TECHNICAL SESSION NO. 4:
CATV System Level Control

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Participants:
Mordechai Weiss
"Solving Temperature Problem Using Dual Carrier Automatic Slope and Gain (ASG) Controls"

Donald B. Gregory
"AGC Operation and System Performance"

George P. Dixon
"Temperature and the CATV System"

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For the last ten years Mordechai has been active in electronic design and engineering management of Communication Equipment and Test Instruments. He has worked for Fisher Radio Corporation, Jerrold Electronics, Bendix Radio and others.

He joined the Equipment Division of AEL as Section Head and Engineering Manager of a very sophisticated and complex digitally tuned electronically swept receiving system project over the HF-VHF-UHF spectrum. Mr. Weiss is presently a CATV Sales Specialist.

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Introduction

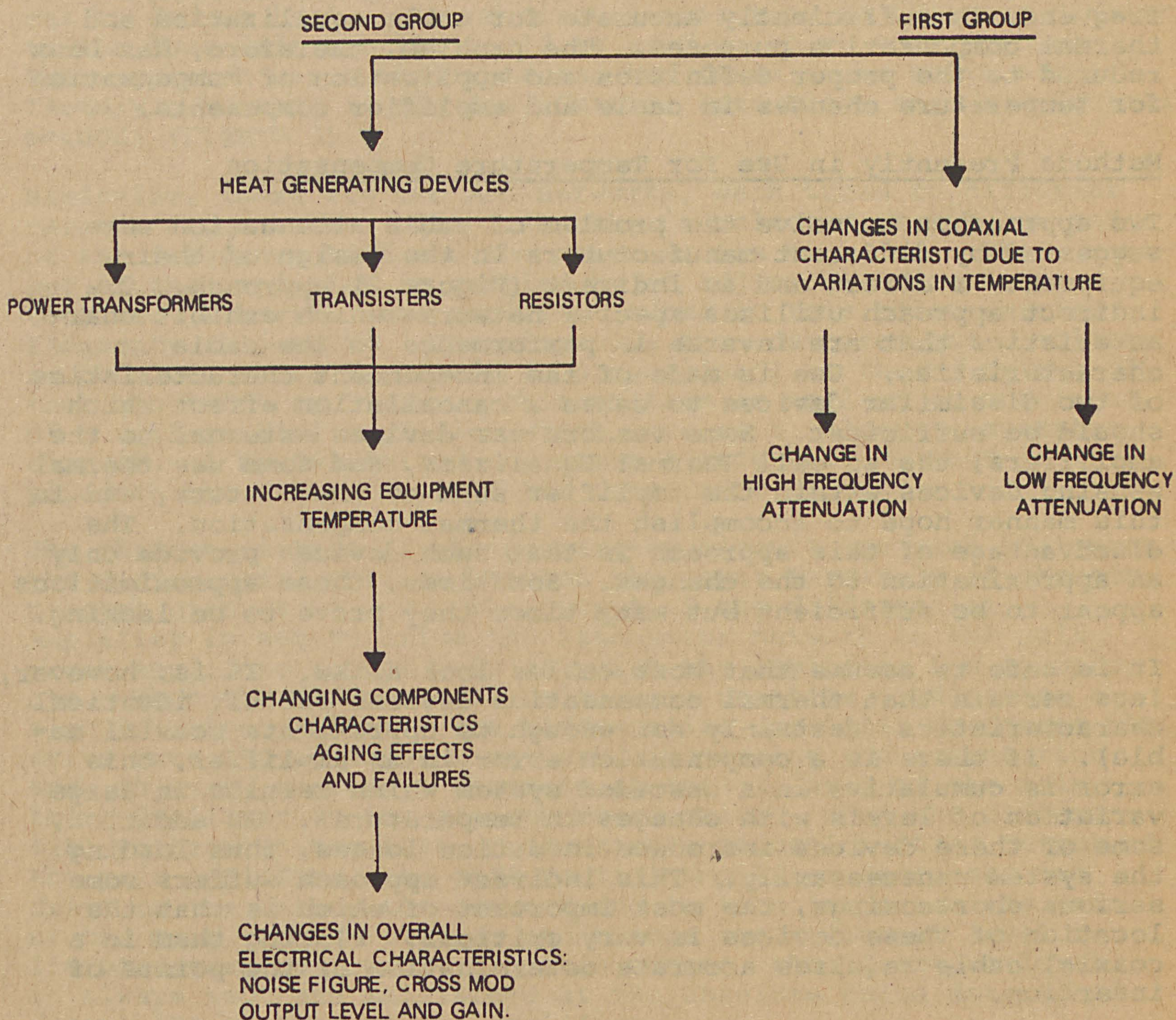
The most critical problem that can beset any CATV System owner or manager is temperature variation and the ability of the CATV plant to withstand such variations.

The effects of temperature variations are divided into two distinctly different groups; changes in characteristics of the electrical components, and changes resulting in failures of components due to excess stress. The first group concerns itself with the proper dynamic performance of the equipment within its specified parameters, while the second group relates directly to the failure rate and reliability of the equipment. (See Figure 1.) In this discussion, I will consider the problems and parameters of the first group, and only mention some factors in the second group.

Definition of the Problem

A CATV system consists of a number of amplifiers connected in cascade through coaxial cables. This system is frequently located in an environment whose temperature swings from -30 degrees F. to +120 degrees F., a spread of 150 degrees F.

Coaxial cable also changes its characteristics with temperature. The cable attenuation is changed by approximately 0.1% per 1 degree F. This change is also frequency dependent exhibiting a different change at low frequencies than at higher frequencies. These changes were analyzed and discussed in the past and it is claimed that the attenuation characteristics can be calculated and predicted. Because of different manufacturing techniques



EFFECTS OF TEMPERATURE CHANGE
Figure 1

and materials used by various suppliers of cable, there are some differences in the characteristics of the same type of cable. It was still felt, however, that one mathematical ratio relating the changes in attenuation characteristics to the inverse of frequency is sufficiently accurate for cable equalization and thermal compensation purposes. The problem, therefore, has been reduced to the proper definition and application of compensation for temperature changes in cable and amplifier components.

