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C-28 **"Tunable Bandpass Filter Based on Two-Dimensional Photonic Crystal Using Ferroelectric Materials"**
Ritwick Das, K. S. Daya, K. Thyagarajan (Indian Institute of Technology)

C-29 **"10 GHz Resonant Type LiNbO$_3$ Optical Modulator Array with Patch Antennas"**
Satoshi Shinada, Tetsuya Kawanishi, Masayuki Izutsu (National Institute of Information and Communications Technology)

C-30 **"Numerical Analysis of a 20GHz Cascaded Resonantly Enhanced Mach-Zehnder Modulator"**
Yuvaraja S. Visagathilagar, Thach G. Nguyen, Arnan Mitchell (RMIT University)

C-31 **"10 Gbps FSK WDM Modulation Using External FSK Modulator"**
Takahisa Fujita*, Tetsuya Kawanishi**, Takahide Sakamoto**, Kaoru Higuma*, Junichiro Ichikawa*, Masayuki Izutsu** (*Sumitomo Osaka Cement Co., Ltd., **National Institute of Information and Communications Technology)

C-32 **"Ridge-Type Zn-Indiffused Mach-Zehnder Modulator in LiNbO$_3$"**
Ruey-Ching Twu*, Chia-Chih Huang**, Chin-Yu Chang***, Way-Seen Wang*** (*Southern Taiwan University of Technology, **Tung Nan Institute of Technology, ***National Taiwan University)

C-33 **"Investigation on the Wavelength Characteristics of a High Extinction Ratio LiNbO$_3$ Optical Modulator"**
Kaoru Higuma*, Shingo Mori*, Tetsuya Kawanishi**, Masayuki Izutsu** (*Sumitomo Osaka Cement Co., Ltd., **National Institute of Information and Communications Technology)

C-34 **"Tunability of Lithium Niobate Loop Resonator"**
J. X. Chen*, T. Kawanishi**, K. Higuma***, S. Shinada**, M. Izutsu**, W. S. C. Chang*, P. K. L. Yu* (*University of California, San Diego, **National Institute of Information and Communications Technology, ***Sumitomo Osaka Cement Co., Ltd.)

C-35 **"A Wide Dynamic Ranged Radio Wave Receiving System with an Optical Modulator and DFB Lasers"**
Kazuhisa Haeiwa*, Takayuki Yamashita**, Yoshikazu Toba***, Masatoshi Onizawa*** (*Hiroshima City University, **NHK, ***NEC Tokin Corporation)

C-36 **"Optical Fiber Link Antenna Measurement System"**
Satoru Kurokawa, Masanobu Hirose, Koji Komiyama (National Institute of Advanced Industrial Science and Technology)

C-37 **"A Study on Sensitivity Improvement of Electro-Optic Detection with Arrayed Photodetectors"**
Kiyotaka Sasagawa, Masahiro Tsuchiya (National Institute of Information and Communications Technology)

C-38 **"All Optical Harmonic Frequency Up-Converters Based on Self-Pulsating Multi-Section DFB Lasers for 60GHz RoF Down-Link Systems"**
Kwang-Hyun Lee*, Woo-Young Choi*, Young-Ahn Leem**, Kyung-Hyun Park** (*Yonsei University, **Electronics and Telecommunications Research Institute)

C-39 **"Microwave Photonic Mixer Based on an InGaAs Photoconductor for Radio over Fiber Applications"**
Ho-Jin Song, Tae-Woo Kim, Seong June Jo, Chung-Hyun Lim, Soo-Ghang Ihn, Jong-In Song (Gwangju Institute of Science and Technology)

C-40 **"Broadband 90 Degree Hybrid Coupler Using Photonic Transversal Approach"**
Hossein Emami, Lam Anh Bui, Arnan Mitchell (RMIT University)

C-41 **"A Study on Nonlinear Distortion Suppression with Wavelength Control of EAM"**
Makoto Yamashita*, Kosuke Uegaki*, Kazuo Kumamoto*, Koji Yasukawa*, Keizo Inagaki**, Takeshi Higashino***, Katsutoshi Tsukamoto***, Shozo Komaki*** (*Osaka Institute of Technology, **ATR, ***Osaka University)

Session D: 18:30 - 20:00

Rump Session (co-sponsored by IEEE-LEOS Japan Chapter: Advanced photonic devices for MWP systems)

