광 주입 방법을 이용한 광학적인 밀리미터파 생성

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Optical Millimeter-wave Generation Using Optical Injection Locking Method

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요 약

최근 인터넷 사용의 급격한 확산으로 인해, 이제까지 전화망을 위주로 발전되어 왔던 통신망의 구조에 많은 변화가 일어나고 있다. 최근 우리나라에서도 지식 정보사회의 기반이 되는 초고속 정보 통신망으로의 접속으로 발전되고 있으며, 이용 환경을 무선 방식으로 제공할 수 있는 30 GHz 주변 대역에서 BWLL 용 주파수를 할당하고 있다. 또한 실내용 초고속 무선 LAN, 차량 충돌 방지 시스템 등을 비롯한 Intelligent Transportation System, 그리고 국방 기술 등 여러 분야에서 밀리미터파 대역 신호를 사용한 기술 개발이 요구되고 있다. 따라서, 본 논문에서는 이러한 밀리미터파를 생성하기 위한 여러가지 방법들을 설명하고, Sideband injection locking 방법을 제안하여 수치적인 컴퓨터 시뮬레이션을 통하여 그 가능성을 분석하였다.

Ⅰ. Introduction

Design of broadband access networks to deliver services such as video-on-demand, interactive multimedia, high-speed internet, and high-density television to homes and industrial and educational institutions has been a subject of intense interest in recent years. Both wireline, hybrid fiber-coax (HFC) and wireless [Local Multi-point Distribution System (LMDS)] access techniques show considerable potential in this regard. These access schemes mainly utilize the lower microwave frequency spectrum (<5 GHz) for distribution of broadband signals. Recently, however, the millimeter-wave frequency band (26~60 GHz) has been considered for wireless access, primarily to avoid spectral congestion at lower microwave frequencies and to offer large transmission bandwidth. Future millimeter-wave broadband access systems may employ an architecture in which signals generated at a central location will be transported to remote base stations for wireless distribution [1, 2]. Optical feeding of base stations in these systems is an attractive approach because it enables a large number of base stations to share the transmitting and processing equipments remotely located from the customer serving area.

Ⅱ. Techniques for Optical Millimeter-wave Generation

In the direct detection links, the millimeter-wave signal is intensity modulated onto the optical carrier from a laser. The optical signal is then transmitted through the optical fiber, and the millimeter-wave signal is recovered by direct detection in a photodiode. In the heterodyne links, two phase-correlated optical carriers are generated in a dual-frequency laser transmitter with a frequency offset equal to the desired millimeter-wave frequency. Both optical signals are then transmitted through the optical fiber, and the millimeter-wave signal is generated by heterodyning method of the two optical signals in a photodiode. The principles of heterodyning detection links are quite different from those of IM-DD links. The major difference is that the IM-DD link transmits the millimeter-wave signal as sidebands on a single laser signal whereas the heterodyning detection link generates the millimeter-wave signal by beating of two laser signals. In this process, the phase noise of the two laser signals transfers directly to the resulting microwave signal. Therefore, it is necessary either to remove the actual laser-signal phase noise or to correlate the phase noise of the two laser signals. Both methods or a combination ideally ensures the generation of a highly phase-stable millimeter-wave [2].

A simplified schematic of the heterodyning principle is shown in Fig. 1. At the transmitter end, two phase-correlated laser signals with a frequency offset of $f_c = f_1 - f_2$ are generated by a dual-frequency laser transmitter. Both laser signals are transmitted through the fiber link to the receiver end where heterodyning takes place in an O/E converter (photodiode). Assuming that the phase correlation between the two laser signals is not altered by the fiber link, the resulting beat signal is a highly phase stable millimeter-wave carrier with a frequency of f_c. However, the phase correlation is altered to some extend by the fiber link which, besides transmission attenuation, may limit the system performance due to dispersion effects and fiber nonlinearities. Both chromatic dispersion and polarization-mode dispersion limit have the obtainable transmission-distance two times the millimeter-wave carrier frequency product of the link [3].

electrical field is represented as follows. Assuming optical source is

$$E_1 = \sqrt{P_1}\cos[\omega_1 t + \Phi_1(t)] \tag{1}$$

$$E_2 = \sqrt{P_2}\cos[\omega_2 t + \Phi_2(t)] \tag{2}$$

Two optical sources are transmitted through fiber into photodiode and generated current component. Current is square of field and is shown in the following equation.

$$I_{PD}(t) \propto P_1 + P_2 + 2\sqrt{P_1 P_2}\cos\left[|\omega_2 - \omega_1| t - |\Phi_2(t) - \Phi_1(t)|\right] \tag{3}$$

$P_1 + P_2$ is a DC element in photodiode current, the other component is desired millimeter-wave signal. We can easily obtain millimeter-wave signal in photodiode by controlling properly to meet desired millimeter-wave frequency difference of the two optical sources. However, the phase components of the two optical sources are random and the signal linewidth generated by beating two optical sources is described as sum of two optical source linewidth which has a several MHz. When a signal with a broad width is transmitted, the overall system performance is limited because its spectral efficiency is small. To overcome this limitation, several methods are reported and proposed as follows. These techniques normally focus on generating millimeter-wave source with low phase noise and several techniques. Techniques are shown as follows.

a. Single Sideband Modulation
b. 2-sideband Modulation
c. Mode locking
d. Optical Phase Lock Loop
e. Sideband Injection Locking

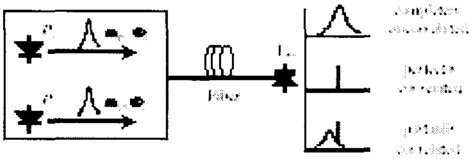

Fig. 1. Millimeter-wave signal gereration by optical beating scheme

III. Proposed Techniques

If master laser is modulated with the sub-harmonic of the desired millimeter-wave band frequency, we can see lots of sidebands generated with difference of modulation frequency in optical spectrum of master laser in Fig. 2. Two sidebands with desired millimeter-wave frequency differences are injected into slave lasers and lock them. These two slave lasers beat each other in photodiode and generate the desired millimeter-wave signal with low phase noise since they are synchronized by the same Master laser. Therefore, this technique is not affected by chromatic dispersion in fiber.

