AUTOMATIC LEVEL CONTROL ISSUES IN AM FIBER SYSTEMS

Frank R. Little
John G. Megna
Heather H. Rand
Frederick T. Zendt

Scientific-Atlanta, Inc.

ABSTRACT

AM fiber optic systems are playing an increasingly important role in the delivery of high quality signals in all types of CATV plant architectures. This paper discusses technical issues in the set-up, operation and maintenance of this equipment which are critical to maintaining system performance. Discussion is also given to the effects of various level control methods on the initial and ongoing system performance capabilities, particularly in light of real world headend and distribution plant operation. Technical and operational trade-offs are contrasted and recommendations are made for different areas of the installation. It is hoped that this paper will clarify some of these issues so that operators can make informed decisions to ensure stable and reliable operation of fiber optic systems, particularly as their use expands in CATV architectures.

INTRODUCTION

Amplitude modulation (AM) based fiber optic transmission systems have become increasingly attractive for transporting multichannel CATV video signals over substantial distances. Although the performance requirements and equipment types vary with different network architectures and applications, the basic means of providing signal transport is the same.

In typical CATV systems, as shown in Figure 1, individual frequency channels from multiple headend modulators feed combining networks. One or more combining networks gather the channels into a single band or multiple bands of frequencies to be transported by the distribution plant. In AM fiber optic systems these bands of channels also provide a modulation input to the laser transmitter(s). The AM laser transmitter conditions the composite headend signals to provide a signal which modulates the semiconductor laser bias current. This results in an intensity (power) modulated optical signal out of the laser. The optical signal is carried by a low loss single mode optical fiber to an optical receiver. A photodetector in the optoelectronic receiver converts the optical signal into an electrical signal current. The electrical signal is a replica of the headend composite channel band used to modulate the transmitter. The received composite signal is amplified and conditioned and fed to the distribution plant.

An important advantage of AM fiber systems is that the same multichannel NTSC, PAL, or SECAM signal format is maintained through the system. No format conversion electronics are required at either end of the optical link. This makes the AM fiber optic system "friendly" to the CATV system tie-in points. Because of this advantage, AM fiber optic systems generally require less equipment space in the installation. An AM system is also less costly to install, particularly on a per channel basis, than either FM or digital systems.

The single mode optical fiber used in AM fiber systems possesses attenuation characteristics which change extremely little with temperature variations, unlike coaxial cable. In most current AM fiber architectures, little compensation for the optical fiber response is required. However the carrier-to-noise ratio (CNR) and distortion performance (CTB,CSO) of AM fiber systems is tied directly to the relative level of the modulating multichannel carriers. Because of this, the issue of signal level control is important throughout initial equipment set-up, ongoing operation, and system maintenance. The practical, operational, and technical tradeoffs of level related performance issues are discussed in the following paragraphs.

