Microwave Signal Mixing by Using a Fiber-Based Optoelectronic Oscillator for Wavelength Division Multiplexed (WDM) Systems

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We report on microwave signal-mixing functionality for a fiber-based optoelectronic oscillator. Two wavelength division multiplexed (WDM) channels carrying RF signals at 1320 and 1312 nm are simultaneously upconverted/downconverted by the fiber-based optoelectronic oscillator. The conversion efficiency is found to be approximately −8 dB, and the incoming signals have no effects on the local oscillator spectral purity. This new functionality may be useful in fiber-fed phased-array antenna systems and hybrid WDM/subcarrier multiplexed (SCM) communications systems.

I. Introduction

Photonics technology has been growing rapidly into microwave systems with the advancement of optical component technology. In addition to microwave transmission for subcarrier systems [1] and satellite communications [2], many new functions have been demonstrated, such as microwave generation, filtering, and mixing, which traditionally are performed by the microwave electronics. Additionally, emerging wavelength division multiplexing (WDM) technology finds its place not only in the increase of system capacity but also in microwave signal processing, such as true time-delay control for phased-array antenna systems [3]. A novel microwave fiber-optic link has been proposed where the information data are upconverted/downconverted by two external modulators [4]. Such a scheme offers the advantage of avoiding the need for high-speed photodetectors and microwave mixers. However, one difficult task remains to be solved: The electrical local oscillator (LO) still is needed. The high-frequency LO generally is obtained by multiplying a low-frequency standard through numerous stages of multipliers and amplifiers, which is bulky and cumbersome. Recently, a new kind of a fiber-based photonic oscillator has been proposed and demonstrated [5]. Such an oscillator can generate microwaves with high spectral purity up to 75 GHz. Many other interesting capabilities, such as subcarrier/clock recovery and microwave regeneration, have been demonstrated with this approach [5]. Here we propose a new function for this microwave oscillator, namely, photonic microwave mixing for WDM systems [Fig. 1(a)]. In this approach, WDM channels carrying RF signals are simultaneously downconverted to IF frequencies by a fiber-based local oscillator and detected by a low-speed detector array. In the demonstration, the RF signals carried on the 1320- and 1312-nm wavelengths are simultaneously downconverted/upconverted by the photonic oscillator at approximately 5 GHz. The conversion efficiency is found to be −8 dB, and the local oscillator spectral purity is not affected by the incoming signals.

