridging and line extender) within this constraint establishes the feeder system S/N for amplifiers of a given noise figure and feeder leg cascade length.

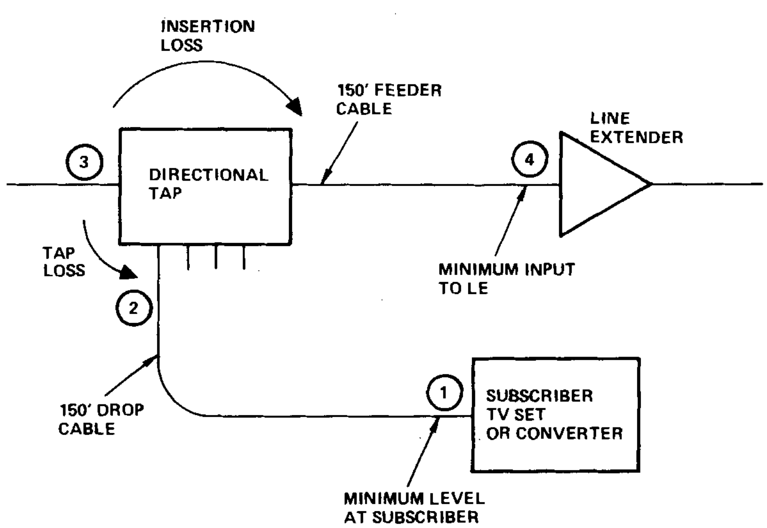
Noise and distortion accummulates along the trunk system cascade as stated previously. This fact means that noise and distortion in the trunk system near the head end is much less than at the trunk line extremities. Therefore, the feeder system fed from the trunk system consisting of a small number of trunk amplifiers can be allowed to operate in modes which tend to produce more distortion than would be allowed near the end of long trunk line cascades. Examples of these modes are: higher signal levels in feeder system, longer cascade of feeder amplifiers, lower output capability (assumed lower cost) line extenders.

Feeder amplifiers designed to serve the maximum number of subscribers require the highest possible signal level output with low enough distortion to meet system objectives. The maximum gain required for a feeder amplifier, and in particular a line extender, is therefore equal to the difference between minimum input and maximum output signal power. Examples which follow will clarify the requirements of a line extender amplifier.

MINIMUM INPUT LEVEL TO LINE EXTENDER AMPLIFIER

The minimum input to the line extender is a function of the minimum input signal delivered to the subscriber receiver terminals.

The determination of this level will be clarified by referring to Figure 5 and the following example.



MINIMUM INPUT LEVELS, SUBSCRIBER RECEIVER AND LINE EXTENDER

FIGURE 5

It has been shown (4), (5) that a minimum level of 0 dBmv or greater at location 1.0 in Figure 5 will result in picture quality which is system S/N limited and not television set limited.

To determine the minimum line extender (LE) input level, the attenuation between points 1 and 3 in Figure 5 will be calculated at the highest frequency supplied to point 1. Adding this attenuation in dB to the minimum subscriber level at point 1 establishes the input level to the directional tap. From this level is subtracted the sum of tap insertion loss plus feeder cable span loss to arrive at the minimum input level to the line extender.

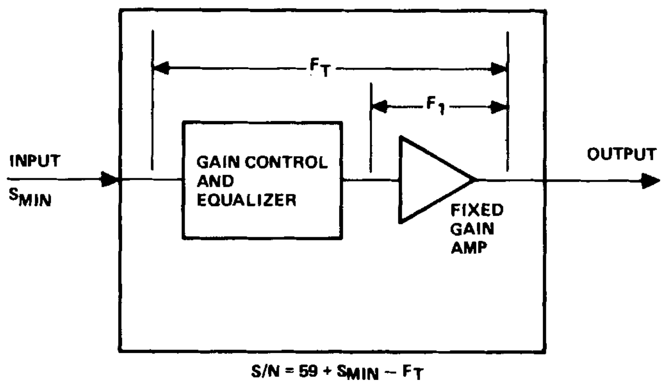
TABLE I LOSSES IN DB (Freq = 270 MHZ)

