LEVEL CONTROL CONCEPTS FOR MULTICHANNEL AND TWO-WAY SYSTEMS

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ABSTRACT

System level control design philosophy is presented for multichannel and two-way transmission systems. Techniques for channel selection are introduced. Appendix II and III covers these techniques. These techniques are used to reduce the effects of second-order and third-order distortion products. Reasons for not standardizing pilots are clarified in conjunction with multichannel requirements and pilot placement.

Amplifier design approaches follow to fulfill system requirements. A novel automatic gain control (agc) amplifier design incorporated at Anaconda Electronics Company is discussed. Design techniques are used which provide level stability and desirable transient response.

New amplifier design approaches are presented. These are termed reverse gain control amplifier and weighted agc amplifier.

I. INTRODUCTION

Today new and advanced technology is causing greater capability, flexibility and diversity for every new and existing cable TV system. Consequently new philosophies are emerging to control system parameters. Particularly important is the control of exogenous parameters such as channel placement, signal levels and pilot carrier placement. These are essential elements in the vector of control for each system design whether it is for one-way or two-way usage. Control of these elements is required for reliable system operation.

The system level control philosophy presented is in a general context so it will apply to a large class of system. Level control is required to maintain adequate signal to noise ratio and acceptable distortion levels. These parameters are related to channel selection, frequency response, and pilot carriers.

Two-way system level control is accomplished by use of open and closed loop control techniques combined with single and dual cable designs. This way, the resulting systems remain simple and economical. The system with short haul trunk lines originating at the head end or hub type of system uses reverse gain control amplifiers. For long haul trunk lines dual cable is used with agc amplifiers and combining networks.

II. LEVEL CONTROL DESIGN PHILOSOPHY

A properly designed system, be it one-way or two-way, has safety margins built in to maintain adequate signal to noise ratio and distortion at suitably low levels. These safety margins are required to accommodate variations in amplifier performance with input signal level variation, temperature, inaccuracies in desired amplifier placement, and amplifier control settings (gain and equalization). The input signal level variation at a particular amplifier is due to the frequency response of the preceding amplifiers being temperature sensitive as well as the attenuation of the preceding cables being a function of temperature. Cable attenuation in decibels is described by

$$A = q_o + q_1 f^{\frac{1}{2}} + q_2 f \qquad (1)$$

where f is frequency and the other terms are a function of temperature and a particular manufacturer. The optimum amplifier design in terms of noise figure, distortion, load capacity, gain distribution and other costs will not be considered here. A conjugate gradient optimization algorithm can be used in such a design. References for conjugate gradient techniques are [1] and [2].

The fundamental problem here is the control of amplifier output levels. The need to control these levels is readily seen from equations (2) and (3) for signal to noise ratio and cross modulation respectively [3].

$$10 \log(S/N)_m = S - G - F_{db} - 10 \log KTB - 10 \log m \qquad (2)$$

$$XM_m = XM_R + 2(S_R - S) - 10 \log(N_c - 1) - 20 \log m \qquad (3)$$

where
S = amplifier operating output in dbmv
G = amplifier gain in db
The other terms are defined in Appendix I. These equations, in a less general form, have been used in earlier papers [4], [5]. Second order distortion terms may be a factor as well as other third order products. Appendix II and III discusses distortion and channel selection respectively. For a particular channel allocation design, a means of evaluating intermodulation distortion is given by

$$IM_m = IM + (S_R - S) - 10 \log m \qquad (4)$$

where

IM_m = intermodulation at the output of the mth amplifier in cascade

IM = intermodulation at the output of a single amplifier

S_R = amplifier reference output in dbmv

S = amplifier operating output in dbmv

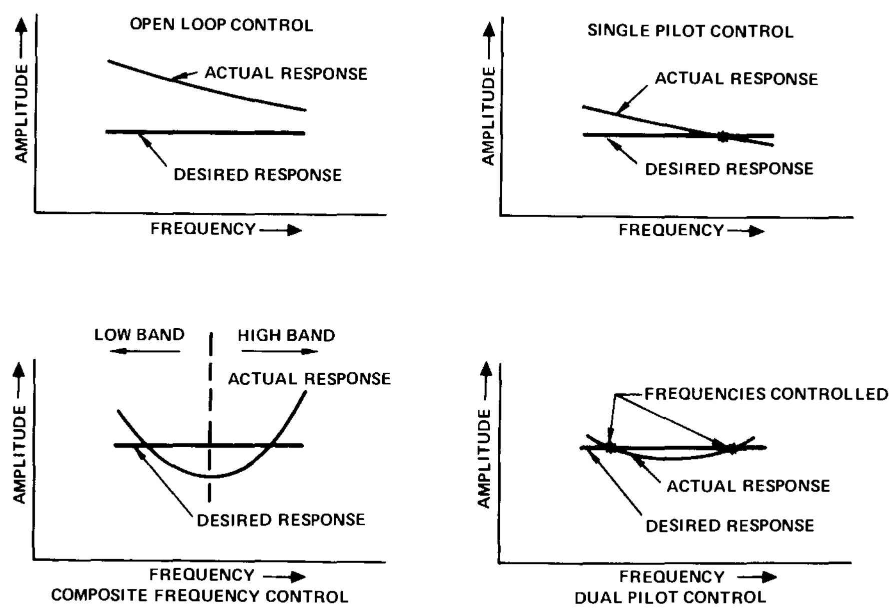
These equations are for what is termed a "well behaved amplifier" [5]. Furthermore, they assume all amplifiers have the same distortion and noise properties. Additionally, all amplifiers are supposed to have equal gain and output levels. Tests, over temperature, must be conducted to correlate computed results, from these equations, with actual test data.

