RETURN SYSTEM AGC IN TWO-WAY CATV SYSTEMS

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INTRODUCTION

I. This paper will examine the problem of automatic gain control (AGC) for the return direction in two-way systems. In contrast to the downstream direction where one or two pilots are distributed over the system, a return system will use a multiplicity of pilots. These pilots are injected at system extremeties and travel back to the head end unless prevented from so doing. The problems and desirability of stopping pilots is considered as applied to various types of pilot. The types of pilot considered include CW pilots, audio frequency modulated pilots, pilots with synchronized frequencies and also pilot control signals consisting of band limited white noise.

The problem of location of return pilot generators is examined along with the necessity for precise level control of all imput signals for the return system. The latter consideration becomes obvious when one realizes that the only reason for using automatic gain control in a system is to preserve the system tolerance, even if the automatic gain control performance in a system is perfect.

II. The AGC requirements for a two-way system in the forward direction are essentially the same as for a typical one-way system. The control signals normally used are CW pilot carrier, modulated pilot carrier, or an off air video signal. The choice is usually determined by system or equipment requirements.

In the forward direction, the signals entering the system can be tightly controlled at the head end and there is a known relationship between the levels of these signals and the pilot carrier levels. Since the signals all enter the system at a common point, the relationship between these signals remains constant at this point. If the system is designed so that the pilot carrier or carriers control both amplifier gain and tilt then the signal levels will remain constant relative to the pilot carrier level throughout the entire system.

In the return direction, however, the situation is not nearly so simple. Each trunk termination where return signals may be entering the system must be considered as a separate head end. Since the distance from the many various points of origination to a common point for both the return signals and the return pilot carriers are not the same, there is no fixed relationship between the levels of these signals and the levels of the return pilot carriers. Under these conditions, the return pilot carrier is primarily a system gain control. Level control must be achieved by other methods which will be discussed later.

Let us now look at the above mentioned signals which are typically used for AGC control in the forward direction and examine their adaptability as a reference signal for the return system AGC.

I. CW Pilot Carrier

Using a CW pilot carrier for AGC control in the return direction on a two-way cable system can cause a number of problems. In the forward direction one or two pilot carriers or control frequencies are chosen. These pilot carriers follow the many branches in the system outward and appear at the termination of every trunk branch.

In the return direction, however, a pilot carrier would have to be originated at many, if not all, of these branch terminations. Unless the frequency of these pilot carriers is precisely controlled from the head end, it is very unlikely that any two pilot carriers would have exactly the same frequency (±.005% for crystals frequently used in CATV equipment). Two different pilot carriers with slightly differing frequencies would be combined at a branch juncture. At the first AGC station following this branch junction there would be a 6db increase in pilot carrier level relative to the desired carrier levels. At every branch junction (a split in the forward direction) in the system, the total pilot carrier energy, assuming a peak detector in the AGC, would be the voltage addition of the pilot carrier signals in the two combining branches.

In addition, the combination of two pilot carriers differing slightly in frequency would appear effectively as a single side band modulated carrier with the frequency of modulation equal to the difference in frequency between the two pilot carriers. If the circuitry in the AGC were not capable of removing the modulation, it would be transferred to every other carrier passing through the amplifiers under control of that particular AGC circuitry.

Trapping out one of the carriers by 39db or more before combination would insure that the combination of the two carriers would be no more than .1db above the original pilot carrier level at every branch junction. Each pilot carrier junction would add an additional .1db to the pilot carrier level. This would prevent a rapid buildup of the pilot carrier level but would not completely solve the problem that the main pilot carrier which is not trapped out would be modulated by all the pilot carriers that were trapped out. In any event, attainment of 39db of trapping would be expensive and difficult to achieve. It would also introduce additional chroma delay into the system.