Feeder Cable Type Drop Cable Type	412 RG/59	412 *RG/59	500 RG/59	500 *RG/59
150' Drop Cable	8.4	5.4	8.4	5.4
Tap Loss (4-Output, 11 dB Tap)	11.0	11.0	11.0	11
SUM A	19.4	16.4	19.4	16.4
Tap Insertion Loss	2.5	2.5	2.5	2.5
150' Feeder Cable Loss	2.8	2.8	2.1	2.1
SUM B	5.3	5.3	4.6	4.6
Amount LE Input Level Above Subscriber Level (A-B)	14.1	11.1	14.8	11.8
Subscriber Level in DBMV	6	6	6	6
Minimum Input to LE in DBMV	20.1	17.1	20.8	17.8

*RG/59 (Type) Drop Cable Belden 8228

Feeder cable attenuation values are based on nominal catalog values at 70°F for Anaconda Sealmetic (SLM) 412 and 500. Drop cable values are extrapolated to 270 mHz from Belden Catalog No. 871.

The minimum level at point 4, the LE input, is 14.1 dB (for RG-59 drop cable and 412 feeder cable of length noted above) above the subscriber level in dBmv. For this example assume a subscriber level of 6 dBmv. Then the minimum LE input level is 20.1 dBmv.



LINE EXTENDER AMPLIFIER S/N

FIGURE 6

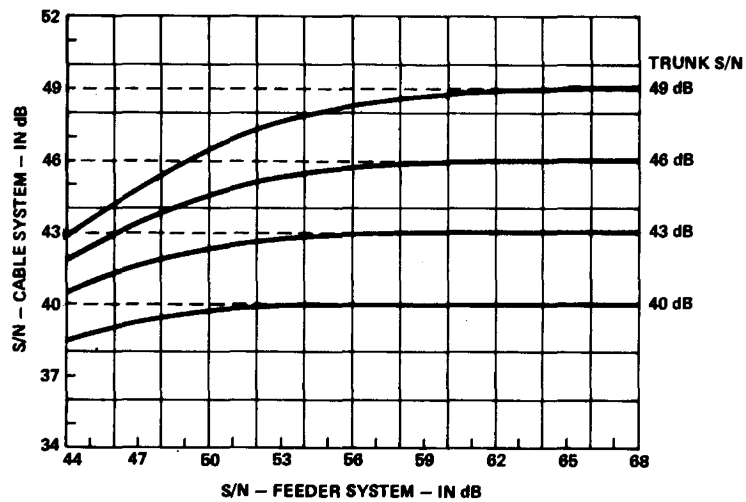
The affect of the line extender noise figure (F) on feeder system S/N (Figure 6) can now be determined by referring to the equation below:

$S/N = 59 - F + S_{min}$ dB
S/N for single line extender

$S/N = 59 - F + S_{min} + \text{Log } n$ dB
S/N for cascade of n identical line extenders

A noise figure of 20.1 dB results in a single LE S/N of 59 dB for the minimum input signal calculated previously.

The affect of feeder system S/N as a function of trunk system S/N on subscriber drop S/N is shown in Figure 7. Note that for a trunk system S/N of 43 dB, the most distant subscriber in the feeder system suffers almost no S/N degradation for a cascade of two identical line extenders, each with an S/N of 59 dB. This fact is extremely significant in terms of LE amplifier circuit design, because an LE S/N of 59 dB for the minimum signal level calculated above means that the LE noise figure can be 20.1 dB.