Methods Presently in Use for Temperature Compensation

Two approaches to solve the problem of cable attenuation were suggested by different manufacturers in the design of their equipment, a direct and an indirect (Figure 2) approach. The indirect approach utilizes special networks which exhibit characteristics that are inverse in performance to the cable characteristics. Use is made of the independent characteristics of two dissimilar devices to cause a cancellation effect which should be sufficient. Some vendors use devices external to the amplifiers, the so call Thermal Equalizers, and some use thermal sensing devices within the amplifier such as thermistors, and in this manner hope to accomplish the thermal compensation. The disadvantage of this approach is that such devices provide only an approximation to the changes. Sometimes, these approximations appear to be sufficient but many times they prove to be lacking.

It is safe to assume that most cables look alike. It is, however, less certain that thermal compensation devices exhibit identical characteristics (certainly not enough to approximate coaxial cable). If there is a compensation error in an amplifier, this error is cumulative in a cascaded system which results in large variation of levels with changes in temperatures. In addition, some of these devices introduce insertion losses, thus loading the system unnecessarily. This indirect approach suffers some serious shortcomings, the most important of which is that the location of these devices is very critical. Placing them in a coaxial cable requires accurate determination of the points of insertion.

Different component values have to be used for different lengths of cables in a system; they are very seldom interchangeable and each amplifier in the system has to be trimmed to match the cable equalizer which it follows or drives, depending on the situation. In addition, in time and under power stress, these components age and exhibit different characteristics requiring realignment or replacement. A partial solution to the problems was afforded by utilizing direct means to recognize level changes and to retain the levels at a predetermined and constant value. This was accomplished by an AGC network. This direct method did partially solve the problem, but the variation of levels was reduced, not eliminated.

The Auto-Slope and Gain Control Approach

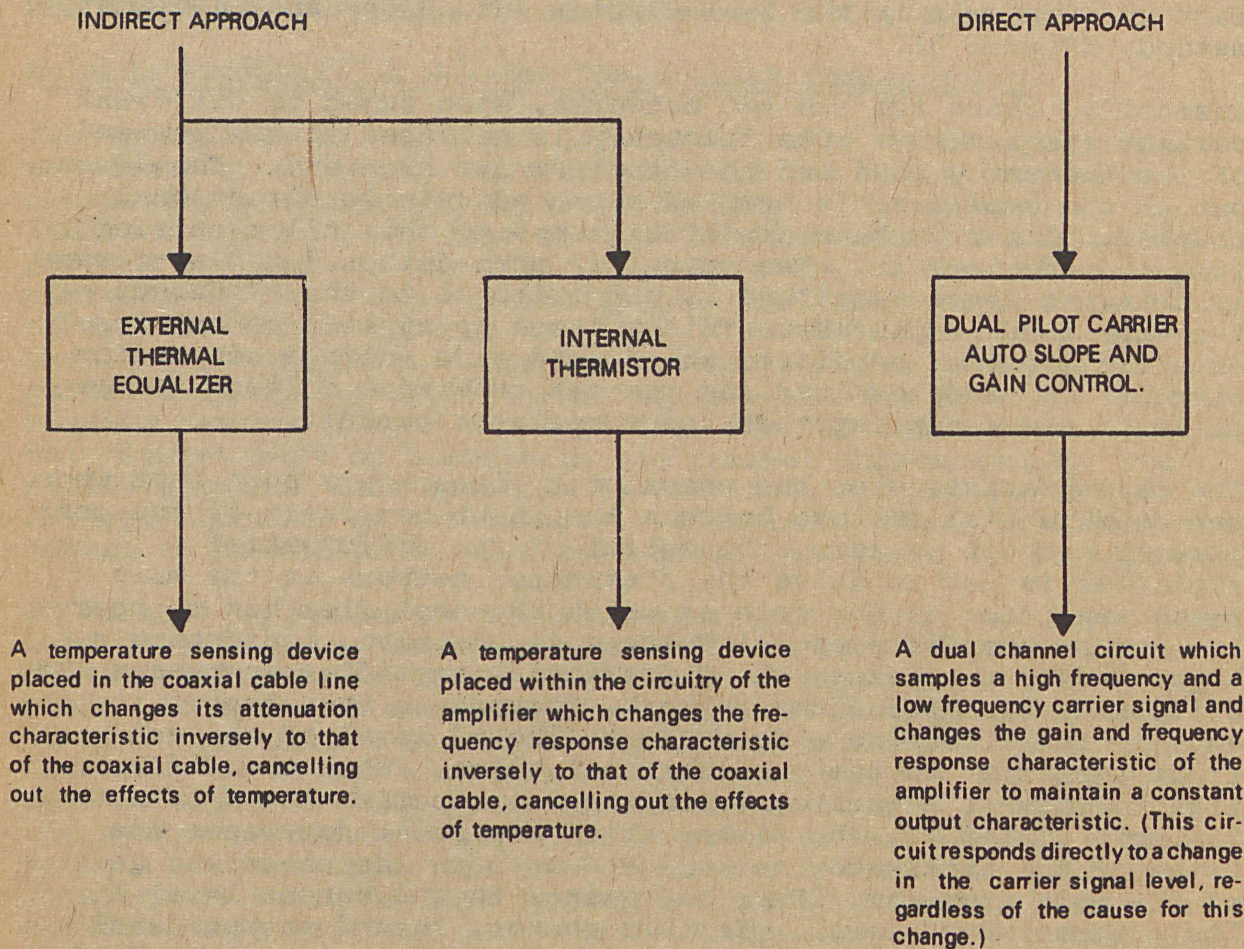
Variations in slope, however, were still significant and depended directly on the length of cable that was involved. It was logical to deduct that a second circuit operating in a manner similar to the Auto Gain Circuit could be used to solve this problem. This approach was actually tested and found to be quite satisfactory. We call it the Dual Carrier Auto Slope and Gain Control method, (Figure 3).

