

Research Article

IOT-Based Injection-Locked Microwave Photonic Frequency Division Signal Processing

Lin Wang ¹, Guangying Wang ², and Jingxu Chen ²

¹School of Electronic and Electrical Engineering, Zhaoqing University, Zhaoqing 526061, China

²Institute of Photonics Technology, Jinan University, Guangzhou 510632, China

Correspondence should be addressed to Lin Wang; 1910300328@mail.sit.edu.cn

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When building an injection-locked microwave photonic frequency division signal processing model for the Internet of Things, the waveform and frequency of the microwave have an important impact on its performance. How to optimize and adjust the injection-locked microwave photonic frequency division signal processing effect needs more research and exploration. Taking the traditional mode architecture as a reference, this paper constructs an injection-locked microwave photonic frequency division signal processing model based on the Internet of Things. In this paper, the popular deep analysis method is used to optimize the model, and the photonic technology is matched with the microwave analysis. The purpose of this construction is to weaken the microwave integration error and improve the calculation accuracy to a higher level. In addition, aiming at the difficult problem of microwave signal generation, this paper uses the optical injection method to lock the microwave photons and generate waveform signals, which makes the model data more representative, so as to solve the problems of unstable microwave signals and high transmission costs. This paper also discusses the possibility of microwave photon filtering and frequency division signal processing of microwaves. The optimal solution is determined by analyzing the experimental results of various technical means, thus proving that the injection-locked microwave photonic frequency division signal processing means has better stability and a higher fitting degree.

1. Introduction

Traditional microwave technology has solved many scientific and technological problems due to its unique microwave conduction mode. However, with the innovation of technology, the problem of technological bottlenecks has become increasingly prominent. In the field of optics, technologies such as semiconductor lasers and photodetectors are led. Scientific and technological means have shown a thriving development trend, which provides excellent means and ideas for solving the bottleneck problem of microwave technology. In view of this, microwave photonics, which combines microwave and optics, came into being. The application principle of microwave photonics is mainly reflected in the use of optical principles to replace the original processing methods in the electrical field, reducing energy loss, improving broadband speed, and reducing

electromagnetic interference from many aspects. Because of its stable and efficient characteristics, it is not only used in military communication and civil communication but also has a wide range of applications in home communication, such as civil network switching, microwave communication, and optical fiber conduction.

Optical injection technology mainly improves the applicability of processing information and feedback information by optimizing the application performance of distributed feedback semiconductor lasers [1]. Through the optical injection locking mode, the semiconductor laser can expand the broadband amplitude, strengthen the resonance peak, reduce signal interference, and reduce noise and other functions [2]. The booming development of the Internet of Things has led to the continuous application of low-power RF transceiver components to wireless networks, which has also made it a new research hotspot. Low-power RF

transceiver components can reduce power consumption to a watt level, which is achieved by optimizing the circuit structure and directly supplying power to wireless network nodes after energy collection, thus eliminating the trouble of replacing the power supply [3]. This low-cost and high-efficiency IoT network can be used in many aspects of social life, for example, urban construction detection, biological tracking and control, experimental process monitoring, social security, and citizen health management [4]. On the other hand, in the microwave field, power, frequency, and phase are three important parameters to measure the strength of microwave signals. Among them, the signal amplitude of microwave power is extremely important. In a series of transmission and transformation processes of microwave signals, the measurement of microwave power is electromagnetic measurement [5]. Taking communication as an example, microwave power measurement not only undertakes monitoring, circuit maintenance, and efficiency control but also realizes the supervision of various microwave power detectors [6, 7]. The principle of microwave technology is to convert light wave signals into low-frequency electrical energy or thermal energy. Therefore, this paper is guided by the application of microwave photonics, explores the characteristics of optical injection-locked semiconductor lasers, and proposes a new microwave photonic filter and frequency division signal processing scheme [8].

2. Related Work

At present, the common microwave power detectors in life mainly include the following types, such as diode type, thermal resistance type, and capacitive type. The literature considers that the first two are active devices [9]. The diode microwave power detector uses the rectification principle of diodes to convert microwave signals into low-frequency signals for acquisition and processing. The advantages of this method are fast response and wide capture range [10]. It converts the signal into heat energy and indirectly obtains the microwave power data according to the influence of temperature on the resistance value; while the rest are passive devices [11]. The capacitive microwave power detector completes the microwave power measurement through the conversion of electricity and force. The advantages of this method are mainly reflected in the accurate numerical value, high linearity, and high measurement mean square [12]. The literature suggests that with the advancement of MEMS technology, thermoelectric microwave power detectors based on this technology have attracted more and more attention. This is mainly because of its lighter volume and mass, and higher processing costs compared with traditional detectors [13]. It has low output and larger output, so it has a broader prospect in the application of portable equipment. The literature points out that microwave photonics can be studied through the following aspects: such as optical generation of microwave/millimeter-wave signals, optical domain processing of microwave/millimeter-wave signals, and optical carrier microwave/millimeter-wave signal transmission

technology [14]. The literature studies various aspects including microwave technology and optical communication technology according to its arguments and also proposes some targeted solutions. The experiment believes that the total microwave photonic technology in practice is far more complex and changeable than expected. According to the literature, a microwave photonics system should not only be used as a functional module, such as a microwave photonic filter and signal source in optical fiber communication but also be responsible for amplifying microwave signals [15]. The literature points out that the current research focus on microwave photonic technology is still focused on improving the quality of microwave signals and microwave processing. The literature also admits that the microwave photonics field generally uses the abovementioned methods to achieve microwave signal regeneration [16]. However, with the exploration of the field of microwave photonics, people's attempts at some interdisciplinary subjects are also common, such as optically controlled phased arrays and optical-borne wireless communication technology. The literature summarizes the scope of application of these technologies, of which applications in radar, wireless communication, measurement, etc., are the most common. The literature points out that the waveform signals involved in these systems and the study of high-quality frequency arbitrary waveform regeneration technology are particularly important.

