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B2L-A Oscillators and Optoelectronic Integration

Time: **Thursday, October 4, 2007, 10:30 - 12:00**
Place: **Crystal Ballroom**
Co-Chairs: Arne Alping; *Ericsson*
Tetsuya Kawanishi; *NICT*

Hybrid Dual-Loop Optoelectronic Oscillators

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Abstract — **We report a simple and cost-effective configuration for dual-loop optoelectronic oscillators (OEO) composed of electrical and optical loops. Our scheme uses the electrical loop as a high-Q filter for single-mode oscillation at millimeter-wave bands. We experimentally demonstrate single-mode oscillation at 30 GHz with the side-mode suppression ratio larger than 50 dB and the single-sideband phase noise of about -103.33 dBc/Hz at 10-kHz frequency offset.**

I. INTRODUCTION

Oscillators are one of key components required in many applications such as micro/millimeter-wave communications, imaging, remote sensing, and radar systems [1]. In particular, optoelectronic oscillators (OEO) have been actively pursed since they can generate modulated optical signals as well as high-spectral-purity micro/millimeter-waves [2-4].

Generally, an OEO consists of an optical pump source and an optical feedback loop including an optical intensity modulator, an optical delay line, an O/E converter such as a photo diode (PD), and optical/electrical amplifiers. Fig. 1 shows the typical setup for an OEO [2]. As shown in Fig. 1, light signal is detected by an O/E converter, amplified, and fed back to the modulator as the modulating signal. If the round-trip gain is larger than the round-trip loss, oscillation will start.

In an OEO, its phase noise characteristics can be improved by increasing the length of the optical delay line [3]. A high-Q electrical band pass filter (BPF) is required for the single-mode oscillation since an OEO has multi modes with their mode-spacing inversely proportional to the delay-line length [4]. However, high-Q electrical BPFs especially at millimeter waves are expensive. On the other hand, a dual-loop OEO composed of shorter and longer optical loops can oscillate at a single frequency [5]. It is because its mode-spacing is determined by the shorter loop, while the phase noise characteristics are determined by the longer loop. However, the configuration for a dual-loop OEO is complex and its realization is expensive since it requires as many PDs as the number of feed-back loops as shown in Fig. 2.

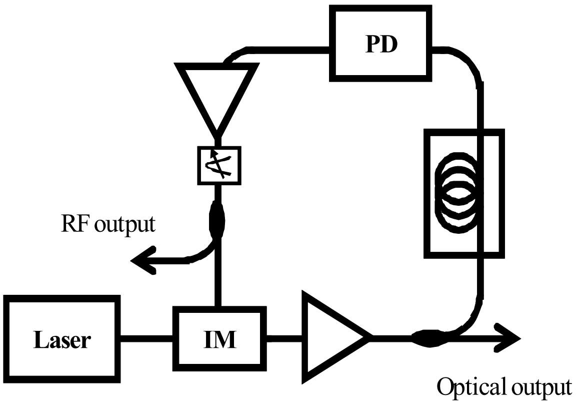

Fig. 1. Typical configuration of optoelectronic oscillators. IM: intensity modulator. PD: photo diode

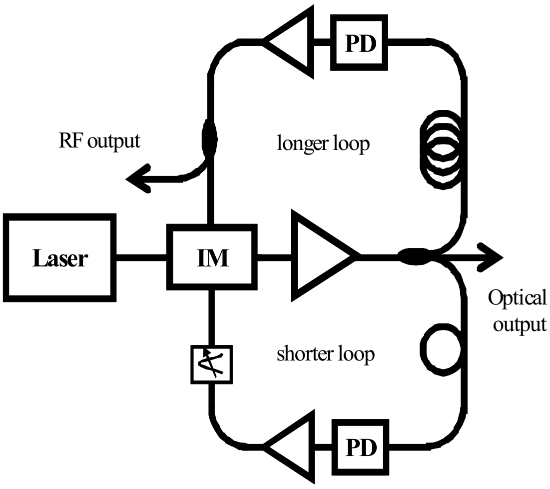

Fig. 2. Configuration for a dual-loop OEO. IM: intensity modulator. PD: photo diode

In order to realize a simple and compact dual-loop OEO, the hybrid configuration based on a microwave photo heterojunction bipolar transistor has been proposed and successfully demonstrated at a few GHz [6-7].

