CONTROLLING THERMALLY-INDUCED LEVEL CHANGES IN TAPPED-FEEDER DISTRIBUTION SYSTEMS

Peter Deierlein
Magnavox CATV

Abstract

With the introduction of fiber-optic trunk systems and fiber-to-the-bridger system design concepts, tapped-feeder cascade lengths have doubled. As a result, feeder performance has become a more critical factor in overall system performance. Seasonal temperature changes can cause significant variations in distribution signal levels. Considering the presence of taps, tapped-feeder level changes have different characteristics than level changes in conventional trunk lines. These changes are magnified by the longer feeder cascades which are common in modern system designs. Consideration of feeder level changes must therefore become an integral part of modern system performance evaluation.

INTRODUCTION

Conventional CATV level control systems are used only in Trunk amplifiers, where precise RF level control is required to achieve maximum performance over long cascades. These control systems compensate level changes that result from thermally-influenced variables: cable attenuation and amplifier gain. Closed-loop control systems are required because minor open-loop errors would become major when multiplied by the cascade length. To achieve the best combination of cost and performance in conventional systems, tapped-feeder distribution cascade lengths are kept short, negating the requirement for active feeder level control.

Modern fiber-optic distribution systems eliminate long trunk cascades by substituting a single low-attenuation optical fiber, with the output of the optic receiver often directed immediately into the tapped-feeder system. Although fiber-optic performance advantages permit additional cost savings by allowing longer feeder cascades, the feeder signal levels may then require active control in order to realize the additional potential. Besides being complex and expensive, trunk-type level control systems are not intended to correct for changes in tap attenuation. This paper documents the effect of taps on thermal level stability, and suggests new approaches to controlling signal levels in tapped feeders.

EFFECT OF TAPS ON CATV SYSTEM PERFORMANCE

CATV systems are designed for "zero gain," with the gain of each amplifier station replacing the loss of the transmission-line segment which precedes it. The transmission-line segments are subdivided into the basic categories of "Trunk" and "Feeder," each consisting of coaxial cable plus a combination of splitters, taps, and other hardware necessary to meet system requirements.

In Trunks, taps are seldom used, and the sum of all losses other than cable loss is generally low. To maintain a constant amplitude frequency response through long cascades, amplifiers and their control systems compensate for the cable's well-documented characteristics.

In Feeders, taps are numerous, and their combined loss can dominate the total loss of the transmission-line segment of which they are a part. A tap's insertion loss differs significantly in the frequency domain from that of an equivalent length of cable, and the ratio of tap loss to cable loss can vary considerably from segment to segment. This is particularly apparent when comparing a segment in a rural area to one in a densely populated urban center.

While adjustable amplifier frequency response permits compensation of a wide range of initial tap-to-cable loss ratios, the effect of temperature change on frequency response due to the variability of these ratios is not clear. The characteristics of these thermally-induced level changes must clearly be understood before control can be provided. The first step in this process is defining tap performance over the applicable temperature range.

MEASURING TAPPED-FEEDER PERFORMANCE OVER TEMPERATURE

Theoretically, tap insertion loss should be constant regardless of frequency, and should not be temperature sensitive. However, due to the realities of broadband transformer performance, actual tap performance is loosely defined. Tap insertion loss specifications are generally given as either a maximum limit or a "nominal," with no specific data on thermal stability.

Tap Measurement Procedure

A high-precision method of tap insertion loss performance was developed. Magnavox 8000 series multi-pads were connected in strings of 5 equal-valued types, using 6 dB pads as interconnects. After making insertion loss measurements over frequency and temperature in an environmental test chamber, the test was repeated with only the 6 dB pads. The process was repeated using various values and types of taps, and the data was captured by a computer. This procedure yielded averaged insertion loss data with over 4 digits of precision, permitting highly accurate computer simulation of long feeder cascades.

Measured tap insertion loss changes over the -30F to 100F temperature range generally amount to well under .2 dB per tap; thus the requirement for a high degree of precision. While this may seem to be an insignificantly small change, the total change over an entire feeder cascade is significant. In Figure 1, tap data from 2-way, 4-way, and 8-way tap measurements are averaged and plotted along with cable characteristics. In both cases, insertion loss change over the -30F to 100F temperature range is plotted as a percentage of maximum insertion loss at 68F.

