SYSTEM STABILITY AND CONTROL - A NEW AUTOMATIC CONTROL APPROACH

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ABSTRACT

The need for automatic piloting of signals in a cable system is well established. As technology has advanced and the demand for cable services has grown, demands on the piloting system have become increasingly more complex. While new systems with extended performance have been designed, it is desireable that new equipment be compatable with old systems as well.

A new approach to automatic control systems utilizes the popular dual-pilot AGC and ASC scheme with some powerful new capabilities: plug-in filters for complete pilot frequency flexibility and plug-in servo cross-coupling networks. The combination of these two features greatly improves the agility and transient response of existing systems into which it may be substituted. In addition, it also permits complete flexibility with any pilot arrangement.

The theory of automatic gain and slope control (AGC and ASC) has been addressed in the literature. Some of the requirements for an AGC/ASC module are:

1. Temperature Stability: The primary cause of varying cable signal levels is environmental temperature change. The AGC/ASC module must maintain a fixed gain independent of temperature if it is to correct the changes induced by this variable.
2. Ease of set-up: The set-up procedure should be simple, quick, and be easily performed in the field. This saves time resulting in lower system installation and maintenance costs.
3. Isolation from trunk amplifier: The AGC/ASC module should have little or no effect on trunk amplifier performance except to control signal levels in the desired fashion.
4. Low power consumption: The less power consumed by the AGC/ASC, the more reliable the system is and the more power there is available for other system modules and accessories.
5. Transient stability: The transient response of a single station must be well-damped to prevent the build-up of large low-frequency fluctuations in a long cascade.

While all of these factors are important, one of the most difficult design problems is posed by transient stability. The innocuous, well-behaved response of an AGC/ASC amplifier to induced transients can be greatly misleading in a cascade of these same amplifiers. This paper will consider stability problems in a dual-pilot AGC/ASC system and show how they can be virtually eliminated in existing and future systems.

A notable cause for stability problems is the placement of the pilot channels at frequencies far removed from the slope pivot frequency in the trunk amplifier. Because of demands for higher frequency capabilities (more channels) the high pilot carrier is typically pushed further up the frequency spectrum to gain adequate sensing and leveling of these higher ranges.

In some systems the high pilot and low pilot carriers are on opposite sides of the slope pivot point. If the low pilot controls amplifier slope and the high pilot controls amplifier gain, then as the slope control is varied, the high and low pilot levels adjust in different directions. The variance of the high pilot to adjustments of the slope control voltage is a function of the frequency separation from the pivot point - the greater the distance the greater the change in high pilot level for the same change in slope control voltage. Placing the high pilot near the high end of the frequency spectrum (where it should be for good gain sensitivity) creates a system where small changes in the slope control voltage produce a large system closed loop correction at the high frequency pilot. At some frequency spacing this eventually leads to unstable dynamic performance. By coupling some slope control voltage into the gain control circuit, the slope pivot point can effectively be moved to the high pilot point or above, resulting in a system with better dynamic performance. Likewise, by making the amplifier slope respond to gain control voltage, interactions from high pilot to low pilot can be reduced. In any system, if flexibility with respect to pilot frequency and band splits is desired, cross-coupling improves the slope and gain control interactions.

A Scientific-Atlanta Trunk station was set up (see Figure 1) using a 400 MHz trunk amplifier and automatic control module (ACM). Taps were used on the trunk input and output to simultaneously sample the input and output RF levels. Two Hewlett Packard 8558B spectrum analyzers were used as tuneable detectors allowing individual monitoring of the input and output high and low pilot carriers. HP 8640B signal generators were used to generate the 77.25 MHz (low) and 379.25 MHz (high) modulated pilots. A Spectral Dynamics SD375 dynamic analyzer was used to obtain the transfer function (both magnitude and phase) of the trunk/ACM pair. From this information one can readily show instabilities in the servo loop response due to the imprudent selection of pilot frequencies with respect to the slope pivot frequency, which is 200 MHz. This combination of pilots has not been recommended in the past and is chosen to illustrate a potentially unstable servo response. Four particularly important transfer functions were measured:

1. The response of the high pilot output to high pilot input modulation (T11).
2. The response of the high pilot output to low pilot input modulation (T12).
3. The response of the low pilot output to high pilot input modulation (T21).
4. The response of the low pilot output to low pilot input modulation (T22).