Basically, there are two AGC networks, each tuned to different carrier frequencies. One frequency is selected at the low end of the frequency band and the other at its high end. The r-f output of the amplifier is sampled by an adjustable directional coupler. A narrow band amplifier tuned to this pilot carrier frequency follows it. The output is then detected and a voltage is obtained whose magnitude is proportional to the r-f output of the main trunk amplifier. This voltage is applied to one input of a differential amplifier which acts as a voltage comparator circuit. A predetermined and pre-set reference voltage is applied to the other input of the comparator circuit.

The characteristics of the comparator circuit are such that when the differential voltage between the input terminals of the comparator circuit is zero, the output of the differential amplifier is set to drive the attenuator network in the main trunk amplifier to the gain at which the amplifier has to operate. When the differential voltage is positive, indicating a high r-f output voltage, the differential amplifier increases the drive into the attenuator network, increasing the attenuation and, in turn, causing a decrease at the r-f level of the main trunk amplifier to the predetermined value. When the differential voltage is negative, indicating a reduction in r-f output of the main amplifier, the differential amplifier decreases its drive of the attenuator network and in turn increases the gain of the main trunk amplifier and brings the r-f output level to its predetermined level. In this manner, the r-f output level is always kept and maintained at the absolute value determined during the setting of the amplifier.

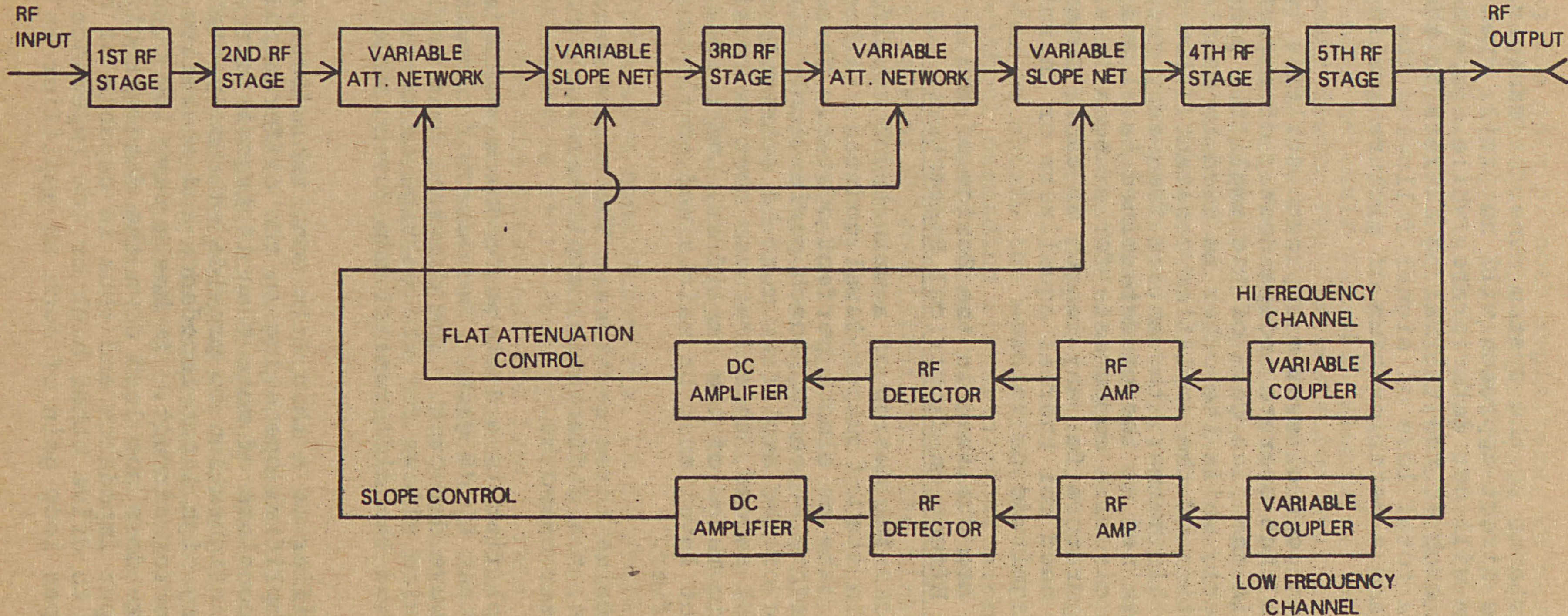
It should be borne in mind at this point that it does not matter what caused the r-f level to change at the input, and that any changes in r-f levels in preceding stages are not cumulative. For example, if 50 amplifiers are put in cascade, and the output levels of all of them change in the same direction by 1 dB, the total change at the output of the fiftieth amplifier will be whatever changes in output level a single amplifier exhibits, or 1 dB. When these numbers are used in a system having an indirect temperature compensation technique such as thermal equalizers or thermistors, the total RF output change will be 50 x 1 or 50 dB.

Let me digress for a moment! This comparison is most dramatic



POSSIBLE SOLUTIONS FOR CABLE ATTENUATION DUE TO TEMPERATURE CHANGE PROBLEM

Figure 2



AUTOMATIC SLOPE & GAIN CONTROL AMPLIFIER

Figure 3

and is of utmost importance to the system owner or manager. A system built using the direct approach will not fail, even the quality of the picture will not deteriorate, while a system using the indirect approach such as the thermal equalizers or thermistors will experience a total loss of signal following the twentieth amplifier, and a deterioration of picture quality after the tenth amplifier.

The auto-slope and gain control system approach utilizes two pilot carrier circuits that operate independently of one another. One is used to maintain the flat gain of the amplifier constant, (high frequency carrier), while the other is used to maintain the slope characteristics of the amplifier constant, (low frequency carrier). In this manner, the entire frequency response of the system is maintained at the predetermined level and tilt. The two pilot carrier circuits compensate for changes in slope due to changes in temperature for any length of cable automatically, eliminating the need for thermal equalizers or thermistor networks of various magnitude or values.

Special Circuits That Are Utilized in the Design of the ASG Network and Their Effect on Electrical Parameters.

