# All-fiber-based generation of multi-channel optical frequencies

**Byung Jae Chun, Young-Jin Kim, Sangwon Hyun, Yunseok Kim and Seung-Woo Kim***

Ultrafast Optics for Ultraprecision Technology Research Group,
Korea Advanced Institute of Science and Technology, Science Town, Daejeon, 305-701, South Korea
* Corresponding author / E-mail: swk@kaist.ac.kr, TEL: +82-42-350-3257, FAX: +82-42-XXX-XXXX

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*The frequency comb of a mode-locked femtosecond laser enables direct calibration of optical frequencies with reference to the atomic clock of time standard. A single comb is capable of providing as many as several millions of evenly-spaced optical modes simultaneously with all of them being collectively stabilized to a precision level of one part in 1015. The concept of optical frequency generator (OFG) is to produce any wanted optical frequency by using the frequency comb as the ruler, so the generated optical frequency can be utilized for high precision spectroscopy, frequency calibration, optical communication and distance/length metrology. Some applications demand multiple frequencies be generated at the same time as found in multi-wavelength interferometry for absolute distance measurements. Here in this paper we describe an all-fiber-based scheme that generates four channels of difference wavelengths with high stability.*

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## 1. Introduction

Stabilizing control of the frequency comb of a mode-locked femtosecond (fs) laser has permitted the advance of the precision frequency measurement in the optical regime. The stabilized frequency comb provides about millions of evenly-spaced optical modes that can be stabilized simultaneously to a precision level of one part in $10^{15}$ to the time/frequency standard[1,2]. Although the frequency comb has superb characteristics, but it is not easy to directly apply for absolute distance measurement or multi-wavelength LIDAR because of its weak optical power of each frequency mode. Therefore, the concept of optical frequency generator (OFG) which supplies a single optical wavelength with functional power referenced to the frequency comb is one of the recent important issues that could find applications in high precision spectroscopy, frequency calibration, optical communication and distance/length metrology[3,4]. Especially for the absolute distance measurement based on the principle of multi-wavelength interferometry, several different single optical frequencies with high frequency stability are necessary at the same time[5]. Here, in this paper, we introduce a novel apparatus which can generate different single optical frequencies from the frequency comb. External phase lock-in scheme is implemented for construction of four channel OFGs. All-fiber based system design guarantees the system stability and insensitivity to environmental fluctuation.

## 2. All-fiber multi-channel optical frequency generator

Fig. 1(a) shows the system configuration of the multi-channel OFG designed and tested in our investigation. An Er-doped fiber laser generates a train of short pulses at a 100 MHz repetition rate with an average power of ~20 mW. The resulting frequency comb yields a 50 nm bandwidth centered at 1550 nm. The comb is stabilized to the Rb clock by controlling the pulse repetition rate and also the carrier-offset frequency using an f-2f interferometer [6]. The stabilized comb is sorted in parallel into four channels of different frequency regimes through an array waveguide grating (AWG) comprised of multiple fiber Bragg grating (FBG) filters with each having a 100 GHz bandwidth of band-pass filtering. Each channel has a distributed feedback (DFB) laser and a photodetector monitoring the beat frequency between the DFB laser and the band-passed comb. The signal-to-noise ratio of the beat frequency turns out to be more than 30 dB for each channel, by suppression of unwanted side modes using four different FBG filters centered at 1530, 1530.8, 1553.6, and 1554.4 nm, respectively. The beat signal is then amplified and fed into the phase locked loop (PLL) so that the output frequency of the DFB laser can be locked with reference to the Rb clock. Each DFB laser can be tuned in the range of 2 nm by controlling its temperature and injection current.

