Compact Optical Fiber Amplifiers with Fast AGC or for Analog Signal Transmission

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ABSTRACT With the growing use of optical fiber networks Furukawa Electric is working on the development of a full range of optical fiber amplifiers. In recent years wavelength-division multiplexing (WDM) systems have been faced with a need for add/drop capability to allow dynamic change in the number of channels. And the frequent increases and decreases in channels using the add/drop function brings with it rapid changes in the input power level of optical fiber amplifiers. This makes it necessary to have amplifiers that are capable of fast automatic gain control (AGC) to track these rapid changes in input power levels. Further, FTTC or FTTH systems (fiber to the curb or home respectively) have to provide television signal transmission capability in addition to telecommunications. Since TV transmission is generally by analog signals, a necessary specification for optical fiber amplifiers for analog transmission is low signal distortion. This paper reports on two types of compact optical fiber amplifiers that have been developed: the first with fast AGC for transient control, and the second for analog signal transmission.

1. INTRODUCTION

In recent years there has been a need for flexibility in the metro access networks that connect users with backbone networks to allow rapid modification of transmission capacity in response to user needs. It is therefore hoped that it will be possible to adapt wavelength-division multiplexing (WDM) systems to new technologies that use dynamic change in the number of channels in configuring optical fiber networks. This requires the introduction of optical add/drop multiplexers (OADMs), devices that can add or drop any desired channel from the multiplexed signal, and erbium-doped fiber amplifiers (EDFA) to compensate for the loss of optical components. Frequent adding or dropping of channels using an OADM results in rapid changes in the input power level to the optical fiber amplifier. If the response time of automatic gain control (AGC) for the optical fiber amplifier is slow, it will be unable to keep up with the rapid changes in input power level, giving rise to transient changes in output power level. Since changes in output power result in degradation of transmission quality (system performance), it is necessary the AGC be fast enough to suppress these output excursions.

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Fiber-to-the-curb or -to-the-home systems (FTTC or FTTH respectively) are expected to provide TV signal transmission capability in addition to telecommunications, and these TV signal transmission systems also need optical fiber amplifiers to compensate for losses in the optical components of the distribution system. Since TV transmission is generally by analog signals, the need for optical fiber amplifiers with low signal distortion is particularly acute. This is because if signal distortion is great, picture quality on the TV receiver will be degraded. Equipment must also be suitable for outdoor installation (−20 to 75°C) This paper reports on two types of compact optical fiber amplifiers that have been developed: the first with fast AGC for the control of transients, and the second for analog signal transmission.

2. COMPACT OPTICAL FIBER AMPLIFIER WITH FAST AGC

2.1 Configuration

Figure 1 and Table 1 show the full-optics configuration of a compact optical fiber amplifier with fast AGC. The outline dimensions adopted are 150×125×20 mm (without the heatsink), the de facto standard. Figure 2 shows the appearance. This compact package houses laser diodes, photodiodes, variable optical attenuator (VOA), erbium-doped fiber and an EDF heater to reduce the temperature dependence of the EDF, and a printed

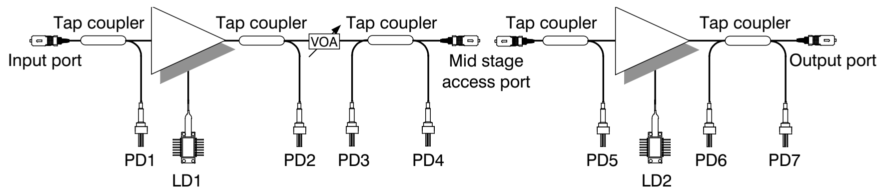

Figure 1 Full-optics configuration of compact optical fiber amplifier with fast AGC.

Table 1 Full-optics configuration of compact optical fiber amplifier with fast AGC.

Item	Specification
Number of laser diodes	2
Number of photodiodes	7
Number of VOAs	1
EDF heater	Yes
Mid-stage access (MSA)	Yes
Output power	Up to +23 dBm
Dimensions	150×125×20 mm (without heatsink)

Figure 2 Appearance of compact optical fiber amplifier.

circuit board for the control circuitry. There is a mid-stage access (MSA) I/O optical port for the insertion of optical components that give rise to MSA loss, together with a 25-pin D-sub, the de facto standard electrical connector.