The secret of the successful design of a main trunk amplifier is the ability to maintain its r-f output level constant; a highly stable amplifier will make an almost perfect system. Three conditions must be met before we can approach perfection. First the frequency response of the amplifier must be extremely flat (± one-tenth of one dB) second, this flatness must be retained over the entire dynamic range of the amplifier, and third, a highly stable r-f output level must be maintained at the output terminal of the amplifier.

The ASG circuitry contains three sections: The narrow band amplifiers and detectors, the differential amplifiers, and the attenuator and equalizer networks.

The narrow band r-f amplifier is a 4-stage feedback amplifier that is set at a constant 60 dB gain. The detector circuitry is a dual diode full-wave detector. The constant gain amplifier detector combination allows for the voltage to remain constant at the input of the differential amp during wide ranges of temperature.

The differential amplifier is a thin film monolithic integrated circuit operational amplifier operating in the differential mode. The circuitry consists of more than 14 transistors connected in a special configuration to provide extremely stable DC gain. It has a very high input impedance and therefore does not load down the detector circuit. It has a very low output impedance and therefore does not load down the detector circuit. It has a very low output impedance and thus is capable of being a good current source to drive other high or low impedance circuits. The typical open loop gain of such an amplifier is 90 to 100 dB.

Adding the gain of both amplifiers, we have an open loop gain in excess of 150 dB. This entire gain is used to maintain the output level stable at the preset level. Attention is drawn to this figure as it is this value of available gain that makes possible the excellent stability of the amplifier.

The attenuator (The "Diat"$_{tm}$) and equalizer networks contain PIN diodes as their variable elements. A PIN diode is a semiconductor device that is resistive over a very wide frequency range, over 1000 MHz. It is therefore frequency independent at the frequencies that are used presently in CATV equipment. By changing the current through the PIN diode, a change in resistance is accomplished. In the Attenuator network, changing the current will change the flat gain characteristics of the amplifier. In the equalizer network, changing the current will change the slope characteristics of the amplifier. The resistance value of the PIN diode can change over a wide range and as a result a wide range of attenuation is obtained.

In order to obtain the most effective performance of the amplifier without degrading its electrical parameters, it is important to design these parameters into the main trunk amplifier very carefully. The main trunk amplifier consists of five stages of r-f amplification. The first stage is designed to exhibit optimum noise figure values. It is important not to inject any circuitry in front of this stage in order to degrade its noise figure value. The last stage is designed to provide maximum r-f power level with minimum of intermodulation and crossmodulation distortions. For least distortion, it is preferred to operate this stage with as minimum an r-f level as possible. The last stage, therefore, should not be followed by any lossy components.

For distortion considerations, it is preferable to operate all stages at their minimum r-f levels. Therefore, in order to accomplish optimum performance, attenuation of signal is best accomplished if it is equally divided among all the stages rather than the first and the last. This is precisely the design approach that was followed in this amplifier. There are two identical attenuator circuits and two identical equalizer circuits in this amplifier. The attenuator and equalizer networks are placed before the third and fourth stages. In this manner, all the desired performance parameters are successfully met.

The amplifier is aligned for best frequency response and input and output VSWR. In varying the gain of the amplifier from maximum to minimum, the frequency response does not change. This is an extremely important feature as it has direct bearing on costs and savings in manpower and money to a CATV system. You all know how expensive it is to send out technicians periodically to adjust gains of the amplifiers during changes in seasons. It is also usually necessary to check and reset the relative amplitude of the different channels as changing the gain of the amplifier changes its frequency response characteristics. Now, with a wide dynamic range gain control circuit, which is uniform over the entire bandwidth of the CATV system, this problem is eliminated.

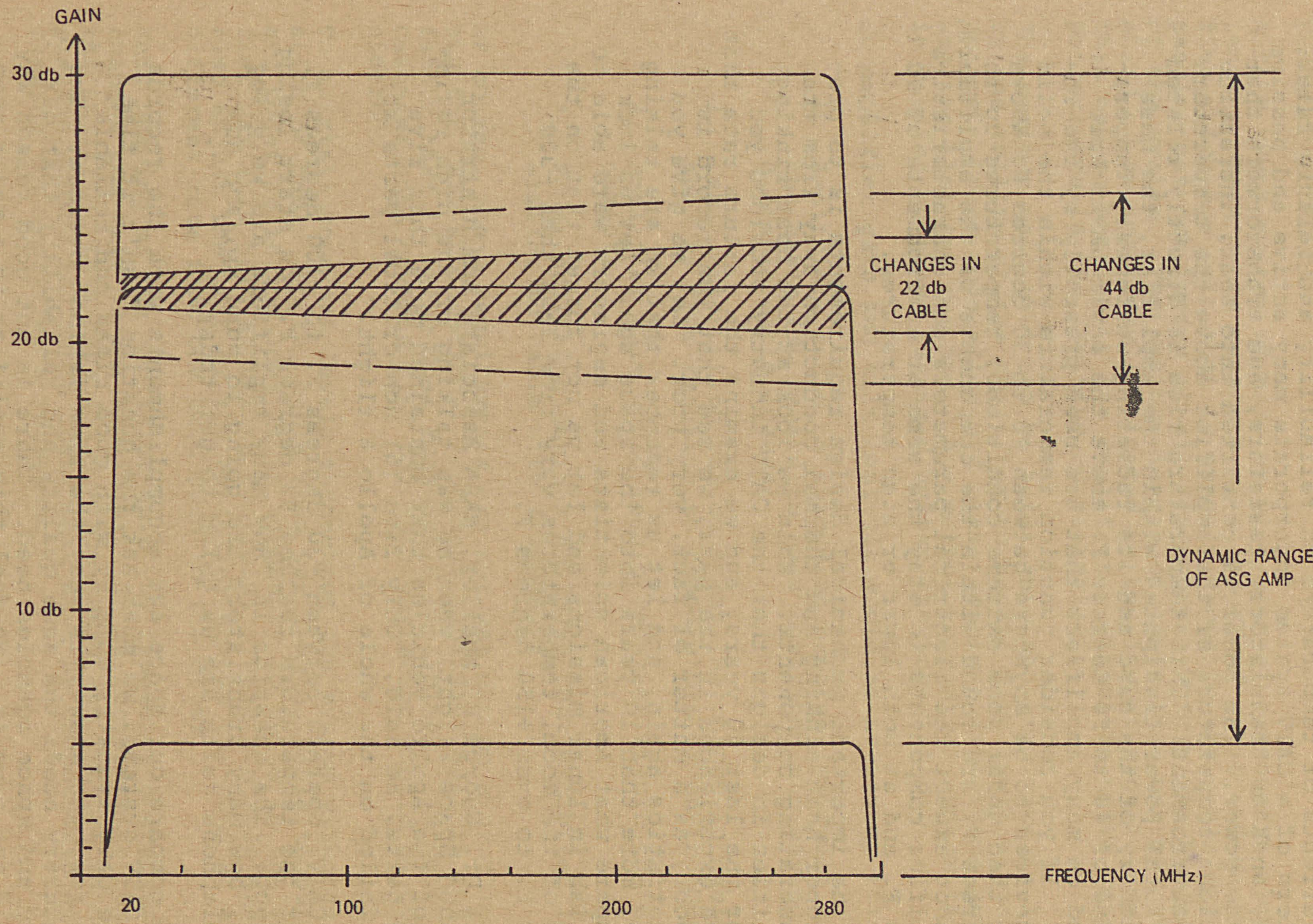
To illustrate the effectiveness of this design, I wish to mention some of the performance parameters that can be verified in the Lab, where proper test facilities are available. Maximum gain of 32-34 dB may be observed. Minimum gain of less than 5 dB were measured, 2-4 dB was typical. This means that gain variation of dynamic range in excess of 25 dB are obtained with this amplifier. The gain of the amplifier was set at a nominal 22 dB, for the 22 dB spacing that is considered generally common in CATV systems. Crossmod data was taken using a 12 channel test set. The output level of the amplifier was set at +32 dB mV output and crossmod reading below -90 dB were recorded (-98 dB). The output level was then increased in 2 dB steps up to +40 dBmV and the crossmod curve changed in steps of 4 dB indicating a linear and well-behaved amplifier. The gain was then changed by ±8 dB and data was taken in a similar way. The results were compared and it was verified that crossmod values were within less than 5% of one another as the gain was changed from 16 dB to 30 dB, (See Figure 4.)