Several kinds of measurement systems using microwave photonic technology have been reported in the literature [17]. One of the principles is that the feedback signal is frequency-converted and then processed and measured. Based on this idea, the literature measures the DFS by obtaining the frequency difference between the unknown and the feedback signal through photon mixing. Although this method is a breakthrough, some kinds of literature believe that the measurement of DFS requires not only the photon frequency offset but also the photon frequency offset [18]. Considering its direction, therefore, it is possible to change the thinking to combine the optical frequency shift with the frequency mixing, and use the reference signal and the echo signal frequency to compare the frequency of the Doppler frequency shift to determine the direction of the Doppler frequency shift. This method has higher accuracy [19]. The literature uses two series-connected EOMs to perform DFS measurements, which mainly measure the DFS of plus or minus 90 kHz at 10, 15, and 30 GHz, using a laser light source, a photodetector (PD), and an electrical modulator (EOM) to measure the DFS. The low-frequency electrical signal is processed to obtain the Doppler frequency shift [20].

3. IoT Technologies and Applications

3.1. IoT Structure. The vigorous development of the Internet of Things reflects the power of science and technology, and it is not limited to the assistance of science and technology and has its own unique advantages. The definition of the Internet of Things varies according to different application conditions. The more general point of view is the network that

connects objects. The conventional Internet of Things not only has a primary perception layer but also has a core network layer and a final application layer structure. Among them, the basic perception layer is at the forefront, covering a variety of sensors, representative spectral sensors, spectral sensors, humidity sensors, etc.; the network layer, as the link between the upper and lower layers of the Internet of Things, is mainly responsible for the transmission and processing of information data; and the application layer. It is an intelligent application formulated according to the actual needs of life. The structure division of the Internet of Things is shown in Figure 1.

3.2. Technology Application. In order to solve the problems of harmonic distortion and heat loss in microwave photons, a low-power sensor scheme using self-powered RF transceiver components for the Internet of Things is proposed. As shown in Figure 2(a), one of the main structural elements of this scheme is thermoelectric. The microwave signal detector is matched with a thermoelectric-optical integrated microenergy harvester. The former uses a microwave coupler for frequency detection; the latter is composed of photovoltaic cells and hybrid thermoelectric generators, which are also the main components to reduce energy consumption.

The demonstration of a self-powered low-power thermoelectric-optical integrated micro-sensor is shown in Figures 2(b) and 2(c). Based on the positive correlation between the temperature of the transceiver or load and the transmit power, the MEMS micro thermocouple can be used as a sensor. The microwave detector of the temperature element further monitors the degree of harmonic distortion by analyzing the correlation, so it can realize power overload protection, avoid damage to the component machine, and detect aging components in time. In addition, the MEMS miniature thermocouple is used as a thermoelectric generator, which can realize secondary energy recovery, and store electric energy through DC-DC conversion to avoid energy loss. It can supply power to the microwave system to achieve self-powering of the microwave system. The current single thermoelectric power supply capacity is obviously insufficient, so the use of photovoltaic energy collectors and thermal energy collectors to supply power together will be a good solution. The advantage of this approach is that both are solid-state converters, with components that have a longer life, lower maintenance costs, and less ambient noise.

4. Optical Injection Locked Microwave Photonic Signal Generation

4.1. Principle of Optical Injection Locking. At present, in the research on the combination of optical injection locking technology and microwave technology, the most common one is for the generation of microwave signals, that is, frequency doubling of microwave signals. Using optical injection locking technology, the lasing field of the master and slave lasers can be easily made through phase synchronization and correlation. The content of this paper

includes the use of optical injection locking technology to complete the photonic microwave signal frequency doubling. Similar to the output light field of a semiconductor laser, if the energy loss during the injection process is ignored, the output light field after injection locking can be expressed as follows:

$$\frac{dE(t)}{dt} = \frac{1}{2}g[N(t) - N_{th}](1 + j\delta)E(t) + \kappa E_{inj}(t) - j\Delta\omega_{inj}E(t). \quad (1)$$

The last two terms on the right side of the equation are the injection terms, that is, the output light field and the injected light field of the slave laser, which are respectively defined as follows:

$$\begin{aligned} E(t) &= \sqrt{S(t)} \exp[j\psi(t)], \\ E_{inj}(t) &= \sqrt{S_{inj}(t)} \exp[j\psi_{inj}(t)]. \end{aligned} \quad (2)$$

The abovementioned Equation (1) can also be split into the form of the semiconductor laser rate equation:

$$\begin{aligned} \frac{dS(t)}{dt} &= g[N(t) - N_{th}]S(t) \\ &\quad + 2\kappa\sqrt{S(t)S_{inj}(t)} \cos[\psi(t) - \psi_{inj}(t)], \\ \frac{d\psi(t)}{dt} &= \frac{\delta}{2}g[N(t) - N_{th}] \\ &\quad - \kappa\sqrt{\frac{S_{inj}(t)}{S(t)}} \sin[\psi(t) - \psi_{inj}(t)] - \Delta\omega_{inj}, \\ \frac{dN(t)}{dt} &= J(t) - \gamma_N N(t) \\ &\quad - \{\gamma_p + g[N(t) - N_{th}]\}S(t). \end{aligned} \quad (3)$$