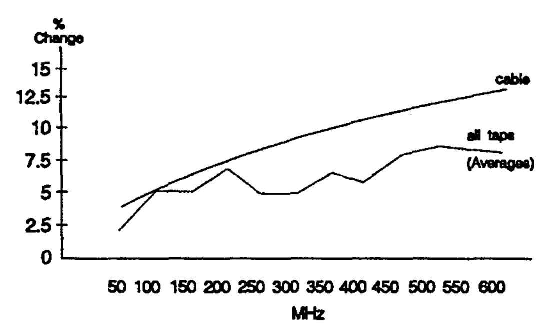

Figure 1.
Insertion Loss Change Over 130F, Relative to 600 MHz Loss

Figure 1 graphically illustrates two important differences between cable and taps. The tap's thermal change function is complex over frequency (even after averaging), and the average change is lower. Both of these factors have a potential impact on the performance of the thermal compensation system. Figure 1 shows the average thermal change function of all the taps tested; characteristics of individual taps are considerably more erratic and vary between types and lots. The thermal change function is therefore predictable only in a general case.

Tapped-Feeder Analysis

The type of tap used is generally dictated by subscriber density in the area served, and feeders can range in length from a few hundred feet to over a thousand feet (between amplifiers). The impact of this is illustrated in Figure 2, where the thermal characteristics of three hypothetical feeders have been plotted using the measured tap data. The high-density model has a total of 64 subscriber drops over 333 feet using 8-way taps; the medium-density model has a total of 20 drops over 721 feet using 4-way taps, and the low-density model has a total of 6 drops over 937 feet using 2-way taps. In each case, the cable length was adjusted for 25 dB loss (taps plus cable) at 600 MHz using .412 cable at 68F. Longer distances are possible using low-loss cable, which does not alter the plot. The data is plotted to show thermal change in dB over the -30F to 100F temperature range, with a plot of trunk characteristics for reference.

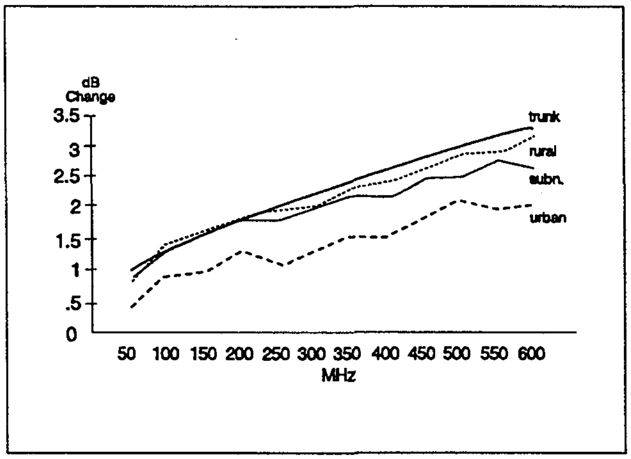

Figure 2.
Change Over 130F (100F -30F)
25 dB Span @ 600 MHz (68F)

In Figure 3, the same data used in Figure 2 has been normalized to the trunk cable characteristics, and shows level change deviation over 4 feeder spans. This models a typical four line extender cascade (not including line extender anomalies), and helps illustrate the thermally-induced frequency response distortion due to taps. The tap effects are shown over a long cascade to model fiber-to-the-bridger applications.

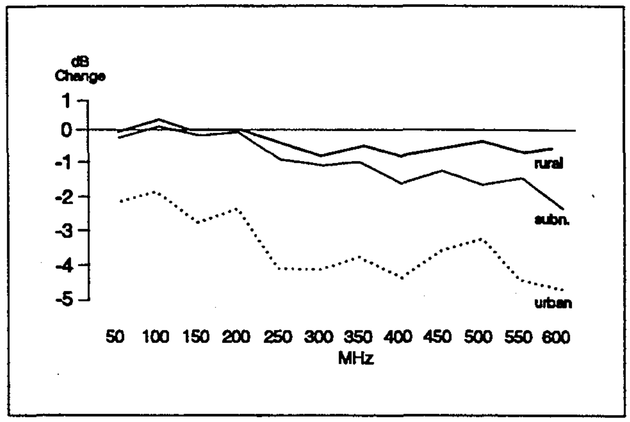

Figure 3.
Cascade of 4, Change Over 130F
- Relative to "Ideal" Cable Compensation
- Actual Open-Loop System Would Not Be This Good

Keep in mind that Figure 3 does not show the total change, only the difference between cable and tapped-feeder (The reference line represents the change in 100 dB of trunk cable). Tap loss in the low-density "rural" and medium-density "suburban" models is generally less than 35% of the total and shows little deviation from the cable except at high frequencies. The distortions in the high-density "urban" model are more severe due to the large number of taps, which comprise over 70% of the total feeder loss. While a closed-loop level control system could hold the levels constant at one or two frequencies, the response irregularities would remain in all three cases.