You will recall that previously I used the example of 50 amplifiers in cascade and indicated that a change in 1 dB at the output level of every amplifier in a similar manner will not affect the system performance. Changes of 1 dB are not uncommon in existing amplifiers. However, now to illustrate my point, I am going to increase the change in level from 1 dB to 8 dB. A system utilizing this amplifier, and this amplifier only, will provide satisfactory performance under such a change. This significant improvement in performance is contributed largely to the utilization of the two stages of the PIN diode attenuator networks.

Let us now consider the meaning of an ±8 dB dynamic range on other system parameters. Let us see what it means to us in terms of temperature changes and lengths of coaxial cable. We know that the attenuation of a coaxial cable changes by approximately .1% per 1 degree F., or 10% per 100 degrees F. Let us now take an 80 dB cable and allow the temperature to change by 200 degrees F. or ±100 degrees F. The cable attenuation will vary by ±8 dB, which is the value that was tested. Remember now that 16 dB does not represent the full dynamic range of the amplifier.

Concluding Remarks

Up to now I was talking about changes in parameters due to change in temperature. I would like to make some comments as



CHANGE IN 22 AND 44 db OF CABLE VS FREQUENCY DUE TO ± 100°F TEMPERATURE CHANGE

Figure 4

to the effects of temperature on reliability and failure rates. Amplifiers of a CATV system incorporate many active and passive devices, such as transistors, resistors, and transformers that dissipate power. The power is converted into heat, increasing the ambient temperature of the amplifier above the temperature of the environment. This temperature rise is directly related to the total power dissipated within the amplifier, the mass and geometry of the case and its radiating surfaces. Temperature rise of 40 to 50 degrees F. above the environment were measured on many amplifiers that are used presently by the industry. If you consider junction temperature within the solid state devices to be anywhere between 10 to 30 degrees F. above ambient then under some extreme conditions, temperatures up to 200 degrees F. are found within the components of the amplifiers. One cannot expect the electrical parameters and characteristics of amplifier components to stay the same at environments of 70 degrees F. and at both lower or high temperatures.

One of the important mechanical design requirements is to provide proper heat sinking and thermal conduction away from the heat generating components. When we look at the heat sinking capabilities in designs that the CATV industry provided you with for the last 20 years, and we examine the failure rate that you have experienced in the past, we see that the record is quite poor, as a matter of fact, very poor. Let me give you some statistics again, and let us remember that we are talking in 1969, more than 10 years into the space age. Let us look and compare what American scientists and engineers were able to accomplish in lunar missions and let us not forget that on the surface of the moon, temperatures vary from less than -300 degrees F. to over +150 degrees F.

To quote Dr. George E. Mueller, NASA Associate Administrator for Manned Space Flight, when he was talking of the high reliability of the Apollo vehicles that contained more than five million parts, he said, "Only five (5) non-critical parts actually failed on the whole of Apollo 8 flight."

We, in CATV, operate between -30 degrees F. to +100 degrees F. Whenever the temperature reached 80 degrees F. you start losing your sleep. The question is "How many amplifiers are we going to lose, how many transistors are going to burn up, and how many telephone calls are we going to get today."

When we compare our space age accomplishments with the records of our CATV systems, we must ask the question "Isn't it time that the CATV industry come up with good clean and reliable gear?" Yes, the answer is yes, the time is long overdue. The CATV industry needs the same quality and reliability that our military and space agencies need. There is not good reason why we should not have it. We feel this amplifier is a major step in this direction.

Thank you.

DONALD B. GREGORY

A CATV trunk system is made up of cycles of components along its length. Each cycle consists of a length of cable and an amplifier which has gain that is exactly opposite the cable and passive network losses at all frequencies within the bandwidth of the system. The maximum length of cable that can be used ahead of an amplifier is limited by the lowest signal levels that can be handled by the amplifier. Signal to noise ratio performance is the limiting characteristic.