The transfer function shows the magnitude (dB) and phase (degrees) of the signal output as a function of the signal input. Since the ACM uses peak detectors, its sensing is relatively unresponsive to low-frequency video components. There are however, other low-frequency signals present in a cable system as noise . To improve immunity to low-frequency noise, a low servo loop bandwidth is desired. There is, conversely, a practical limit to how low the bandwidth can be set. Making it too low will make the system difficult to set up because it results in a long system response time. In this system, the cross-over frequencies are approximately .5 Hz (high) and .7 Hz (low). Ideally, the transfer function should show unity gain (or less for cross-coupling coefficients) at higher frequencies and very high attenuation of low frequency inputs. This means that low frequency disturbances will be greatly suppressed. The preferred frequency response is well-damped, with no peaking or ringing in the transfer function.

Transfer function data was taken to 200 Hz. However, no significant perturbations in the response were noted in any case beyond 10 Hz (see Figure 2). Therefore, for the sake of brevity subsequent figures shall include only transfer functions to a maximum modulation frequency of 20 Hz. Figure 3 shows the response for the worst case of T12.

The Scientific-Atlanta Automatic Control Module (ACM) allows substitution of plug-in cross-coupling networks for different combinations of pilot carriers and the appropriate network was plugged into the ACM. (New Scientific-Atlanta Trunk amplifiers have the cross-coupling designed into them). Figure 4 shows the station response (T12) with cross-coupling. Figure 4 shows how the inclusion of cross-coupling improves the control system stability. Notice how the peak shown in Figure 3 has been greatly reduced. The inclusion of cross-coupling yields even greater stability improvements in long cascades, as will be shown shortly.

It would be meaningful to predict beforehand what the response of a cascade of many amplifiers would be. This can be accomplished by assuming a modulated source and multiplying it by the transfer function measured previously. The output would then be substituted as the source for the next trunk station and be multiplied by the transfer function again, until the desired cascade length is reached. A computer program was written to perform this multiplication and the results are given in graphical form. Figure 5 shows the predicted response of twenty cascaded trunk stations before, and Figure 6 shows the results after cross-coupling the slope and gain controls.

The system in Figure 5 is very unstable and would be unuseable. It shows a high degree of peaking in the vicinity of 2 Hz which would manifest itself in wild level variations at low frequencies. The system would be driven beyond its AGC and ASC ranges and may be very difficult to measure. Small deviations of the input level would cause the dynamic range of the AGC and ASC-controlled amplifiers to be exceeded somewhere down the cascade. On the other hand, the cross-coupling added in Figure 6 predicts a stable, well-behaved cascade of amplifiers.

"The proof of the pudding is in the tasting" and happily, the test results bear out the mathmematical predictions. When the test set up of Figure 1 was extended to include 20 cascaded amplifiers, the results were as follows:

Figure 7: This graph shows the measured results of cascading 20 identical amplifiers with the characteristics given in Figure 3.

Figure 8: The measured results of 20 cascaded amplifiers with cross-coupling are given here. Note the dramatic improvement in system stability. There has been a reduction of system peaking by more than 72dB!

CONCLUSION

The use of cross-coupling provides flexibility in the selection of pilot carrier frequencies. With plug-in filters and compensation networks, a potentially unstable pilot combination can usually be salvaged. Systems can be upgraded without replacing the AGC/ASC modules. Only the plug-in filters and compensation network need be changed - a modification that could be done in the field resulting in cost savings for system upgrades. Systems with unusual pilot frequency requirements can now be handled and performance of existing systems can be improved through the use of higher pilot frequencies.

