Photonic-based Millimeter Wave Wireless Link

Sungil Kim[1, 2]

[1]Future Technology Research Department, Creative Future Research Laboratory
Electronics and Telecommunications Research Institute
138 Gajeong-ro, Yuseong-gu, Daejeon 305-700, Republic of Korea
[2]Department of Advanced Device Technology
Korea University of Science & Technology (UST), Republic of Korea

Abstract— We modified a conventional double sideband-suppressed carrier (DSB-SC) scheme to increase frequency tunability, to overcome electronic dependency, and to reduce evaluation cost. Some achievements are listed in this paper. Especially, based on our results, we have accomplished a continuous wave (CW) in the mm-wave frequency bands using a local oscillator with one-sixth frequency of a wanted mm-wave frequency. Using the DSB-SC scheme and some electronics, a high-speed wireless link operating up to 10 Gbps is successfully demonstrated and verified.

1. INTRODUCTION

Now a days, millimeter (mm)-wave frequency bands have become important as a candidate frequency band for wireless links of 5G networks. This is because wide bandwidths to increase data rates up to several Gbps can be obtained in the mm-wave frequency bands with minimizing interference to allocation frequency bands [1].

There are several application fields as shown in Figure 1 based on high-speed and high-quantity data transfer abilities of wireless links using mm-wave bands. One is a fixed wireless access between two fixed locations as broadband networks and temporary broadband convergence network (BcN) to recover a disaster area. Data services for enterprises, which are for an online video meeting and transferring high capacity data, are also one of application fields. Another important application area is indoor amusements such as a game and a 3D home theater service. This is because of characteristics of mm-waves, which are line-of-sight propagation and relatively high attenuation on air. The other is a telemedicine services such as remote diagnosis and surgery.

Figure 1: Various application fields of wireless links using mm-wave bands.

Mm-wave generation schemes can be classified into two types according to major sources such as electronics and photonics. Comparing with those based on electronics, those based on photonics have had some advantages, which are wide tunability, easy to implementation, narrow spectral linewidth, and room temperature operation [2]. Photonic based schemes generally make an mm-wave signal as two different optical signal with difference wavelengths are beaten on an electro-optic convertor, which is a photomixer or a photodetector. Those are composed of electronic components, which are a driver amplifier for an optical modulator, a local oscillator, and so on, and optical components, which are an optical source, an optical modulator, and some passives. Accordingly, electronic performances of the components such as an operation band-width of the optical modulator, a frequency of the local oscillator, and so forth can limit a frequency of a generated mm-wave signal.

In this paper, we have presented various photonic-based continuous wave (CW) generation schemes based on a popular photomixing technique, which is called as double sideband suppressed carrier (DSB-SC) scheme. The various photonic-based CW generation schemes are modified scheme of the DSB-SC scheme to overcome electronic dependency, and to reduce evaluation cost. Using the generated mm-wave CW, a wireless link composed of a transmitter and a receiver is demonstrated to find out a feasibility of a high-speed wireless link on mm-wave bands. Based on our experimental results, an mm-wave CW of 120 GHz with −3 dB line width of 400 Hz is generated. A high-speed wireless data successfully transfers with 3 m long up to 10 Gbps. Consequently, our results can be useful for developing mm-wave wireless link up to several tens Gbps.

2. EXPERIMENTAL RESULTS

Figure 2 shows a schematic of a CW mm-wave generator using high-order harmonics modulated lightwaves [3]. That is composed of an optical source, two 3-dB couplers, a local oscillator, an optical modulator, two erbium-doped fiber amplifiers, a circulator, a terminator, a notch filter, and a photomixer. The high-order harmonics modulated lightwaves (HML) have been built by a conventional double sideband suppressed carrier scheme adopted with an optical feedback loop.

An optical and an electrical output power are shown in Figure 3. The optical output power is measured at the end of the notch filter using an optical spectrum analyzer (OSA) and the electrical output power is detected by the photomixer operating up to 140 GHz. With the optical feedback loop, lightwaves with 0.96 nm wavelength difference is generated using the LO of 20 GHz, and the CW of 120 GHz is achieved by beating them as illustrated in Figures 3(a) and (b). Comparing to

