Research on Optoelectronic Oscillator Based on Phase Locked Loop Control

Shi Linyun, Shi Chunxia

Baoji Vocational Technology College, Baoji 721301, China

Keywords: Phase locked loop, Optoelectronic oscillator, double loop structure, Stability

Abstract: Optoelectronic oscillators can be widely used in electronics and communication fields due to their advantages. However, due to the performance of the components and the use environment, it is necessary to optimize its performance to improve the stability. Combined with previous research experience, this paper proposes an optoelectronic oscillator based on phase locked loop control. The performance test shows that the stability is greatly improved compared with the conventional double-ring structure optoelectronic oscillator, and it can be applied and produced.

1. Introduction

Optoelectronic oscillator (OEO) is the product of photonic microwave generation technology. The original optoelectronic oscillator uses a single-ring structure [1]. However, the single-ring structure of the optoelectronic oscillator has an obvious disadvantage, that is, there is a contradiction between the high Q value of the system and the single-mode output of the signal, which increases the difficulty in manufacturing the radio frequency filter and the cost of use. In order to solve this problem, in 1994, X. Steve Yao and L. Maleki proposed a double-ring structure optoelectronic oscillator, which effectively solved the shortcomings of long-fiber short-mode output [2]. In recent years, the majority of scholars have conducted in-depth research on OEO, and proposed a variety of new structure OEO. These new structures are based on the improvement and optimization of the double-ring structure electric oscillator, and the main purpose is to improve the overall performance and stability of the optoelectronic oscillator. For example, a double loop structure optoelectronic oscillator based on the principle of wavelength division multiplexing proposed by Jia et al. [3], an injection-locked double loop structure optoelectronic oscillator proposed by Okusag [4]. These studies provide an empirical reference for the theoretical improvement and practical application of optoelectronic oscillator. Because OEO can produce high-performance signals with high spectral purity and low phase noise, it can be applied to many fields such as radar, communication, and instrumentation systems. This requires continuous optimization and improvement of its performance to improve the stability of OEO. Based on this, this paper proposes an OEO based on phase locked loop (PLL) control to further improve the theory of optoelectronic oscillator and promote its promotion and application.

2. The Basic Principle of Optoelectronic Oscillator

The basic structure of the single-ring OEO is shown in Figure 1. It includes a variety of optoelectronic devices: lasers, electro-optical modulators, long fibers, optical filters or microwave filters, microwave amplifiers or optical amplifiers, photo detectors, power splitters, and so on. The laser optical signal is modulated in the electro-optic modulator and then sent to the optical fiber for transmission, and then converted into an electrical signal by the photo detector. After being amplified and frequency-selected, it is again sent to the electro-optic modulator to modulate the optical carrier. The start-up of the loop is due to noise inside the active device, which is provided by the amplifier with sufficient gain and the signal is increasing in amplitude over multiple cycles. The nonlinearity of the final system leads to gain compression, which establishes a stable oscillation when the gain approaches 1. OEO can be viewed as a closed microwave photonic link. Thanks to its low loss and ultra-wideband characteristics, it is capable of producing signals with higher spectral

  DOI: 10.25236/icbsis.2020.023

purity than conventional microwave oscillators.

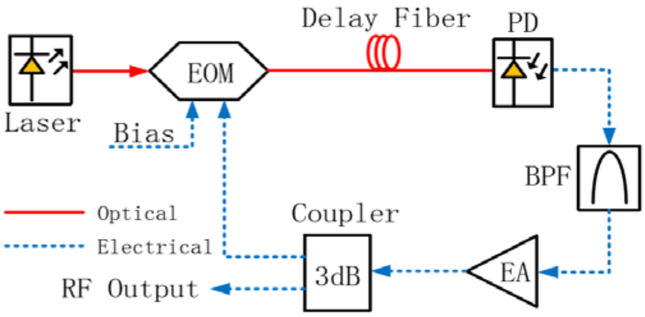

Fig.1 The Basic Structure of Oeo.

3. Principle of Oeo Based on Pll Control

As mentioned above, the single-ring structure combined OEO has a significant disadvantage, that is, the long fiber is not easy to single-mode output, and the long fiber link is susceptible to environmental temperature and vibration and causes link delay variation. Ultimately, these shortcomings can cause OEO frequency drift and stability to deteriorate. In order to solve the above two problems at the same time, this paper proposes an OEO based on PLL control. On the one hand, injection locking is used to improve the near-carrier phase noise and spurious suppression of OEO. On the other hand, the OEO output signal is phase-detected with the external injection source, the frequency stability is improved by the PLL, and the near-carrier phase noise of the OEO is further improved.