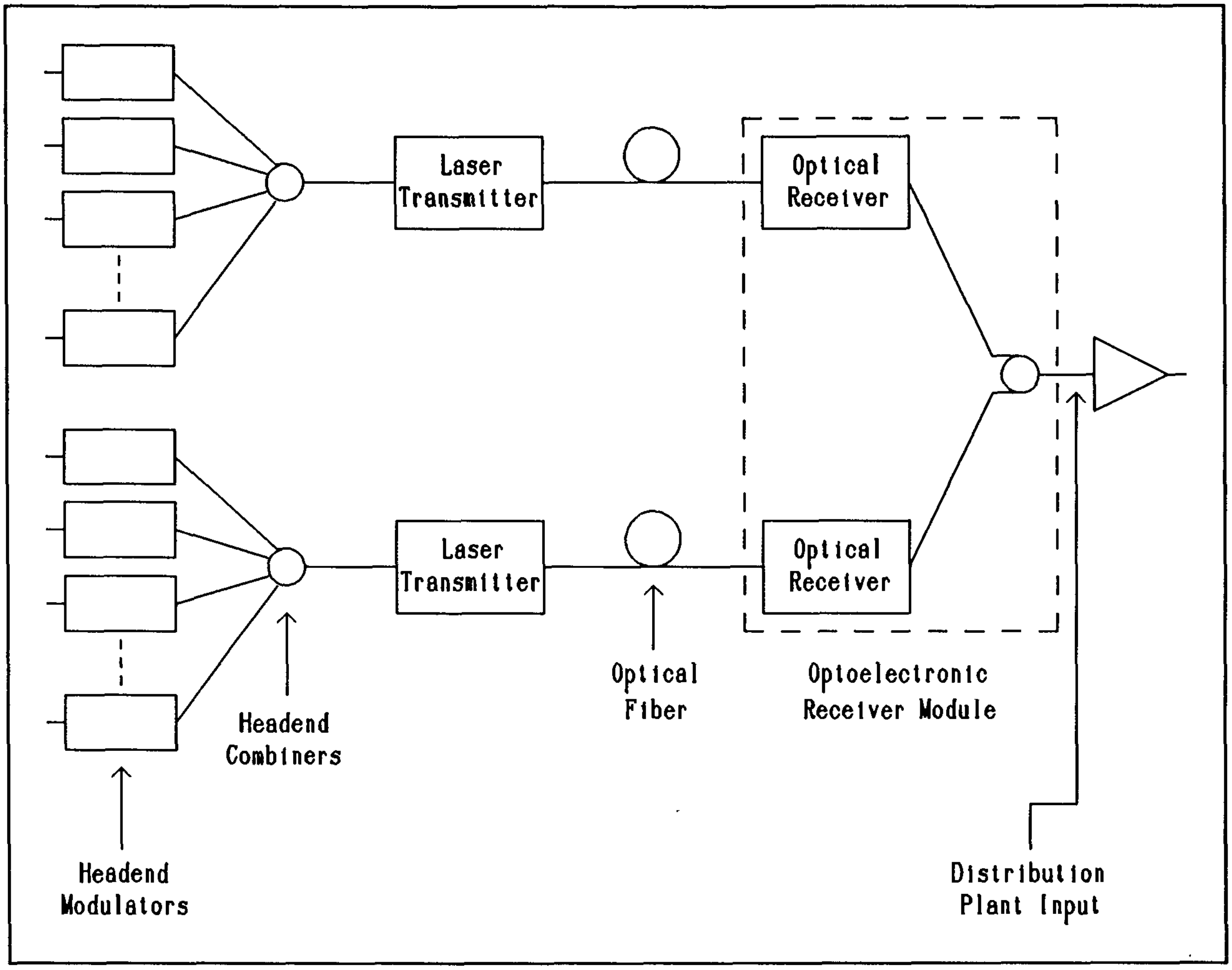

Figure 1. Typical Dual Band CATV AM Fiber Optic System.

LEVEL RELATED PERFORMANCE ISSUES IN HEADEND FEED AND AM TRANSMITTER

The composite FDM output from the headend which feeds the AM laser transmitter(s) can exhibit significant variations due to several factors. Since this headend composite output directly modulates the laser transmitter, variations in the modulating signal must be examined to understand their impact on overall system performance.

Figure 2 is a simplified block diagram of a laser transmitter. The signals modulating an AM laser have certain ideal requirements. The laser used in the transmitter exhibits optimum performance for a given application when operated at a specific composite modulation index. The RF drive level per channel modulating the laser is the determining factor in the modulation index of the laser. Ideally, it is imperative to precisely maintain the laser's modulation index at its optimum value to ensure specified system CNR and intermodulation distortion performance. If the laser modulation index is too large, the CNR performance improves, but the distortion performance is compromised. On the other hand, if the laser modulation index is too small, the distortion performance improves, but the CNR performance degrades.

In general, a larger composite modulation index is required to meet higher system CNR specifications. However, a maximum modulation index exists for each laser at which point laser distortion performance begins to deteriorate rapidly due to signal clipping. In high CNR performance systems, the laser is generally operating at or near its maximum modulation index. It is therefore critical that the modulation index and hence composite RF drive power be held constant.

