Optical Millimeter-wave Signal Generation using Injection Locking Scheme

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광주입 방법을 이용한 밀리미터파 신호 생성

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요 약

본 논문에서는 반도체레이저를 이용한 밀리미터파 대역의 신호를 생성하는 방법에 대해 제안하였다. 광대역에서의 밀리미터파 신호를 얻기 위해서는 원하는 공진 주파수대역의 신호를 얻기 위해는 서브 하모닉의 좁은 신호 성분의 하모닉 신호인 다중의 신호를 서로 beating하여 원하는 주파수 대역의 신호를 얻을 수 있다. 따라서 본 논문에서는 반도체레이저를 사용한 광주입 방법을 통하여 실제적으로 원하는 주파수 대역의 신호를 얻기 위해 실험적으로 고찰하였으며, 신호 성분의 성능을 구하기 위해 phase noise 성분을 측정하였다.

ABSTRACT

A new technique for generating millimeter-wave signals from a semiconductor laser is presented. The method multiples the signal frequency by using optical injection of short optical pulses at a sub-harmonic of the cavity round-trip frequency to drive the laser oscillating at its resonant frequency. A 32GHz signal is generated using a multisection semiconductor laser operated under continuous wave conditions, by injection optical pulses at a repetition rate equal to the fourth subhamonic(8GHz). The generated millimeter-wave signal exhibits a large submamonic suppression ratio(>17 dB), large frequency detuning range (>300 MHz), low levels of phase-noise(-77.5 dBc/Hz), and large locking (>400 MHz)

키워드
Frequency detuning, Optical injection locking

Ⅰ. Introduction

The Generation of high-frequency signals using semiconductor lasers has attracted increasing attention in recent years due to its important role in high-speed optical communications and microwave photonics systems. High-frequency signals can be generated by a variety of techniques including Q-switching, gain-switching, active mode-locking, passive mode locking, and hybrid mode-locking of the semiconductor lasers. Among these methods, the passive mode-locking technique is practically attractive because it can generate millimeter-wave signals at frequencies over 100 GHz without the limitations imposed by the

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available drive electronics. Its inherent drawbacks of large phase-noise and difficulty in synchronization with external circuits can be overcome by implementing stabilization schemes such as subhamonic optical or electrical injection techniques.[1] It is well known that passive mode-locking of a semiconductor laser relies on the presence of an intracavity saturable absorber to facilitate mode-locking. Recently we have shown that for the generation of high-frequency signals, it is not essential to have the saturable absorber and we demonstrated the generation of 1.5 GHz pulses from an external cavity by injecting optical pulses at a repetition of 250 MHz.[2] This new method used optical injection of short optical pulse sat a subharmonic of the cavity round-trip frequency to drive the laser to generated a signal at its resonant frequency. In the paper, we extend the technique to demonstrate the generation of a millimeter-wave signal at a frequency of 32 GHz from a multisection semiconductor laser via the injection of an 8 GHz optical pulse train. We also investigate the performance of the signal generation scheme and show that generated high-frequency signal(> 17 dB), large frequency detuning (>300 MHz), and the level of phase-noise is comparable to that of the injected signal

II. Experimental Results

The experimental setup of the proposed technique to generate high-frequency signals is shown in Fig.1. The slave laser is a long cavity multisection semiconductor laser which consists of the three gain sections, a phase control region, and a DBR section. In this experiment, all the gain sections were uniformly pumped. Without external light injection the multisection laser exhibits a continuous wave(CW) outputs, with only one mode in the detected optical spectrum a wavelength 1557 nm. The laser threshold current was 18 mA and the cavity resonant frequency is 32 GHz.

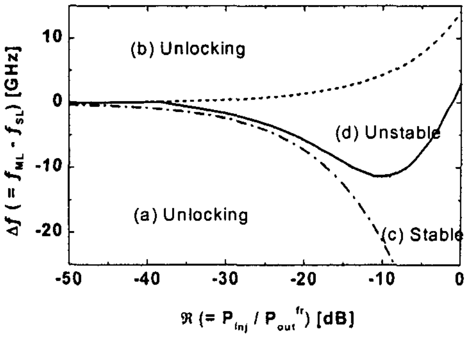


Figure 1. Characteristics of locking regimes.

They are characterized into three regimes unlocking, unstable locking, and stable locking. The shaded area inside the unstable locking regime denotes the place where the chaos occurs. The chaos area outside the locking reg imes is not taken into account, here. The master laser is a 1548 nm gain-switched distributed-feedback (DFB) laser diode. The injected signal repetition rate was adjusted to be the fourth subharmonic of the slave laser round-trip frequency. The output pulses from the master laser were compressed to 7 ps using a 1km long dispersion compensating fiber with dispersion parameter D= -26 ps/km/nm, and amplfied by an erium-doped fiber amplifier(EDFA).