Effect of Amplifiers

Thermally-induced amplifier gain change differs from that of Trunk or Feeder in that the amplifier gain change is relatively constant over the active frequency range. The gain change varies based on the number and type of hybrids used, and is typically between 1 and 2 dB over the 130F range.

CONTROL SYSTEMS

"Closed-loop" control systems are defined as those where the controlled variable is fed back to be compared with a reference. Hence, the term "feedback control system" is also used to define such systems, and the term "open-loop" defines control systems which do not use feedback. While open-loop control systems have stability, cost and simplicity advantages, their usefulness in CATV level control applications is limited due to relatively poor accuracy and linearity.

In CATV applications, closed-loop systems are generally referred to as "automatic" controls. Actually, CATV amplifier systems have true closed-loop control of only one or two "pilot" channels, while the remainder of the channel level controls are open-loop functions of the closed-loop system. True closed-loop control accuracy is provided only at the pilot channel(s) because only their levels are fed back to the control circuitry. Providing closed-loop control for all channels is neither required nor feasible for the application and would probably be a problem from a maintenance point of view. (The time required for setup and periodic adjustment of every channel level, at every amplifier in a system, would be prohibitive.)

Open-loop control systems can perform quite well if the control function accurately matches system variables. In conventional trunk amplifier cascades, amplifier gain and cable attenuation are the only significant variables, and their performance over frequency is well-characterized. Combined open-loop and closed-loop level errors in automatically-controlled trunk amplifiers typically amount to less than 2 dB over a 16-amplifier cascade.

Control Functions

Regardless of whether or not they include automatic control systems, CATV amplifiers generally require gain control and frequency response control. Since these functions are often electrically controlled, they form a part of a closed-loop control system; however, they are open-loop functions from a broadband point of view. Of the three commonly used control functions, the Slope and Bode functions are different methods of frequency-response control, while the Gain function affects all frequencies equally.

The Gain function is used in all CATV amplifiers for manual level control, and can be used in either open-loop or closed-loop configurations to correct for thermally-induced gain changes in amplifiers. In closed-loop applications, Gain control can be used with the Slope function to correct for thermally-induced cable attenuation changes.

The Slope function permits the frequency response to be manually or automatically adjusted from a relatively "flat" low-attenuation response to a sloped response where the attenuation varies from over 8 dB at low frequencies to near zero at high frequencies. While Slope is theoretically a linear function, CATV applications of the Slope function are designed to approximate the non-linear characteristics of coaxial cable. CATV Slope functions must also be tailored to the bandwidth of the amplifier in which they are used. They have a "pivot" frequency where attenuation remains constant regardless of the degree of slope. This characteristic reduces interaction with the Gain function, and placement of a pilot channel near the pivot frequency provides increased stability in closed-loop dual-pilot applications.

The Bode function was developed specifically for the compensation of thermally-induced attenuation changes in coaxial cable, where attenuation change increase is non-linear with frequency, as was shown in Figure 2. The Bode function is best used in the closed-loop configuration, since manual adjustment can be tedious due to interaction with the Gain function. The Bode function is never used with the Slope function and is completely independent of amplifier bandwidth, but since it is specifically matched to cable, performance is compromised by the addition of taps.

APPLICATIONS

Trunk amplifiers have traditionally used combinations of Gain control and either Slope or Bode control in automatic systems with closed-loop feedback using two "pilot" channels. The two pilot channel frequencies are generally separated by at least 50% of the total bandwidth, with the Bode function (if used) controlled by the highest-frequency pilot. If the Slope function is used, it is always controlled by the lowest-frequency pilot, and in either case, the Gain function is controlled by the remaining pilot.

Dual-pilot configurations are ideal for long cascades, as the inevitable open-loop errors are reduced by closing the control loop at two points on the frequency spectrum. Dual pilots are used in most automatic Slope/Gain applications, as the Slope and Gain functions must work together to compensate for cable change. While the Bode function is capable of compensating for cable change with only a single pilot, a second pilot improves the Gain control accuracy and helps correct minor open-loop Bode errors which would multiply in long cascades.