II. CW Pilot Carrier with the Frequency Controlled from the Head End

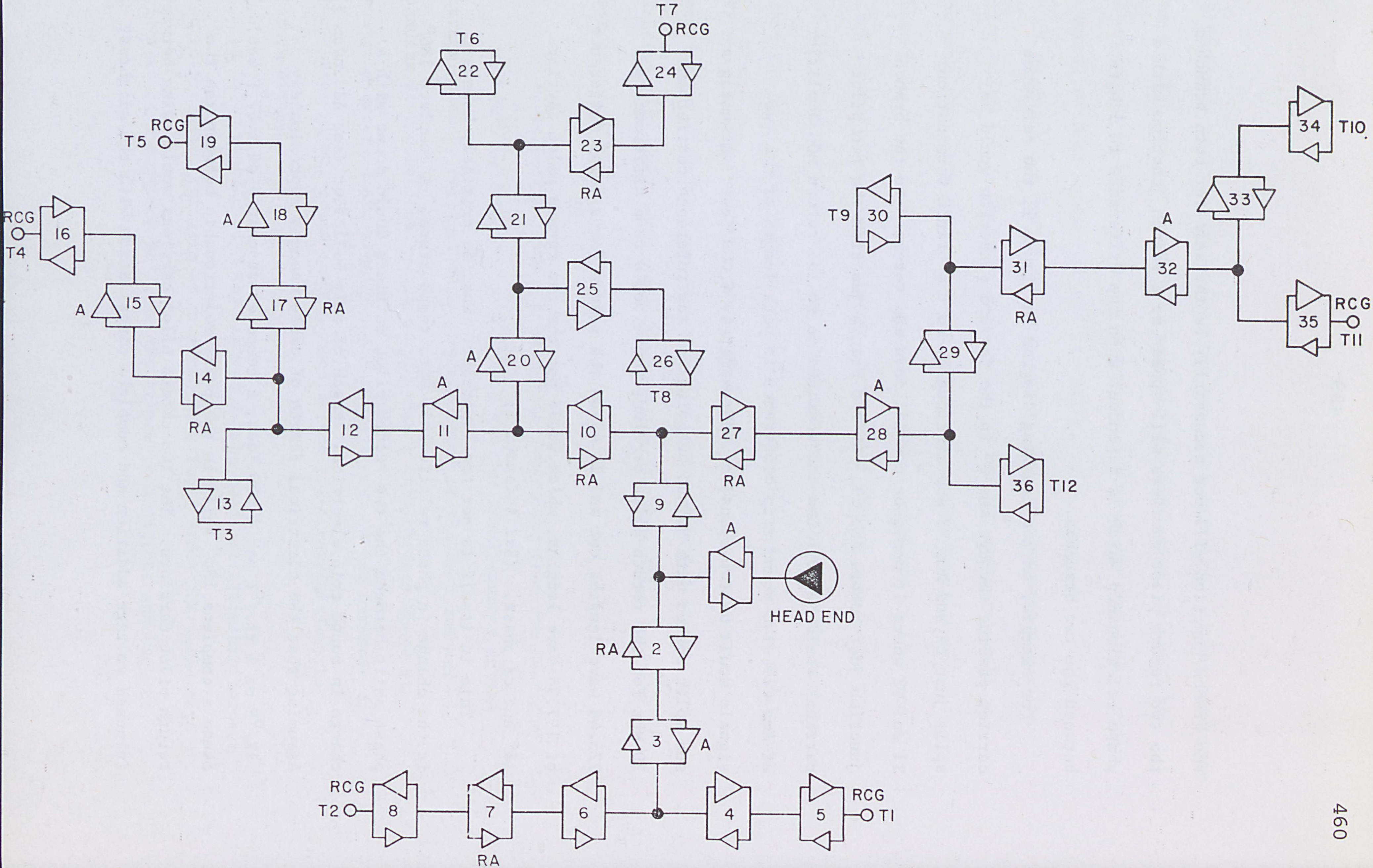
It would be feasible to precisely control the frequency of the return pilot by originating a single carrier at the head end and sending it through the system to the branch terminations where it would be received and counted down in frequency. A sub harmonic of the source signal could then be used as the pilot carrier for the return system.

A major problem with this scheme is the phase relationship between two return pilot carriers at a branch junction. Since the round trip distance from a branch split to the branch terminations and back to the branch junction will not necessarily be the same for both branches, the two return pilot carriers will appear at a branch junction with a phase relationship which is dependent upon the difference in length between the two branches.

For example, on the trunking diagram in figure 1, the reference carrier passing through Amp #2 in the forward direction would be split just beyond Amp #3 and continue on to the branch terminations T1 and T2 where it would be counted down and returned to the branch junction just before Amp #3. At the branch junction the two pilot carriers would be combined and continue on to the return AGC amplifier at Amp #2. The round trip difference in path length of the two signals would be two spans, or approximately 4,000 feet. Assuming a sub split system with 90 Mhz outgoing for the reference carrier and 30 Mhz for the return pilot carrier, there would be a difference of 223.46 wave lengths out and 74.49 on the return for a total difference of 297.95 wave lengths, which would put the two return pilot carriers 18° out of phase. (See Addendum I)

This in itself is not too important. What is critical, however, is the change in phase relationship with temperature. A complete 180° phase shift between the two return pilot carriers would occur with a change in round trip electrical length of only 6.71 feet (see Addendum I). Assuming that the electrical length of cable changes approximately .1%/$^{\circ}$F or 1 ft./$^{\circ}$F per 1,000 feet, a temperature change of 1.67°F would cause a complete 180° shift in the phase relationship between the two return pilot carriers. The two return pilot carriers would swing between in phase voltage addition and complete cancellation with the slightest

TWO WAY SYSTEM TRUNKING DIAGRAM



change in temperature. This signal variation would also appear to the AGC circuitry as a double side band AM modulated wave. Since the frequency of modulation would be typically much less than one cycle per minute, it could not be filtered out by any practical AGC circuitry and the return system levels would hunt continuously.