An optical bandpass filter was used to reduced the spontaneous emission noise from the EDFA, while a polarization controller was used to adjust the polarization of the injection signal. The pulse from the master laser were launched into the slave laser

via an optical circulator. The output of the

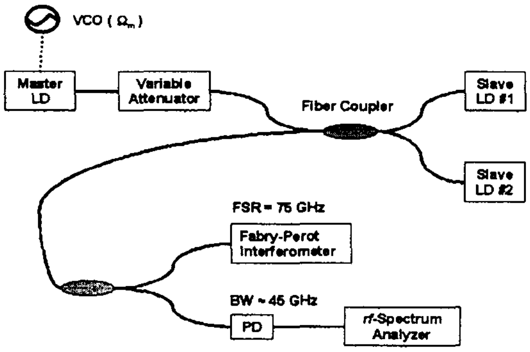
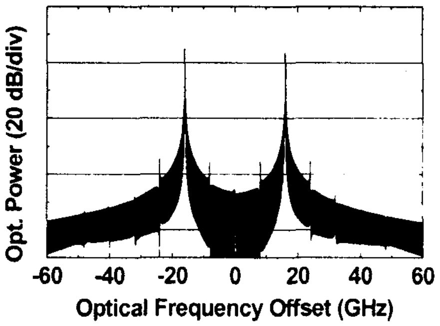


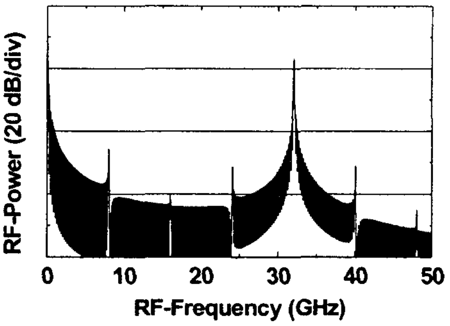
Figure 2 . Experimental Setup

slave laser was then measured using a streak camera, an optical spectrum analyzer and a radio frequency(RF) spectrum analyzer in conjunction with a high-speed photodetector(PD) with a bandwidth of 45 GHz. Another optical bandpass filter was employed after which may be present. After injection of the optical pulses from the master laser, output from the slave laser exhibits sinusoidal modulation. Fig.4 shows the measured optical spectrum of the slave laser after subhamonic optical injection. The laser was biased at Ib = 23mA and the optical injection power was Pinj = 2.3 dBm after taking losses into account. Before injection the slave is operating under CW conditions with a single mode oscillating. After injection however, multimode operation is observed with a mode spacing of approximately 30GHz, as can be seen from Fig.3.

This change in the optical spectrum is attributed to the modulation effect of the injected optical pulse train. When the pulse train is injected into the slave laser it causes gain modulation, which further induces optical modulation of the slave laser. Due to the cavity resonance of the slave laser, only fs = 4finj~ 32GHz and 4kfinj, (k = 2,3, ..) components are supported, where fs is the generated signal frequency. All other component and its harmonics are resonantly enhanced. Therefore a multimode output is observed in the measured optical spectrum from the slave laser with mode frequencies corresponding to f0, f0fs, f02fs, where fo is the central optical frequency. This observation is consistent with the theoretical prediction in reference that weak gain modulation can bring about a large optical modulation, when modulated exactly at the intercavity mode spacing frequency.[3]



(a) RF-Spectrum



(b) Optical Spectrum

Figure 3. Spectral dependence on the incident ML powers(R = -37.2 dB)

Simulation result is referred in reference.[3]

Figure 4 shows the measured RF spectrum of the detected output from the slave laser after subharmonic optical injection, with the same experimental parameters as in Fig.2. The RF spectrum shows a signal component at 32GHz which is much larger in power than its subhamonic component(at 8, 16, and 24GHz). For example, the measured RF power at the injected signal frequency of 8GHz is some 17 dB lower than that at the generated signal frequency of 32 GHz. This large subhamonic suppression or low level of amplitude modulation is attributed to the modulation response of the laser cavity.

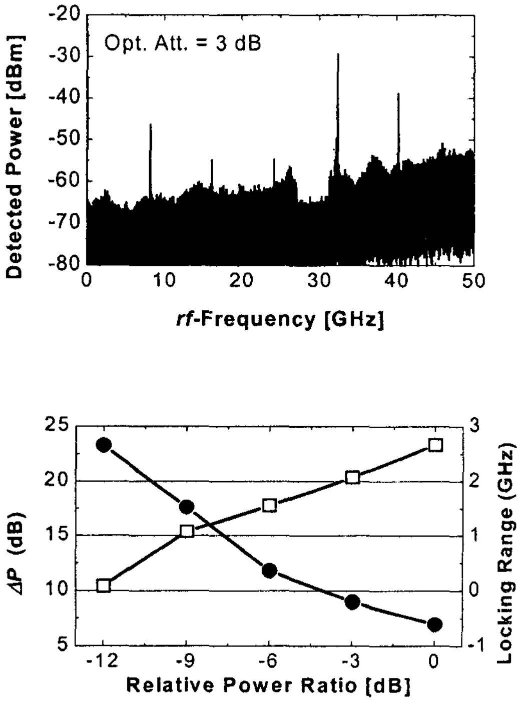


Figure 4. Measured RF spectrum of the detected slave laser output

The generated signal frequency components at 32GHz is enhanced because it is close to the modulation passband response peak corresponding to the cavity resonant frequency, while its subhamonics are greatly suppressed due to roll off in the modulation response at these frequencies.