Once correlation is completed, bounds on the system performance can be established from these equations. Thus, minimal standards of performance for signal to noise ratio and distortion are assured provided the output levels are controlled.

A suitable technique of level control advocated is the combination of open and closed loop control in the form of thermally compensated and agc amplifiers respectively. The ratio between the number of thermally compensated amplifiers and agc amplifiers in a cascade depends on the system noise and distortion requirements as they relate to temperature range and cascade length.

III. LEVEL CONTROL TECHNIQUES

The level control techniques presently used in one-way systems are reviewed in Figure 1. The shortcomings of open loop control and single pilot control are reviewed graphically. Any control scheme consisting of more than two carrier frequencies can be defined as composite frequency control. Usually the response is averaged over two bands of frequencies. In dual pilot control one pilot usually controls the amplitude at a single frequency while the other pilot controls the degree of equalization based on the amplitude at another frequency.



LEVEL CONTROL TECHNIQUES (CASCADE RESPONSE)

Figure 1

IV. CONTROL TECHNIQUE SELECTION

Since manufacturing tolerances exist between cables and uncertainties in response flatness exist with placement, temperature, taps, splitters, etc., an adjustment capability must be provided in at least some of the trunk line amplifiers. This further complicates the level control problem since we demand response stability with temperature changes for the multitude of adjustment possibilities.

With the amplifier frequency response changes over temperature reduced as well as practical, the next step is to select an agc approach with corresponding pilot placement which will provide for adequate level control. Also, pilot carrier amplitude and its effect on distortion must be considered and the pilot carrier(s) controlled must be representative of the process. This can be done by placing the pilot carriers at usable frequency band edges or within the band as shown in Figures 2 and 3. Here, frequency response, over temperature changes, is shown to be related to pilot carrier placement.

For a limited bandwidth and a short haul trunk line, thermal compensation combined with single pilot control may be adequate. Proper application of equations (2), (3), and (4) in conjunction with the channel selection techniques of Appendix III will generally answer this question.

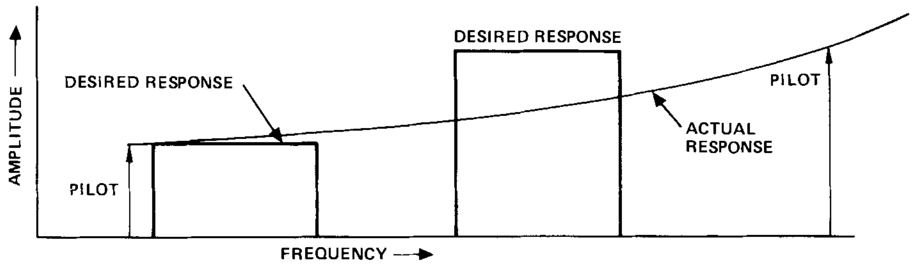
Since every equipment manufacturer's trunk line equipment has a different frequency response with temperature the techniques used or required for adequate control are different. Also for different systems with varying channel and bandwidth requirements it may be necessary to have pilot carrier frequency flexibility for improved level control.

There are also different points of view concerning dual, composite and modulated pilots within the industry.

Pilot carrier frequency standardization could unnecessarily limit system performance. Furthermore, present designs could be obsoleted by standardization rulings. Any plans to standardize pilots will have to satisfy individual system requirements in terms of bandwidth and channel selection.

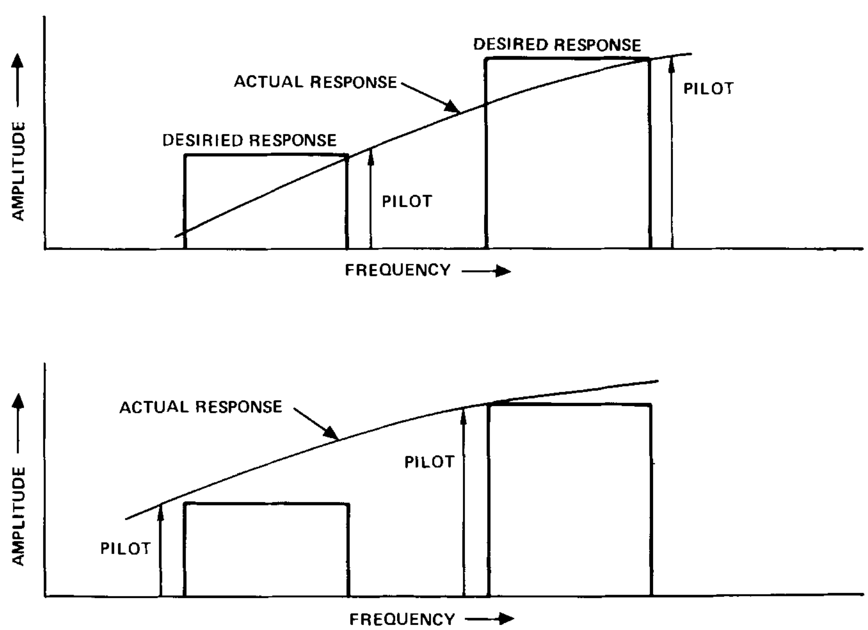
V. TWO-WAY SYSTEM LEVEL CONTROL HIERARCHY

A level control design philosophy, consisting of open and closed loop control techniques, can be applied to the reverse direction of a two-way system. Equations (2), (3), and (4) do not generally apply for the reverse direction. A correction noise term related to number of subscribers is required in equation (2). The information coding techniques incorporated will affect the system distortion requirements. Also access techniques to reduce queueing and prevent overload conditions are needed. Level control techniques may be considered independent of these factors. This viewpoint is pursued here.