Assuming a mid split system with 242 Mhz outgoing for the reference carrier and 121 Mhz for the return pilot carrier, there would be a difference of 601.01 wave lengths out and 300.51 wave lengths on the return for a total difference of 900.51 wave lengths which would put the two return pilot carriers 184^{o} out of phase. (See Addendum 1) The phase shift vs. temperature for the mid split system is even more radical than for the sub split system. A complete 180^{o} phase shift between the two return pilot carriers would occur with a change in round trip electrical length of only 2.22 feet (see Addendum I). Assuming that the electrical length of cable changes approximately 1 ft./^{o}F per 1,000 feet, a temperature change of .55^{o}F would cause a complete 180^{o} shift in the phase relationship between the two return pilot carriers.

III. Modulated Pilot Carrier

The use of a return pilot carrier with a single modulating frequency would incur essentially the same problems as would be incurred with use of a CW return pilot carrier. These problems could be circumvented by using a different crystal controlled modulating frequency in the range of 1 Khz to 10 Khz for every return carrier generator in the system. The return AGC amplifiers could then be designed with a very sharply tuned audio filter to respond only to the appropriate return pilot carrier, ignoring all others. This would entail the use of matched return carrier generators and AGC amplifiers which would in turn cause a tremendous stocking problem and allow for no interchangeability of return carrier generators or AGC amplifiers.

In order to prevent amplifier overload due to an increase in the number of return pilot carrier signals on the system as you approached the head end, it would be necessary to utilize some pilot carrier trapping at various locations in the system.

Use of a modulated pilot carrier in the forward direction only, however, does have some advantages over use of a CW pilot carrier in that it simplifies the AGC circuitry and the problems involved in the temperature stabilization of a DC amplifier.

It does, however, present the possibility of modulation transfer. This is the phenomenon of the transfer of the modulation of the pilot carrier through the action of the AGC to every channel passing through the amplifier controlled by the AGC. The time constant or filtering action of the AGC should be capable of rejecting the pilot carrier modulation so that the transferred modulation is down at least -90db or by an amount equivalent to the crossmod specification of the amplifier for full channel loading at operational output levels.

To fully appreciate the modulation transfer caused by amplifier gain variations which occur at the modulating frequency rate, consider that a gain change of 0.05% is equivalent to -60db crossmod. (See Addendum II) It should be noted that AGC amplifiers which were designed to operate strictly from a CW pilot carrier should be checked very carefully for modulation transfer before they are used in a system with a modulated pilot carrier. It is most likely that they will be found to be unsatisfactory.

Use of a live video signal for a return pilot carrier may be considered, however there is no guarantee of the presence of a live video signal in the branch to be controlled at any particular time. It would be necessary, therefore, to employ one of the types of return carrier generators previously discussed for use as a standby carrier generator.

The three types of return pilot carrier systems which we have just discussed all have some serious drawbacks which make their use difficult or impractical, if not impossible. Another type of signal, however, which appears to have excellent potential as a return pilot carrier is a white noise signal.

IV. Narrow Band Noise Spectrum as a Pilot Carrier

Consider the use of a 1 Mhz wide white noise spectrum as pilot carrier for the return AGC system. White noise may be defined as a random process with constant spectral density. The random signal distribution and phase relationship of this type of signal will prevent the modulation and phasing problems encountered with the mixing of two or more coherent signal sources as in the previous cases.

In order to keep the return pilot carrier level from building up everytime two AGC controlled branches are combined it will be necessary to trap out one half of the return pilot carrier whenever combination occurs. This could be accomplished by trapping out one of the pilot carriers by 16db or more, as opposed to 39db or more for the combination of two coherent, signals and allowing the other to continue unimpeded. A more reasonable approach would be to allow the two pilot carriers to combine at a branch junction and then trap the resultant signal by 3db.

One advantage of this method is that now, no one return pilot carrier is originating from a primary or controlling source. Since each pilot carrier source is contributing only a fractional part to the total pilot carrier energy, failure of any one pilot carrier source will not cause a complete disruption of system levels. For example, refer to the trunking diagram in figure 1. Note that there are a total of six return pilot carrier sources, one located at each of the following branch terminations: T1, T2, T4, T5, T7 and T11. If any one of these sources failed, the change in level at Amp #1 due to this failure would be $10 \log_{10} 1-\frac{1}{2^N}$ where N is the number of times the pilot carrier is combined with pilot carriers from other branches.

Let us examine in detail the resultant level changes which would occur with complete failure of one or more of the return system pilot carriers. Whenever a pilot carrier is combined and trapped down 3db there will be remaining 1/2 of its original signal energy. Every time two return pilot carriers are combined, the remaining energy will be one half the sum of the two pilot carriers before combination. If a pilot carrier from a specific return carrier generator is combined and trapped 3 times, its remaining energy level will be $1/2^N$ or 1/8 of its original energy level.

