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FIBER-OPTIC COMMUNICATION LINE AMPLIFIERS

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This article discusses the application of fiber-optic amplifiers used in fiber-optic communication lines, considers the characteristics of fiber-optic amplifiers, and analyzes the main classes of EDFA amplifiers.

Optical amplifiers are an integral part of fiber optic communication systems of various types. The most popular type of such amplifiers is based on an erbium – doped optical fiber (EDFA). Due to a number of their characteristics, EDFA amplifiers are widely used in optical information transmission systems, including systems with dense spectral densification DWDM.

The need for optical amplifiers (OP amps) for digital fiber-optic networks arose already with the introduction of SDH (synchronous digital hierarchy) technology. At high transmission speeds (from 2.5 Gbit / s and above) and fairly long sections of fiber-optic communication lines (FOCL), it was often necessary to use various types of converters – electro – optical (EOP) and optoelectronic (OEP), as well as regenerators-devices that restore the original form of the transmitted signal after passing the regeneration section. At the same time, since the 1980s, the direction of purely optical signal processing has been developing. In optical regenerators, as a rule, the optical signal is received, amplified, restored in shape, and transmitted to the input of the next regeneration section. Today, it is not possible to implement a fully optical circuit in a fiber optic communication system, but this is a matter of the near future. However, using the OP-AMP, you can significantly increase the length of the regeneration section, reduce their number. This simplifies the transmission scheme and reduces the cost of equipment. Optical amplifiers are also successfully used in CATV analog cable television networks, when a single common signal is transmitted to a significant number of consumers. For reliable reception of analog CATV signals, a higher signal-to-noise ratio on the receiver side is required than for digital systems. The overall signal in CATV networks should be very powerful, as it is distributed among hundreds and thousands of subscribers. OUS are able to solve such problems. They will also find application in FTTH technologies (Fiber to the Home – fiber to the apartment). Indeed, in this case, it is necessary to provide subscribers with inexpensive, and therefore not very sensitive receivers. Consequently, high signal strength is also required in FTTH networks.

EDFA-amplifiers-general principles

Most often, doped segments of optical fibers are used as the active medium of the OP AMP. In such a fiber, signals of certain wavelengths can be amplified by the energy of the external radiation of the pump. Rare-earth elements are used to dope the fiber. So, neodymium (Nd) and praseodymium (Pr) are used in the OP amp operating in the 1300 nm range, for the 1550 nm range – erbium (Er), in the 1470-1650 nm range, another rare earth element – tullium (Tu) is used.

The most widely used op-amps are based on erbium – doped fiber-EDFA (Erbium Doped Fiber Amplifier). This is mainly due to the development of dense optical multiplexing (DWDM) technology. It is thanks to the advent of amplifiers with such a combination of qualities as EDFA, communication lines and networks based on DWDM systems have become economically attractive. Indeed, conventional electronic regenerators, in order to restore the level of the optical signal, convert the input optical signal into an electrical one, with subsequent amplification and shape correction, and then convert it again into an optical signal. Considering that DWDM technology uses up to several dozen channels at different wavelengths within the transparency window, the regenerator becomes the most complex and expensive part of the system. In contrast, EDFA amplifiers do not recognize or convert the signal, but simply increase its power, immediately in the entire operating band – from about 1525 to 1565 nm. Therefore, unlike regenerators, they are practically independent of the protocol and the transmission speed. The operating range of the EDFA with a width of about 40 nm almost exactly corresponds to the transparency window of the quartz fiber. These 40 nm can accommodate several dozen DWDM channels.

Since EDFA amplifiers are independent of the network protocol, they can be directly connected to different equipment without fear of interfering with each other. Networks with EDFA amplifiers have a number of advantages. For example, the capacity of such networks can be increased economically and gradually, adding new channels as the demand increases. The use of EDFA optical amplifiers allows you to create fully optical networks in which signal processing by electronic devices occurs only at the start and end points of the network.

Of course, the use of EDFA is not a panacea for all problems. After all, an amplifier without a regeneration function increases the total power of the input signal, including additive noise – as a result, the signal-to-noise ratio decreases. It also does not compensate for the effects of various nonlinear effects, including dispersion of different nature (unless, of course, the amplifiers are equipped with built-in dispersion compensators). Therefore, despite the certain ease of use of the op-amp, it is necessary to carefully consider their parameters and some features of the application. First of all, a decrease in the signal-to-noise ratio at the output of the op amp leads to a decrease in the threshold sensitivity of the terminal receiver. Moreover, this ratio is less, the more OP-AMP is used when creating a specific communication line. Therefore, in SDH networks on long-distance sections, it is preferable to use conventional electro-optical regenerators with the restoration of the shape of the transmitted optical signals. The disadvantages of using an OP AMP in DWDM systems include the non-uniformity of the amplitude-wave characteristic. Its compensation leads to a decrease in the output power and, consequently, to a decrease in the length of the fiber optic cable. Let's consider the main parameters of EDFA and their impact on the use of OP-amp in fiber optic communication systems.