PILOT SELECTION EXAMPLE (CASCADE RESPONSE)

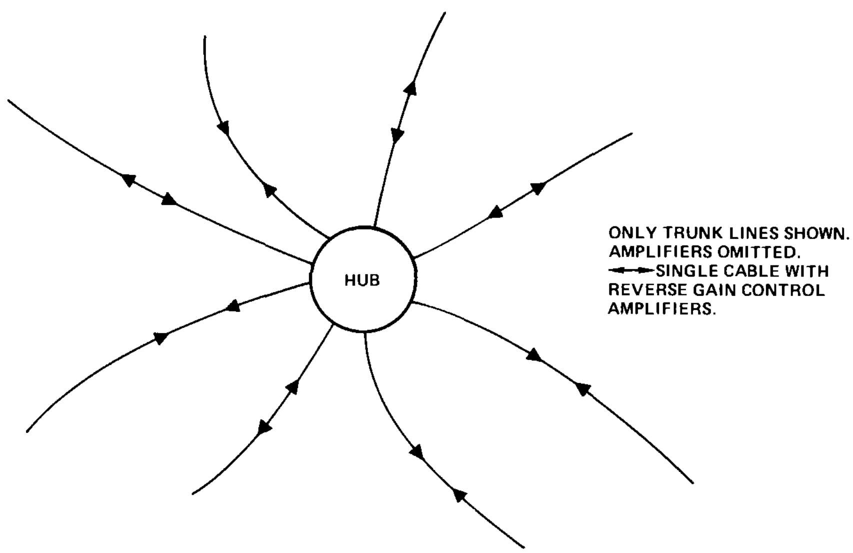
Figure 2



PILOT SELECTION EXAMPLE (CASCADE RESPONSE)

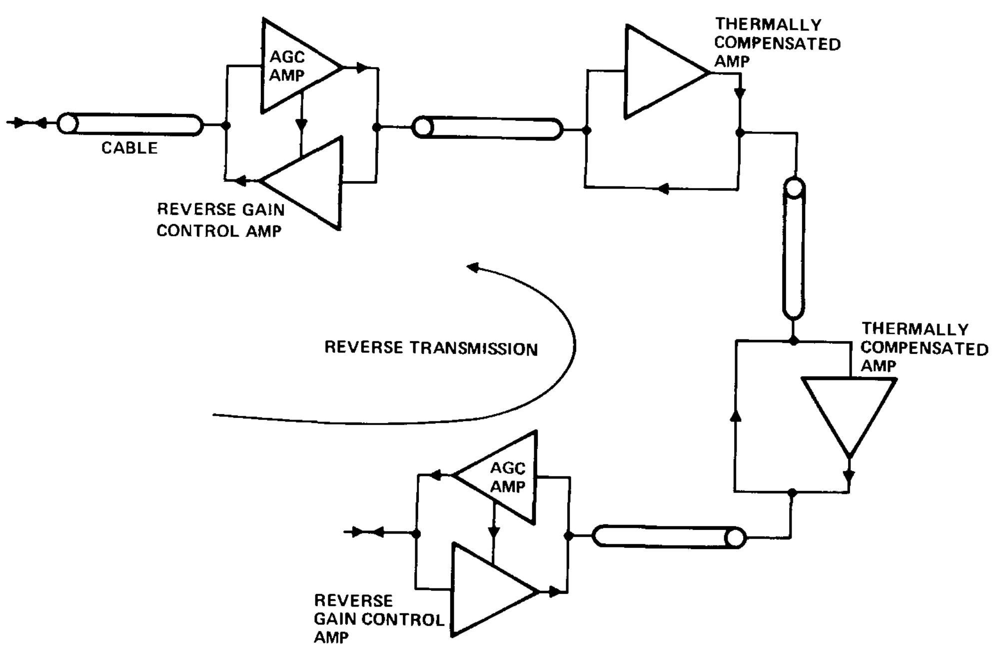
Figure 3

For short haul trunks or a hub type of system, open loop control can be applied. This approach is indicated in Figures 4 and 5 where reverse gain control amplifiers are used to control the gain.



TWO-WAY SYSTEM STRUCTURE (HUB SYSTEM)