Chairs: Yuzo Yoshikuni (NTT Corporation)
Tetsuya Kawanishi (National Institute of Information and Communications Technology)

18:30-19:00 D-1 **"Characteristics of 60 GHz Analog RF-Optic Transceiver Module"**
Jeha Kim, Yong-Duck Chung, Kwang-Seong Choi, Young-Shik Kang, Kyoung-Ik Cho (Electronics and Telecommunications Research Institute)

19:00-19:30 D-2 **"UTC-PD Based Optoelectronic Devices for High-Speed and High-Frequency Applications"**
Satoshi Kodama, Hiroshi Ito (NTT Corporation)

19:30-20:00 D-3 **"Ultrafast All-Optical Switch in Silicon Wire Waveguides"**
L. R. Nunes, T. K. Liang, K. S. Abedin, T. Miyazaki, M. Tsuchiya (National Institute of Information and Communications Technology)

All Optical Harmonic Frequency Up-converters Based on Self-pulsating Multi-section DFB Lasers for 60GHz RoF Down-link Systems

Kwang-Hyun Lee[1], Woo-Young Choi[1], Young-Ahn Leem[2], Kyung-Hyun Park[2]

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***Abstract* — We propose and experimentally demonstrate all optical harmonic frequency up-converters using self-pulsating multi-section DFB lasers for RoF down-link systems. 60GHz signals are generated by locking the 4th harmonic frequency component (59.34GHz) of a self-pulsating multi-section DFB laser with the injection of an external optical signal modulated at the fundamental frequency (14.835GHz). Successful up-conversion is demonstrated for 150MHz IF signal to 60GHz.**

***Index Terms* — Self-pulsation, all optical harmonic up-converters, RoF, mm-wave generation.**

I. INTRODUCTION

Recently, many research groups have actively studied radio-over-fiber techniques (RoF) as a promising candidate for merging the wireline networks and broadband wireless networks using optical fiber [1-2]. It is because low-loss and wide bandwidth characteristics of fiber make it possible to implement flexible and cost-effective fixed-mobile systems. Especially, for millimeter wave band signals (>30GHz), the RoF technique is considered as a promising technique.

Frequency up-conversion is needed in RoF systems in which data are transmitted in IF. All-optical frequency up-conversion provides an interesting research opportunity as well as a possibility for cost-effective system realization. In particular, such possibility is even greater if the function of all-optical up-conversion can be done in the central office (CO) since this allows simplification of the base station (BS). In this scheme, however, fiber dispersion can cause serious performance degradation [3]. In this paper, we propose and experimentally demonstrate an all-optical harmonic frequency up-conversion scheme that is free of above problem. In our scheme, mm-wave signals (59.34GHz) are generated with sub-harmonic signals (14.835GHz) by the use of harmonic injection locking of a self-pulsating DFB laser located at CO.

II. SELF-PULSATING MULTI-SECTION DFBLASER

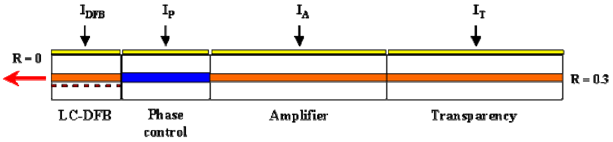

Fig. 1. 4-section DFB laser.

Fig. 1 shows the self-pulsating 4-section DFB laser that is used as an all-optical frequency up-converter in our investigation. The laser has sections for DFB, phase control, amplification, and transparent transmission. Phase control and amplification sections adjust the phase and amplitude of the feedback optical signal into the DFB section after reflecting from the facet in the right side and transmission through the transparency section. The length of the transparency section is set for the desired self-pulsation frequency. When the applied bias to the DFB section is above the threshold current, pulsation in the device is due to beating of two compound cavity modes [4], and the pulsation frequency can be tuned by controlling bias currents applied to four sections. However, pulsation mechanism is different, if the applied bias to the DFB section is below the threshold current. In this case, the DFB section works as a just wavelength selective reflector and the 4-section DFB laser operates as a single cavity laser diode having multi modes. The multi modes can be mutually locked by the nonlinear mechanism, such as the self-induced carrier-density modulation or four-wave mixing, of the interaction between the optical modes, resulting in passive mode locking [5].

Fig. 2 shows the measured RF and optical spectrum of the 4-section DFB laser when the applied bias to the DFB section is below the threshold current. From many optical side modes shown in the optical spectrum, the device is expected to produce many harmonic frequency components in

RF domain.