Single-pilot configurations are available in some line extenders, and they offer a significant reduction in cost and complexity (compared to dual-pilot systems). They are considerably better suited to cable applications than purely open-loop systems. Since the highest amplitude carrier levels have a greater effect on overall system distortion, the pilot is usually selected near 3/4 bandwidth. The simplest single-pilot configuration is direct control of the Bode function; the pilot can also be used to control the Gain function directly with the Slope function operating as an open-loop function of the Gain control voltage. While this "coupled" Slope/Gain function would not match pure cable as well as the Bode function, it has proved to be a good approximation.

Open-loop thermal sensors have been used in some trunk amplifiers for level control in short cascades, but this approach has generally been restricted to Return amplifiers and line extenders. Open-loop thermal Gain compensators are available as replacements for plug-in attenuator pads, making it simple to add thermal compensation to existing equipment.

Open-loop thermal compensation works well only when the thermal sensor is located in the same environment as the controlled variable. While this is not a limiting factor in amplifier gain compensation, it makes the open-loop approach a poor choice for cable compensation. In cable, the variable is distributed over the entire length of the cable, and the temperature of the amplifier may differ substantially from that of the cable. Throughout its length, cable often passes through areas of differing ambient temperature conditions, and jacketed cable can be subjected to temperature differentials of over 25F (relative to ambient) due to solar-heating effects.

Since most real systems require both amplifier gain compensation and cable (or tapped-feeder) compensation for adequate control, a combination of open-loop thermal compensation and closed-loop tapped-feeder compensation is a good option for single-pilot applications. The tapped-feeder compensation can be implemented as either a Bode function or a coupled Slope/Gain approach, with advantages to each. The Bode function provides a better match to pure cable or rural tapped-feeder, and it is not bandwidth-dependent. The coupled Slope/Gain approach is simpler overall because the amplifier gain compensation function can be added by simply changing component values (without adding passive insertion loss).

SYSTEM PERFORMANCE

As shown in Figure 3, the open-loop cable compensation limitations illustrate the inadequacy of open-loop compensation in tapped-feeder systems. However, that example remains an "ideal" case which does not include the effects of temperature differentials or amplifier anomalies. By their very nature, closed-loop systems can correct for such errors, but since such errors are unpredictable by definition, they will not be evaluated further. Suffice it to stipulate that actual system performance will generally be poorer than that shown in Figure 3 and all to follow.

This system performance analysis shows how the closed-loop systems deal with the measured thermal response non-linearities introduced by taps. To that end, the same measured data which was used to generate Figure 2 is factored (as in Figure 3) as appropriate to model the ideal characteristics of three functions (Gain, Slope, and Bode), in four combinations. Each of Figures 4 through 7 is displayed under the same conditions as Figure 3: The cumulative change in frequency-response of four 25 dB spans of cable or tapped-feeder is modeled over a 130F temperature range (from 100F to -30F), neglecting amplifier anomalies.

In the dual-pilot configuration shown in Figure 4, the low-frequency pilot at 100 MHz controls a linear Slope function, while the high-frequency pilot at 450 MHz controls a Gain function. Note that the trunk cable plot is severely curved due to the cumulative difference between the linear Slope function and the non-linear cable characteristics. This effect would not be as pronounced in a real system (since CATV Slope functions are not perfectly linear), and all four plots would therefore be somewhat less curved at the ends. Amplifier Gain compensation is accommodated automatically by the closed-loop Gain function.

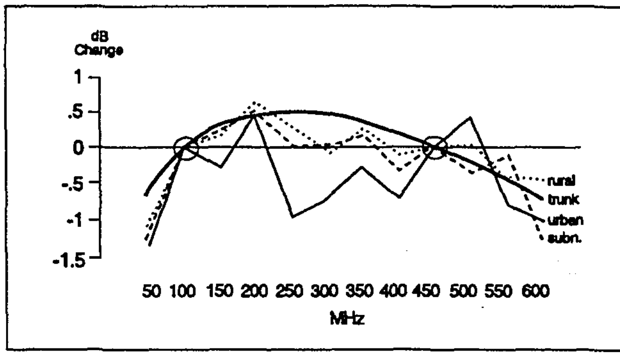

Figure 4.
Cascade of 4 Dual Pilot Slope/Gain
Over 130F -
Pilots at "O"

Figure 5 is also a dual-pilot configuration, with the 100 MHz low-frequency pilot controlling a Gain function, and the 450 MHz pilot controlling a Bode function. Since the Bode function compensates exactly for cable, the trunk cable plot is coincidental with the 0 dB reference line. Note that all three tapped-feeder plots now have a slight "belly" in the 250-400 MHz range which is more pronounced in the high-density "urban" example. Amplifier Gain compensation is accommodated automatically by the closed-loop Gain function.

