

High-power EDFA applied in distributed optical fiber Raman temperature sensor system

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Abstract In this paper, a high-power erbium-doped fiber amplifier (EDFA) for the temperature sensor system is theoretically designed and experimentally demonstrated. It consists of an erbium-doped fiber that is pumped bidirectionally with two 980-nm high-power laser diodes (LDs). At the EDFA input, an optical isolator (ISO) is used to ensure that the signal pulse transmits forward only. After that, a wavelength division multiplexer (WDM) is employed to combine the forward pump laser (980 nm) and incident optical pulse (1550 nm) into the erbium-doped fiber for direct amplification in the optical domain. At the EDFA output, another WDM couples the backward pump laser (980 nm) into the erbium-doped fiber and outputs the amplified optical pulse (1550 nm) with an ISO followed to isolate the backscattering light. According to this structure, we carried out the experiment in the condition as follows. For 980 nm pump LD, the operating current is 590 mA, and the setting temperature is 25°C. For EDFA, the length of erbium-doped fiber is 12.5 m, and the power of 1550 nm input signal is 1.5 mW. As a result, the power of pump LD is 330 mW, and the power uncertainty is 0.5%. The power of EDFA output at 1550 nm is 300 mW, and the power uncertainty is ± 3 mW.

Keywords erbium-doped fiber amplifier (EDFA), fiber sensor, bidirectional pump, laser diodes (LDs) driver, thermoelectric cooler (TEC)

1 Introduction

In the distributed optical fiber Raman temperature sensor system, the measure of temperature is based on the optical time domain reflection (OTDR) principle. For longer

sensor distance, 1550-nm laser is transmitted as light source along the G.653 fiber in this temperature sensor system. However, the spontaneous Raman backscattering light generated by 1550-nm laser is weaker than that generated by short-wavelength laser. In this condition, it is very necessary to enhance the signal source to improve the signal-to-noise ratio (SNR) of backscattering light. So the erbium-doped fiber amplifier (EDFA), a kind of optical amplifier that works at 1550 nm, is applied to amplify the light source [1].

The technology of distributed optical fiber sensing was brought forward in the end of 1970s. Since then, a series of distributed sensing systems based on different mechanisms were studied and used in many fields gradually. Nowadays, this has been one of the most promising technologies in fiber-optic sensor. The distributed optical fiber temperature sensor system can sense the change of temperature along the optical fiber by the form of continuous function of distance. The fiber used in distributed optical fiber sensor is not only transport media but also sensing media. It has the following characteristics: resistance to electromagnetic interference and fire, small size, and little effect on temperature field [2].

2 Theory

In the distributed optical fiber Raman temperature sensor system, the measure of temperature is based on the OTDR principle. Accurate and clear signal acquisition of spontaneous Raman backscattering is essential in OTDR. It is significant that the backscattering light from the sensor optical fiber can be detected, whereas the backscattering Raman signal with the information of temperature is quite weak and even completely submerged in noise. The measurement accuracy of the whole system has relationship with the SNR of anti-Stokes and Stokes backscattering. Weak signal measurement must be used in

this system. Generally speaking, by using common 1550-nm laser diode as light source, the power of Stokes or anti-Stokes light is quite weak and even completely submerged in noise. Therefore, we need more powerful 1550-nm light source to generate detectable scattering signal. At least, the power of backscattering signal is expected to be more than -50 dBm.

EDFA, made by doping the silica fiber with erbium ions, can operate in a broad range within the 1550-nm window at which the attenuation of silica fiber is minimum, and therefore, it is ideal for the optical fiber communication systems operating at this wavelength range. So, in this sensor system, EDFA can be used to amplify 1550-nm signal. According to the research performed in recent years, it is known that the pumping of erbium-doped fiber at 980 or 1480 nm is the most efficient way. High gain (30–50 dB), large bandwidth (≥ 90 nm), high output power (10–20 dBm), and low-noise figure (3–5 dB) can be obtained using an erbium-doped fiber amplifier optimized for 1550-nm range [3].

3 Design and analysis

In this temperature sensor system, there are four modules as follows: low-power 1550-nm laser diode, EDFA, sensor optical fiber, and detection module. By using EDFA, the low-power 1550-nm laser light can be amplified to a sufficient powerful signal in the optical domain. With this amplified laser light, the sensor fiber would generate a detectable backscattering signal. As a result, the SNR can be increased obviously, and the problem of weak signal detection is resolved [4].