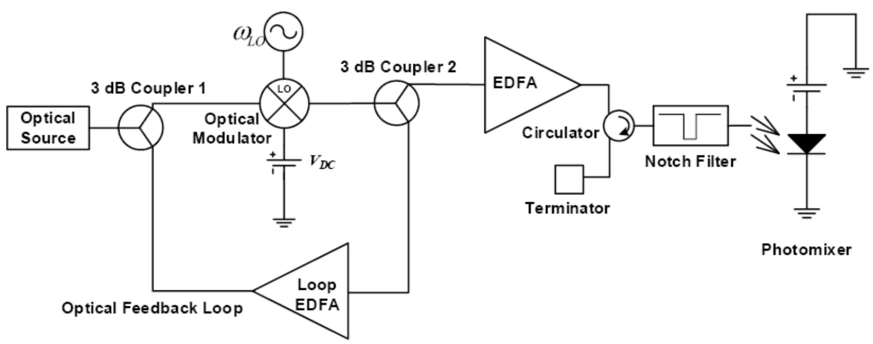
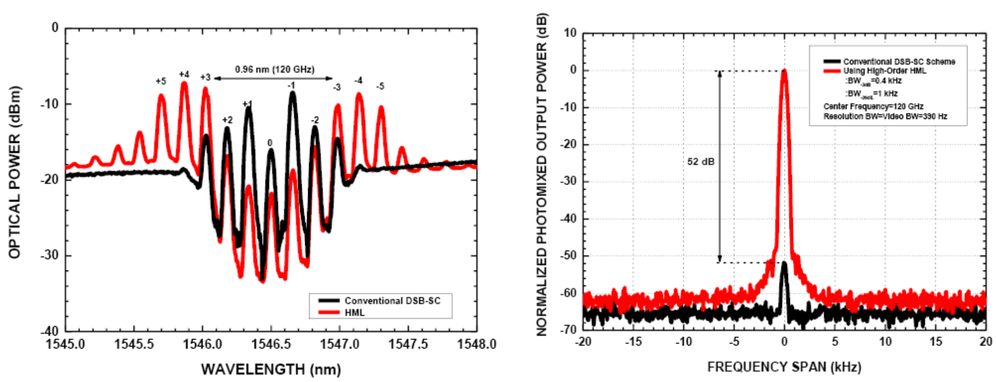


Figure 2: A schematic of a CW mm-wave generator using high-order harmonics modulated lightwaves.



(a) (b)

Figure 3: (a) The optical and (b) the electrical output power of the CW mm-wave generator with the HML in comparison of the conventional DSB-SC scheme using 20 GHz of the local oscillator and the optical feedback loop.

the conventional DSB-SC scheme with the LO of 20 GHz (black lines), the CW mm-wave generator with the HML (red lines) is superior to 52 dB in the electrical output power when the LO of 20 GHz is used. Accordingly, that with the HML can be overcome an electrical dependency of the conventional DSB-SC scheme which should be used a LO of 60 GHz to make the 120 GHz CW.

To reduce implementation costs of the photonic-based mm-wave generator, the optical source, which emits a single wave-length optical signals, is replaced by the erbium doped fiber amplifier (EDFA) as a broadband optical source, which is already installed in the conventional DSB-SC scheme, with a notch filter [4]. As the output of the EDFA inserted to the input of the notch filter is reflected according to the fiber brag grating wavelength of the notch filter, we can obtain several wavelengths and double sideband optical signals by feedbacking them. A schematic of a CW mm-wave generator composed of the EDFA as the broadband optical source, a 90 : 10 coupler, an optical modulator, a circulator, the notch filter, and the photomixer is illustrated as Figure 4 and its characteristics are shown in Figure 5.

The optical output power of the CW mm-wave generator (red lines) using the broadband optical source and the notch filter as shown in Figure 5(a) is similar to that of the conventional DSB-SC scheme (black lines). The optical characteristics of the EDFA (EDFA Output) and the notch filter (TNF: Transmission characteristics; RNF: Reflection characteristics) are also in Figure 5(a). Using the photomixer operating frequency ranges from 90 GHz to 140 GHz, the CW of 120 GHz was generated. The output power generated by the CW mm-wave generator using the broadband optical source and the notch filter (red lines) are comparable with that generated by the conventional DSB-SC scheme (black lines). Accordingly, our scheme can be helpful to make a cost effective photonic-based mm-wave generator as basic experimental reports.

To verify a feasibility of a wireless communication link using mm-waves, a mm-wave generator,