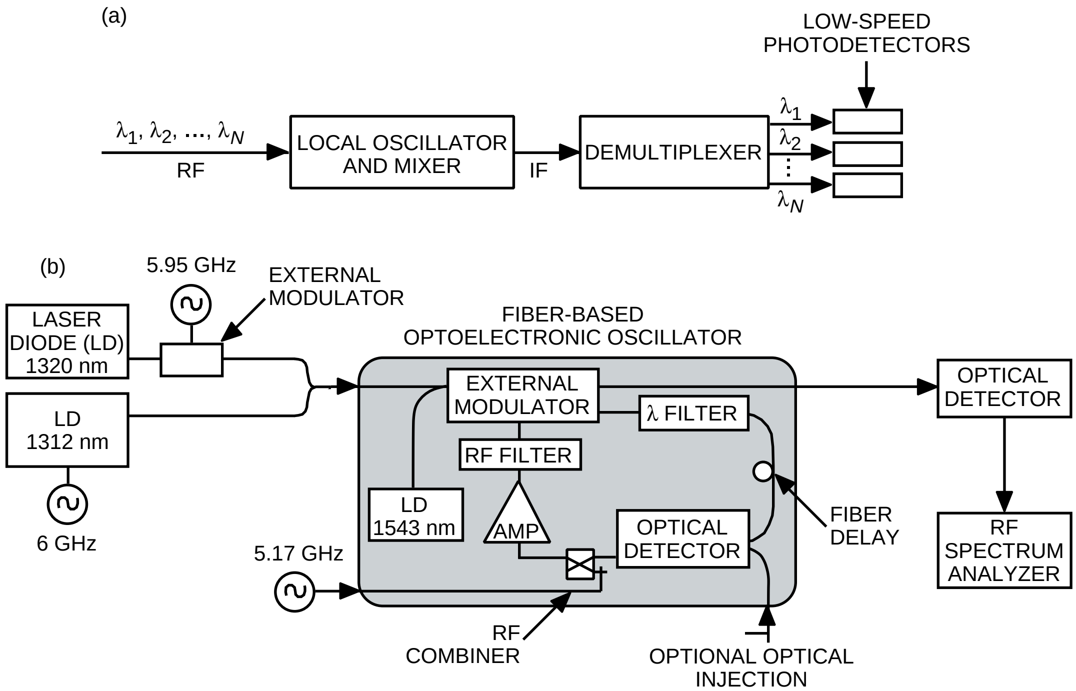

Fig. 1. The fiber-based optoelectronic oscillator: (a) conceptual diagram of the new function and (b) the experimental setup.

II. Experimental Demonstration

The optoelectronic oscillator is basically a microwave delay line with the open loop gain larger than 1 [Fig. 1(b)]. The oscillator loop consists of light being modulated by an external modulator; transmitted by a fiber delay line; and detected by a photodetector, the output of which is electrically amplified and fed back into the modulator RF drive port. Just as does a fiber-based ring laser, a fiber delay offers the advantage of an effective high-Q, which results in superior RF spectral purity. Using the local oscillator as a mixer eliminates the problems of RF isolation and RF power sharing between the modulator and the local oscillator. Although a high-speed detector and a modulator are used in the local oscillator, the cost is highly justified by the resulting spectral purity of the RF signal generated by this approach, especially for the high frequency in the millimeter-wave range. Figure 1(b) also shows the experimental setup. Two optical signals at 1320 and 1312 nm are modulated at approximately 6 GHz with frequencies 50 MHz apart. The combined signals are used to simulate the WDM signals that will be processed by the optoelectronic oscillator. The pump for the oscillator is at 1543 nm. The power into the modulator is −6.6, −4.5, and 6 dBm for 1320, 1312, and 1543 nm, respectively. The output from one port of the modulator is coupled into the oscillator loop and passes through a 1.5-μm filter, which attenuates 1.3-μm signals with a 60-dB rejection ratio. The output from the other port is detected and monitored by an RF spectrum analyzer. The fiber delay of the oscillator is about 1 km, and the mode selection is done by electrically injecting −50-dBm RF signals at 5.17 GHz. The resulting signal-to-side-mode ratio of the RF signal of the local oscillator is over 65 dB.

Figure 2 shows the measured RF spectra at the output of the local oscillator. Figure 2(a) shows the two unconverted RF signals at ∼6 GHz; Fig. 2(b) shows the downconverted signals at approximately 800 MHz; and Fig. 2(c) shows the upconverted signals at 11 GHz. The input power into the optical detector is −13.8 and −11.50 dBm for 1320 and 1312 nm, respectively. The RF power from the detector is amplified by about 20 dB.