The gain characteristics of EDFA depend mainly on their pumping schemes. EDFA can be pumped at 980 or 1480 nm and with different configurations: backward, forward, or bidirectional. The pumping at 980 nm provides lower noise figure than pumping at 1480 nm. Therefore, preamplifier version of EDFA chooses 980 nm for pumping wavelength. On the other hand, 1480-nm pumping has higher quantum efficiency and so provides higher output power at a lower cost, and therefore, it is preferred for booster amplifier operations [5–7]. In forward pumping, both the signal and pump lights propagate in the same direction through the fiber, whereas in the backward pumping, they propagate in the opposite direction. The forward pumping direction provides the lowest noise figure. In fact, the noise is sensitive to the gain, and the gain is the highest when the input power is the lowest. Backward pumping provides the highest saturated output power. Bidirectional pumping scheme has a higher performance than the other two by combining the lowest noise figure and the highest output power advantageous, although it requires two pump lasers. In addition, in this scheme, the small signal gain is uniformly distributed

along the whole active fiber. So, to obtain the highest power-gain as possible, this EDFA in the sensor system is pumped bidirectionally by two 980-nm high-power laser diodes (LDs).

The structure of this high-power EDFA is shown in Fig. 1. It consists of two unidirectional optical isolators (ISOs), two wavelength division multiplexers (WDMs), two pump LDs, and an erbium-doped fiber. At the EDFA input, the ISO1 ensure that the signal pulse transmit forward only. After that, the WDM1 combines the forward pump laser light (980 nm) from PUMP1 and incoming optical pulse (1550 nm) into the erbium-doped fiber. Erbium ions are excited to the high-energy level by the 980-nm pump laser light and quickly decay into metastable energy level. These metastable ions emit the same light as the input signal when they come back to ground state with the stimulation by the 1550-nm laser light. At the EDFA output, another WDM couples the backward pump laser (980 nm) into the erbium-doped fiber and output the amplified optical pulse (1550 nm) with an ISO afterward to isolate the backscattering light.

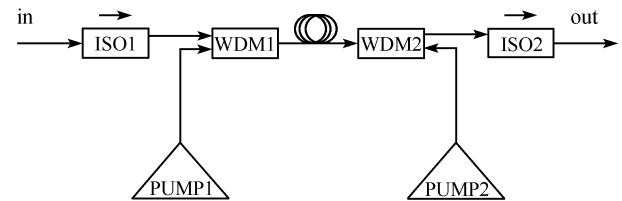


Fig. 1 Configuration of EDFA

For high gain, the two 980-nm pump LDs must be operated in high power. At the same time, the signal light into the sensor fiber is expected to be stable in this temperature sensor system. Therefore, the power of pump laser must be stable so that the optical power into the sensor fiber can be invariable. So the driver of pump LD should not only operate the laser in high power but also avoid the power fluctuation.

In this EDFA system, the driver of the pump LD consists of driver control module and temperature control module, and each module is operated independently. In the driver module, as shown in Fig. 2, OPA569, a rail-to-rail I/O, 2 A power amplifier, is used to drive the LD. The OPA569 is unity-gain stable, has low DC errors, is easy to use, and free from the phase inversion problems found in some power amplifiers. High performance can be maintained at voltage swings near the output rails. So, to a certain extent, the power stability has been maintained. Otherwise, the OPA569 provides an accurate user-selected current limit that is set with an external resistor (R_{SET}), and its output can be independently disabled using the enable pin so that the laser diode can be protected from breakdown. The limit current I_{LIMIT} is calculated by