In this paper, we report a different type of a hybrid dual-loop OEO oscillating at millimeter-wave bands in which the shorter optical loop is replaced by an electrical loop composed of an electrical amplifier and an electrical BPF. In our scheme, a BPF having low-Q in the electrical loop can produce single-

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mode oscillation. We experimentally demonstrate the hybrid dual-loop OEO having single-mode oscillation at 30-GHz band with the side-mode suppression ratio (SMSR) larger than 50dB.

II. OPERATING PRINCIPLE

Fig. 3 shows the configuration of the proposed hybrid dual-loop OEO. The electrical loop consists of an electrical amplifier, an electrical BPF, and RF couplers. A portion of the oscillating signal in the electrical loop is coupled into the optical loop by RF couplers, and fed back to the electrical loop again after circulating the optical loop. As a result, only the mode which can survive in both loops can oscillate in the dual-loop OEO.

Fig. 4 (a) and (b) schematically show the signal spectrum of a single-loop oscillator composed of an optical or an electrical loop alone, respectively, while Fig. 4(c) shows that of the hybrid dual-loop OEO. As shown in Fig. 4 (a), the optical-loop modes are separated by the mode-spacing Δf determined by the optical-loop length. For 1-km optical-loop, Δf is about 200 kHz. With this, an electrical BPF having Q larger than 10^5 is needed for the single-mode selection at 30 GHz. The requirement on filter Q can be reduced by adding an electrical loop having an amplifier. The oscillating mode in the electrical loop can have very high-Q, even if a low-Q BPF is used as shown in Fig. 4 (b). If two loops are closed and coupled to each other, only the mode satisfying both optical and electrical oscillation can survive and the single mode oscillation can be achieved as shown in Fig. 4 (c).

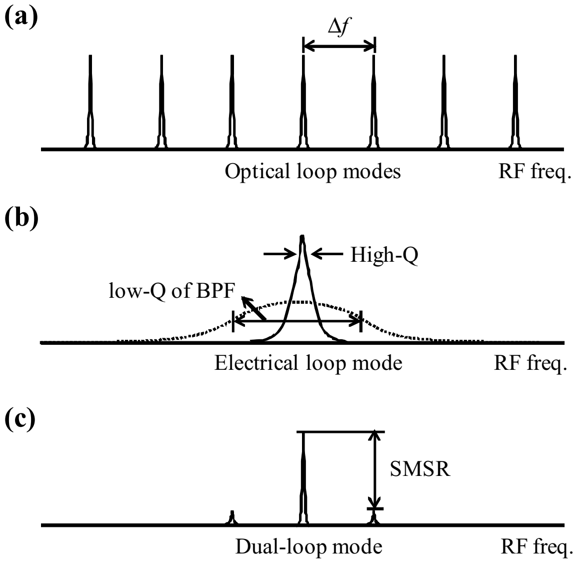


Fig. 4. Output signals of a single-loop oscillator composed of an optical loop (a) or an electrical loop alone (b) and the hybrid dual-loop OEO including both loops (c).

III. EXPERIMENTAL SETUP AND RESULTS

Fig. 5 shows the experimental setup for the demonstration of single-mode oscillation at 30 GHz with the hybrid dual-loop OEO. The electrical loop was composed of an electrical amplifier having RF gain of 28.4 dB, an electrical BPF having Q value of 10^3 at 30 GHz and the insertion loss of about 3.16 dB, and a 4-port 3-dB RF coupler having the additional insertion loss of about 1.8 dB. The optical loop was configured with two electrical amplifiers having the total gain of about 36 dB and optical components including a Mach-Zehnder Modulator (MZM) having 40-GHz modulation bandwidth, an Er-doped fiber amplifier, an optical filter, an optical attenuator, 2.8-km long single-mode fiber, and a high-speed PD with 60-GHz bandwidth. The tunable laser source (TLS) produced optical signals at 1549.4 nm. An optical filter was inserted for filtering out the upper sideband in MZM output signals to avoid the RF signal fading problem induced by fiber dispersion [8] and an optical attenuator was used for reducing optical power injected into the PD below its saturation power (~3 dBm).