The maximum gain that can be built into the amplifier is limited by the ability of the amplifier to handle high level signal swings. Cross modulation and other spurious distortion products are the limiting factors. Any method to control system levels is limited by these required system characteristics.

No amplifier gain and tilt controls would be necessary if:

1. Amplifiers could be spaced at precise intervals along the cable (No regard to pole locations and having predictable cable losses).

2. Cable attenuation was constant (No change in cable losses such as from reaction to temperature of environment).

3. Amplifier gain would remain constant within the environment.

4. Power splitting devices employed that exhibited losses similar to cable with frequency.

Of course, these requirements are not yet met on a practical basis for CATV applications. Constant amplifier gain is the one factor that is being most reasonably controlled. In very long cascades some compensation for this variation should be considered.

To maintain constant levels throughout the system with the variation of cable length, cable loss per length, cable temperature, and power splitting loss it is necessary to build in the amplifier variable gain adjusting controls. These controls must also adjust the gain of the amplifier across the band at a different rate from one band edge to the other.

This skewing of the amplifier gain vs. frequency characteristic changes the tilt of the amplifier. It is necessary to build in the amplifier this capability since there are factors (such as passive device and cable loss) that must be compensated by skewing the amplifier's response.

A method to enable these operations to take place in the amplifier is to place manually operated controls in the amplifier. This is practical for initial set-up of a CATV system, but as the system experiences changes in its environment, its losses change. The primary changing factor is cable loss. The rate that cable loss changes is precisely predictable as it heats and cools. A practical method to compensate for these changes is to sample at some frequency the result of the cable loss at the amplifier and adjust the gain of the amplifier by some automatic means. The response of the amplifier can be skewed at a predictable rate to compensate for the cable loss function with frequency. This cycle of cable and amplifier then has at its end points stable signal levels. The limit of the stability is then affected by the amount of interference by other factors. To overcome these unpredictable variations and the tracking error of the automatic gain controlled amplifier it is necessary to include a separate sampling function in the amplifier. This sample should be selected at a frequency removed from first frequency sample. In a practical CATV system the two sampled frequencies can be:

1. in the guard band between Channels 4 and 5 (72 to 76 MHz such as 73.5 MHz).

2. above the highest signal frequency in the system (such as 271.24 MHz).

These selections then give a "handle" on the two ends of the system which makes it practical to adjust the amplifier gain and skew the response automatically to compensate for normal smooth loss versus frequency characteristics that could arise on the system.

The location of these control functions within the amplifier is also extremely important. If the attenuator is located at an intermediate position in the amplifier the input stages will have to be capable of handling high signal levels when input signal levels are high (see figure 1). If the attenuator is located at the input of the amplifier its loss will directly contribute to the degradation of the signal to noise ratio (see figure 2). Due to recent state-of-the-art developments it is now possible to build automatically controlled attenuators at very high frequencies that exhibit extremely low minimum insertion loss. The placement of the attenuator at the input of the amplifier allows it to work over its entire gain range and deliver a constant signal to noise ratio and also a constant signal handling capability (constant cross modulation and other distortion products). Note that the signal levels at all amplifier stages in the amplifier remain constant. This means that a system designed for any particular set of conditions will maintain constant performance characteristics as normal loss variations take place on the system. This premise will hold for the following conditions:

1. AGC employed at each amplifier location.

2. the CATV system designed within the dynamic range of the AGC system.

The variable equalizer which automatically tilts the frequency response of the amplifier may be located at any convenient location in the amplifier since it has only a small effect on the overall signal swing in the amplifier (see figure 2).

An amplifier with characteristics of:

1. Operational gain: 22 dB @ 270 MHz

2. AGC range: ± 4 dB @ 73.5 MHz
± 8 dB @ 271.25 MHz

will hold signal levels constant at all points in the bandwidth over a cable temperature range of 290° F. Of course, this would be much more AGC range capability than normally needed, so a slight modification of the performance/cost trade-off is practical. The signal to noise ratio and the signal handling capability is sacrificed by only a minor amount. Figure 3 shows the effects on levels (and performance) by using manual gain control amplifiers at every other amplifier location which yield a more economical system design. This configuration will yield constant levels at each AGC amplifier output port over a 145° F cable temperature range. Nearly all CATV systems constructed in the United States will experience less than a 145° temperature swing (including cable temperature rise in sunlight) This then allows manual gain amplifiers to be used at every other location to obtain a cost saving if desired.

Investigation of the degradation of signal to noise ratio and cross modulation can be made for this application of an AGC amplifier at every other trunk location. A cycle on the trunk line is now considered as:

1. a span of cable (22 dB @ 270 MHz)

2. a manual gain control amplifier

3. a span of cable (22 dB @ 270 MHz)

4. an automatic dual pilot gain controlled amplifier (see figures 3a, 3b, 3c).

Calculations of degradation of desirable system characteristics are given in Appendix A. One amplifier pair with AGC at each location would produce a signal to noise ratio 54 dB. One amplifier pair with AGC at every other location is 53 dB, therefore, the degradation is 1 dB of signal to noise ratio.

Cross modulation degradation by use of manual gain amplifiers at every other location is calculated in Appendix B. Note that the degradation caused by using a manual gain amplifier at every other location would be 2 dB. The cost of the system could be reduced (savings being the cost of the AGC system at every other trunk amplifier location) at the small increase of system degradation. Likewise, it is obvious for optimum system performance use of automatic gain control amplifiers at every trunk location would be necessary.

Level control of feeder lines is not as critical as the trunk system, but some method of reducing the level swing with temperature provides better system performance. Either single pilot AGC line extenders or thermal control would be adequate since these units are used in limited cascades.