The OEO based on PLL control proposed in this paper is a new type of OEO combining injection locking technology and PLL technology. Its structure is shown in Figure 2. The system mainly includes an LD, an MZM, a single-mode fiber, a PD, two adjustable attenuators (Att), a microwave amplification module (Amp), a BPF, a VCPS, a PS, two directional couplers (DC), two power dividers, one mixer, one LPF, one servo circuit and one external high stability reference source (Ref). The mixer is used as a phase detector, and the loop filter in the PLL is included in the servo circuit. The frequency of Ref is the same as the OEO main mode oscillation frequency, where Ref serves two purposes: one is as an out-of-frequency injection source, coupled to the OEO free-oscillation signal to the modulator, so that the OEO's main mode is injected locked within the locked bandwidth. Second, as an external reference source of the PLL, the output signal of the OEO is phase-detected by the mixer and then input to the servo circuit, and then fed back to the phase of the VCPS control loop. Finally, the output signal of the system is split into two channels, which are connected to the phase noise measurement system (PNMS) and the spectrum analyzer (SA).

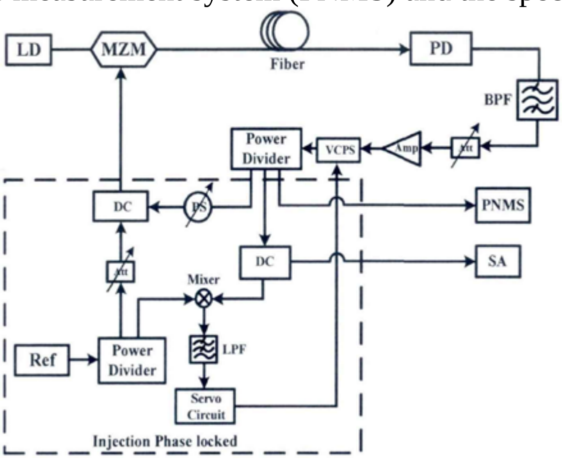

Fig.2 The Principle of Oeo Based on Ppl Control.

For ease of analysis, Figure 2 is simplified to the form of Figure 3. Since a VCPS is built into the OEO loop, the OEO can be seen as a VC-OEO. The output signal of Ref is divided into two paths through the coupler: one is injected into the VC-OEO through the adjustable attenuator, and the other is coupled to the output signal of the VC-OEO after being phase-shifted by 90° manual adjustment. The role of the servo circuit is to ensure that the phase difference between the two signals before mixing is an odd multiple of π/2. When the frequency of the external injection signal coincides with the frequency of the VC-OEO output signal, it can be locked. At this time, the phase difference between the two signals before mixing is just an odd multiple of π/2, the feedback signal of the servo circuit to VC-OEO is zero, the bias voltage of VC-OEO built-in VCPS is unchanged, and VC-OEO maintains a stable working state. When the VC-OEO is disturbed by external temperature or other factors, the frequency drift occurs. At this time, the DC component of the two signals is not zero after mixing. This DC component generates a feedback voltage through the servo circuit to act on the voltage-controlled phase shifter in the VC-OEO, so that the bias voltage changes, and finally the frequency after the drift can be pulled back to ensure the injected signal frequency is precisely aligned with the VC-OEO main mode frequency.

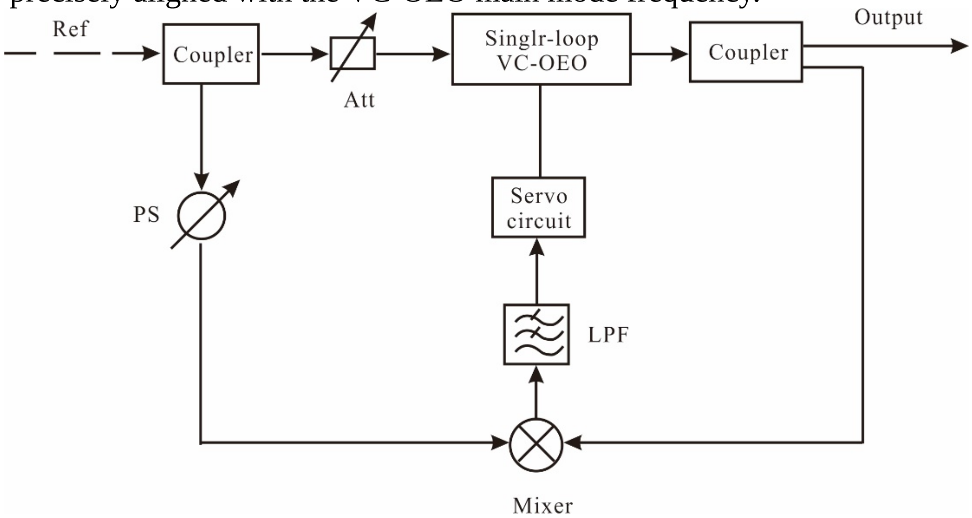

Fig.3 The Simplified Principle of Oeo Based on Ppl Control.