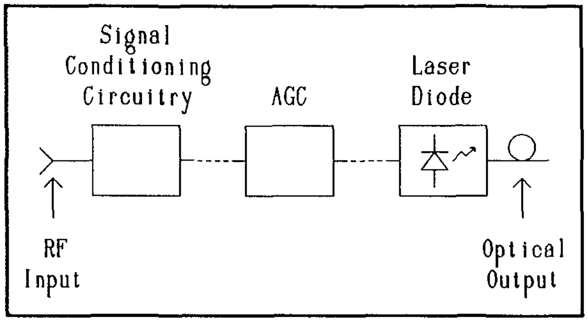

Figure 2. Simplified AM Laser Transmitter Block Diagram.

Channel loading also has an effect on laser modulation index. As channel loading increases, the laser composite modulation index increases, and the intermodulation distortion performance degrades. Thus, when increasing channel loading, the RF drive level per channel should decrease for every channel in order to preserve the composite modulation index and hence intermodulation distortion performance.

In practice, a laser transmitter is not modulated by ideal signals. The headend output RF level varies due to different factors. The addition or removal of a coupler, tap, or other equipment in the headend wiring scheme causes a change in the resultant headend RF output level. The headend RF output level also varies slightly with time, temperature, regular maintenance, and adjustment. Modulators may be added to or removed from the headend, thereby changing the transmitter's channel loading and the laser's composite modulation index. This changes the laser transmitter's distortion performance due to the change in laser modulation index.

The possibility of an RF overdrive condition from the headend feed must be addressed also. During headend equipment installation, or even during regular maintenance, the headend RF output level may inadvertently increase to an extremely high level relative to the specified RF drive level of the transmitter. This level may cause performance degradation, and may even irreversibly damage the laser. This is an extreme example of non-ideal RF signals modulating the laser.

Many situations exist in which the RF signals modulating the AM laser transmitter are not ideal. Therefore, appropriate circuitry may be incorporated into the transmitter to reduce the undesirable variations in RF level. An automatic gain control circuit (AGC) can be used to compensate for variations in RF level. The AGC circuit monitors the RF level feeding the transmitter and adjusts the gain through the transmitter in order to supply the laser with the appropriate RF drive level. The AGC has a range of input RF levels for which it can maintain a specified RF drive level to the laser. In this application, two alternative AGC implementations could be used.

One implementation is a pilot carrier type of AGC. This circuit monitors the RF level of only one or two pilot channels and adjusts the level of the entire spectrum of channels to compensate for the change in pilot levels. This type of AGC is useful if all channels vary in the same way and by the same amount. However, if additional modulators are brought online in the headend resulting in an increased channel loading to the laser, or if individual channels vary randomly due to time or temperature, the AGC does not change the RF drive level to the laser unless the RF level of the pilot(s) has changed. As a result, the composite modulation index of the laser changes due to the increase in channel loading or individual channel level variation, and the laser's distortion performance will in general degrade. Another disadvantage of a pilot carrier type AGC is that it cannot effectively be used to provide RF overdrive protection since it only adjusts the laser RF drive level if the pilot signal level changes.

A composite power AGC is another variation of the AGC circuit. This type of AGC monitors the composite RF power modulating the transmitter and adjusts the level of the entire spectrum of channels by the same amount to maintain a constant composite power. The advantage of a composite power AGC for an AM laser transmitter is that it maintains a constant laser modulation index with headend RF level variations and changes in channel loading. Therefore, optimum transmitter distortion performance is preserved. In addition, the composite power AGC can be used to guard against an RF overdrive condition. If the level from one modulator increases by a large amount, the composite power AGC detects the increase in transmitter input composite power and adjusts the RF level modulating the laser.

Considering the variations that can occur in the RF drive to the transmitter, if an AGC circuit is incorporated in the AM laser transmitter, the composite power type AGC is preferred. This type of AGC is effective in maintaining specified intermodulation distortion performance, and in preventing RF overdrive related damage to the laser.

LEVEL RELATED PERFORMANCE ISSUES IN THE AM OPTICAL RECEIVER

Ideally the optical signal illuminating the receiver's photodiode has a constant average intensity, constant modulation index, and single wavelength. The intensity of the received optical signal and the modulation index determine the RF gain required in the receiver for best performance. A single wavelength optical signal is less affected by fiber dispersion and other nonlinear effects in the optical plant.