If, for example, Amp #10 were receiving pilot carrier energy from return carrier generators hypothetically located at branch terminations T3, T4, T5, T6, T7 and T8, the fractional part of the total signal contributed by each return carrier generator would be 1/4, 1/8, 1/8, 1/8, 1/8 and 1/4, respectively.

Since the system shown on the trunking diagram is small (13.5 miles of trunk) and has only 12 terminations, let us simulate a larger system by assuming that there is a return carrier generator located at each one of these terminations. If the return carrier generator located at termination T5 were to fail completely, the return AGC module at Amp #17 would go to full gain since there would be no return pilot carrier whatsoever at that AGC location. At Amp #10, the next return AGC in the path between termination T5 and the head end, there would normally be return pilot carrier signals from 6 different terminations, T3, T4, T5, T6, T7 and T8, each contributing a fractional part equal to $1/2^N$ of the total return pilot carrier energy. Failure of the return carrier generator at T5 would leave $1-\frac{1}{2^3}$ or 7/8 of the original signal level remaining for a change of only 0.58db. Failure of the return carrier generators at both T4 and T5 would cause a change of 1.23db in the level of the return pilot carriers at Amp #10. Failure of the return carrier generators at T4, T5 and T8 would leave $1-(\frac{1}{2^3}+\frac{1}{2^3}+\frac{1}{2^2})$ or 1/2 of the original signal level remaining, resulting in a 3db change in the return pilot carrier level at Amp #10.

In a section of a large system with over 200 strand miles of CATV plant, there could be well over 100 branch terminations requiring up to 50 return carrier generators. Under these conditions, failure of any one or even a few return carrier generators would have a small effect on the total system performance.

Another advantage of combining the return pilot carriers and then trapping them down 3db is that the resultant pilot carrier will then be more representative of the signal variations caused by thermal changes in the individual branches. In other words, it would tend to have an averaging effect for thermal changes in branches of different lengths. This would tend to keep the system operating in a reserve tolerance range that would be equally distributed between crossmod and noise.

Note for example, on the trunking diagram that the return pilot carriers originating at terminations T1 and T2 will both have an equal effect on the return AGC module located at Amp #2. The level correction applied at Amp #2 will be an average of the level changes occurring in the two branches which are joined just before Amp #3.

Again, refer to the trunking diagram in figure 1. This diagram represents the trunking layout for a small 45 mile system with approximately 13.5 miles of trunk and a total of 36 trunk stations including terminating bridging amplifiers. The system uses eight AGC's in the forward direction, eight AGC's in the return direction, one forward pilot carrier and six return pilot carriers.

The locations of the AGC amplifiers in the forward direction were chosen on the following conditions:

1. AGC every third station.
2. An AGC which would normally fall one location beyond a trunk split is backed up and located before the split.
3. An AGC is located no more than two spans from a terminating bridging amplifier.

Since these rules are mutually exclusive in many cases, compromise must be made by applying weighting factors to the above rules or by using judgment based on the desired results.

In the return direction, the situation is somewhat more complex in that the return signals may be arriving at a return AGC via two or more paths of different length. For example, Amp #21 is receiving signals from T6 and T7 while Amp #10 is receiving signals from T3, T4, T5, T6, T7 and T8. Even in a common path, a return AGC may be receiving signals over varying lengths of cable. Amp #17, for example, is receiving return signals from Amps #19, #18 and #17, each a different length path requiring a different thermal compensation at Amp #17.

Unlike in the forward direction where this type of signal level error will affect only those stations or subscribers between which level correction is applied, any level errors in the return direction produced by thermal changes or equalization errors will be carried back through the entire system to the head end where it will appear as a level error, consequently picking up additional crossmod and noise at every return station along the way. Level errors in the return direction caused by thermal changes or improper equalization are therefore potentially much more serious than the same type errors in the forward direction. In fact, they are equivalent to head end level errors in the forward direction.

The locations of return AGC amplifiers were chosen on the following conditions:

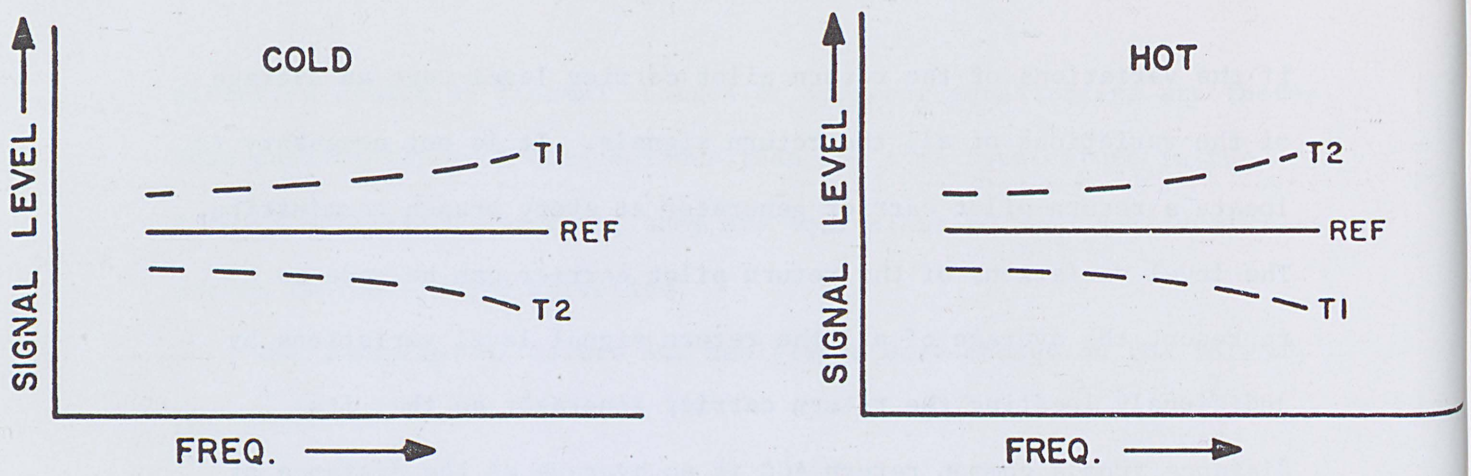
1. AGC every third station.
2. A return AGC is located, where possible, so that it is the same number of spans from all other control or originating points. For example, return AGC Amp #10 is receiving signals from AGC Amps #14, #17 and #23, and terminating bridging Amps #13 and #26. Note that all five paths are three spans in length. Return AGC Amp #2 is receiving signals from AGC Amp #7 and terminating bridging Amp #5. Again note that all paths are three spans in length.

This tends to establish a fixed relationship between the levels of the return signals entering the system from the various branch terminations and the levels of the return pilot carriers on the system.

Consider the case where return signals are entering the system at every amplifier location. Under these conditions it is impossible to have a fixed relationship between every one of the return signals and the return pilot carrier. The optimum condition would be achieved if the variations of the return pilot carrier level were an average of the variations of all the return signals. It is not necessary to locate a return pilot carrier generator at every branch termination. The level variations of the return pilot carrier can be made to represent the average of all the return signal level variations by judiciously locating the return carrier generator so that its distance from a common return AGC is an average of the distance of all the signals entering the system.

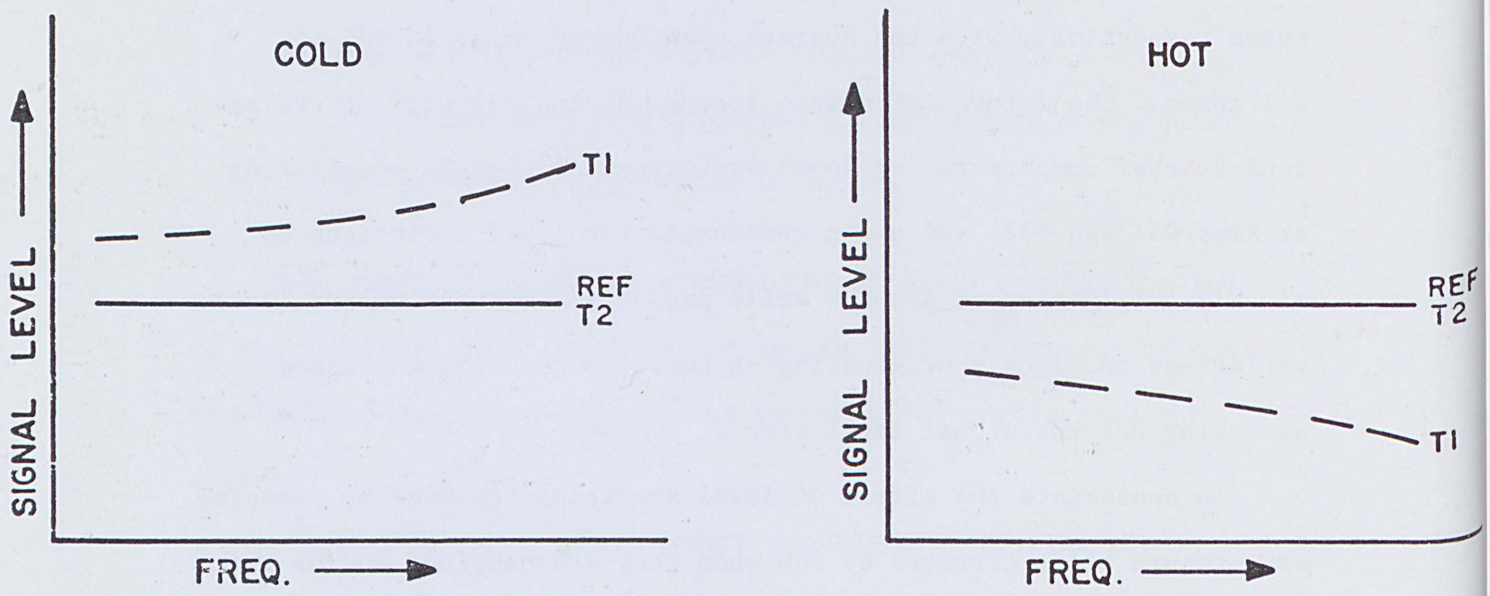
On the trunking diagram, figure 1, note that the return AGC module located at Amp #31 is controlled by a return pilot carrier source at branch termination T11. The return amplifier module at Amp #31 is receiving signals from Amps #31, #32, #33, #34 and #35. Note that the corresponding span lengths to Amp #31 are, allowing 1/2 a span for the feeder run, 1/2, 1 1/2, 2 1/2, 3 1/2 and 2 1/2 spans respectively with the average span length being 10.5/5 or 2.1 spans. The return AGC module located at Amp #31 will, therefore, tend to over compensate for level variations on signals originating at Amps #31 and #32, and under compensate for level variations on signals originating at Amp #34 while properly compensating for level variations on signals originating at Amps #33 and #35, therefore averaging out the signal level errors.