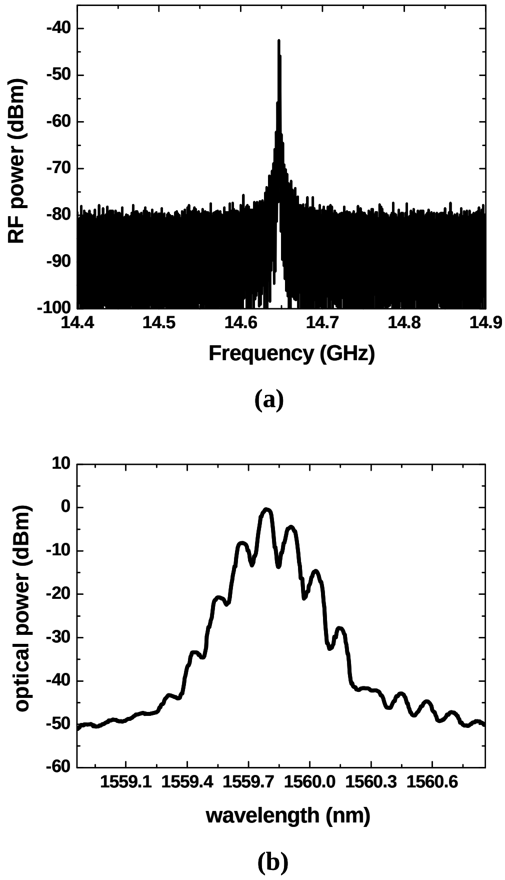

Fig. 2. Measured (a) RF spectrum and (b) optical spectrum of 4-section DFB Lasers operating as a passive mode-locked laser. (DFB: 30mA, Phase: 10mA, Amplifier: 100mA Transparency: 77mA)

III. HARMONIC INJECTION LOCKING

The phase-quality of RF signal shown in Fig. 2(a) can be enhanced by the injection locking of the device with an external optical signal modulated at the frequency (f_{LO}). Fig. 3 shows the experimental setup used for injection locking characteristic measurement. In this setup, an optical band-pass filter before the PD was used to select only the output signal of 4-section DFB laser. The 4-section DFB laser was biased to operate in passive mode-locking mode for generating many harmonic components. The power and the wavelength of the injected signal to the 4-section DFB lasers were about 6dBm, 1570nm, respectively. Fig. 4 shows the measured RF spectrum of the locked signal. As compared with free-running signal (fig. 2(a)), it has much narrower linewidth. In addition, harmonic frequency components were produced that were also locked by the injected f_{LO}. Fig. 5 shows the 4th harmonic component (59.34GHz).

To analyze the signal quality of locked signals more accurately, we measured the phase noises of the fundamental and 4th harmonic components, and Fig. 6 shows the result. The measured phase noise value for the fundamental and 4th harmonic is -94.17dBc/Hz and -82.83dBc/Hz, respectively. The phase noise of the 4th harmonic component is degraded about 12dB, agreeing with the theoretical value [6].

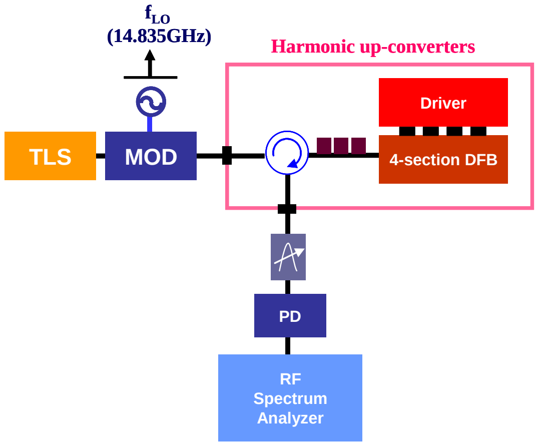

Fig. 3. Experimental setup for the injection locking. TLS: tunable laser source, MOD: modulator, PD: photo diode.