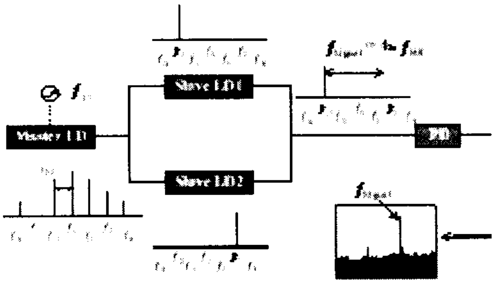

Fig. 2. Millimeter-wave generation using sideband injection locking method

IV. Simulation Results

In the numerical simulation, we have assumed three identical semiconductor lasers for one ML and two SLs in Fig. 2. It is assumed that the ML is modulated at 8 GHz so that the optical spectrum exhibits the 2 sideband power larger than the other sideband power in the optical spectrum, where the average ML power is of 3 mW. We have designated the 2 sidebands as target sidebands of two SLs, whose beat signal frequency is 32 GHz in the RF-spectrum. The ML output power passing through an optical attenuator is injected into two SLs as illustrated in Fig.2. The adjustment of the ML bias level or the modulation power will change the IM / FM indexes deviating the whole optical spectrum, consequently. By controlling optical attenuator, the ML injection power can be adjusted with no deviation of the optical spectrum. We have investigated the effect of the unselected sidebands on the spectral characteristics for the different ML powers. In the numerical simulation, we have not considered the path length differences in the path to two SLs from ML and the path to PD from two SLs. The SL transient responses are solved by the fourth order Runge-Kutta integration of the field rate-equations. Two SLs are both assumed biased at 1.96*Ith*, at which they emit the optical power of 5 mW in the free-running state. *Ith* is 33.5 mA, here. Then, one of the two SLs is frequency detuned to become locked to the +2 or, -2 target sideband for the different ML powers. The optical spectra of the locked SL can be obtained from the fast-Fourier transformation (FFT) of the SL output power at the steady-state solution of the transient response.

Figure 3 shows the optical and RF-spectra of two SLs, which have the frequency separation of 32 GHz in the free-running state. Each SL has the positive (negative) frequency detuning by 16 GHz from the ML center frequency and its frequency in the free-running state agrees with the frequency of the +2 (or -2) target sideband. The optical power ratio between the ML average power and each free-running SL is of 17.2 dB, here. The desired beat signal at 32 GHz is little distinguishable. The additional frequency-detuning offsets from the target sideband frequency are required for the stable locking due to the *R*-dependent asymmetry of the stable locking regime.

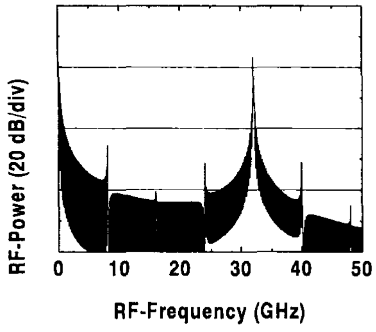

Fig. 3. Spectral dependence for the different power ratios

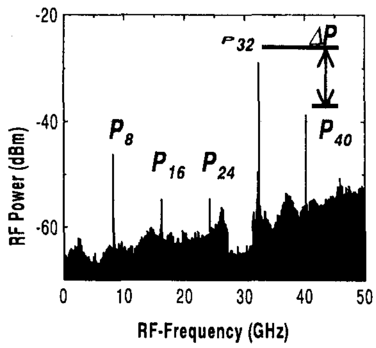

Fig. 4. Measured RF-spectra in the 32 GHz beat signal generation

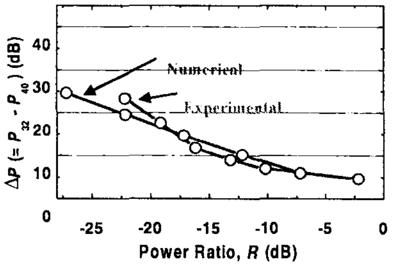

Fig. 5. Comparison of measured and calculated P between P_{32} and P_{40}

Ⅳ. Results

In conclusion, we have investigated the spectral characteristics of the semiconductor lasers locked to the sidebands of the master laser, which were expressed by a series of the Bessel function. The numerical model for the semiconductor lasers based on the typical Langs equation has been extended in order to take into account the simultaneous injection of the multiple sidebands of the directly modulated ML. The numerical simulations have showed that the unselected sidebands can affect the optical and RF-spectral characteristics even when the semiconductor laser is stable-locked to the target sidebands. Due to the presence of the unselected sidebands, the unwanted powers in the optical and RF-spectra will increase with the ML power, and be combined with the fiber chromatic dispersion so that they may degrade the overall system performance. We have found that the simulation results are in good agreement with the experimental results.

References

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