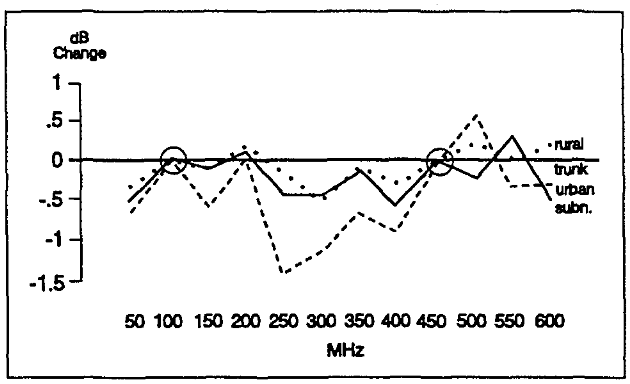

Figure 5.
Cascade of 4 Dual Pilot Gain/Bode
Over 130F -
Pilots at "O"

In Figure 6, the Gain function is controlled by a single pilot at 450 MHz. The Slope function is open-loop-coupled to the Gain function, and is designed to compensate for cable at 100 MHz. Comparing Figure 6 to Figure 4, note that while the cable plots match exactly (0 dB at 100 and 450 MHz), the tapped-feeder plots are equal only at 450 MHz. The resulting error is much less than the purely open-loop configuration shown in Figure 3, even at low frequency. Amplifier Gain compensation can be accommodated as necessary by changing component values.

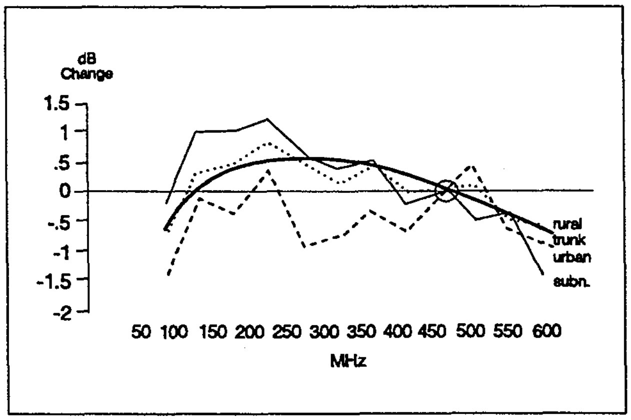

Figure 6.
Cascade of 4 Single Pilot Coupled Slope/Gain Over 130F - Pilot at "O"

Figure 7 shows a Bode function controlled by a single pilot at 450 MHz. As in Figure 5, the trunk cable plot is coincidental with the 0 dB reference. Amplifier Gain compensation cannot be accommodated by the Bode function, and must be added separately (if necessary).

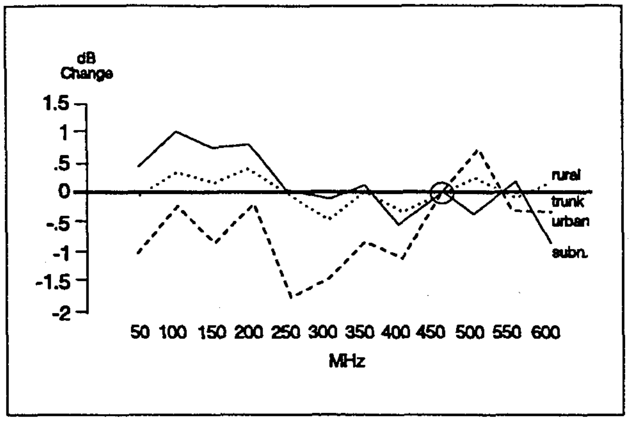

Figure 7.
Cascade of 4 Single Pilot Bode Over 130F - Pilot at "O"

CONCLUSIONS

Where wide temperature variations exist, uncontrolled level changes build up rapidly in cascade; this applies equally to trunk and feeder.

Tap thermal change is slightly lower than that of an equivalent section of cable; the difference is particularly significant in high-density areas.

The tap thermal change function is complex and unpredictable over frequency, but is generally similar to cable.

Simple open-loop compensation performs poorly in most CATV applications, but remains preferable to no compensation at all.

Dual-pilot control offers little advantage over single-pilot control in tapped-feeder applications; it is not worth the additional cost and complexity.

The single-pilot Bode function offers slightly better compensation flatness than the coupled-Slope/Gain function, but usually requires a separate Gain compensation function for good performance.