In addition to similar characteristics to electronic amplifiers, such as gain, noise factor, dynamic range, and amplitude-wave response, the OP AMP has its own unique parameters. The main ones are the saturation power, the medium gain, the enhanced spontaneous emission (SPI), and the sensitivity to the polarization of the input optical signal.

As in electronic amplifiers, the gain of the OP amp depends on the level of the input signal. Up to a certain (small) level of the input signal, the gain is almost constant. Further, it begins to fall exponentially with an increase in the input power level. This flat part of the characteristic is the OP AMP saturation region and is explained by a decrease in the multiplication factor k caused by a shortage of working particles capable of generating secondary photons with an increase in the input signal. This region can be characterized by the Ph saturation power at the output of the amplifier at the level of -3 dB of the output characteristic (the gain of the medium drops twice). It should also be noted here that the amount of gain can be affected by the polarization of the input signal, which is not controlled in the FOCL, but can change under the influence of random changes in the shape of the core and other reasons.

Dynamic range (SNR) is defined as the range of input power of an optical signal at which the gain remains constant. Naturally, it is associated with another parameter-the noise coefficient, which depends on the level of USI, the residual pump signal and crosstalk. The greatest influence on the noise factor is exerted by the USI. It occurs under the influence of random disturbing factors, for example, when the op-amp is heated. This noise not only reduces the dynamic range, but also reduces the maximum allowable gain.

The decrease in the dynamic range is characterized by a noise coefficient F = SNRxx/SNRX, where SNRxx and SNRX are the values of the dynamic range at the input and output of the op amp.

The gain in the OP amp is caused by the fact that under the influence of laser diode (LD) radiation in some active medium having two energy states, an increased population of the level with a higher potential energy is created. As a result of this pumping, the medium becomes active, i.e., capable of generating secondary photons with a multiplication factor of k. Some op-amps use a more complex, three-level interaction mechanism for pumping. The scheme for creating overpopulation is as follows: from the first level, the particles are transferred to the second, from which they move to the third level as a result of relaxation. Due to the significant difference in the time of life at the third level, a sufficient population is created for strengthening. This type of OP AMP also includes EDFA.

LDS with wavelengths of 980 and 1480 nm are suitable for pumping EDFA. LD at 980 nm uses a three – level model of interaction with the active medium, and LD at 1480 nm-a two-level model. LDS at 980 nm allow you to get a very low noise factor, 3-5 dB, which is better for multi-channel systems and preamps of DWDM systems. On the other hand, LDS at 1480 nm with a noise factor of 5 dB are more reliable and cheaper. Some models of EDFA amplifiers use pumping at two wavelengths, which to some extent allows you to combine the advantages of both methods.

In EDFA with single-stage pumping, the maximum achievable output power is about 16 dBm. At the same time, the noise coefficient in the low-power signal region is 5-6 dB. In the double-pumped EDFA (980 and 1480 nm), higher output power values are achieved – up to 26 dB. To reduce the noise level in such a design, a multi-stage scheme is used: after the first gain stage, an optical insulator is placed, which prevents the propagation in the opposite direction of the USI of the second stage.

The amplitude-wave characteristic (AVC) of EDFA with an unevenness of ±10 dB practically covers the band of 1520-1570 nm, has a maximum gain (40 dB at Rvc = -30 dBm) at a wavelength of 1535 nm and a plateau (gain of 30 dB) in the range of 1540-1569 nm. You can align the characteristics of the amplifier for use in DWDM systems by using various filters. As a result, it is possible to achieve an uneven ABC of 0.1–0.2 dB. However, the gain is reduced to 16-18 dB in the OP AMP with one pump LD and to 19-22 dB - with two LDS. Another way to reduce the unevenness of the ABC is to use fluoride-based fibers as the active medium, since they have a more uniform spectral distribution of the gain than for quartz fibers. But such amplifiers have a higher noise level.

To equalize the time delays that occur during the propagation of signals of different wavelengths in the fiber optic system, EDFA (especially two-stage) uses dispersion compensation devices.

EDFA amplifiers can be divided into three main functional classes:

– high-power amplifiers (boosters) installed directly behind the transmitter. They work with a large input signal, provide the maximum allowable gain and a high output signal level, and are not critical to the noise level;

– line amplifiers are installed on the communication line as repeaters. They amplify the signal as much as possible, while introducing as little noise as possible;

– preamps installed directly in front of the receiver. They work with very weak signals (from -45 to -30 dBm) and are therefore extremely critical to the noise level of the amplifier.

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