CABLE SYSTEM S/N APPORTIONMENT BETWEEN TRUNK AND FEEDER

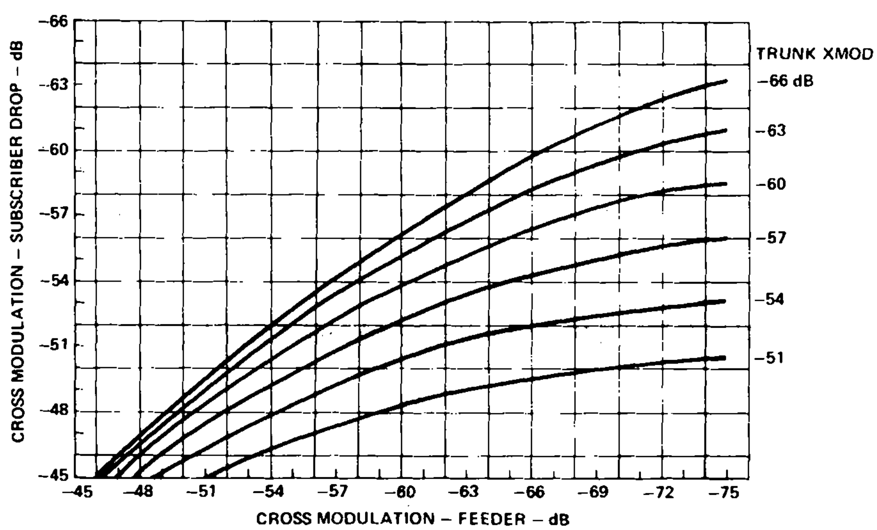
FIGURE 7

Integrated circuit broadband amplifiers can be designed and manufactured with a variety of frequency response shapes and with access to multiple gain stages. However, one of the most economical designs is a fixed gain block with flat frequency response. Permitting an LE station noise figure in the 16 to 20 dB range would allow use of a fixed gain, input-output integrated circuit amplifier of economical design. The line extender station block diagram is then accurately represented in Figure 6. A high noise figure line extender requires education of the customer because a high noise figure does not necessarily mean a low S/N. The individual system component or amplifier specifications must be related to system performance to realize the most economical design.

FEEDER SYSTEM DISTORTION

The feeder system is allowed to produce an amount of distortion equal to the difference between the distortion objective at the subscriber and the amount of trunk system distortion. The examples and discussion which follow mention only crossmodulation distortion, which to date has been a familiar system performance limiting parameter. However, similar and possibly additional analyses must be made to account for second and third order intermodulation products as well as triple beats in systems carrying more than 12 channels.

A relationship between crossmodulation at the subscriber drop as a function of trunk and feeder system crossmodulation is shown in Figure 8.



SUBSCRIBER XMOD APPORTIONMENT BETWEEN TRUNK AND FEEDER

FIGURE 8

The axes of this figure have been interchanged from those of Figure 5 in (5). The chart of Figure 8 is useful in determining the allowable feeder system crossmodulation distortion as a function of the crossmodulation objectives at the subscriber and the trunk system crossmodulation.

Feeder system distortion determines the maximum output level at which the line extender can be operated. From the method described previously, the minimum LE input level is defined. The LE gain required in the feeder system is now defined.

Some general considerations related to feeder system amplifier performance are summarized below.

Bridger Amplifier

1. System crossmodulation distortion performance can easily be limited by the bridger amplifier, since it operates at the highest level.

2. Cold temperature operation is the most critical for the bridger amplifier driven from an MGC amplifier or an intermediate bridger in the span preceding an AGC amplifier. The level will be the highest and therefore the crossmodulation distortion will be the worst.

3. There may be a system distortion advantage in operating the four (4) output bridger at a level lower than the line extender. Uniformity of feeder system levels is lost, but improved distortion performance results.

4. The bridger amplifier noise figure is relatively unimportant because its input level is relatively high, typically only 10 to 12 dB below the trunk output level.

Line Extender

1. For rigid feeder system level control, an AGC line extender (10) should be placed in each bridger amplifier leg where an MGC trunk amplifier drives the bridger, including intermediate bridger stations preceding AGC trunk amplifier stations.

2. Every other line extender in a feeder cascade should contain an AGC amplifier.

3. Level control to the subscriber home may be more critical in a converter system than a non converter system.

4. Open loop thermal compensation is advisable in each line extender.

5. Noise figure of line extender amplifier is relatively unimportant because it operates at level approximately 10 dB above trunk amplifier.

Channel Levels Across Band at Subscriber Receiver Terminals

The difference in levels between channels across the system bandwidth is becoming increasingly important for broadband (greater than 50-216 mHz) multichannel (greater than 12 channel) systems. Subscriber converters developed to date have a limited dynamic range so that the level spread across the bandwidth and the absolute level stability are critical.

The level spread from channel to channel across the band at the subscriber receiver or converter terminals is a function of the following:

1. Block tilt of channel levels (set at head end)

2. Type of feeder cable (loss per 100 feet)

3. Length of feeder cable preceding tap

4. Number of taps and splitters (and amount of flat loss in feeder line)

5. The magnitude of tap loss

   5.1 Frequency response of tap loss (flat and/or slope)

6. Type of drop cable (loss per 100 feet)

7. Length of drop cable

Amplifier Coefficient System

To further exemplify the sources of noise and crossmodulation distortion in the cable distribution system, use is now made of an amplifier coefficient system.