When the modulated signal light is injected into the slave laser and locked, the number of photons, optical field phase, and carrier number of the slave laser will reach a relatively stable state, namely:

$$\begin{aligned} \frac{dS(t)}{dt} &= 0, \\ \frac{d\psi(t)}{dt} &= 0, \\ \frac{dN(t)}{dt} &= 0. \end{aligned} \quad (4)$$

It can be concluded that:

$$\Delta\omega_{inj} = -\kappa\sqrt{1 + \delta^2}\sqrt{\frac{S_{inj}(t)}{S(t)}} \sin[\psi(t) - \psi_{inj}(t) + \tan^{-1}\delta]. \quad (5)$$

In the locked state, the detuning frequency is a fixed value. According to the formula, it can be known that the slow-varying envelope of the laser output light field and the

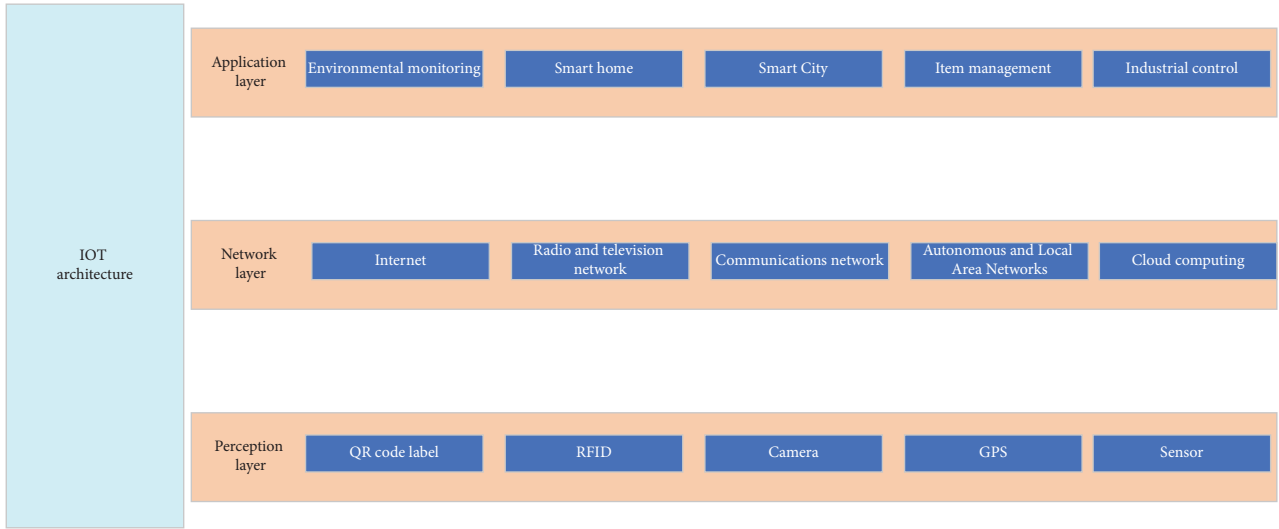


FIGURE 1: The structure of the internet of things.