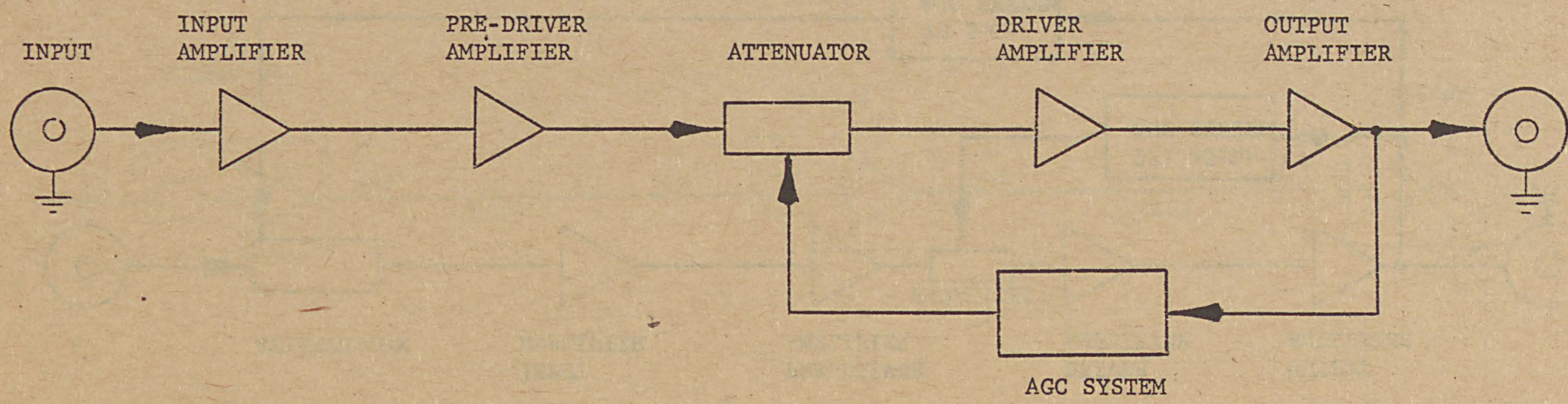

INPUT
INPUT AMPLIFIER
PRE-DRIVER AMPLIFIER
ATTENUATOR
DRIVER AMPLIFIER
OUTPUT AMPLIFIER
AGC SYSTEM

FIGURE 1

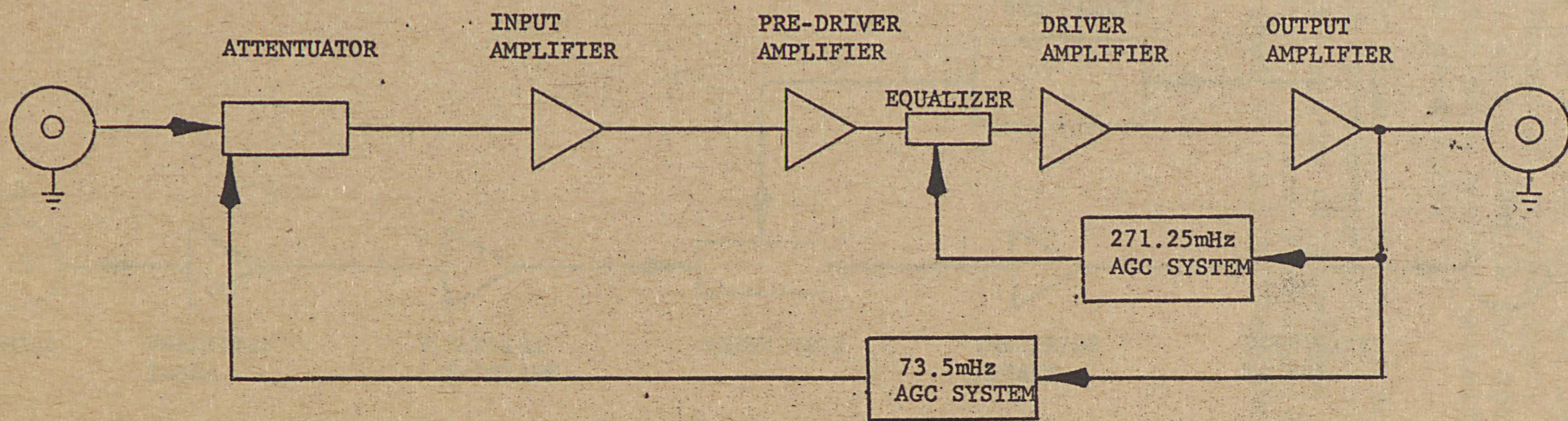

ATTENTUATOR
INPUT AMPLIFIER
PRE-DRIVER AMPLIFIER
EQUALIZER
DRIVER AMPLIFIER
OUTPUT AMPLIFIER
271.25mHz AGC SYSTEM
73.5mHz AGC SYSTEM