Carson (9) outlines a method for calculating amplifier cascade performance with amplifiers of different characteristics. Taylor, in reference (13), clarified the data obtainable from the principles outlined in (9), and his format is used in what follows. The different characteristics can be noise figure, distortion due to different operating level or distortion characteristics, number of channels (such as transportation amplifier), etc. The method basically normalizes the performance of each amplifier type in the cascade to a reference trunk amplifier.

After each component of the system which generates noise and/or distortion has been normalized to an equivalent reference amplifier (component coefficient), the component coefficients are summed to equal a total equivalent cascade. The system S/N and crossmodulation distortion are then determined by the following familiar equations:

S/N (System) = S/N (Ref Trunk) - 10 Log C_n

Where C_n is the equivalent cascade of reference trunk amplifier.

XM (System) = X_1 (Ref Trunk) + 20 Log C_x

Where C_x is the equivalent cascade of reference trunk amplifiers.

The following example is given to illustrate the principle involved:

Given: Trunk Amplifier

XM = -82 dB at level of 40 dBmv (12 channels)

X_1 = -98 dB at operating level of 32 dBmv

Line Extender

XM = -82 dB at level of 40 dBmv (12 channels)

X_3 = -78 dB at level of 42 dBmv

Line Extender Coefficient

L_1 = 10 raised to exponent $(X_3-X_1)/20$=10 amplifiers

In other words, a single line extender produces as much crossmodulation as a cascade of ten (10) trunk amplifiers operated at a level of 32 dBmv.

A separate coefficient for noise must be calculated. The resulting coefficient is the equivalent number of reference trunk amplifiers to which the line extender is equivalent in terms of S/N degradation. The method for making this calculation is contained in Appendix B.

Component Coefficients as Function of Temperature

Three sets of coefficients are required to characterize the system S/N and XM as a function of temperature. The coefficients for each component are initially calculated for nominal temperature. At the maximum temperature, a set of coefficients is required to determine the worst case S/N. At the minimum temperature, a set of coefficients is required to determine the worst case crossmodulation.

For every one (1) dB increase in level due to cable attenuation reduction at low temperatures, a 2 dB increase in crossmodulation results in the "well behaved amplifier". The level variation of each component in the system which produces crossmodulation is accounted for and a coefficient for low temperature operation assigned to each component. Total system crossmodulation distortion at low temperature is then calculated by summing each of the component coefficient. Since levels increase at low temperature, the S/N will not be reduced.

In a similar manner, a set of coefficients is required at the high temperature to determine the amount by which the S/N is reduced because of the increased cable attenuation. Crossmodulation distortion is less than at the minimum temperature due to cable attenuation change, because the increased cable attenuation results in lower levels. However, care must be taken in the amplifier design to insure that gain reduction due to AGC action does not increase the amplifier distortion.

The component coefficients at low and high temperature depend upon the amount of level control in the system. The spacing of AGC amplifiers and degree of thermal compensation are the controlling factors in wide temperature range operation for maximizing S/N and minimizing crossmodulation.

An example of the coefficient system follows and is made under the following assumptions:

1. Crossmodulation, noise figure, and gain values are those given in Appendix A and B.

2. Cable attenuation changes .12% per degree F

3. Trunk amplifier spacing is 22 dB with AGC amplifiers spaced every other trunk station position.

4. Bridger coefficients calculated with bridger driven from MGC trunk amplifier.

5. Line extenders spaced at 12 dB of cable.
6. AGC line extender spaced every other position.
7. Noise figure and crossmodulation constant as function of gain.
8. Trunk amplifier output level 32 dBmv.
9. Bridger amplifier (4 outputs) output level 38 dBmv.
10. Line extender output level 43 dBmv.
11. Crossmodulation changes 2 dB for 1 dB of output signal level change.

The amplifier coefficients and system S/N and crossmodulation distortion are calculated for temperatures 0°F, 70°F and 110°F and are shown below:

TABLE II

		S/N		Crossmodulation	
Cascade	Actual	Equivalent		Equivalent	
Temperature		110°	70°	70°F	0°F
Trunk	20	27.58	20	20	24.455
Bridger (4-Out)	1	.276	.225	19.953	28.842
Line Extender	2	.287	.225	25.178	45.972
Coefficient C_n		28.14	20.45		
System S/N (dB)		44.01 dB	45.39 dB		
$S/N = 58.5 - 10 \text{ Log } (C_n)$					
Coefficient C_x				66.13	100.27
System Crossmodulation (dB)				-61.59	-57.97
$XM = -98 + 20 \text{ Log } (C_x)$					