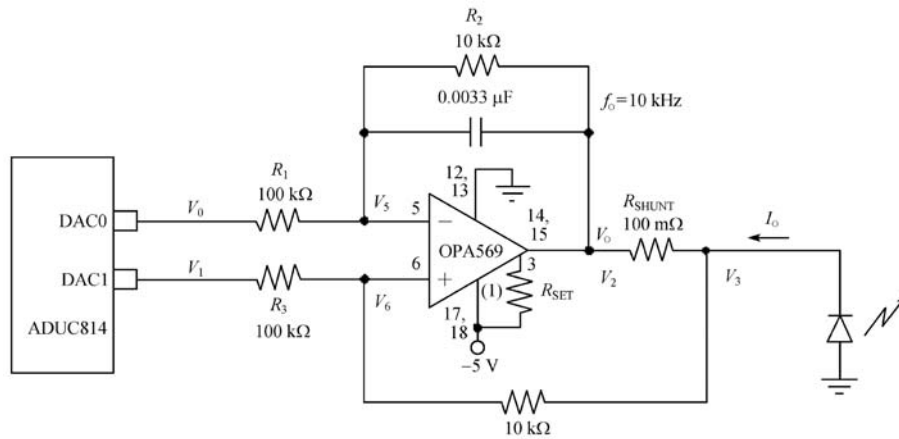


Fig. 2 LD driver module (see <http://focus.ti.com.cn/cn/docs/prod/folders/print/opa569.html>)

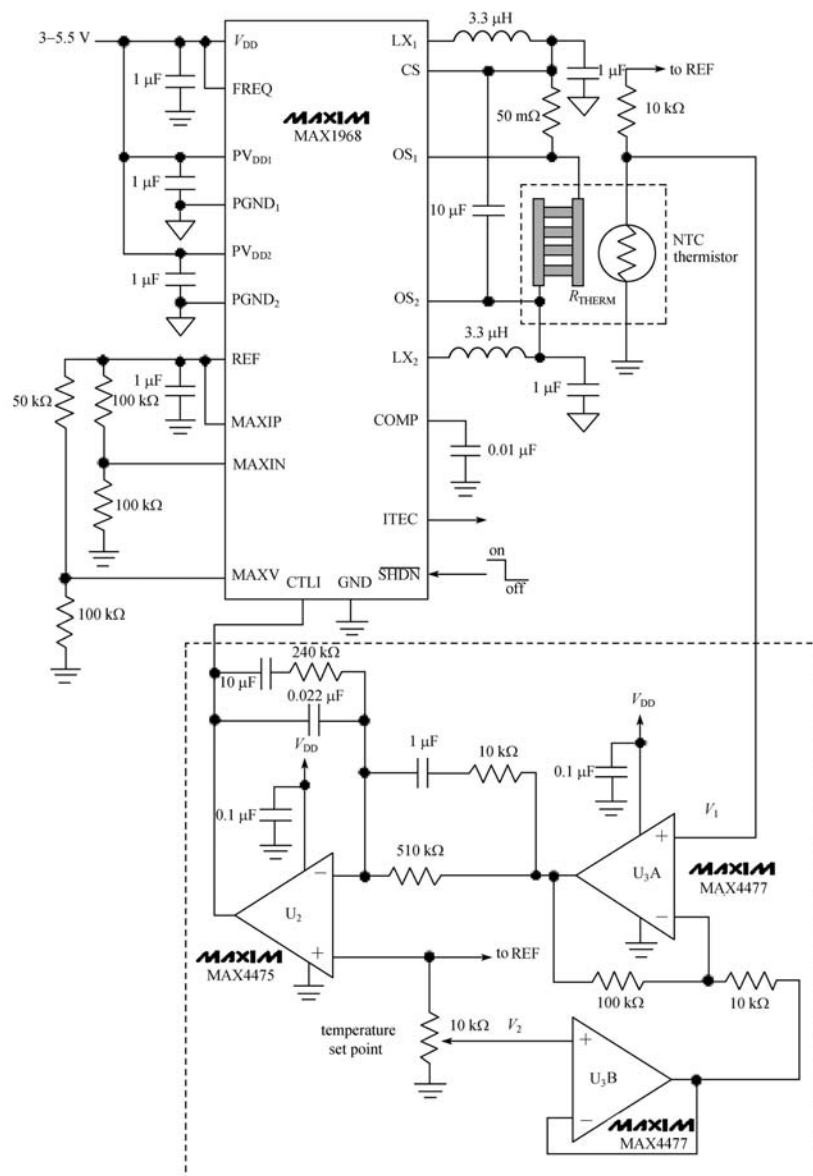


Fig. 3 LD temperature control module (see http://www.maxim-ic.com.cn/quick_view2.cfm/qv_pk/3377)

$$I_{\text{LIMIT}} = 9800(1.18/R_{\text{SET}}).$$

To this pump LD, the maximum operating power is 330 mW when it was driven at the maximum operating current of 580 mA. So we set the R_{SET} to 20 k Ω . The operating current from OPA569 is controlled by ADUC814, which is a microcontroller with 8-kbit flash and dual 12-bit voltage output digital-analog (DA) converters. This microcontroller can make the LD operating current more stable, and the written procedures in its Rom can be changed to operate the LD in different currents. The OPA569 input pins are directly controlled by two DA pins from ADUC814. In this condition, the drive current is controlled by the voltage of DAC0 and DAC1. Considering the possible impact of static electricity, the driving method is chosen to be negative current output, which means that the driver offers negative driving current, and LD anode is grounding.