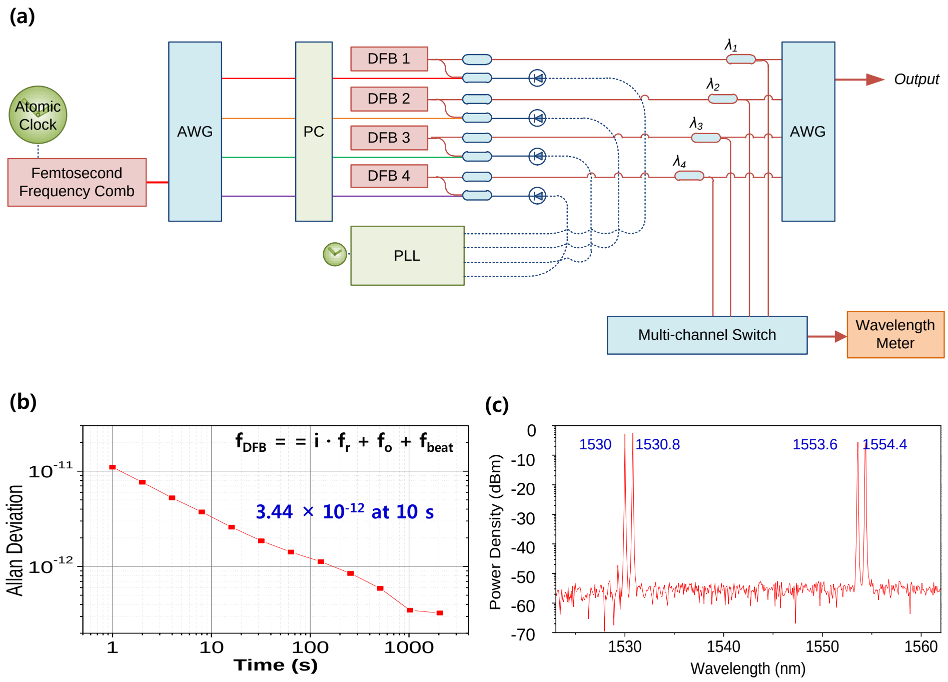


Fig. 1 Multi-channel optical frequency generator: (a) Overall scheme for the multi-channel optical frequency generator. (b) Allan deviation for multi-channel OFG. (c) Optical spectrum of multi-channel OFG.

In the process of phase-locking, the beat signal between a DFB laser and the frequency comb is fed to the PLL and then regulated to control the injection current to each DFB laser. In consequence, the frequency stability of the DFB laser is measured as $3.44 \times 10^{-12}$ at 10 s averaging in terms of Allan deviation as plotted in Fig. 1(b). The four channels have almost the same performance. The positions of four wavelengths are decided to construct a multi-wavelength interferometer with the requirement of extending the non-ambiguity range over more than several meters (See Fig. 1(c)).

## 4. Conclusions (Times New Roman 10pt)

In conclusion, a multi-channel optical frequency generator based on fiber optics was demonstrated. Four DFB lasers are stabilized to the selected modes from frequency comb by well-established phase-locking techniques to the level of 10-12. It preserves the outstanding performance of the frequency comb in terms of the accuracy, stability, and tunability. This apparatus would be applied for diverse metrology systems for frequency calibration, high precision spectroscopy, multi-channel LIDAR as well as the real-time absolute distance measurement.

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## REFERENCES

1. R. Holzwarth, Th. Udem, T.W. Hänsch, J. C. Knight, W. J. Wadsworth, and P. St. J. Russell: Optical frequency synthesizer for precision spectroscopy, Phys. Rev. Lett. 85, pp. 2264-2267 (2000).
2. D. J. Jones, S. A. Diddams, J. K. Ranka, A. Stentz, R. S. Windeler, J. L. Hall, and S. T. Cundiff: Carrier envelope phase control of femtosecond mode-locked lasers and direct optical frequency synthesis, Science 288, pp. 635-639 (2000).
3. J. Jin, Y.-J. Kim, Y. Kim, S.-W. Kim, and C.-S. Kang: Absolute length calibration of gauge blocks using optical comb of a femtosecond pulse laser, Opt. Express 14, pp. 5968-5974 (2006).
4. Y.-J. Kim, J. Jin, Y. Kim, S. Hyun and S.-W. Kim: A wide-range optical frequency generator based on the frequency comb of a femtosecond laser, Opt. Express, 16, pp. 258-264 (2008).
5. S. Hyun, Y.-J. Kim, Y. Kim, Jonghan Jin and Seung-Woo Kim: Absolute length measurement with the frequency comb of a femtosecond laser, Measurement Science and Technology, 20 (2009).
6. Y. Kim, S. Kim, Y.-J. Kim, H. Hussein and S.-W. Kim: Er-doped fiber frequency comb with mHz relative linewidth, Opt. Express, 17 (2009).