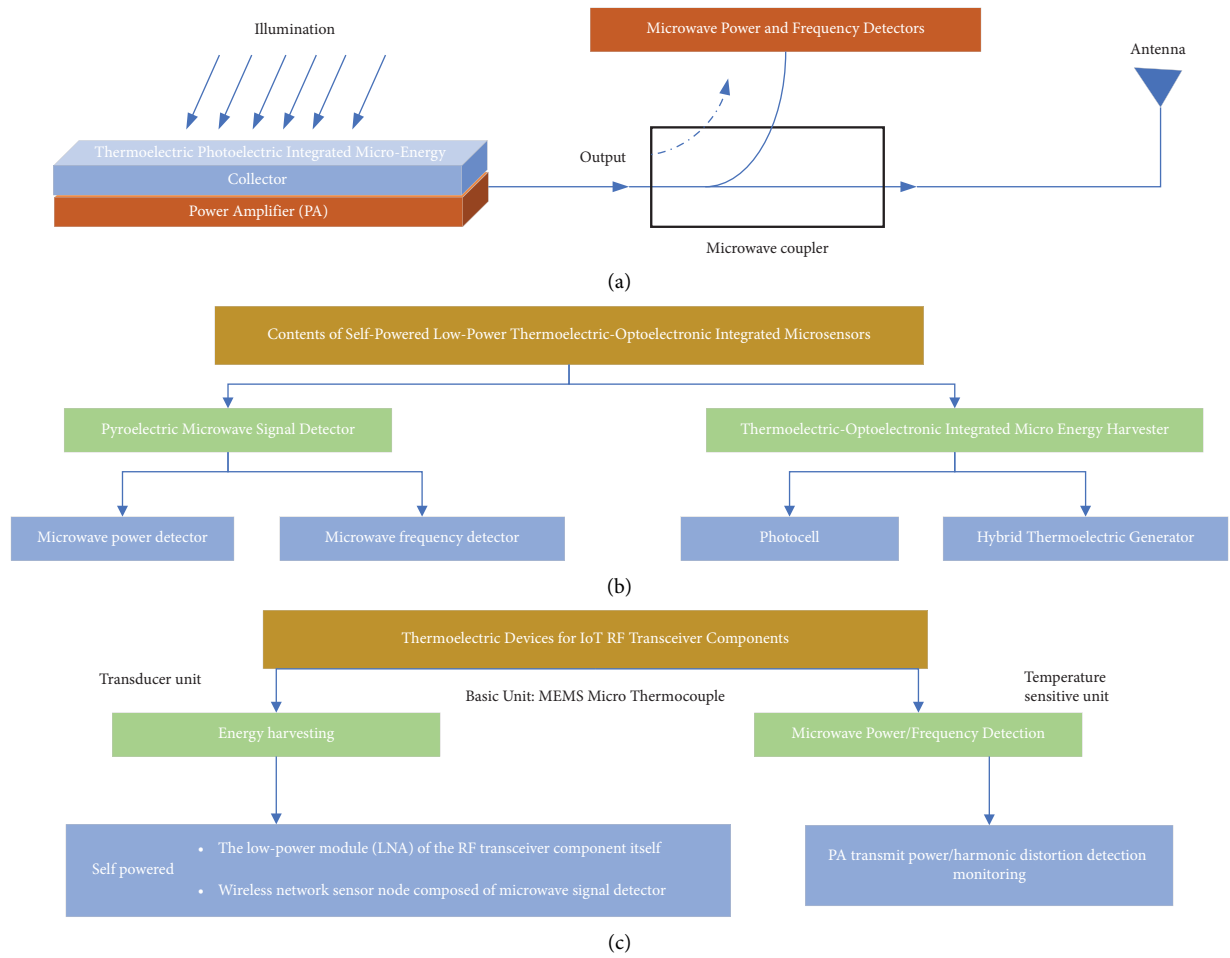


FIGURE 2: (a). Microwave power detector, microwave frequency detector, and thermoelectric-optical integrated microenergy harvester for IoT RF transceiver components; (b). Contents of self-powered low-power thermoelectric-optical integrated microsensor; (c). The role of thermoelectric devices in the scheme.

carrier phase are related to the injected light field. If the injected light is a phase modulation signal, the output light field phase is locked. And the envelope phase of the output signal is locked when an intensity-modulated signal is injected. The research in this paper mainly utilizes the injection locking technique to lock-in amplification of weak power high-order modulation sidebands. Injecting an external continuous light source can more effectively generate an amplified frequency-doubled optical microwave signal. This is because the low-frequency modulated signal light has a certain amplification effect when injected into the slave laser, and further amplification of the high-order sideband can be obtained. High-frequency optical microwave signal with a frequency of about 20 times.

4.2. Microwave Photons. The practicality of microwave photonics is higher, and how to generate high-purity, low-phase noise microwave signals and how to process and transmit the microwave signals is a hot topic at present. Microwave signals with high purity and low phase noise can be generated through optical principles and methods.

The advantage of processing optical signals by optical methods is that it can break through the thinking mode of traditional circuit design and improve the degree of signal control and sampling range. Optical fiber radio mainly uses optical fiber for long-distance transmission of signals, so it has the advantages of low cost, low loss, and resistance to external signal interference. In addition, microwave signals generated by optical methods have the characteristics of high frequency and low phase noise, so they are widely used in radar, wireless communication, and modern network instruments. Aiming at the source of wave signals in microwave communication, the old method is to use frequency doubling to generate microwave/millimeter wave signals, but the cost is high, and the loss of wave signals in coaxial cables is greater due to the long transmission distance. The applicability of this method is not high. But it still has certain advantages. For example, optical fiber can better replace cables for signal transmission, and electrical signals can be better converted into optical signals for long-distance transmission.

According to the current research results, the generation of millimeter waves mainly depends on the generation of high-frequency low-noise microwave signals, which are specifically explained as follows:

4.2.1. Generate Microwave Signal Based on Optical Heterodyne Method. This method mainly uses a photodetector (PD) to capture the optical frequency difference of different illumination wavelengths. Suppose there are two light waves:

$$\begin{aligned} E_1(t) &= E_{01} \cos(\omega_1 t + \phi_1), \\ E_2(t) &= E_{02} \cos(\omega_2 t + \phi_2). \end{aligned} \quad (6)$$

Considering the bandwidth limitation of the PD, the output current of the PD is given as follows:

$$I_{RF} = A \cos[(\omega_1 - \omega_2) + (\phi_1 - \phi_2)]. \quad (7)$$

It can be found from this that the electrical signal generated by the PD is equal to the frequency difference between the two input optical signals. If the bandwidth of the photodetector is unlimited, this method can generate an electrical signal of the order of THz, but due to the fact that the light wave of the free oscillator has no phase correlation, the phase noise of the microwave signal will increase accordingly. In response to this problem, some kinds of literature have proposed many solutions, which can be summarized into the following categories: (1) optical injection locking method, (2) optical phase-locked loop method, (3) external modulation method, and (4) dual wavelength laser method.

4.2.2. Generate Microwave Signal Based on Photoelectric Oscillator. In order to enhance the detection capability of the airborne radar, the phase noise of the microwave signal obtained by the radar is required to be lower than a certain threshold. Therefore, a large number of experiments and types of research on how to enhance the performance of OEO have been put on the agenda, such as: how to reduce the phase noise, while enhancing the stability of the microwave signal and increasing the microwave output frequency. At present, the latest research shows that the lowest phase noise is the OEO structure using 16 km single-mode fiber, and the phase noise can reach as low as -163dBc/Hz@10 kHz, but its tunable frequency range is only 4 GHz, which greatly limits its use in social life. application. In order to solve this problem, some kinds of literature propose a construction method based on MPF, which makes the highest tunable threshold reach 38.38 GHz. In view of the fact that the energy storage element of OEO is an optical fiber delay line, the influence of environmental factors such as temperature and humidity on the performance of optical fiber is more prominent, resulting in poor stability of OEO.