Figure 4



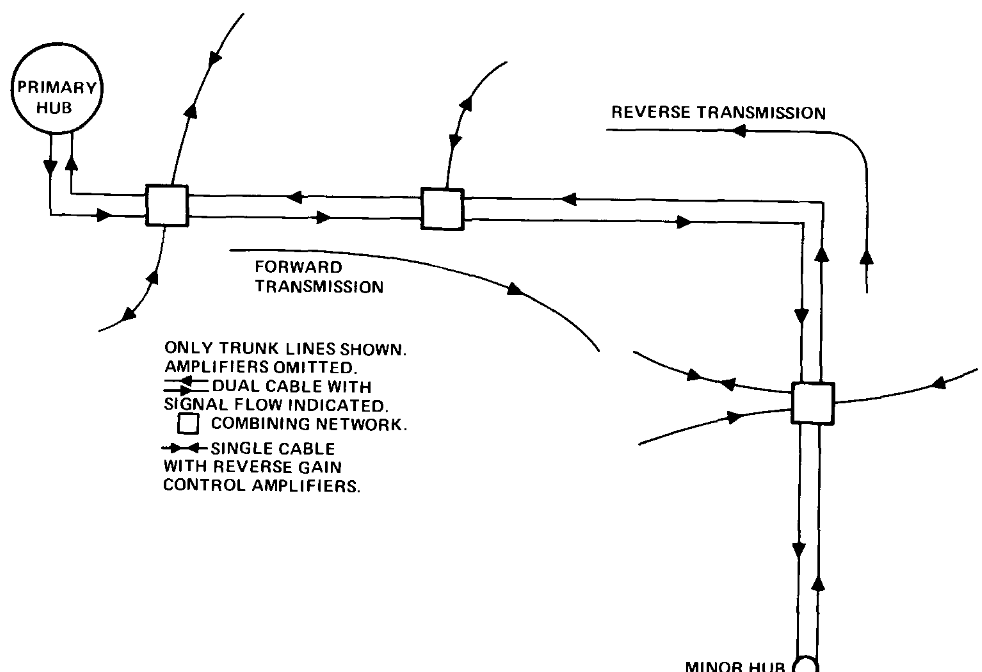
TWO-WAY COMMUNICATIONS WITH REVERSE AMPLIFIERS

Figure 5

Figure 5 illustrates this concept where the split band filters are omitted for simplicity. Reverse gain control amplifiers are used as needed and their gain is controlled by the agc amplifiers in the forward direction. Since this is open loop control its application is limited and for a long haul trunk a minor hub with a pilot carrier generator is required.

Since a system's structure is not made up entirely of long cascades, a combination of open and closed loop control techniques can be applied. Figure 6 shows such a system where a minor hub with a dual cable is provided. The dual cable portion of the system makes level control more easily achievable from an engineering standpoint. Added cost is the price paid for this approach. For short trunks which are branches of this long trunk line open loop control is used with reverse gain control amplifiers and split band filters. Since these cascades are relatively short, acceptable group delay and frequency response characteristics can be realized to achieve the desired system performance.

The combining networks of Figure 6 can also contain access electronics as part of a subscriber selection scheme. In this manner noise at the head end for the reverse direction can be maintained at acceptable levels.



TWO-WAY SYSTEM STRUCTURE (LONG HAUL TRUNK)

Figure 6

A savings in cost may be realized by exploiting the system map to find a hub type of structure where reverse gain control amplifiers can be utilized and long haul trunk lines avoided. This could also result in improved performance with a possible cost reduction for the forward direction. Due to the simplicity of the reverse gain control amplifier the major cost factor is the additional size of the housings and the addition of two-way filters. This is small compared to the extra cable, housings, level control electronics, and powering circuitry for the dual cable system. Clearly, a cost reduction is achievable using the reverse gain control amplifiers.

As two-way system design requirements become better defined, systems and manufacturers with flexibility and capability will be adaptable to the needs of the industry. Existing single cable systems that can incorporate two-way transmission will be needed. New system layouts incorporating dual cable will have insurance for future two-way usage. For these reasons a combination of open and closed loop control techniques are needed.

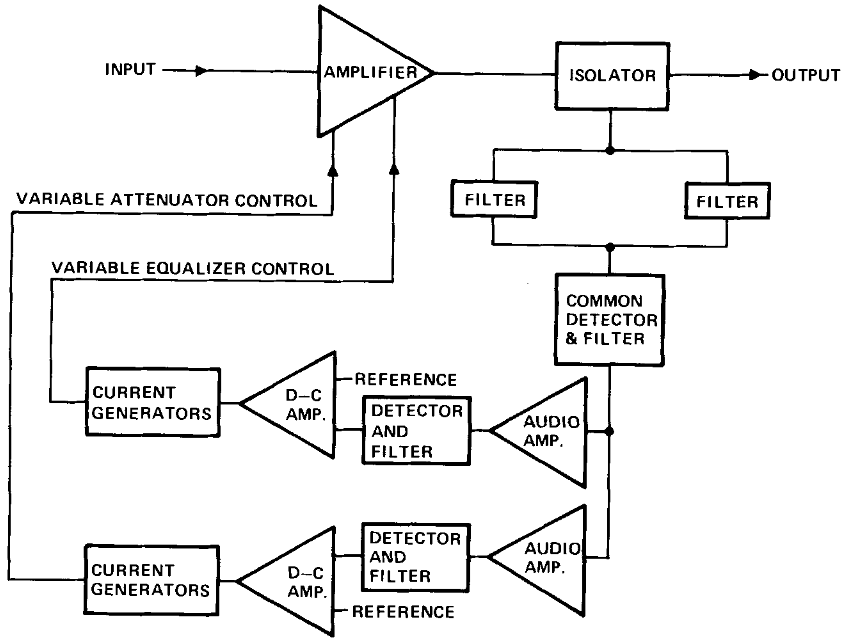
VI. ONE-WAY AGC AMPLIFIERS

Some of the hardware required in a one-way multichannel cable system is a dual pilot agc trunk line amplifier and a agc distribution amplifier or line extender.

The agc trunk line amplifier utilizes a dual modulated pilot and advanced design techniques to achieve long term stable operation and desirable transient response.