Frequency detuning is an important parameter when evaluating the performance of high-frequency signal generation techniques. Frequency detuning defines the range of frequencies over which the generated signal from the range of frequencies over which the generated signal from the slave laser can vary due to changes in the repetition frequency of the master laser, without causing significant changes in the detected RF power or phase-noise of the generated signal. Large frequency detuning is desirable because high-frequency signals with a tunable frequency range are useful for a range of system applications. Here we define the frequency detuning as the range of frequencies generated from the slave laser where the RF power of the generated signal is within 3 dB of its value at zero detuning(corresponding to the resonant frequency of 32GHz) Fig.4 shows the measured RF power of the generated signal frequency as a function of frequency detuning, with Ib=23 mA and Pinj=2.3dBm. The results indicated that the RF power of the generated signal frequency exhibits a frequency detuning range larger than 300 MHz.

The large frequency detuning observed in this signal generation scheme can be attributed th the broad bandwidth of the modulation response of the laser cavity. The suppression of undesired submarmonic components is also an important measure in evaluating the quality of the generated millimeter-wave signal. We define the subhamonic suppression ratio, △P the ratio of the detected RF power of the generated signal at 32 GHz to the sum of the RF powers of all the subharmonic frequency components. The solid circles in Fig.4 show the measured △P as a function of frequency detuning. The △P exhibits a similar variation with frequency detuning as the measured RF power of the generated mm-wave signal, with a maximum subharmonic suppression greater than 17 dB. Over a 300 MHz frequency range, △P was larger than 14 dB, and any amplitude modulation imposed by the injected optical pulse train is less than 4%. The resulting phase-noise of the generated millimeter-wave signal is another important parameter in determining the suitability of this scheme to a rangeof optical communication and microwave photonic applications. Phase-noise measurements were carried out using a RF spectrum analyzer with phase-noise measurement utility software, which is based on the direct spectral density measurement method.

III. DISCUSSION OF RESULT

Figure 5 shows the measured phase-noise at a carrier offset frequency of 10 KHz of the generated signal at 32 GHz as a function of frequency detuning. The phase-noise of the signal was approximately 77.5 dBc/Hz at zero detuning. For comparison, the corresponding phase-noise of the 8GHz and 32GHz frequency components in the detected RF spectrum of the master laser were 90 dBc/Hz and 77.5 dBc/Hz, respectively. If we define the locking range as the frequency range over which the generated signal frequency can be tuned from the cavity resonant frequency of the slave laser with the signal phase-noise remaining within 1 dB of that at zero frequency detuning. The locking range is larger than 400MHz. This is significantly larger than that observed when operating the monolithic laser as a passively mode-locked device and stabilized via subharmonoc optical injecting.

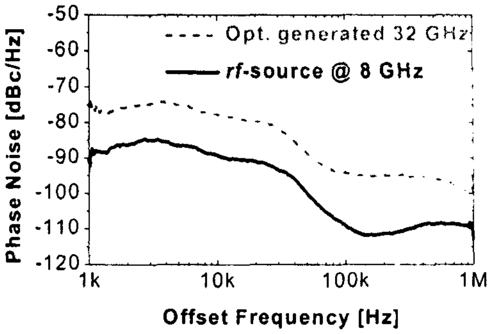


Figure 5. Measured phase noise of the optical millimeter-wave signal as offset

V. CONCLUSION

We have experimentally demonstrated the generation of optical millimeter-wave 32 GHz signal by injecting optical pulses from a master laser with a repetition rate equal to a subharmonic frequency of the slave laser. The method does not required an intracavity saturable absorber in the slave laser and can reduce the limitations imposed by high frequency drive electronics. The high frequency signal exhibits a large subharmonic suppression ratio(>17dB), large frequency detuning range (>300 MHz), low levels of phase noise (-77.5dBc/Hz), and large locking range(>400 MHz). The High-frequency signal can be used in the field of LMDS(Local Multipoint Distribution System), WLL(Wireless Local Loop) and MBS(Mobile Broadband System)

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저자 소개

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Prof. Jung-Tae Kim received his B.S.degree in Electronic Engineering from Yeungnam University in 1989 and M.S. and Ph.D. degrees in Electrical and Electronic Engineering from the Yonsei University in 1991 and 1996, respectively. From 1991 to 1996, he joined at ETRI, where he worked as Senior Member of Technical Staff. In 2002, he joined the department of Electronic and Information security Engineering, Mokwon University, Korea, where he is presently a professor. His research interest is in the area of information security technology that includes Information security system design, Microwave photonics system and Optically fed Wireless Communication.