4.3. Signal Generation. How to realize the RF arbitrary waveform signal with ultrahigh repetition frequency is a major photonic microwave problem that scientific researchers have always wanted to solve. In terms of current research technology, converting a low-frequency local oscillator signal (electrically modulated signal) into a high-rate waveform signal is the main research idea to solve this problem. As one of the simplest and most efficient methods, optical injection locking technology is also widely used. This paper first introduces the scheme of using injection locking technology to generate the triangular wave. Secondly, according to this scheme, the generation of frequency-doubling triangular waves is realized. The principle of the scheme based on the DFB-LD injection locking process and time domain synthesis is as follows: the tunable laser emits continuous light and is modulated by the MZM to obtain a sinusoidal signal. And then the sinusoidal signal is divided into two channels, one of which is injected into the DFB-LD for locking modulation. The high-order sideband of the signal, and then the envelope signal of the modulation

frequency amplified by three times can be obtained. Finally, the required triangular wave can be synthesized by the phase and power superposition of the two signals.

Here, the power of the two signals is controlled by the polarization controller and the beam combiner to form a triangular wave with a corresponding proportional relationship. Figure 3 simulates the process of synthesizing the triangular wave. The triangular wave signal of the red solid line is formed by the superposition of the other two sinusoidal envelope signals.

Although the method provided in this paper generates triangular waves, the modulation frequency of triangular waves still has some problems. When a higher repetition frequency is required, the actual cost value increases. By comprehensively considering the modulation characteristics of MZM, when MZM is at matb and MITB points, the frequency doubling signal can be directly output. Therefore, this modulation characteristic of MZM can be combined with the injection locking process to generate triangular waves. This process can be roughly as follows: the continuous light emitted by ECL is captured and modulated by MZM, amplified by fiber amplifier (EDFA), and then divided into two channels by the coupler. The low-power channel signal is injected into DFB-LD to generate a signal of six times the frequency. Finally, the frequency-doubled triangular wave is output through PD detection. By the above-mentioned operation, the problem that the actual cost increasing due to the higher repetition frequency can be solved.

According to the Fourier analysis method in analysis, the Fourier expansion of a periodic triangular wave can be expressed as follows:

$$T_{tr}(t) = DC + \sum_{N=1,3,5,\dots}^{\infty} \frac{1}{N^2} \cos(N\omega_m t). \quad (8)$$

It can be seen from the abovementioned formula that a periodic triangular wave is composed of an infinite number of cosine signals in phase and with a frequency interval of 2. Moreover, the order of the harmonic is negatively correlated with the amplitude coefficient, and the influence of the harmonic component after the third order on the waveform envelope can be ignored. Therefore, a triangular wave signal can be expressed as follows:

$$T_{tr}(t) = DC + \cos(\omega_m t) + \frac{1}{9} \cos(3\omega_m t). \quad (9)$$

Converted into relative power ratio:

$$L_p = 10 \lg \frac{P_1}{P_3} = 10 \lg \frac{1}{(1/9)^2} 10 \lg 81 \approx 19.08 \text{ dB}. \quad (10)$$

It can be seen from the formula that the first and third harmonic power ratio of the synthesized triangular wave envelope signal should reach about 19.08 dB. In this scheme, the carrier suppression modulation method is used to obtain the second harmonic optical microwave signal as the initial fundamental frequency signal, and the optical field output after the carrier suppression modulation can be expressed as follows:

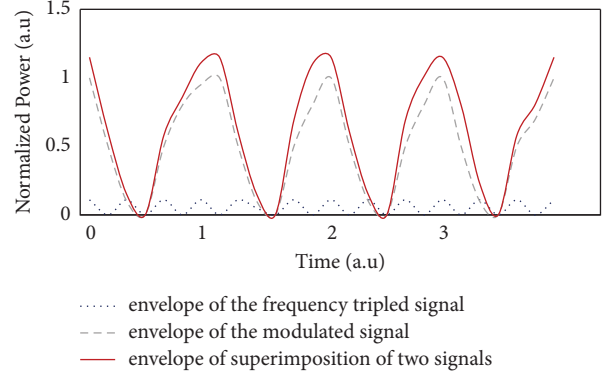


FIGURE 3: Simulation results of triangular wave synthesized by modulation signal and injection locking signal.

$$\% E_{out}(t) \approx E_{in}(t) J_1(\beta) \{ \cos[(\omega_0 - \omega_m)t] + \cos[(\omega_0 + \omega_m)t] \}. \quad (11)$$

In the study, the continuous light emitted by ECL is modulated by carrier suppression using a 3 GHz sinusoidal drive signal to obtain a more accurate double frequency envelope signal. When the modulated signal is injected into the DFB-LD after splitting, the 5th order sideband of the modulated light falls into the stable locking region of the slave laser by adjusting the wavelengths in front of the master and slave lasers and is locked and amplified. Figure 4 shows the signal locking spectrum. It can be found that the 6th harmonic signal is the strongest and the suppression ratio of high and low harmonics exceeds 9 dB. At this time, multiple harmonic components are included, resulting in the waveform is not completely standard. In addition, by comparing the graph in Figure 4, it can be found that after injection locking, a partial red shift occurs from the wavelength of the laser.