A block diagram explaining the design is presented in Figure 7. Here the signals from the two parallel bandpass filters enter a common averaging detector and filter. Economy and additional filtering of channels adjacent to each pilot carrier is achieved in this manner. At the detector output the unfiltered frequencies are designated f_1 and f_3. They are the modulating frequencies for the pilot carrier frequencies f_2 and f_4. Thus, low level d-c detection schemes requiring extremely stable components and references are avoided. Additionally, the audio amplifiers have bandpass responses for the frequencies f_1 and f_3. The signals at the audio amplifier outputs are large in amplitude compared to the signals out of the common detector. Now large signal detection follows and the resulting signals are compared to their appropriate references. The remainder of the diagram is fairly self explanatory with the exception of the isolator. This block consists of a stable low loss magnetic component which couples the amplifier output, at a reduced level, into a low distortion cascode amplifier.

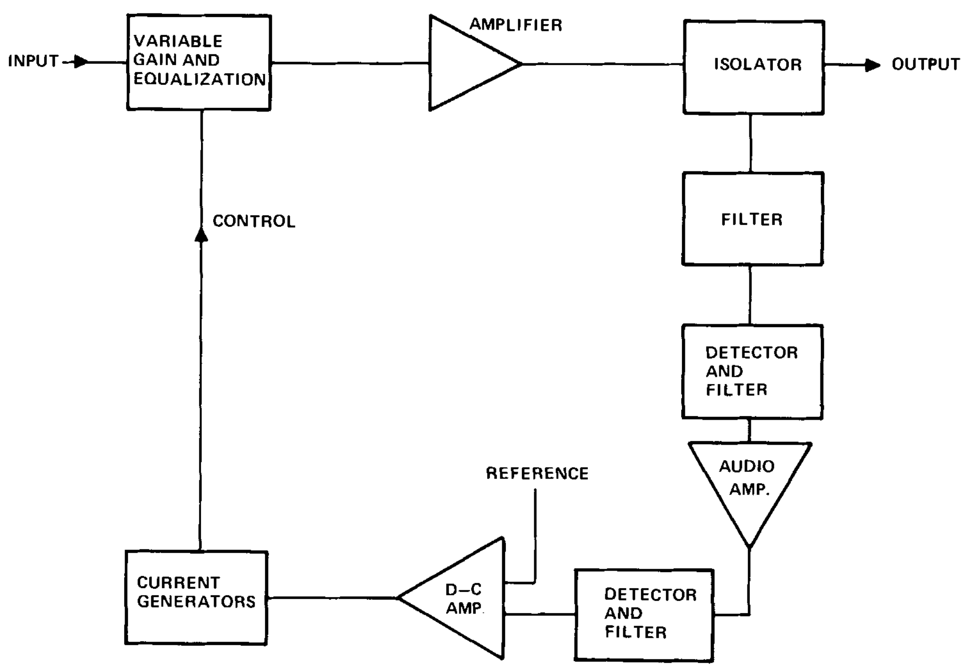
The transient response design is realized using state variable techniques. The detailed design formulation is found in Appendix IV.



AGC TRUNK LINE AMPLIFIER

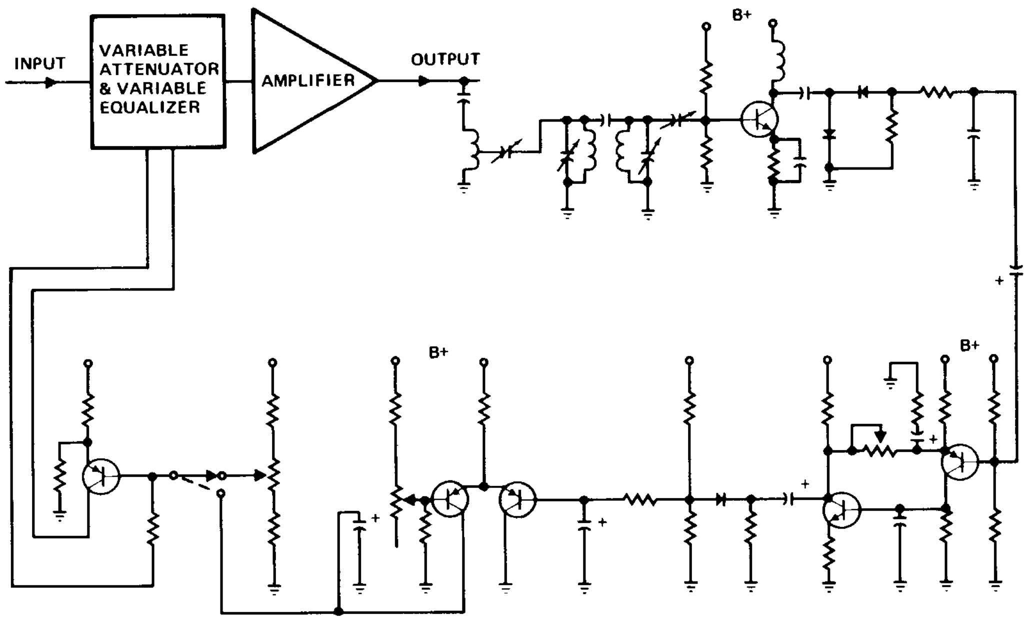
Figure 7

Since the agc line extender cascadability requirements aren't as stringent as those of the trunk line its design is compact while using only one modulated pilot carrier. This block diagram is in Figure 8; and Figure 9 shows the associated feedback circuitry.