In our setup, the OEO composed of the optical loop alone did not oscillate because the small-signal open-loop gain was lower than unity. However, once both loops were closed, the

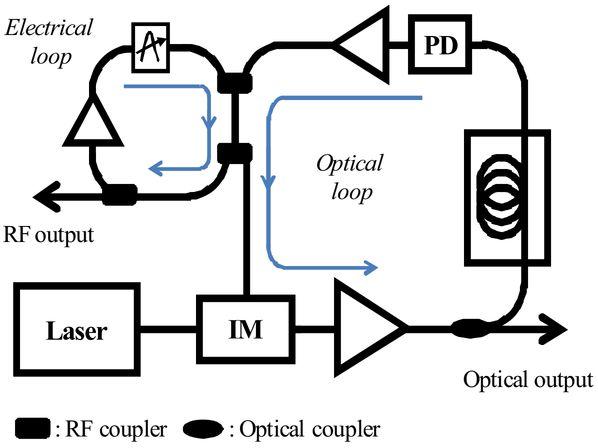


Fig. 3. Configuration of the proposed hybrid dual-loop OEO.

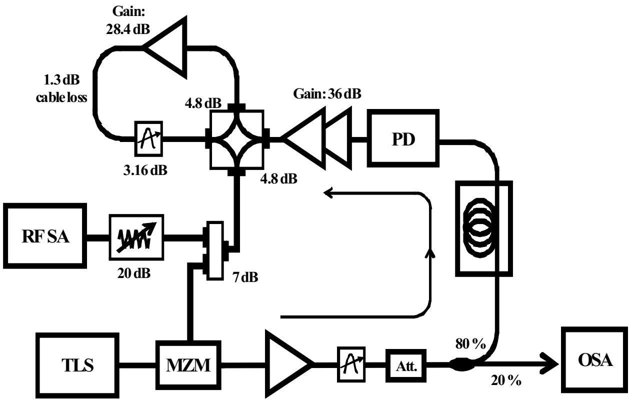
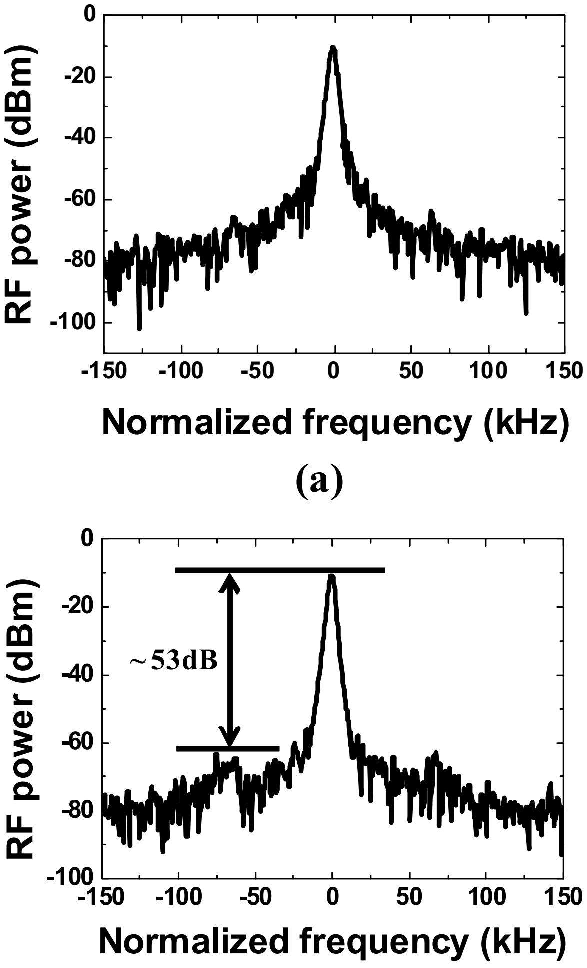


Fig. 5. Experimental setup for the demonstration of the hybrid dual-loop OEO. Att.: attenuator. MZM: Mach-Zehnder modulator

hybrid dual-loop OEO oscillated at the frequency determined by the electrical BPF since the combined loop gain was larger than unity [5]. The oscillation signal was measured by an RF spectrum analyzer (HP8563E) connected with an external mixer (HP11970A), and the optical signal was measured by an optical spectrum analyzer (MS9710B). The output electric power was attenuated by 20 dB not to exceed the maximum input power (-6 dBm) for the mixer.