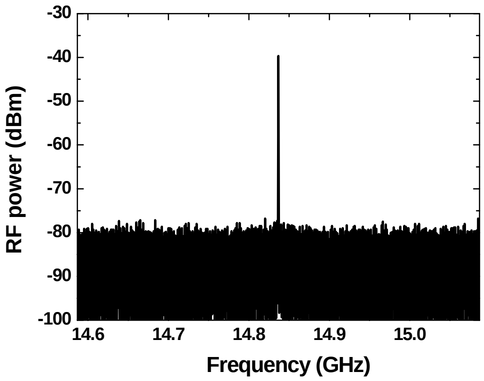

Fig. 4. Measured RF spectrum of the locked signal.

IV. HARMONIC UP-CONVERTERS

To carry out all optical harmonic up-conversion experiment, we modulated the external optical signal with both the fundamental frequency (f_{LO}) required for the harmonic frequency locking and IF (f_{IF}) signal that needs to be up-converted to the mm-wave band, and this optical signal was injected into the 4-section DFB laser, as shown in Fig. 7. The spectrum of the resulting up-converted double-sideband IF signals along with the 4th harmonic signal is shown in Fig. 8, demonstrating the successful up-conversion.

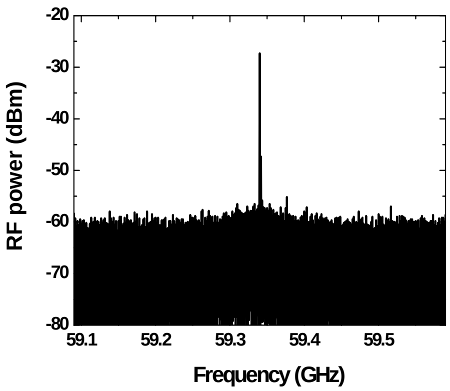

Fig. 5. Measured RF spectrum of the 4th harmonic frequency component.

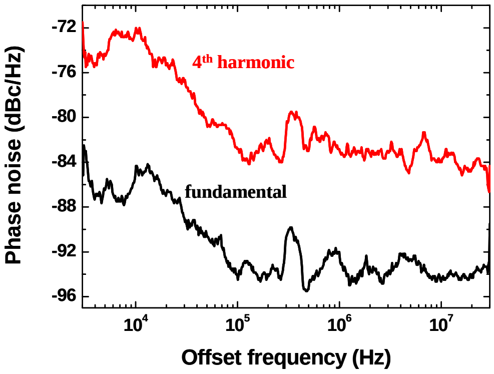

Fig. 6. Measured phase noise of the fundamental and 4th harmonic component

V. CONCLUSIONS

In this paper, we have proposed and experimentally demonstrated an all-optical harmonic frequency up-converter using a self-pulsating 4-section DFB laser. We successfully demonstrate that the proposed method can up-convert IF signal (150MHz) to the mm-wave band (59.34GHz) using sub-harmonic LO signal (14.835GHz) by the harmonic injection locking technique.

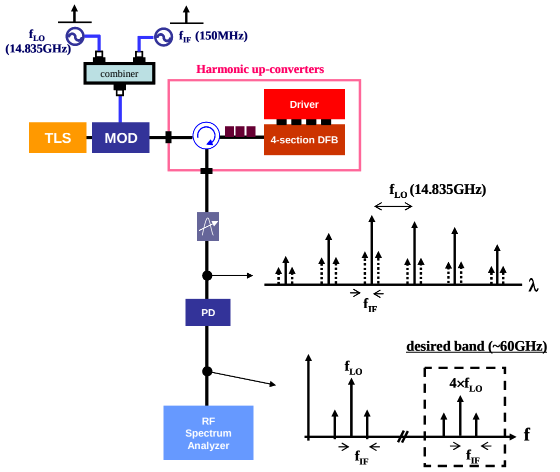

Fig. 7. Experimental setup for harmonic up-converters and schematic diagram for describing the operation principle of harmonic up-conversion

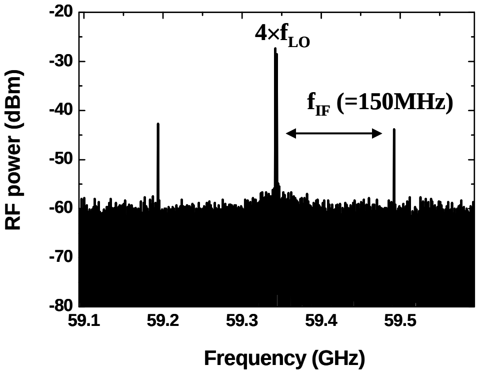

Fig. 8. Measured RF spectrum of the up-converted signal

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