AGC LINE EXTENDER

Figure 8



FEEDBACK CIRCUITRY FOR AGC LINE EXTENDER

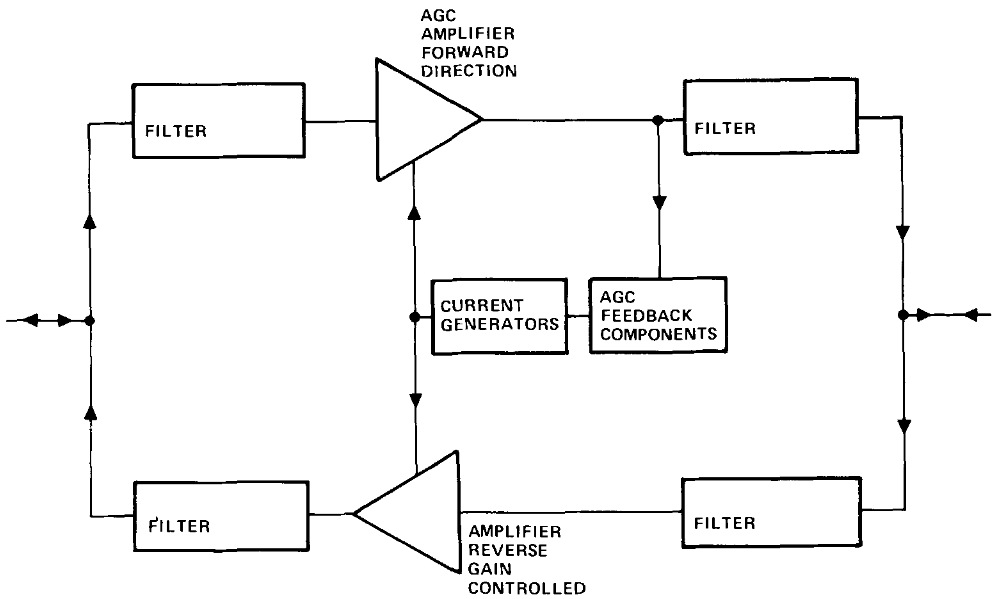
Figure 9

VII. NEW DESIGNS

A reverse gain control amplifier and weighted agc amplifier are new designs for level control applications.

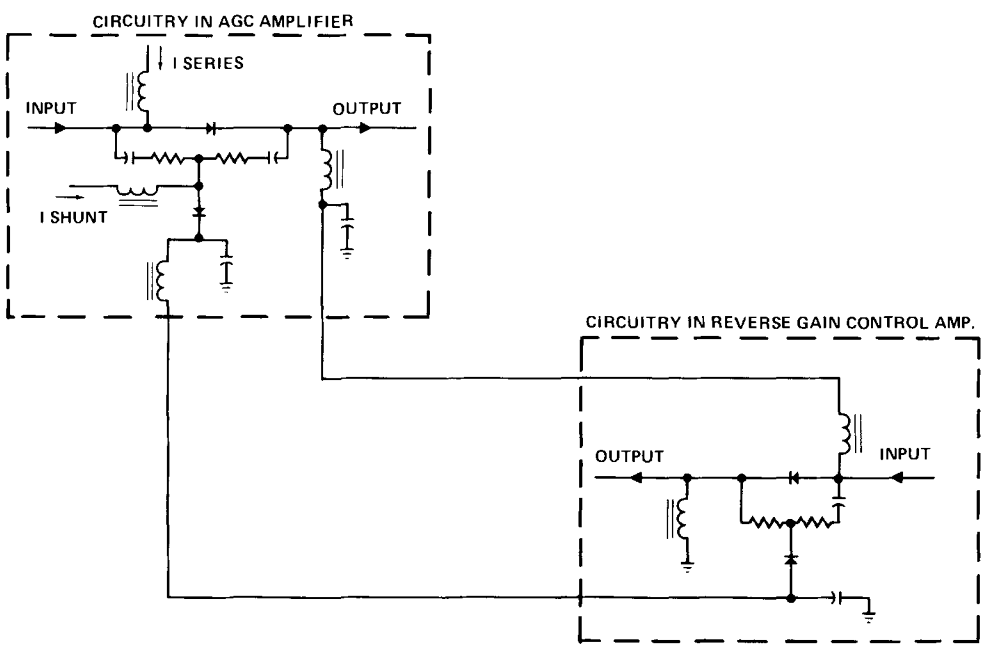
The reverse gain control amplifier is used exclusively for two-way system applications while the weighted agc amplifier can be used in either one-way or two-way systems. Figure 10 is a block diagram of the reverse gain control amplifier showing how it is used with a agc trunk line amplifier. Here the current generators used in the forward direction are shared by the reverse gain control amplifier. Additional electronics for agc feedback components are not necessary. A circuit example of this technique is found in Figure 11.

The weighted agc amplifier is similar in design to the agc trunk line amplifier of Figure 7. It has two distinct advantages overall. The primary difference in electronic components is the addition of a summing amplifier (See Figure 12). Functionally the two pilot carrier amplitudes are used to determine the setting of the variable attenuator. This complements the action of the variable equalizer and results in an extended agc range. Furthermore, redundancy is built into this design. For example, if one pilot carrier is interrupted some level control is maintained. In comparison with conventional designs, a pilot loss will result in no control and either the amplifier gain or equalization will go to its maximum value.