The system S/N and crossmodulation in the table above could be calculated by a number of methods. Each method would result in the same answer if the identical assumptions are used for each method. The coefficient C_x = 66.13, at 70°F, is the equivalent number of reference trunk amplifiers which generate a total system crossmodulation distortion of -61.59 dB. Note that for the assumptions made, which are realistic, the amount of distortion generated in the 4-output bridger amplifier is equivalent to the distortion which would result from a cascade of 19.95 reference trunk amplifiers. Because of system level variation due to cable attenuation change, the crossmodulation distortion generated at 0 degrees F is equivalent to that generated by a cascade of 28.84 reference trunk amplifiers. Table II graphically displays the sources of system S/N degradation by the different types of amplifiers used in the system.

CONCLUSION

Cable distribution system performance as related to system levels have been described. Clear insight into cable distribution equipment and system requirements is provided by use of signal level as a vehicle for analysis and design. This approach can result in providing guidelines for more economical designs.

An amplifier coefficient analysis and/or the use of Figures 7 and 8 are helpful in determining the allowable apportionment of noise and distortion between trunk and feeder systems.

ACKNOWLEDGEMENT

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APPENDIX A CROSSMODULATION COEFFICIENT

Reference Trunk Amplifier

M1	=	-82 dB	Xmod at reference level (12 channels)
Y1	=	40 dBmv	Reference Level
F1	=	9.5 dB	Noise Figure at 270 MHz
G1	=	23 dB	Gain of Reference Amplifier
Q1	=	20 (Log (N9-1)- Log (11))	N9 is actual number of channels

X1 is crossmod of reference amplifier

X1 = (M1 + Q1)-(2)(Y1-E1)   Where E1 is output level

Bridger Amplifier

M2	=	-82 dB	Xmod at reference level (12 channels)
Y2	=	40 dBmv	Reference Level
F2	=	12 dB	Noise Figure of bridger amplifier
G2	=	27 dB	Gain of bridger amplifier
E2	=	Output level of bridger amplifier	
X2	=	(M2 + Q1) -2 (Y2 - (E2 + 7)	Crossmod of bridger at level (E2 + 7) dBmv

The bridger coefficient or number of equivalent trunk amplifiers in cascade (in terms of Xmod) is:

B1 = 10 raised to the power (X3 - X1)/20

Line Extender

M3	=	-82 dB	Xmod at reference level (12 channels)
Y3	=	40 dBmv	Reference Level
F3	=	12 dB	Noise Figure at 270 mHz
G3	=	22 dB	Gain of line extender

X3 = (M3 + Q1) -2 (Y3 - E3)   X mod at level E3

The line extender coefficient (or equivalent number of trunk amplifiers is cascade, in terms of Xmod) is

L1 = 10 raised to the power (X3 - X1)/20

For a cascade of N2 line extenders,

L1 = (N2) (L1)

<u>Total System Crossmod Coefficient CX (at nominal temp)</u>

The total cascade number is then -	EQUIVALENT CASCADE	ACTUAL CASCADE
Total trunk cascade	N1 amplifier	N1
Bridger Coefficient	B1	1
Line Extender	L1	N2

System Coefficient = N1 + B1 + L1 = C_X

System Crossmod = X1 + 20 Log (C_X)

APPENDIX B - SIGNAL TO NOISE RATIO COEFFICIENT

Reference Trunk Amplifier

S1 Trunk S/N Ratio

$S1 = 59 - F1 + (E1 - G1)$ dB Equation

Bridger S/N Ratio

$S2 = 59 - F2 + (E2 + 7 - G2)$ dB Equation

Equivalent Trunk Cascade (In terms of S/N)

N3 = 10 raised to the power (S1 - S2)/10

Line Extender S/N Ratio

$S3 = 59 - F3 + (E3 - G3)$

Equivalent Trunk Cascade of single LE (In Terms of S/N)

Q4 = 10 raised to the power (S1 - S3)/10

N4 = (Q4) (N2) Where N2 = number of LE in cascade

System Noise Coefficient	EQUIVALENT CASCADE	ACTUAL CASCADE
Total Trunk Cascade	N1 Amplifiers	N1
Bridger Coefficient	N3	1
Line Extender Coefficient	N4	N2

System Noise Coefficient $C_n = N1 + N3 + N4$

System S/N = S1 - 10 Log (C_n)