FIGURE 2

FIGURE 3a

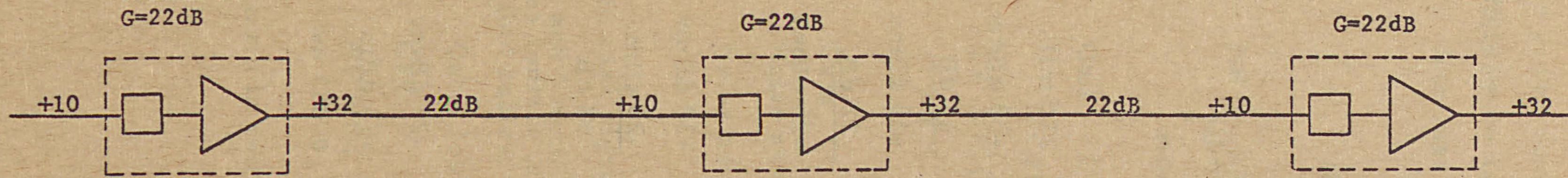


FIGURE 3b

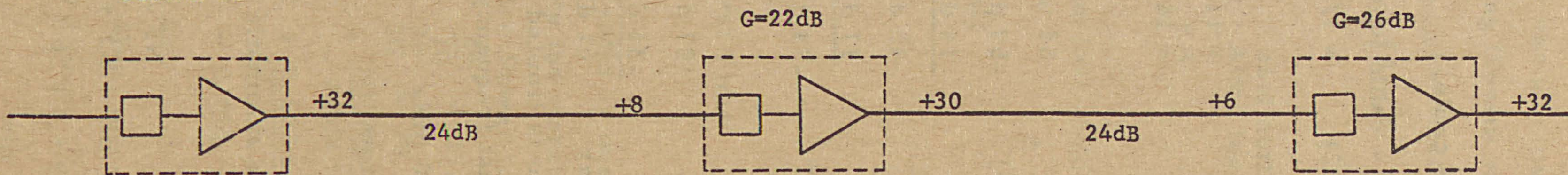
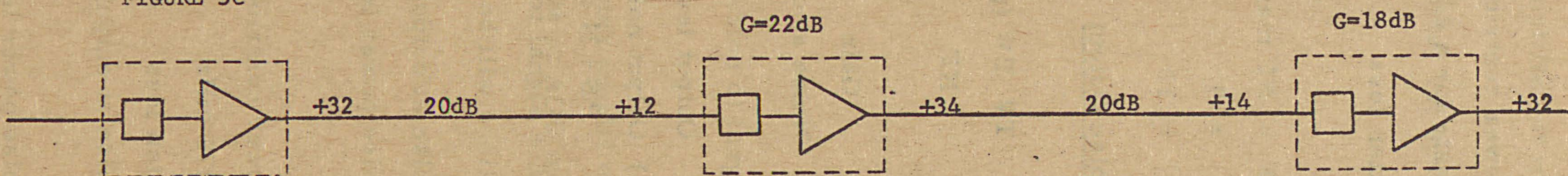


FIGURE 3c



APPENDIX A

I. Noise power contribution by one manual gain amplifier when adjusted to compensate for a 22 dB span of cable.

Atten loss = 1/2 (G_{max} - cable loss)
= 1/2 (26 - 22) = 1/2 (4) = 2 dB

NF = NF max. gain + Atten loss
= 9 + 2 = 11 dB @ 270 mHz
= 12 + 2 = 14 dB @ 54 mHz

Noise Output

	54 mHz	270 mHz
TV BW (per channel)	-59 dBmv	-59 dBmv
NF	14 dB	11 dB
	-45 dBmv	-48 dBmv
Gain	11 dB	22 dB
Noise at output port	-34 dBmv	-26 dBmv
Signal to noise ratio		
Output level	+27 dBmv	+32 dBmv
(-) Output noise	-34 dBmv	-26 dBmv
S + N one amplifier	61 dB	58 dB

Since signal to noise ratio is limited at 270 mHz, further calculations will be made at that frequency only.

Noise at output port @ 270 mHz -26 dBmv
Noise power level: ref 1 mw -75 dBm
0.033 nw

II. Noise power contribution by one automatic gain amplifier at maximum gain at 270 mHz.

Atten loss = 0 dB, NF = 9 dB
Noise at output port = TV BW + NF + Gain
= -59 + 9 + 26 = -24 dBmv
Noise power level: ref. 1 mw -73 dBm
0.052 nw

Appendix A - (Continued)

III. Noise power contributed by one automatic gain amplifier at minimum gain at 270 mHz

Attn loss $= 1/2\ (G_{max})$ - cable loss $+\triangle$cable, 1st span)

$= 1/2\ (26 - 20 + 2)$

$= 1/2\ (8)$

$= 4$ dB

NF = NF max gain + Atten loss

= 9 + 4

= 13 dB

Gain $= G_{max}$ - Atten loss - Eq. loss

= 26 - 4 - 4

	@ 270 mHz
TV BW (per channel)	-59 dBmv
NF	13 dB
	-46 dBmv
Gain	18 dB
Noise at output port	-28 dBmv
Noise power level: ref 1 mw	-77 dBm
	0.02 nw

IV. Worse case signal to noise ratio by one pair of trunk amplifiers (1 ea. MGC and 1 each AGC). Note the worse case exists at AGC maximum gain (hot cable). (NP = Noise Power Level)

$$\text{Cable loss} = \log^{-1} \frac{24}{10} = 25.2$$

$$\text{Gagc} = \log^{-1} \frac{26}{10} = 39.8$$

$$\text{NP total} = \text{NPagc} + \frac{\text{NPmgc} \times \text{Gagc}}{\text{cable loss}}$$

$$= 0.052 + \frac{0.033 \times 39.8}{25.2}$$

$$= 0.052 + 0.052$$

$$\approx 0.104 \text{ nw}$$

$$= -70.0 \text{ dBm}$$

$$= -21.0 \text{ dBmv}$$

Appendix A - (continued)

IV.

Signal to noise ratio

Output level @ 270 mHz	+ 32 dBmv
(-) Output noise	- 21 dBmv
S + N Amp pair	53 dB

V. Signal to noise ratio of a pair of AGC amplifiers at hottest cable temperature (same conditions as example of Parts II thru IV) @ 270 mHz.

Atten loss = 1/2 (G_{max} - cable loss)
= 1/2 (26 - 24)
= 1/2 (2)
= 1 dB

NF = NF max gain + Atten loss
= 9 + 1
= 10 dB

Noise Output

TV BW	-59 dBmv
NF	10
	-49
Gain	24
Noise at Output port	-25 dBmv

Signal to noise ratio

Output level	+ 32 dBmv
(-)Output noise	- 25 dBmv
S + N each amp	57 dB
Derate for pair	3 dB
S+N Amp pair	54 dB

APPENDIX B

I. Cross modulation (CM) contribution of one manual gain amplifier at coldest cable temperature. (see figure 3c).

Rated output level (ROL): +32 dBmv @ Ch 13

Cross Modulation: -93 dB NCTA Standard

Actual output level (AOL): +34 dBmv @ Ch 13

Cross Modulation: -89 dB NCTA Standard

from CM = 2 (AOL - ROL) -93

= 2 (+34 - 32) -93

= 2 (2) -93

= -89 dB

II. Cross modulation contribution of one amplifier pair (1 each MGC and 1 each AGC amplifier)

Amplifier	CM	Voltage Factor (ref -100 dB)
MGC	-89 dB	3.5
AGC	-93 dB	2.1
	-85 dB	5.6

III. Cross modulation contribution of one amplifier pair of 2 each AGC amplifiers

CM = CM of one amplifier + 6 dB

= -93 +6

= -87 dB