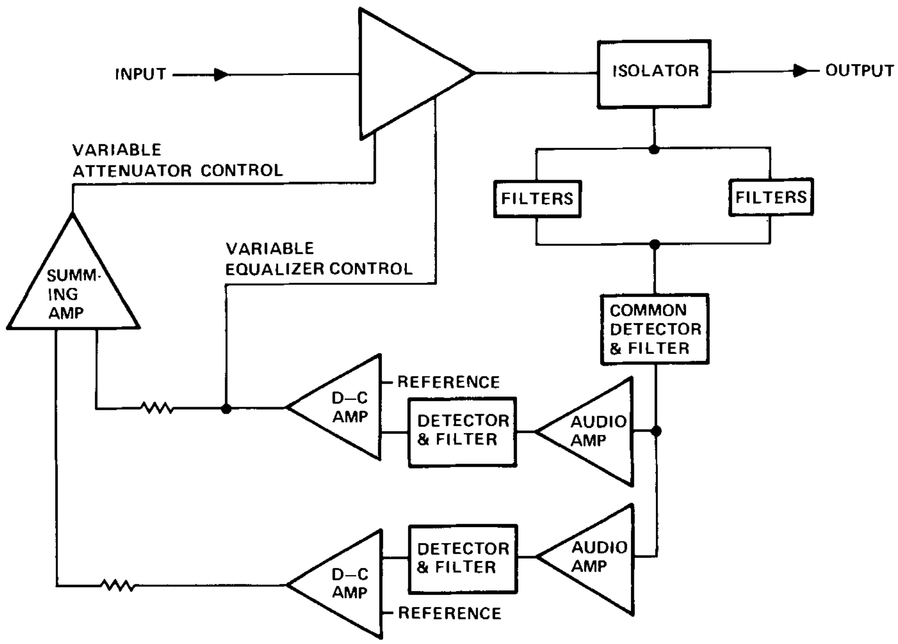
TWO-WAY COMMUNICATIONS WITH REVERSE GAIN CONTROL

Figure 10



CIRCUITRY FOR REVERSE GAIN CONTROL

Figure 11



WEIGHTED AGC AMPLIFIER

Figure 12

VIII. SUMMARY AND CONCLUSION

System requirements as they relate to level control have been emphasized. Additionally, level control philosophies were presented for both one-way and two-way systems. Finally, hardware descriptions were included for completeness.

The need for design techniques to minimize the total system cost while maintaining adequate performance was inferrred in the Two-Way System Level Control Hierarcy section. Procedures of this nature do not exist for the less complex problem of one-way systems. Such procedures could determine parameters such as head end location(s) as well as cable routes and equipment requirements.

APPENDIX I

Definition of Terms

For convenience, equations (2) and (3) are repeated [3]

$$10 \log(S/N)_m = S - G - F_{db} - 10 \log KTB - 10 \log m \quad (2)$$

$$XM_m = XM_R + 2(S_R - S) - 10 \log(N_c - 1) - 20 \log m \quad (3)$$

The terms are defined as follows:

$10 \log(S/N)_m$ = the signal to noise ratio at the output of the mth amplifier in decibels (db)

S = amplifier operating output in dbmv

G = amplifier gain in db

F_{db} = amplifier noise figure in db

KTB = available input thermal-noise power

m = the number of amplifiers in cascade

XM = 20 log(% normal modulation) / (% imposed modulation)

XM_m = cross modulation at the output of the mth amplifier

XM_R = cross modulation at the output of a single amplifier measured for two carriers at the S_R reference output magnitude

S_R = amplifier reference output magnitude in dbmv

N_c = number of channels in the system

APPENDIX II

Distortion Analysis

A Taylor series expansion is used to describe the nonlinearities in an amplifier output signal [6], [7]

$$e_o = \sum_{j=1}^{\infty} a_j e_{in}^j$$

The resulting second order and third order product terms are well known for $e_{in} = A\cos\alpha t + B\cos\beta t + C\cos\gamma t$.

For e_{in} consisting of n sinusoids at frequencies $f_1, f_2, \ldots, f_n$ a matrix $A_1 = (a_{ij})$ is defined where $a_{ij} = f_i + f_j$. References for matrix techniques are [8], [9], and [10]. Similarly a matrix $A_2 = (b_{ij})$ is defined where $b_{ij} = f_i - f_j$. The diagonal elements of A_1 are all the second harmonics generated and the elements from either above or below the diagonal are the sum frequencies of each pair of input frequencies. For A_2 the trace is zero and the off diagonal terms are the difference frequencies.

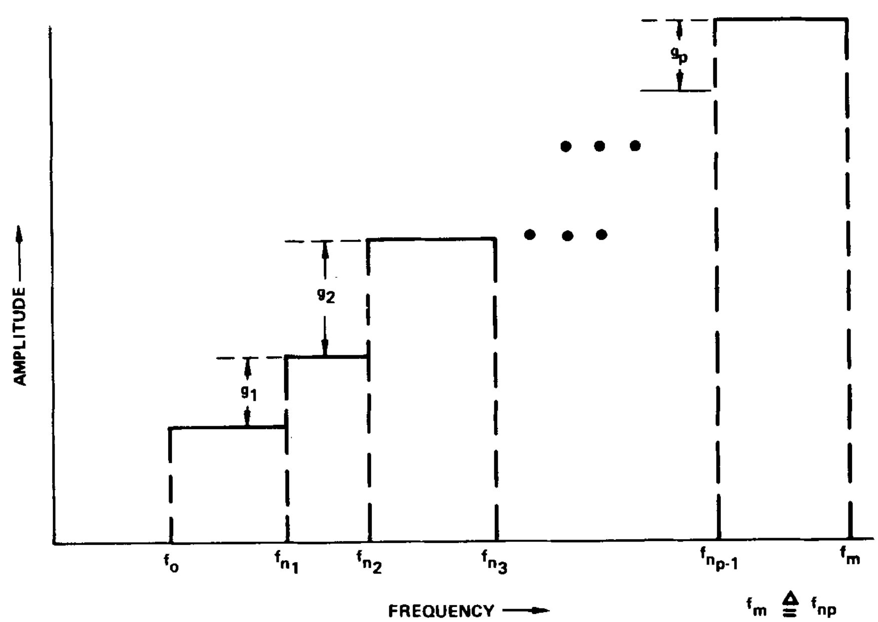
The third order product terms are three types; $3f_i$, $2f_i \pm f_j$ where $i \neq j$, and $f_i \pm f_j \pm f_k$ where $i \neq j$, $i \neq k$, and $j \neq k$. Appropriate matrices can be defined to analyze the resulting distortion terms.