4. Prototype Development and Testing of Oeo Based on Pll Control

4.1 The Development and Testing of Laser Temperature Control and Drive Circuit

The stability of the output optical signal of the DFB laser will greatly affect the stability of the OEO output signal, so a laser controller is usually required to maintain the stable output of the laser. In order to develop an integrated OEO prototype, it is first necessary to design a control module for the laser. The control module generally includes a current driving module and a constant temperature control module. In order to ensure long-term stable operation of the laser at high output power, the control module is required to provide low noise and high stable driving current for the laser, while ensuring the stability of its operating temperature. The microwave fiber link using the laser control module is shown in Figure 4. The driver chip requires low noise, high precision, good stability and the ability to provide multiple operating modes. The temperature control chip requires high efficiency, high temperature control stability, good reliability, zero electromagnetic interference and small size. In this paper, the laser drive current, housing temperature and output optical power variation in the laboratory environment are tested in 6 hours, which can meet the requirements of OEO.

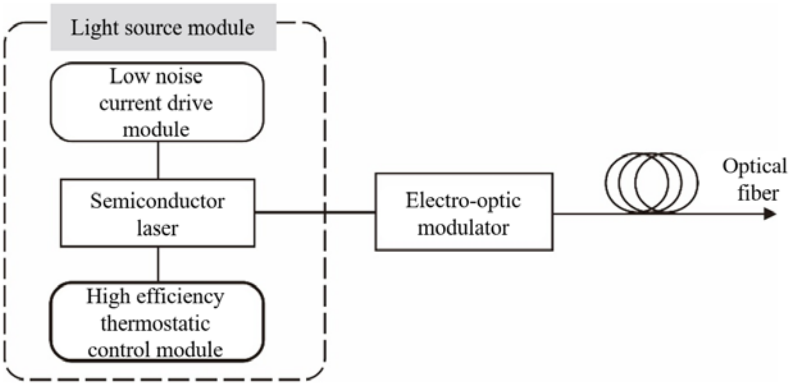

Fig.4 Schematic Diagram of the Laser Control Module

4.2 Development and Testing of Mzm Bias Control Circuit

Since the operating characteristics of MZM will change with environmental factors such as external temperature and vibration, the operating point will drift accordingly. Therefore, stability control must be implemented for the bias point of the MZM. Since the different bias points of the MZM affect the RPN of the entire microwave fiber link, the phase noise of the OEO output signal is further affected. Therefore, another function of the bias control circuit is to achieve accurate control of different bias points of the MZM. Bias control is typically implemented using a closed loop feedback system. The feedback system performs real-time detection of the working point of the MZM. When the drift of the working point of the MZM is detected, the system repeatedly adjusts the DC bias voltage of the MZM through feedback information, thereby suppressing the drift of the DC bias point and ensuring the modulation stability of the entire microwave fiber link.

The bias control circuit mainly comprises an amplifier, a built-in PD, an error comparator, a control circuit and a reset circuit. Since the DFB laser usually operates in a constant current mode, the electrical signal of the PD output of the DFB laser can be used as a reference signal for the bias control, and 5% of the output optical power of the MZM is coupled to the built-in PD of the bias control circuit. The output signal of the built-in PD is amplified and compared with the reference signal and sent to the control circuit. The control circuit then adjusts the DC bias of the MZM until the error is zero. The bias control circuit is tested, and the operating point is basically not drifted, which can meet the stability requirement of the OEO to the MZM bias point.