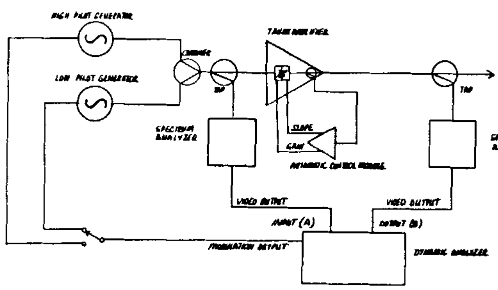

FIGURE 1 – TRANSFER FUNCTION TEST SET-UP

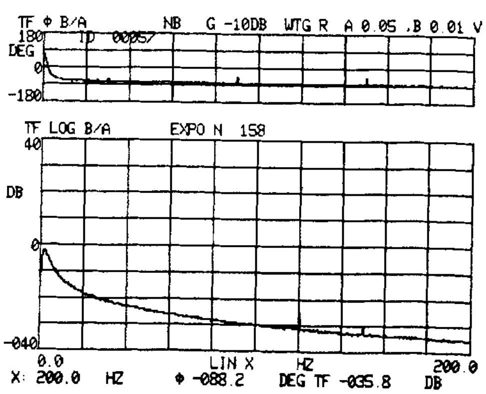

Figure 2

Transfer function for worst case of T12 (taken to 200 Hz). Graph shows trunk amplifier output (B) of high pilot (379 MHz) for modulation of low pilot (77 MHz) input (A) vs. frequency. Single amplifier, no cross-coupling.

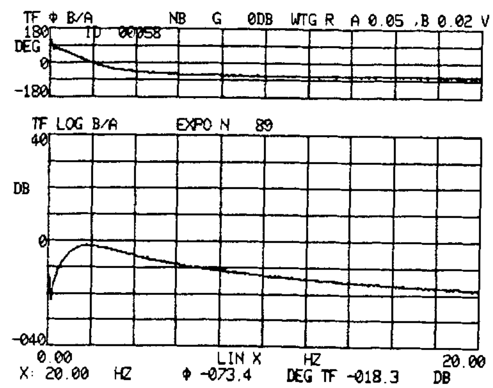

Figure 3

Transfer function for T12 (taken to 20 Hz). Graph shows trunk amplifier output (B) of high pilot for modulation of low pilot input (A) vs. frequency. Single amplifier, no cross-coupling.

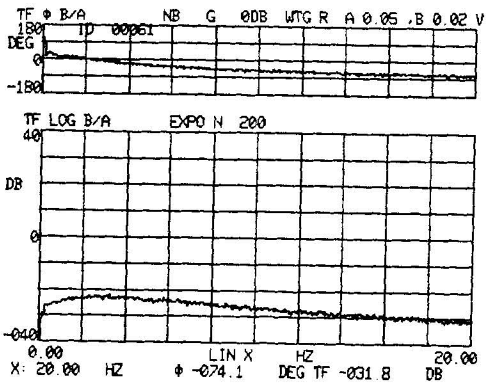

Figure 4

Transfer function for T12 showing trunk amplifier output (B) of high pilot for modulation of low pilot (A) vs. frequency. Single amplifier with plug-in cross-coupling.