Computer analysis programs have been written for general system designs using the above techniques.

APPENDIX III

Channel Selection

For a split band system corresponding to p = 3 in Figure 13 the carrier frequencies selected are within the frequency intervals (f_o, f_{n1}) and (f_{n2}, f_m). Here $f_i, f_k \in (f_o, f_{n1})$ and $f_j, f_l \in (f_{n2}, f_m)$. The index set



GENERAL MULTICHANNEL SYSTEM

Figure 13

I_1 contains i and k. Similarly $j,l \epsilon I_2$. The number of carriers selected is n where n is the number of members in the sets I_1 and I_2.

The intermodulation sum frequencies must satify the following requirements to remain outside of the intervals (f_o, f_{n1}) and (f_{n2}, f_m).

$$\left.\begin{array}{l} f_{n1} < f_i + f_k < f_{n2} \\ \text{or} \\ f_i + f_k > f_m \end{array}\right] \text{— for low band carriers}$$

$$f_j + f_l > f_m \qquad \text{for high band carriers}$$

$$f_i + f_j > f_m$$

For the intermodulation difference frequencies the requirements are:

$$|f_i - f_k| < f_o$$

$$\left.\begin{array}{l} f_{n1} < |f_j - f_l| < f_{n2} \\ \text{or} \\ |f_j - f_l| < f_o \end{array}\right] \text{— for high band carriers}$$

$$f_{n1} < f_j - f_i < f_{n2}$$

or

$$f_j - f_i < f_o$$

The requirements for the $2f_q \pm f_r$ terms cannot be satisfied in general. Here $q,r \epsilon I_1 \cup I_2$. The $2f_i - f_k$ term and $2f_j - f_l$ terms will fall at carrier frequencies for uniform video carrier frequency placement. The $2f_i - f_j$ and the $2f_j - f_i$ terms can be selected to reduce build up of distortion products at a particular frequency.

The desired requirements for the other terms are:

$$f_{n1} < 2f_i + f_k < f_{n2} \text{ or } 2f_i + f_k > f_m$$

$$2f_i + f_j > f_m$$

$$2f_j + f_i > f_m$$

$$2f_j + f_l > f_m$$

Requirements can be established for the $f_q \pm f_r \pm f_s$ terms and the $3f_q$ terms, where $q,r,s \epsilon I_1 \cup I_2$.

It is not possible to satisfy all of the requirements simultaneously for a particular system. What can be done is to weigh most heavily those distortion terms which are characteristic of a particular system. For example, if the a_2 coefficient dominates in $e_o = \sum_{j=1}^{\infty} a_j e_{in}^{j}$ then the second order product distortion requirements are the major consideration.

APPENDIX IV

State Variable Design

The agc trunk line amplifier of Figure 7 is described by two differential equations of the form

$$\ddot{y} + b_1\dot{y} + b_o y = d_1 c_1 + d_2 x$$

$$\ddot{x} + a_1\dot{x} + a_o x = e_1 c_2 + b_2 y$$

where
y is the high frequency pilot amplifier output amplitude

x is the low frequency pilot amplifier output amplitude

c_1 is the reference signal for the variable attenuator control loop or gain loop

c_2 is the reference signal for the variable equalizer control loop or equalizer loop

Now define the following state variables:

$$x_1 = x$$

$$x_2 = \dot{x}$$

$$x_3 = y$$

$$x_4 = \dot{y}$$

State variable techniques can be found in [11], [12].

The system is now formulated in a state variable description and is compactly described by

$$\dot{x} = Ax + Bu$$

where

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -a_o & -a_1 & b_2 & 0 \\ 0 & 0 & 0 & 1 \\ d_2 & 0 & -b_o & -b_1 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & e_1 \\ 0 & 0 & 0 & 0 \\ 0 & d_1 & 0 & 0 \end{bmatrix}$$

$$u = \begin{bmatrix} 0 \\ c_1 \\ 0 \\ c_2 \end{bmatrix}$$

The two poles in the equalizer loop are termed w_1 and w_2 expressed in radians per second and are determined from $a_1 = w_1 + w_2$. The loop gain here is determined from $a_o = w_1 w_2 + K_1$ where $K_o = K_1/w_1 w_2$ is the open loop gain of the equalizer loop.

For the gain loop, $b_1 = w_3 + w_4$ and $b_o = w_3 w_4 + K_3$ where $K_2 = K_3/w_3 w_4$ is the open loop gain of the gain loop. Here the two poles are w_3 and w_4.

The desired transient response design can be computed by solving for x with appropriate values for the elements in the matrices A and B.

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