Fig. 6 (a) shows the measured OEO output spectrum with only the electrical loop. The estimated Q-value was higher than 10^6, in spite of the fact that the BPF having Q-value of 10^3 was used. The center frequency in Fig. 6 (a) was 30.00372 GHz. Fig. 6 (b) shows the output spectrum of the hybrid dual-loop OEO with both loops closed. The spectrum was measured at the center frequency of 30.000038293 GHz. The frequency offset between Fig. 6 (a) and (b) is due to the center frequency drift of the electrical-loop mode. However, once both loops were closed and oscillation started, the oscillating frequency did not change due to the self-locking effect [9]. Fig. 6 (b) clearly shows the single-mode oscillation of the hybrid dual-loop OEO. In the figure, side modes generated by the long optical loop are shown with about 70-kHz separation from the main mode and the SMSR is about 53 dB. This result shows that the electrical loop can effectively suppress undesired side modes from the long optical loop.



(a)

(b)

Fig. 6. Measured output spectrum of the OEO with only electrical loop closed (a) and with both loops closed.

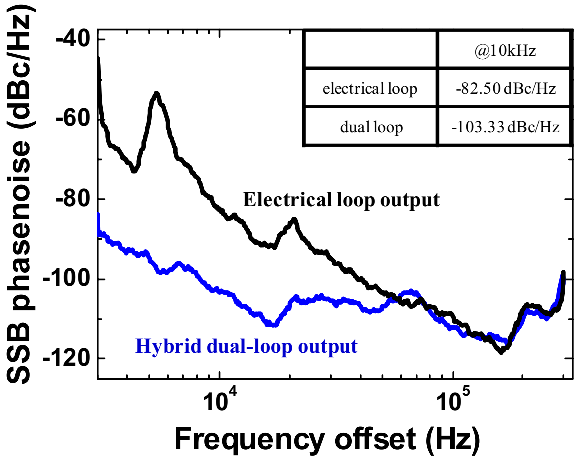


Fig. 7. Measured phase noises of the output signal of the OEO with the only electrical loop closed and with the both loops closed.

Fig. 7 shows single-sideband (SSB) phase noises. For the case of the oscillator composed of the electrical loop alone, SSB phase noise was about -82.50 dBc/Hz at the 10-kHz frequency offset. On the other hand, the SSB phase noise of the output signal generated by the hybrid dual-loop OEO having 2.8-km long single-mode fiber was about -103.33 dBc/Hz. This result clearly shows that the phase noise of the oscillation signal was determined by the long optical loop.

Fig. 8 shows the measured optical spectrum of the hybrid dual-loop OEO. As shown in the figure, the optical carrier was modulated by the signal oscillating at 30 GHz and the upper-

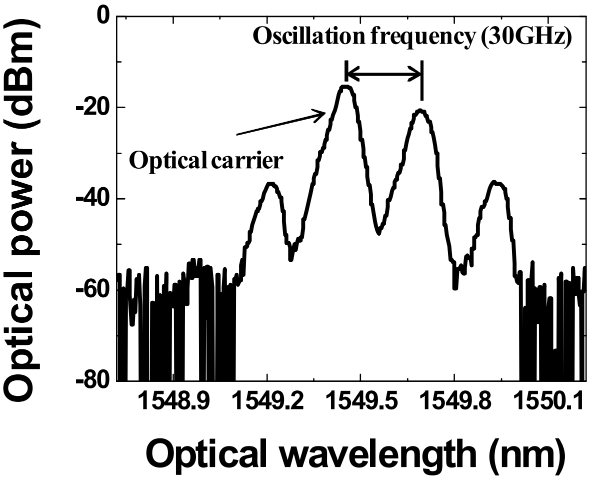


Fig. 8. Optical spectrum of the hybrid dual-loop OEO

side band was suppressed by the optical filter inserted into the optical loop. The second lower-side band shown in the figure was generated due to the MZM nonlinearity.

IV. CONCLUSION

We have presented the hybrid dual-loop OEO composed of electrical and optical loops. In our OEO, the electrical loop works as an active filter having very high-Q ($>10^6$) to select a single mode from multiple optical-loop modes. We successfully demonstrated single-mode oscillation at 30 GHz with SMSR larger than 50dB.

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