To appreciate the effect of level averaging achieved by trapping down return pilot carriers by 3db when they are combined and by the judicious selection of locations for return carrier generators, refer to figures 2 and 3.



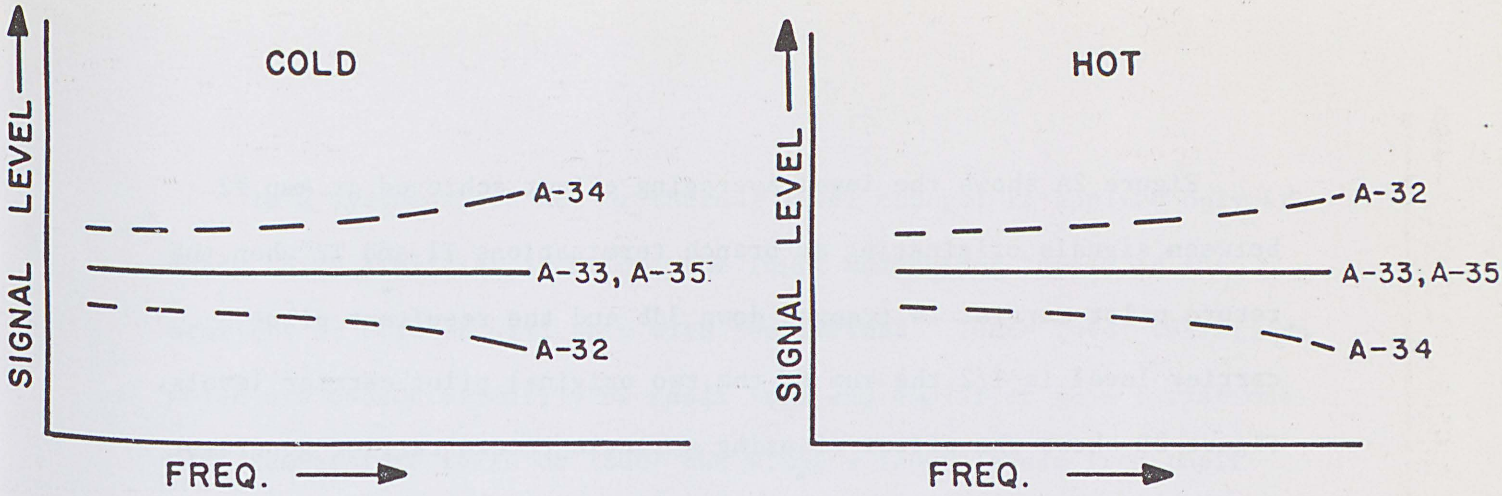
SIGNAL LEVEL VARIATION VS. TEMPERATURE
RETURN PILOT CARRIER AT T1 & T2 TRAPPED DOWN -3dB