In the temperature control module, as shown in Fig. 3, MAX1968, a high-efficiency switch-mode driver for Peltier thermoelectric cooler (TEC) can offer appropriate cooling current according to the change of laser temperature. According to the principle of TEC, the margin of actual temperature and setting temperature of LD is converted into voltage signal. After appropriate hardware and control algorithms, the voltage signal is transmitted to the TEC module. Then, the MAX1968 in the TEC module will offer corresponding cooling current. With the

operation of this module, the pump LD will operate at its most suitable temperature so that the optical power can be stable.

The most appropriate length of the erbium-doped fiber is determined by numerical simulation and experiments. Through numerical simulation, a probable length can be estimated. As a result, the length would be about 13 m to ensure that the output could achieve such a power, which is needed in this sensor system. In the following experiment, the length of erbium-doped fiber will be reduced by 5 mm for each time. With the help of optical power meter, the output powers at different length can be detected. Then, the best length could be found by the times of the experiment.

4 Conclusion

In conclusion, the operating parameters of this EDFA are listed as follows: operating current of pump LD is 590 mA, operating power of pump LD is 330 mW, pump LD output uncertainty is 0.5%, length of erbium-doped fiber is 12.5 m, power of EDFA output with 1.5-mW input is 300 mW, and EDFA output uncertainty is ± 3 mW. In the distributed optical fiber Raman temperature sensor system, under the application of this high-power EDFA, a spectrum of Raman backscattering shown in Fig. 4 can be obtained.

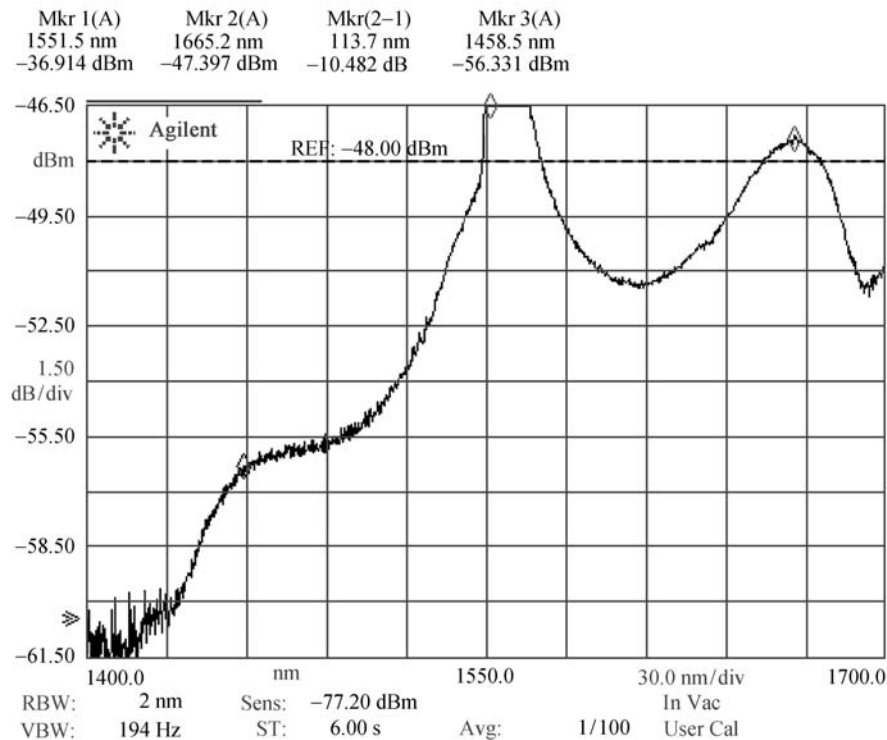


Fig. 4 Spectrum of Raman backscattering in this system

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