Finally, adjust the ODL to match the phases of the two signals, and then use PC3, PC4, and PBC to control the optical power ratio of the two signals, and then the frequency-doubling triangular wave can be detected.

5. Microwave Photon Filtering and Frequency Division Signal Processing

5.1. Light Injection Microwave Photonic Filters. The integration degree of MPF has a high correlation with the algorithm completion degree. Therefore, according to its characteristics, this paper attempts to use the optical injection locking technology as a breakthrough to combine the F-P cavity semiconductor laser into the MPF. This method changes the injection ratio and detuning frequency by changing the wavelength amplification during optical injection locking, thereby realizing a tunable single-passband MPF. This scheme has the advantages of simple structure, low noise and high frequency, and tunable wide-narrow rejection ratio. Its tunable threshold is 32 GHz, which greatly improves the tuning range and provides a new idea for the conversion of optical and microwave signals. By adjusting the bias current injected into the laser, the power

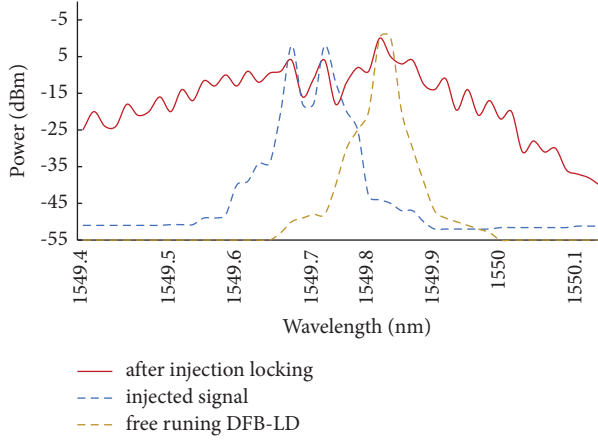


FIGURE 4: Spectrum.

distribution of the four longitudinal modes of the FP laser can be realized, thereby realizing the power redistribution of the longitudinal modes. When continuous light is injected into the FP, the longitudinal mode can be locked by changing the injection ratio and detuning frequency, resulting in the red-shift effect of the cavity mode. In the MPF scheme of the optical injection locking F-P cavity semiconductor laser proposed in this paper, the rate equation of the FP cavity laser can be expressed as follows:

$$\frac{dE_m}{dt} = \frac{1}{2} (1 + i\alpha) [G_m(N) - \gamma] E_m t,$$

$$\frac{dN(t)}{dt} = \gamma_e [C_0 N_{th} - N] - \sum_{m=-M-1/2}^{M-1/2} G_m(N) |E_m(t)|^2,$$

$$f_m = f_0 + m\Delta f_L = f_0 + \frac{m}{\tau_L},$$

$$G_m(N) = \frac{g_C(N - N_0)}{1 + s \sum_{m=-M-1/2}^{M-1/2} |E_m(t)|^2} \left[1 - \left(\frac{f_m - f_0}{\Delta f_g} \right)^2 \right]. \quad (12)$$

In this paper, the stability of MPF was tested. The frequency response amplitude of the MPF is measured every 5 minutes, the center frequency variation amplitude is 57 MHz, and the fluctuation range is less than 0.288 dB, so it has higher stability. And let R and I be fixed, the spectral response curve of the measured MPF is shown in Figure 5. Δf has a negative correlation with MPF. It also appears that the 3 dB bandwidth of the spectral response decreases as Δf decreases, and at high frequencies, another peak appears. Analysis of Figure 5 shows that with the decrease of Δf , the out-of-band rejection ratio of MPF increases.

Finally, the frequency response curve of the MPF as a function of I is shown in Figure 6, and changing I result in a change in the parameters of the FP laser. It can be seen from Figure 6 that as I increases, the center frequency of the MPF increases, and the insertion loss of the MPF increases. When

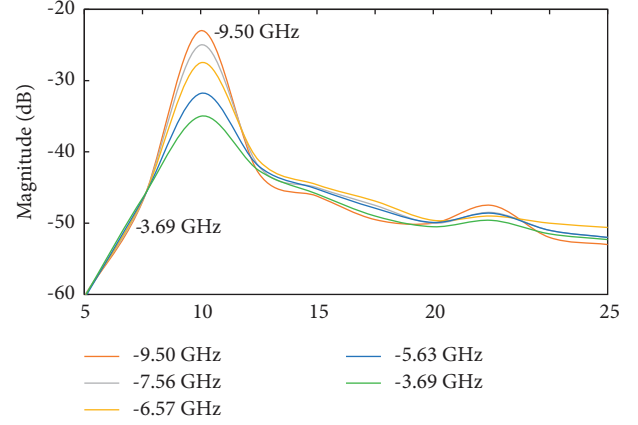


FIGURE 5: Frequency response curve of MPF under different detuning frequency conditions.