Pulse width modulation (PWM) is adopted as the control method for the laser diodes, thermoelectric cooler (TEC) and EDF heater, effecting a reduction in power consumption. A single power supply with a voltage of +5 V is used, and serial communication to the outside of the optical fiber amplifier is provided by RS232:TTL level. Alarm functions include case temperature alarm, loss of output power alarm, pump bias alarm, and loss of input power alarm. Monitoring of the optical input and output power levels is also supported. There is also a control function from outside the optical fiber amplifier, plus optical output shutdown and automatic power reduction (APR) to lower the output to a given level. External control is also possible using the RS232 serial communication port.

A digital system is used for the control of the laser diodes etc., and can be adapted flexibly to changes in the desired specifications by modifications in firmware. The EDF transfer function in particular undergoes significant change according to operating conditions, and the AGC control parameters can be changed dynamically. The presence of a hot swap function means that firmware updates can be carried out even while the optical fiber amplifier is in network service. The optical configuration of the optical fiber amplifier may differ in various ways depending on the final user, but can be addressed by firmware settings alone, with no need to modify the physical circuitry. Here we have developed high-speed digital circuitry and a proprietary control algorithm, achieving fast AGC and realizing outstanding transient performance.

2.2 Transient Performance

The use of an OADM to effect add/drop of any desired channel of a WDM signal results in rapid fluctuations in the optical fiber amplifier input power level. If the response time of automatic gain control (AGC) for the optical fiber amplifier is slow, transient changes in output power level will occur. If these changes are large there will be significant effect on transmission quality (system performance), causing a degradation of the bit error rate. Indicators of transient performance include gain excursion, settling time and gain error. A gain excursion is the maximum value of the change in optical fiber amplifier gain during a rapid change in its input power level, also referred to as overshoot or undershoot. Settling time is transient suppression time--the time until gain stabilizes. Gain error is gain offset--the difference between the gain before the rapid change in input level and the gain after settling.

We therefore, in this work, made rapid changes in the input level of a compact optical fiber amplifier with AGC, and measured the gain transient performance. The increases or decreases in input level that were adopted were 6 dB (equivalent to the add/drop of from 1 to 4 channels) and 15 dB (equivalent to the add/drop of from 1 to 32 channels).

Figure 3 shows transient performance at the 6-dB add condition, with the upper waveform representing the total input power level and the lower representing the output power at one channel. Figures 4 through 6 show analogous waveforms. The measuring conditions are: mid-stage access (MSA) loss of 10 dB, output power level of 19 dBm, gain of 26 dB, and input power level add/drop through-rate of 0.1 μs or less. It was possible to obtain a gain excursion of 0.5 dB, a settling time of 20 μs, and a gain error after settling of 0.2 dB. Figure 4 shows transient

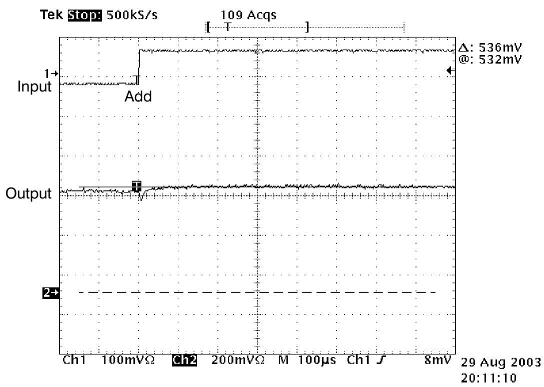

Figure 3 Transients at 6-dB add condition.

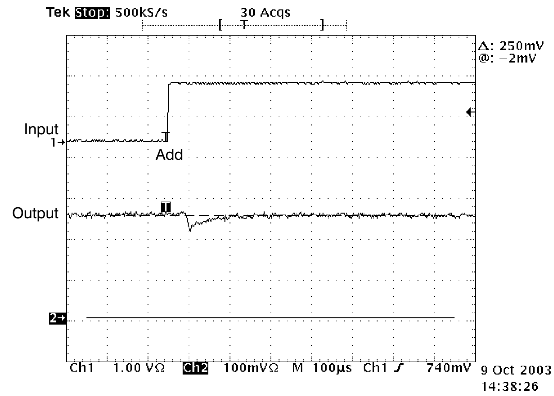

Figure 5 Transients at 15-dB add condition.

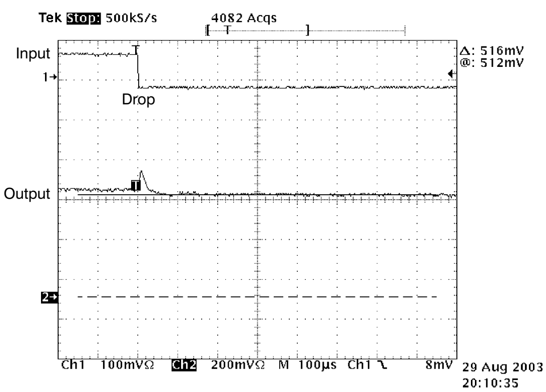

Figure 4 Transients at 6-dB drop condition.