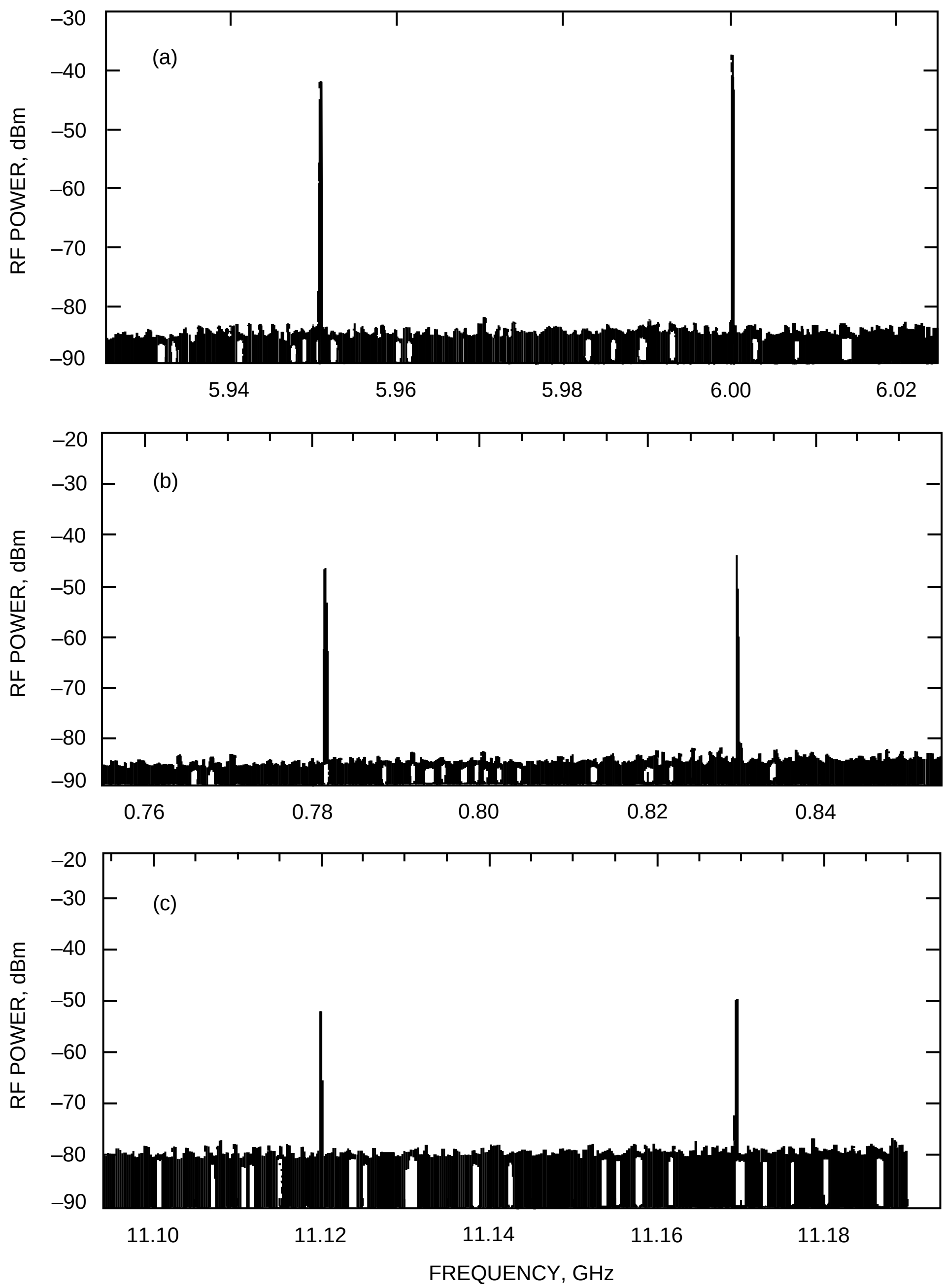

Fig. 2. Measured RF spectrum for (a) input RF signals around 6 GHz, (b) downconverted signals around 800 MHz, and (c) upconverted signals around 11 GHz. Both resolution bandwidth (RBW) and video bandwidth (VBW) are 10 kHz.

Figure 3 shows the performance of the oscillator. Figure 3(a) shows the performance as a mixer. We plot the RF power of the converted signal as a function of the RF power of the unconverted signal. The change of the RF power of the unconverted signal is obtained by changing the RF modulation power to either 1320- or 1312-nm lasers. The conversion is very linear and a nearly 1-dB increase of the unconverted signal power results in a 1-dB increase of the converted signal. There is an approximate 4-dB difference between upconverted and downconverted signals. This is due mainly to the response of the optical detector and the RF cable. Furthermore, the results for these two wavelengths (1320 and