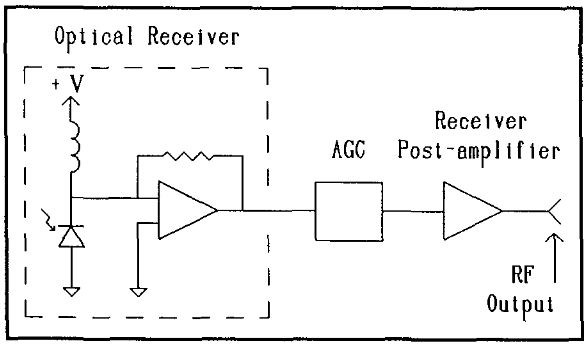

Figure 3. Simplified AM Optoelectronic Receiver Block Diagram.

In practice the quality of the received optical signal is affected by the fiber plant and the optical transmitter. The average intensity of the received optical signal may change due to maintenance or repair of the fiber plant. Additional splices to repair fiber breaks, replacing optical connectors with splices or vice-versa, or entirely rerouting an optical path will all affect the optical link loss. As discussed earlier several aspects of the transmitter design and RF signal source will also affect the optical signal. There may be variations of the laser diode output power due to aging or temperature. The composite modulation index may change as a result of additions or deletions of channels, variation of level or other changes to the laser drive signal.

Receiver performance as measured by carrier-to-noise ratio (CNR) and distortions, composite triple beat (CTB) and composite second order (CSO), is generally degraded by a non-ideal optical signal. All fixed gain optoelectronic receivers provide a specific RF output signal level and distortion performance for a specific optical receive signal. As the optical input power or modulation index increases, the receiver's CNR generally increases, but the receiver's contribution to the system distortion level also increases. Conversely, with decreasing optical input power or modulation index, the receiver's CNR decreases but its contribution to system distortion also decreases. Variations in received optical power from that expected can be due to several factors. The number and quality of connectors and splices used in the field installation may differ from the originally specified plan resulting in a different optical loss. If an OTDR measurement used to determine the optical loss is inaccurate then again the optical power will differ from that expected. Finally, fiber plant maintenance or repair can also alter the link loss.

If variations in optical loss occur, the optoelectronic receiver performance may be affected. If the optical loss is greater than expected the received optical power is lower than expected. Lower than expected received optical power results in a reduced RF output from the photodetector and optoelectronic receiver. Consequently the input level to the receiver post-amplifier is lower. This condition increases the significance of the noise contribution of the receiver post-amplifier to the system CNR. The final result may be a degradation in system CNR. If the optical loss is less than expected, then the received optical power is higher than expected. This results in an increased RF output level from the photodetector and optoelectronic receiver and generally improves the system CNR. However, with the optoelectronic receiver operating at a higher output level its contribution to system distortion is greater. The post-amplifier is also operating at a higher level and may contribute further to the system distortion. Consequently there may be a degradation in system distortion performance.

Changes in the modulation index can also affect the performance of a receiver. If the modulation index increases and all other system parameters remain constant, the RF output level from the photodetector and optoelectronic receiver increases. An increase in this output level causes an increase in the receiver and post-amplifier's contributions to system distortion as discussed earlier. Conversely, if the modulation index decreases and all other system parameters remain constant, the RF output level from the photodetector and optoelectronic receiver decreases. A decrease in this output level causes a degradation in system CNR by lowering signal level while the noise level remains unchanged.

Receiver performance is also affected by the channel loading. When a transmitter without AGC is used and the channel loading changes from the original channel plan, receiver distortion performance also changes. More channels create more beats and hence greater distortion but the receiver RF output level remains the same. For example, an increase in channel loading from 40 channels to 60 channels increases the receiver's contribution to system distortion by approximately 1.8 dB for CSO and 3.5 dB for CTB.

When a transmitter with a composite power AGC is used and the channel loading changes from the original plan, receiver output level and CNR performance may be affected. An increase in channel loading from 40 channels to 60 channels causes the transmitter AGC to reduce the RF input level to the laser by approximately 1.8 dB. This in turn, results in a 1.8 dB decrease in RF output level from the optoelectronic receiver and a corresponding decrease in receiver CNR. Distortion performance however remains unchanged.