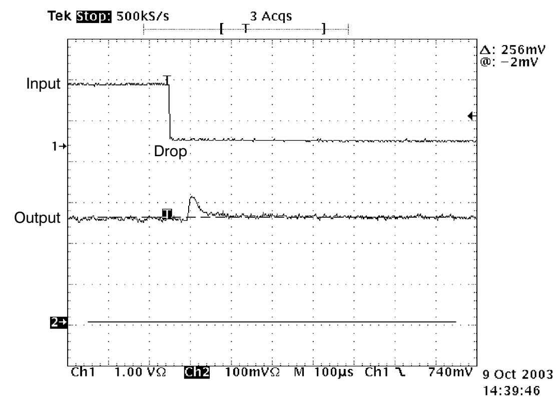

Figure 6 Transients at 15-dB drop condition.

performance at the 6-dB drop condition. The measuring conditions were the same as for the add condition, with a gain excursion of 0.7 dB, a settling time of 70 μs, and a gain error after settling of 0.2 dB. Figure 5 shows transient performance at the 15-dB add condition. The measuring conditions were the same as for the 6-dB add/drop add condition, with a gain excursion of 0.7 dB, a settling time of 70 μs, and a gain error after settling of approximately 0 dB. Figure 6 shows transient performance at the 15-dB drop condition. The measuring conditions were the same as for the add condition, with a gain excursion of 0.8 dB, a settling time of 50 μs, and a gain error after settling of approximately 0 dB.

These characteristics are summarized in Table 2, demonstrating outstanding transient performance.

3. COMPACT OPTICAL FIBER AMPLIFIER FOR ANALOG SIGNAL TRANSMISSION

3.1 Configuration

Figure 7 and Table 3 show the full-optics configuration of a compact optical fiber amplifier for analog signal transmission. The outline dimensions adopted are 150×125×20 mm (without the heatsink), the same as for the compact optical fiber amplifier with AGC. This compact package houses laser diodes, photodiodes, couplers, and a printed circuit board for the control circuitry. Also as

Table 2 Transient performance of compact optical fiber amplifier with fast AGC.

Type of transient	Maximum excursion	Settling time	Maximum gain error
6-dB add	0.5 dB	20 μs	0.2 dB
6-dB drop	0.7 dB	30 μs	0.2 dB
15-dB add	0.7 dB	70 μs	0 dB
15-dB drop	0.8 dB	50 μs	0 dB

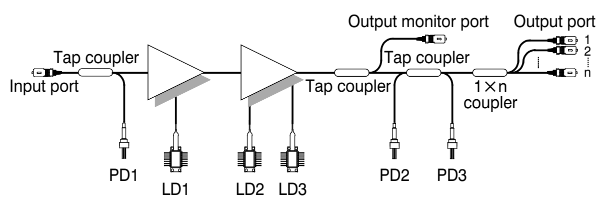

Figure 7 Full-optics configuration of compact optical fiber amplifier for analog signal transmission.

Table 3 Full-optics configuration of compact optical fiber amplifier for analog signal transmission.

Item	Specification
Number of laser diodes	3
Number of photodiodes	3
Output power	Up to +31 dBm
Dimensions	150×125×20 mm (without heatsink)

in the optical fiber amplifier with fast AGC, the electrical connector is a 25-pin D-sub.

The system used for the control of the laser diodes etc. is digital, as in the case of the compact optical fiber amplifier with fast AGC, and can be adapted flexibly to changes in the desired specifications by modifications in firmware. The following functions are also similar to those of the compact optical fiber amplifier with fast AGC: a single power supply with a voltage of +5 V is used, and serial communication to the outside is provided by RS232:TTL level. Alarm functions include case temperature alarm, loss of output power alarm, pump bias alarm, and loss of input power alarm. Monitoring of the optical input and output power levels is also supported. There is also a control function from outside the optical fiber amplifier, plus optical output shutdown and automatic power reduction (APR) to lower the output to a given level. External control is also possible using the RS232 serial communication port. Table 4 shows the optical and electrical performance.

The amplifier can mount 980-nm multimode laser diodes of the 2-W class, making itself possible to be used as a clad-pump optical fiber amplifier with an optical output of up to +31 dBm maximum.