4.3 Development and Testing of Optical Fiber Temperature Control Device

The long fiber ring is usually used in the IMDD link part of the OEO. However, the long fiber is susceptible to changes in the refractive index of the fiber due to the influence of the ambient temperature, resulting in phase jitter of the microwave signal modulated on the optical carrier, which eventually causes the OEO oscillation frequency to drift. Since the temperature drift has a large influence on the phase of the microwave signal, it is impossible to track the phase change of the upper signal only by relying on the PLL. At the same time, the higher the microwave frequency and the longer the fiber, the greater the temperature drift. Therefore, temperature control development of long fiber rings is very necessary. The designed fiber optic temperature control device is shown in Figure 5. The overall design is as follows: The fiber optic ring is placed in a metal box with a thermal pad between the fiber ring and the bottom of the box. A Thermo Electric Cooler (TEC) is placed on the top of the metal box. The TEC has a heat sink on the top surface. The TEC and the top of the box and the heat sink are fixed by thermal silica. The TE leads are connected to an external temperature controller. The inner wall of the metal case has a thermistor fixed by a thermal silica gel, and the wire of the thermistor is connected to the temperature controller through a pre-punched via. The outer part of the metal case is covered with a layer of insulation material, a groove is dug at the top of the insulation layer, and the upper surface of the TEC is exposed to the air [5]. The temperature controller controls the TEC to absorb heat or exotherm by sensing the resistance of the thermistor, thereby realizing real-time control of the internal temperature of the metal case. The temperature control accuracy of the temperature controller is ±0.01 °C. In order to verify the effectiveness of the temperature control device, the phase change of the modulated microwave signal (10 GHz) in the microwave fiber link was investigated separately without the temperature control and temperature control. The results show that the phase drifts only about 20 after temperature control, and the temperature control device can meet the temperature drift requirement of the injection phase-locked OEO to the fiber.

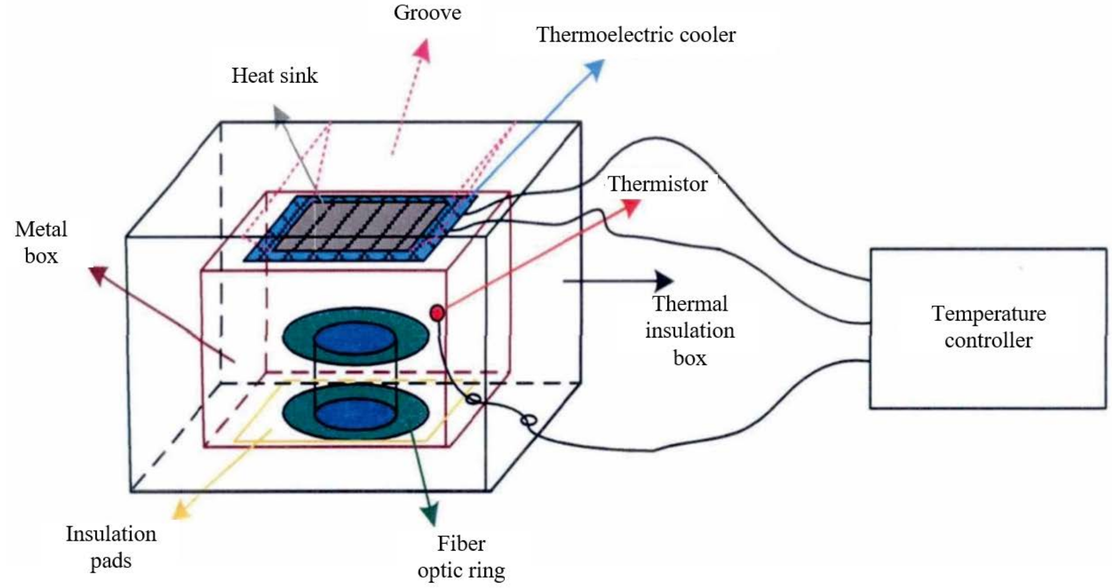

Fig.5 Design of the Fiber Optic Temperature Control Device

5. Conclusion

Through performance testing, the PLL-based OEO developed in this paper has excellent performance and can produce high-performance signals with high spectral purity and low phase noise. This fully demonstrates the scientific nature of the research and development methods in this paper, which can be used in production and practice. Since the OEO developed in this paper involves a plurality of optoelectronic components, in the actual application process, it is necessary to consider the use environment and other factors, and improve the stability of the entire component through the packaging technology.

References

[1] A Neyer, E Voges. Hybrid electro-optical multivibrator operating by finite feedback delay. Electronics Letters, vol. 2, no. 18, pp. 59–60, 1982.

[2] YAO X S, MALEKI L. High frequency optical subcarrier generator. Electronics Letters, vol. 30, no. 18, pp.1525-1526, 1994.

[3] Jia S, Yu J, Wang J, et a1. A Novel Optoelectronic Oscillator Based on Wavelength Multiplexing, no. 2, pp. 213-216, 2015.

[4] Okusaga O, Adles E J, Levy E C, et a1. Spurious mode reduction in dual injection locked optoelectronic oscillators. Optics express, vol. 19, no. 7, pp. 5839-5854, 2011.

[5] Zhou Zhenghua. Study on the stability of optoelectronic oscillators. Southeast University, 2016.