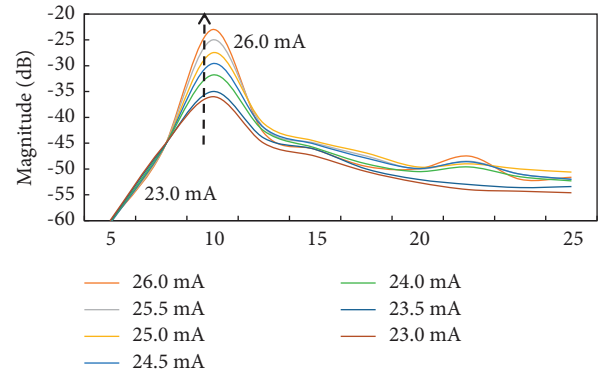


FIGURE 6: Frequency response curve of MPF under different bias current conditions.

the value of I increases, the bandwidth of the spectral response curve and the insertion loss of the MPF both decrease.

5.2. Principle of Microwave Photonic Photoelectric Oscillator.

Once the photoelectric oscillator was proposed, it became the research focus of scientific researchers. After the continuous research and development of scientific researchers, the function of the photoelectric oscillator has become more and more perfect. The basic working principle of the photoelectric oscillator is that after the laser is emitted from the pump laser, it is first modulated by the electro-optical modulator, and then the light is output, and then passes through a certain distance of optical fiber, and finally, enters the photodetector. After the photodetector captures the laser, it amplifies and filters the electrical signal of the laser, and finally, outputs the laser to the RF port of the modulator. The laser processing of the photoelectric oscillator is a positive feedback system. When the gain of the loop is greater than the threshold gain, the photoelectric oscillator can work, the photoelectric oscillator starts to vibrate, and then outputs a microwave input signal of a certain frequency.

The threshold gain of the optoelectronic oscillator can be understood as, in this loop, after the optical power of the laser is output from the electro-optical modulator, the value is related to the voltage $V(t)$:

$$P(t) = (\alpha P_0/2)\{1 - \eta \sin \pi[V_{in}(t)/V_\pi + V_R(t)/V_\pi]\}. \quad (13)$$

When the optical signal is processed by the photodetector, it becomes an electrical signal that is easier to capture, and then amplified by the amplifier to complete the expansion of the electrical signal. The signal is given as follows:

$$\begin{aligned} V_{out}(t) &= \rho P(t) R G_A, \\ &= V_{ph}\{1 - \eta \sin \pi[V_{in}(t)/V_\pi + V_B(t)/V_\pi]\}. \end{aligned} \quad (14)$$

This paper defines the photovoltage:

$$V_{ph} = (\alpha P_0 \rho/2) R G_A. \quad (15)$$

The open-loop small-signal gain of the optoelectronic oscillator is given as follows:

$$\begin{aligned} G_S &= \left. \frac{dV_{out}}{dV_{in}} \right|_{V_{in}=0}, \\ &= -\frac{\eta \pi V_{ph}}{V_\pi} \cos\left(\frac{\pi V_B}{V_\pi}\right). \end{aligned} \quad (16)$$

According to the abovementioned analysis and research, it can be concluded that when the modulator is biased at the quadrature point, we can obtain the maximum small signal gain. Through the analysis of the formula, it can be obtained that the small signal gain value can be positive or negative, and its value is determined by the bias voltage. We can set the forward bias value to be greater than 0, so if the bias voltage is equal to 0, the modulator is biased at the negative quadrature point, and if the bias voltage is equal to the half-wave voltage, then the modulation bias is in quadrature point. According to relevant research, it can be known that in most photonic links, if an external modulator is used, the bias of the electro-optic modulator, whether at the quadrature point or the negative quadrature point, will not affect the performance of the modulator. But in order to start the photoelectric oscillator, the small-signal open-loop gain of the system must be higher than the loss of the system.

Through the abovementioned formula, we can obtain that the threshold value of the optoelectronic oscillator is given as follows:

$$V_{ph} = \frac{V_\pi}{[\pi \eta |\cos(\pi V_B/V_\pi)|]}. \quad (17)$$

Ideally:

$$V_{ph} = \frac{V_\pi}{\pi}. \quad (18)$$

Through the abovementioned analysis, it can be seen that the amplifier cannot determine whether the photoelectric oscillator can start to oscillate. Under certain conditions, the photoelectric oscillator can also start to oscillate without the amplifier. This is because the light source can provide energy

for the photoelectric oscillator. This property of the photoelectric oscillator has high practical value. In actual production and life, the optical fiber can be used to provide energy for the photoelectric oscillator under the condition of long distances. At the same time, the use of the amplifier will also produce certain side effects, such as noise. If the amplifier is not used in the loop, the hidden danger of noise will be eliminated naturally. This operation can further improve the stability of the photoelectric oscillator. In this paper, the responsivity of the photodetector can be set to 0.8 A/W, the optical power value is 25 mW, the half-wave voltage of the modulator is 3.14 V, the impedance is 50 ohms, and the photocurrent is 20 mA, then the photoelectric oscillator system can operate normal vibration, no need to use an amplifier.

5.3. Simulation of Microwave Photonic Signal Measurement.

It can be seen from the laser principle that the measurement range of the frequency point needs to be controlled in order to ensure the effect, that is, the measurement range cannot be larger than the fundamental frequency of a cavity. It can be seen from Figure 7 that when the cavity length value increases, the measurement frequency range decreases, and the variation trend of the measurement range is quite different before and after the inflection point; when the cavity length value decreases, the measurement frequency range increases and the change will be flattened. It can also be seen from the Atlas that if the cavity length exceeds a certain length, the measurement sensitivity will be affected, and when the cavity length is short, the measurement range will be affected. Therefore, in actual use, it can be designed according to the needs. If the range of the measurement frequency is required to be relatively small and high sensitivity is required, then the long cavity length structure should be used.