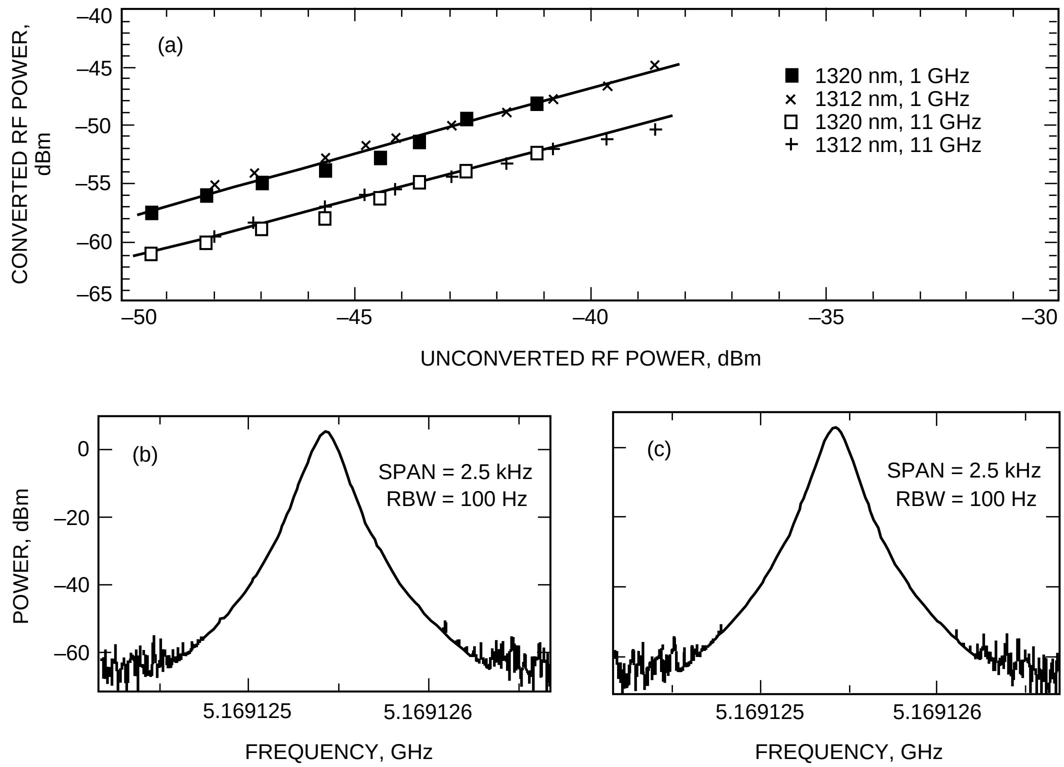

Fig. 3. Performance of the oscillator: (a) the RF power of the converted signal as a function of the RF power of the unconverted signal, (b) the spectrum of the LO when the signals are not injected, and (c) the spectrum of the LO when the signals are injected.

1312 nm) are almost identical, implying perfect operation for the WDM systems. Most significantly, the conversion efficiency (the ratio between the converted signal and the unconverted signal) is around −8 dB, only a 2-dB penalty in comparison with a perfect conversion, which is −6 dB. Note that only −50-dBm of RF power is injected and that the open-loop RF power at the modulator for this injection signal is 12 dBm. However, the oscillation RF power at the modulator is 25 dBm, implying a 13-dB RF gain for this oscillator. Also, the phase noise due to the electrical amplifier is greatly reduced by this high-Q fiber microwave delay line. Finally, the oscillator itself is not affected by processing the signals, because they are effectively rejected by the optical filter in the oscillator loop. Figures 3(b) and 3(c) show the spectrum of the oscillator, and we found no visible difference between whether or not the WDM signals were injected.

III. Summary

In summary, we have demonstrated microwave signal-mixing functionality for a fiber-based optoelectronic oscillator. Two WDM channels carrying RF signals at 1320 and 1312 nm are simultaneously upconverted/downconverted by the fiber-based optoelectronic oscillator. The conversion efficiency is found to be approximately −8 dB, and the incoming signals have no effect on the local oscillator spectral purity. This new functionality may be useful in fiber-fed phased-array antenna systems and hybrid wavelength division multiplexed (WDM)/subcarrier multiplexed (SCM) communications systems.

References

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