3.2 Optical Characteristics

Among the factors contributing to the degradation of picture quality in analog TV transmission are interference due to noise and signal distortion generated by the optical fiber amplifier. The noise figure (NF) is one index representing amplifier noise. Amplifier noise is superimposed on the picture signal, so that when NF is large noise appears in the form of “snow” resulting in an indistinct picture. Indices of signal distortion include composite second-order (CSO) and composite triple-beat (CTB), both of which have a significant effect on picture quality.

Accordingly we measured NF, CSO and CTB for the compact optical fiber amplifier for analog signal transmission. Figure 8 shows the noise figure of the compact optical fiber amplifier for analog signal transmission. It plots NF against wavelength for input power levels of 0 and −10 dB when the output power level is +24 dBm. At operating temperatures from −20 to +65°C and signal wavelengths from 1540 to 1560 nm, an excellent characteristics was obtained, with an NF of 4.93 dB or less at an input power of 0 dBm and 4.51 dB at −10 dBm.

Figure 9 gives the CSO and CTB distortion characteristics. It shows the characteristics for a 5-stage cascade of compact optical fiber amplifiers for analog signal transmission. After the 5-stage cascade it was confirmed that CSO was −72.5 dB and CTB was −71.2 dB.

In addition we carried out a subjective assessment of picture quality using actual picture signals over a transmission line with a 5-stage cascade of optical fiber amplifiers for analog signal transmission. In confirming picture quality on the TV receiver after the 5-stage cascade, good picture quality was obtained, with no picture quality degradation found due to the 5-stage cascade.

Table 4 Performance of compact optical fiber amplifier for analog signal transmission.

Item	Unit	Symbol	Specification
Wavelength	nm	λ	1540 ~ 1560
Input signal range	dBm	Pin	−10.0 ~ 0.0
Output signal range	dBm	Pout	+18.0 ~ +31.0
Noise figure	dB	NF	Typ. ≤ 5.0
CSO distortion	dB	CSO	< −80
CTB distortion	dB	CTB	< −80
PDG	dB	PDG	< 0.3
Power supply voltage	V	—	+5
Communication	—	—	RS232 (TTL level)
Alarm	—	—	TTL level
Electrical connector	—	—	25 pin D-type plug

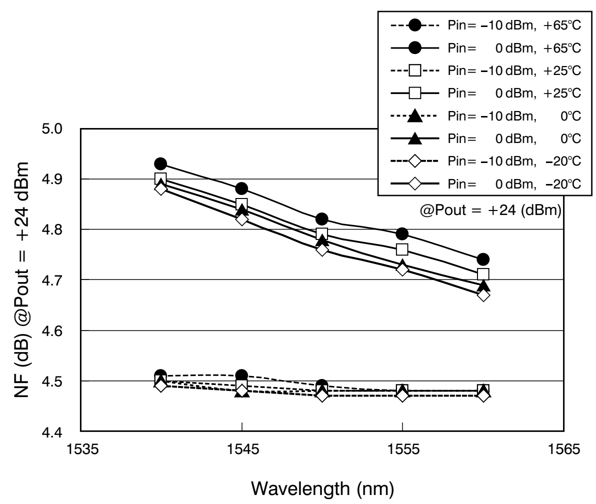

Figure 8 Noise figure of compact optical fiber amplifier for analog signal transmission.

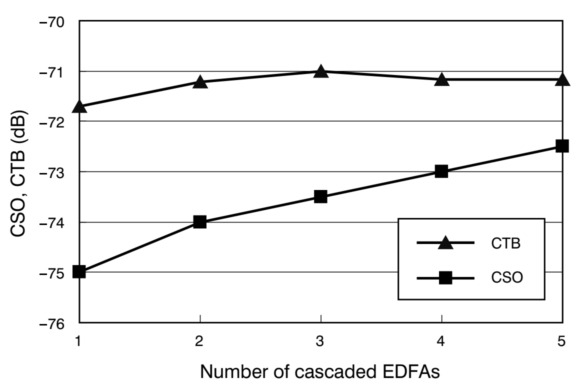

Figure 9 CSO and CTB distortion in compact optical fiber amplifier for analog signal transmission.

4. CONCLUSION

As compact optical fiber amplifier platforms for WDM transmission systems and for analog signal transmission, we have developed:

1) a compact optical fiber amplifier with AGC capable of fast transient control; and
2) a compact optical fiber amplifier for analog signal transmission.

It will be possible, using these platforms, to address a variety of needs for compact optical fiber amplifiers through optimization of the optics configuration and firmware.

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