It can be seen from the abovementioned discussion that if the structure of the measurement system remains unchanged, the fundamental frequency of the cavity will not change. It can be seen from Figure 8 that the larger the harmonic mode-locking order, the smaller the measurement sensitivity, and when the harmonic mode-locking order increases to a certain value, the changing trend will be significantly different.

5.4. Frequency Division Signal Processing. Experiments are carried out on the microwave photon signal, and the measurement effect of the system is judged by the frequency measurement error. The frequency measurement error value of the system for the unknown microwave photon signal can be obtained from Figure 9. It can be seen from the analysis of the values in the figure that the measurement range of this experiment is between 10 and 39 GHz, and the error value of the system is ± 1 MHz. The unknown microwave photon signals in 13 different frequency bands.

The data are used as the main basis to measure the measurement effect of the existing system and the experimental system, and the results reflect the fitness of the system model in this paper. The measurement system proposed in this paper combines two instantaneous frequency

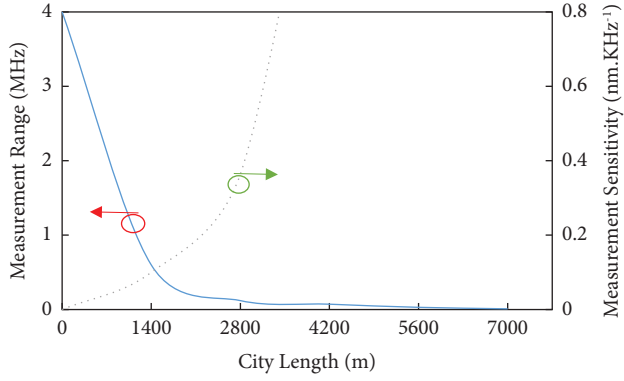


FIGURE 7: Variation of measurement frequency range and measurement sensitivity with laser cavity length L .

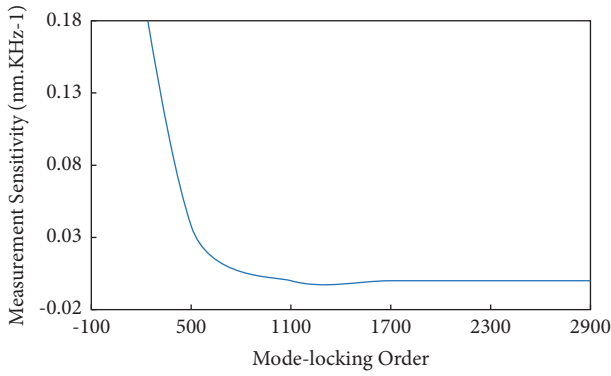


FIGURE 8: Relationship between measurement sensitivity and harmonic mode-locking order.

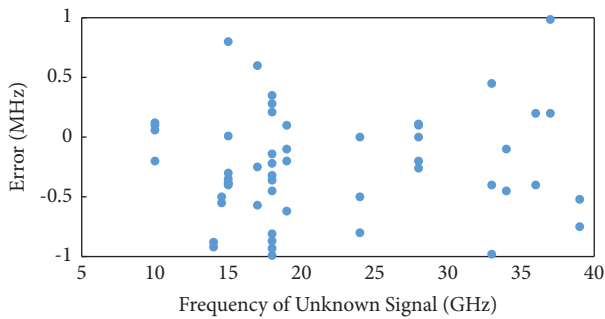


FIGURE 9: Frequency measurement error: measurement range is 9–38 GHz, error $< \pm 1$ MHz.

measurement techniques to process the optical signal. The system can reflect the performance of the two techniques. The advantage is that it adopts the wide measurement range characteristics of the swept frequency receiving system and the characteristics of allowing simultaneous measurement of multiple frequencies, and also combines the high measurement accuracy characteristics of the ACF system. The advantages of the above two systems are reflected in the proposed method. The analysis method based on the experimental results can analyze the problem from an objective point of view, and measure the advantages and disadvantages

of the conventional system, it is necessary to combine the measurement range and measurement accuracy of the system to make scientific judgments. This paper uses the ratio of measurement range and measurement accuracy to measure the measurement effect of the system.

6. Conclusion

The combination of IoT and microwave photonic signals is still in its infancy, and similar studies are rarely reported. This paper expounds on the structure level of the Internet of Things through multi-channel search and extends to its corresponding functions at specific levels. At the same time, it analyzes and summarizes the functional characteristics, thereby spreading the related characteristics of the Internet of Things. Then, the application of transceiver components for microwave photonic signals in the field of the Internet of Things is explained, and the detection and energy collection of microwave photonic signals are demonstrated. In this paper, the microwave photonic signal generation of optical injection locking is introduced, the mathematical model of optical injection locking is proposed, and the characteristics of optical injection locking are analyzed. The manifestations of microwave photon signals are classified and introduced, and the generation of microwave photon signals is simulated. The data simulation and experiment are carried out for the light injection microwave photonic filter, and the principle of the microwave photonic oscillator is introduced. The measurement frequency range of microwave photonic signals needs to be determined according to the actual work needs. If the range is small and high sensitivity is required, a long cavity and a long structure should be used. When measuring high-frequency signals, a short cavity structure should be used to ensure measurement sensitivity. Finally, the experimental comparison of frequency division signal processing is carried out in this paper, and the measurement range and measurement accuracy are combined. It can be seen that the system proposed in this paper has a higher measurement effect.

Data Availability

The data used to support the findings of this study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors have no conflicts of interest.

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