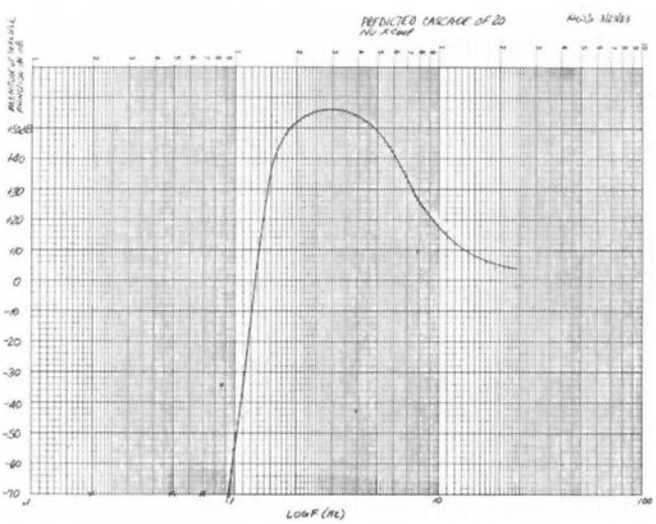

Figure 5

Computer-perdicted transfer function of T12 for a cascade of 20, based on measurement of single amplifier. Graph shows trunk amplifier cascade output (B) of high pilot for modulation of low pilot (A) vs. frequency. Cascade of 20 amplifiers, no cross-coupling.

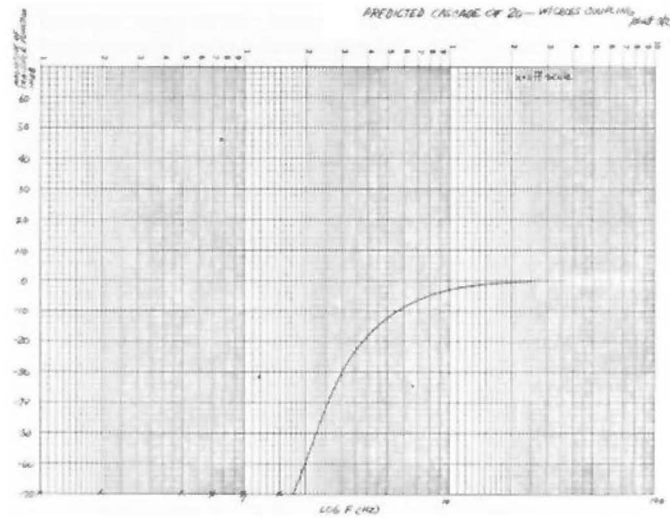

Figure 6

Computer-predicted transfer function of T12 for a cascade of 20, based on measurement of a single amplifier. Graph shows trunk amplifier cascade output (B) of high pilot for modulation of low pilot (A) vs. frequency. Cascade of 20 amplifiers, with cross-coupling.

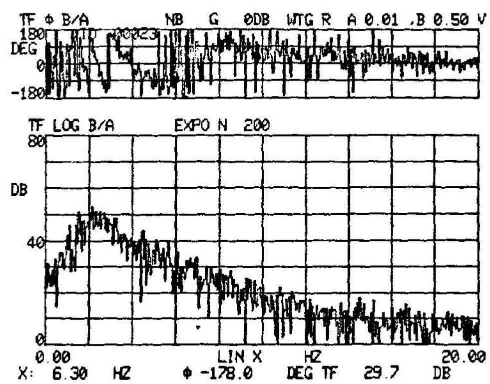

Figure 7

Transfer function of T12 for a cascade of 20 amplifiers. Graph shows trunk amplifier cascade output (B) of high pilot for modulation of low pilot (A) vs. frequency. Cascade of 20 amplifiers, no cross-coupling.

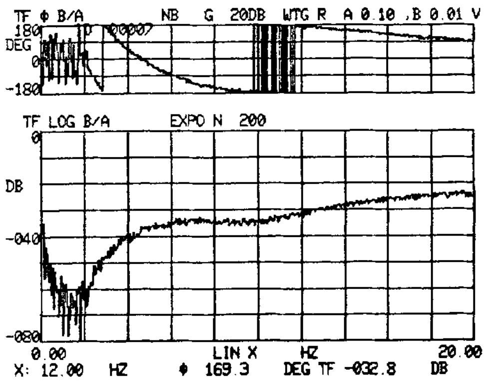

Figure 8

Transfer function of T12 for a cascade of 20 amplifiers. Graph shows trunk amplifier cascade output (B) of high pilot for modulation of low pilot (A) vs. Frequency. Cascade of 20 amplifiers, with cross-coupling.

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