In order to compensate for variations in optical loss, modulation index and channel loading, an AGC circuit may be implemented in the optoelectronic receiver. An AGC incorporated in the optoelectronic receiver provides automatic gain control of the receiver's RF level. Several methods can be used to implement an AGC. Each method has advantages and disadvantages.

A composite RF power AGC maintains a constant RF power at the output of the optoelectronic receiver. This method is advantageous from a distortion standpoint because regardless of variations in received optical power, modulation index, or channel loading, the composite RF power at the receiver output will remain constant. For a given input optical signal, the receiver generated distortion level is primarily a function of the RF power. Therefore distortion due to the receiver will not change. However, this method will not yield optimum receiver noise performance under all conditions. A variation in channel loading causes a change in the RF output level of the receiver because the AGC maintains a constant composite RF power at the receiver output. If the channel loading increases, the RF signal level to the distribution plant decreases and system CNR degrades.

A single carrier pilot type AGC maintains a constant RF channel level at the output of the optoelectronic receiver. The primary advantages of this method are a constant RF output level and a constant contribution to system CNR by the receiver amplifier and post-amplifier. The RF channel output level of the receiver remains constant with variations in received optical power, modulation index, and channel loading. In a multiple band system this AGC approach maintains consistent RF channel level between bands. The disadvantage of a pilot carrier type AGC is the fact that the receiver amplifier's distortion changes with variations in channel loading. If the channel loading increases, distortion due to the receiver amplifier increases and thus, system distortion may increase. However, when using a transmitter with composite power AGC, distortion remains unchanged.

In today's high performance AM fiber optic systems, high CNR is usually the performance specification most difficult to achieve. Proper circuit design can minimize the impact of the receiver amplifier and post-amplifier on system distortion performance. Consequently, in a receiver incorporating AGC, a pilot carrier type AGC is most desirable for use in the optoelectronic receiver. Careful implementation of the pilot carrier type AGC results in optimum receiver noise performance.

OVERALL SYSTEM REQUIREMENTS FOR LEVEL CONTROL

The key to the use of any technology is in assuring that it can provide the expected level of performance, consistency, and reliability necessary for the application. To date most applications of AM fiber optic systems have been in CATV systems where the distribution plant is upgraded, expanded or replaced. In current AM fiber optic system architectures each fiber link serves a large number of subscribers and directly affects the overall signal quality provided. Most CATV operators strive to extend plant service area, expand bandwidth, and improve signal quality and consistency. To achieve these goals the overall system performance must be consistent.

The bottom line of acceptable plant performance can be characterized by signal level stability, carrier-to-noise ratio, distortion performance, and consistent service availability. In the paragraphs above, the impact of various AM fiber signal level control implementations on overall system performance issues was discussed. A summary of the comparative advantages of each implementation is given in Table 1.

The importance of headend signal level maintenance on the performance of the CATV system, including the AM fiber link, is critical and stability can be augmented by the use of a composite power sensing AGC in the AM laser transmitter. At the optoelectronic receiver, control of signal levels feeding the distribution plant is also important. In single or multiple band AM systems the effects of temperature variations on the fiber plant and equipment can be minimized with proper equipment design. However, if an AGC design is to be used in the optoelectronic receiver, signal levels can best be stabilized versus optical loss variations, channel loading variations, and equipment changes by the use of a pilot carrier AGC.

AM fiber optic based CATV distribution systems have the potential to bring increased signal quality, additional channels, and increased service reliability to the CATV operator. The promise of this relatively new technology for CATV systems can be realized through comprehensive and careful development of system architectures and judicious design of equipment.

Table 1. System Performance Characteristics using Transmitter and Receiver AGC Combinations for Fixed Channel Loading.

Laser Transmitter AGC	Optoelectronic Receiver AGC	Consistent System Distortion	Consistent System CNR	Constant System RF Output Level	Effective Laser RF Overdrive Protection
pilot carrier	composite power	no	depends	no	no
composite power	composite power	yes	depends	no	yes
pilot carrier	pilot carrier	no	depends	yes	no
composite power	pilot carrier	yes	depends, but best compromise	yes	yes