FIG. 2A



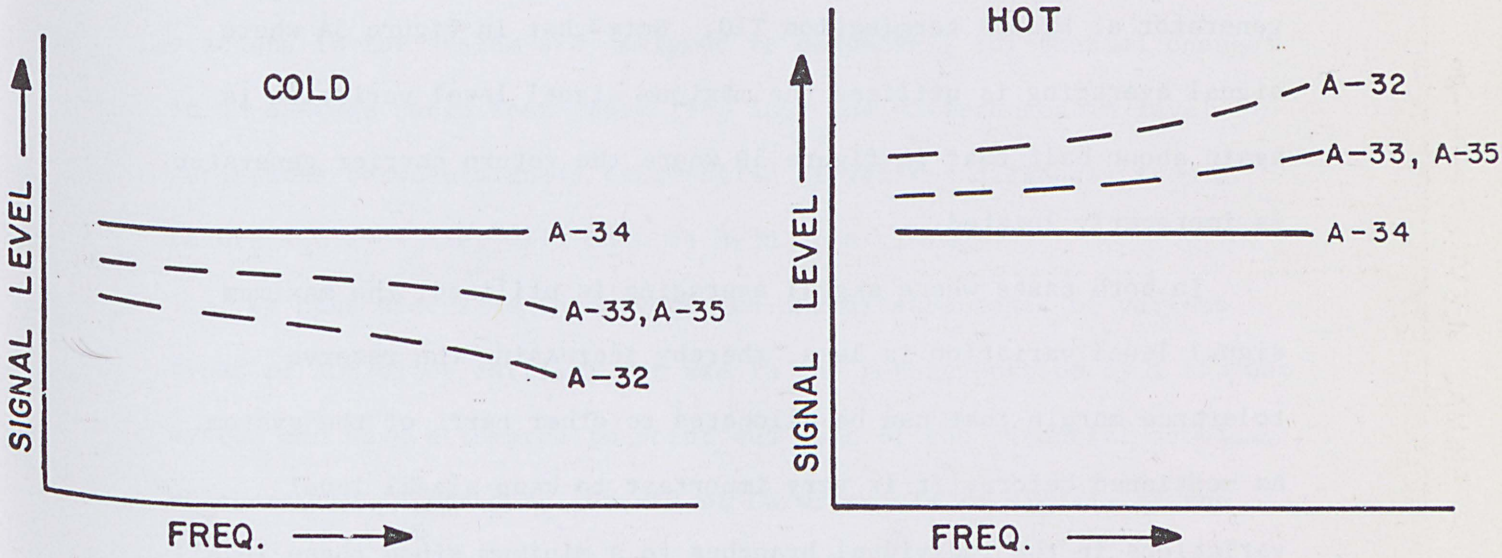
SIGNAL LEVEL VARIATION VS. TEMPERATURE
RETURN PILOT CARRIER AT T2 ONLY

FIG.2B



SIGNAL LEVEL VARIATION VS. TEMPERATURE
RETURN CARRIER GENERATOR LOCATED FOR LEVEL AVERAGING

FIG. 3A



SIGNAL LEVEL VARIATION VS. TEMPERATURE
RETURN CARRIER GENERATOR IMPROPERLY LOCATED

FIG. 3B

Figure 2A shows the level averaging effect achieved at Amp #2 between signals originating at branch terminations T1 and T2 when the return pilot carrier is trapped down 3db and the resultant pilot carrier level is 1/2 the sum of the two original pilot carrier levels. Figure 2B shows the effect of using a single return carrier generator at branch termination T2 only. Note that in figure 2A where signal averaging is utilized the maximum signal level variation is about half that in figure 2B where a single return pilot carrier controls the levels originating at both terminations.

Figure 3A shows the effect of level averaging achieved by selecting the location of the return carrier generator so that its distance from the return AGC is an approximate average of all the other signals entering the system and passing through the same AGC. Figure 3B shows the effect of improperly locating the return carrier generator at branch termination T10. Note that in figure 3A where signal averaging is utilized the maximum signal level variation is again about half that in figure 3B where the return carrier generator is improperly located.

In both cases where signal averaging is utilized, the maximum signal level variation is less, thereby increasing the reserve tolerance margin that can be allocated to other parts of the system. As mentioned before, it is very important to keep signal level variations in the individual branches to a minimum since these level variations will be carried through the entire system back to the head end.

In a system where AGC or thermal level control is applied only at every third amplifier location, the input and output levels at the stations in between will vary with temperature. These level variations which are caused primarily by cable loss and amplifier gain variations with temperature raise or lower the station input levels from their nominal design center. This increases the distortion or noise picked up at these stations, thereby reducing the overall system tolerance reserve.

To reduce signal level and system distortion and noise variations with temperature, AGC or some other type of thermal level control should be applied at every station in both the forward and reverse directions. This is especially true for signals traveling in the reverse direction since, as noted before, these level errors will be carried through the entire system back to the head end. If the manual stations in the system are designed to compensate for thermal changes in an average cable span (open loop AGC) the differences in level variations between signals originating at various distances from a return AGC amplifier will then be held to a minimum.

We have discussed the advantages and disadvantages of various types of AGC pilot carriers for use in the return portion of a two-way system and have attempted to point out some of the potential problems which may be incurred by the use of CW or modulated signals of the type normally used as pilot carriers in the forward direction. We have introduced the concept of a narrow band noise spectrum which, because of its random signal distribution and phase characteristics, is an ideal pilot carrier for the return system.

We have chosen a typical small system and have shown how improved signal level control can be achieved by judiciously selecting the locations of the return carrier generators and AGC amplifiers so that the return pilot carrier level variation is representative of the average level variation of all the return signals at a common point.

We have shown further how the differences in return signal level variation can be held to a minimum by the use of both closed loop and open loop AGC's and how, by holding these level variations to a minimum, we can achieve improved system performance.

ADDENDUM I

Phase difference for different path lengths - Sub-Split Systems

f out = 90 Mhz   f return = 30 Mhz

$$L1 = V/f = \frac{186{,}000 \text{ mi/sec} * 5280 \text{ ft/mi} * .82}{90 * 10^6 \text{ hz}}$$

L1 = 8.95 ft.

L2 = 3 * L1 = 26.85 ft.

Assume 1 way difference in distance between Termination #1 (T1) and Termination #2 (T2) is 2000 ft.

$$@ \text{ 90 Mhz } \frac{2000 \text{ ft.}}{8.95 \text{ ft/cyc}} = 223.46 \text{ cycles}$$

$$@ \text{ 30 Mhz } \frac{2000 \text{ ft.}}{26.25 \text{ ft/cyc}} = 74.49 \text{ cycles}$$

$$297.95 \text{ cycles} = 297 \text{ cyc} + 342^{\circ}$$

Phase Shift vs. Temperature for different path lengths

Change in cable electrical length = .1%/$^{\circ}$F

.001 * 1000 ft. = 1 ft./$^{\circ}$F

360° phase shift = 3/4 L1 + 1/4 L2 = 6.71 ft. out & 6.71 ft. return

180° phase shift = 6.71/2 = 3.355 ft.

$$\text{Temperature change for } 180^{\circ} \text{ phase shift} = \frac{3.555 \text{ ft.}}{2.0\text{K ft.}} = 1.67^{\circ}\text{F}$$

Phase difference for different path lengths - Mid-Split System

f out = 242 Mhz   f return = 121 Mhz

$$L1 = V/f = \frac{186{,}000 \text{ mi/sec} * 5280 \text{ ft/mi} * .82}{242 * 10^6 \text{ hz}}$$

L1 = 3.33 ft.

L2 = 2 * L1 = 6.66 ft.

Assuming 1 way difference in distance between Termination #1 (T1) and Termination #2 (T2) is 2000 ft.

@ 242 Mhz $\frac{2000 \text{ ft.}}{3.33 \text{ ft./cyc}} = 601.01$ cycles

@ 121 Mhz $\frac{2000 \text{ ft.}}{6.66 \text{ ft./cyc}} = 300.51$ cycles

900.51 cycles = 900 cyc + 184^{o}

Phase Shift vs. Temperature for different path lengths

Change in cable electrical length = $.1\%/^{o}F$

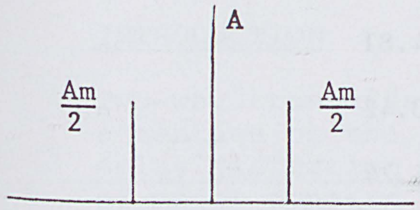
360^{o} phase shift = 2/3 L1 + 1/3 L2 = 2.22 ft. out & 2.22 ft. return

180^{o} phase shift = 2.22/2 = 1.11 ft.

Temperature change for 180^{o} phase shift = $\frac{1.11 \text{ ft.}}{2.0\text{K ft.}} = .55^{o}F$

ADDENDUM II

Transferred Modulation (TM) as a function of amplifier gain variation (m).



For 100% modulation:

Relative level of carrier A = .5

Relative level of each sideland $Am/_2$ = .25

$$A\,(1 + m) = 1$$

(1) $A = \frac{1}{1 + m}$

also $A + Am = 1$

(2) $Am = 1 - A$

substituting (1) above:

(3) $Am = 1 - \frac{1}{1 + m}$

Referencing (3) to the sideband energy level of a 100% modulated signal, we find that the transferred modulation, TM, is:

$$TM = \frac{1 - \frac{1}{1 + m}}{1/2}$$

which reduces to:

(4) $TM = \frac{2m}{1 + m}$

expressed in db:

(5) $TMdb = 20 \log_{10} \frac{2m}{1 + m}$

%m % Gain Variation	TMdb Transferred Modulation in db
100.0	0.
50.0	- 3.52
25.0	- 7.96
10.0	- 14.81
5.0	- 20.42
2.5	- 26.24
1.00	- 34.07
0.50	- 40.04
0.25	- 46.04
0.100	- 53.99
0.050	- 60.00
0.025	- 66.02
0.0100	- 73.98
0.0050	- 80.00
0.0025	- 86.02
0.00100	- 93.98
0.00050	-100.00
0.00025	-106.02