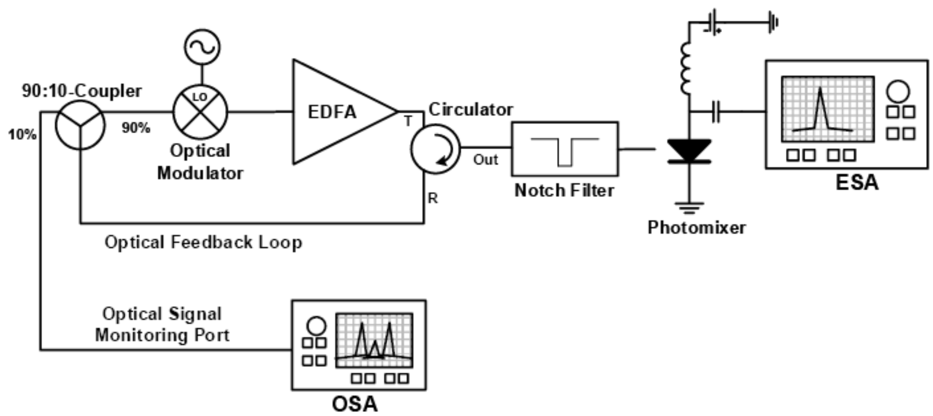
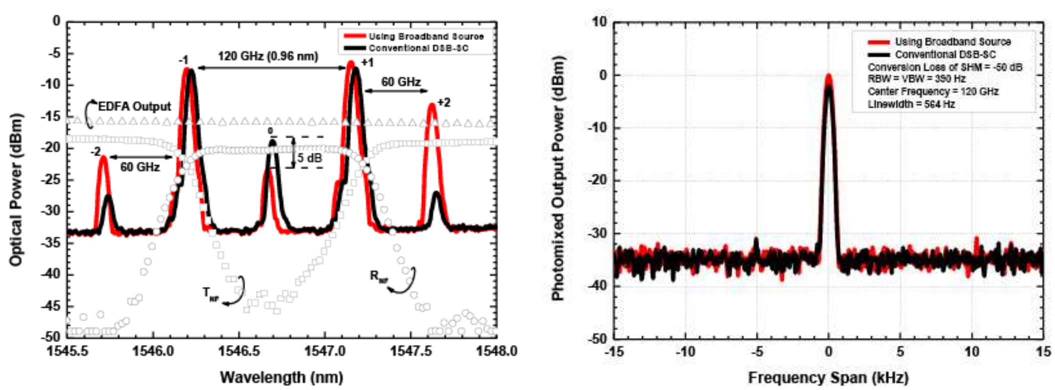
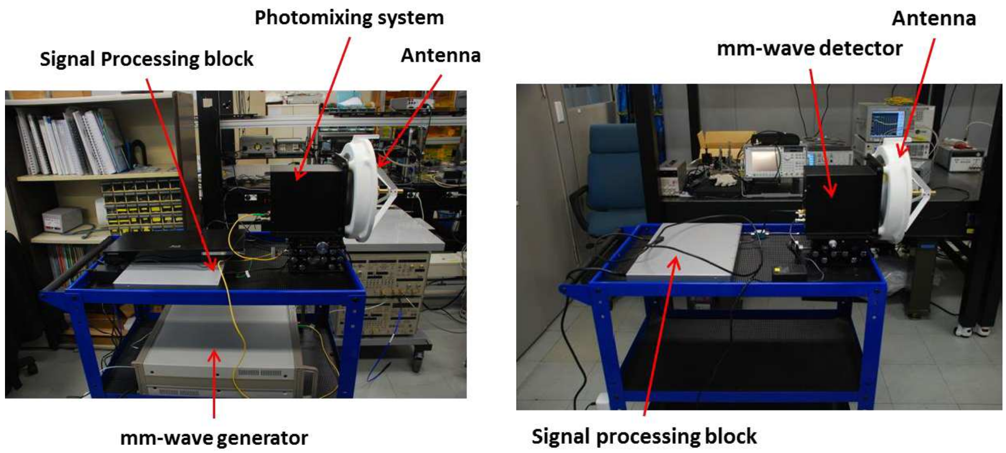


Figure 4: A schematic of a CW mm-wave generator using a broadband optical source and a notch filter with an optical feedback loop.



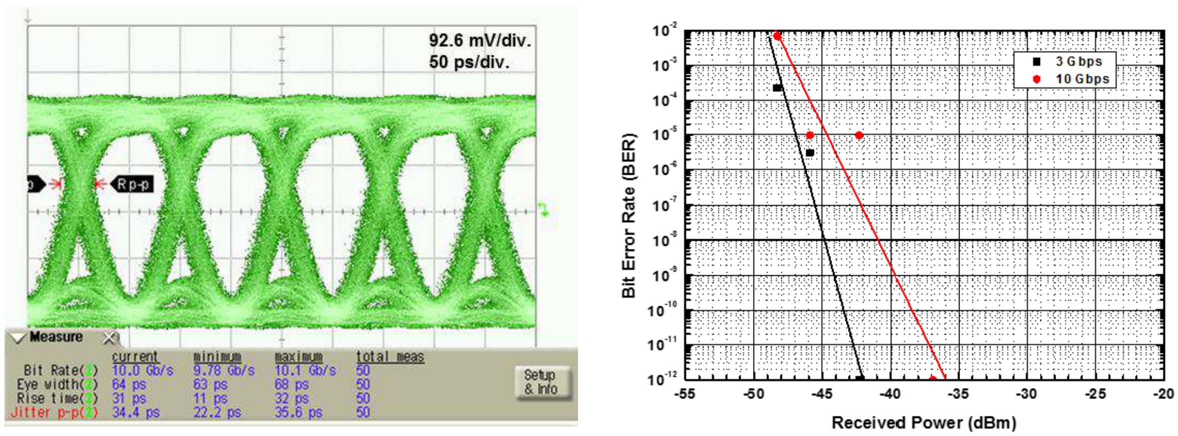
(a) (b)

Figure 5: (a) The optical and (b) the electrical output power of the CW mm-wave generator using a broadband optical source with an optical feedback loop.



(a) (b)

Figure 6: Photographs of (a) a mm-wave transmitter and (b) a mm-wave receiver.



(a) (b)

Figure 7: (a) An eye diagram and (b) bit-error rates measurement result.

which is based on the conventional DSB-SC scheme, and a mm-wave receiver is made as shown in Figure 6 [5]. The photomixing system consists of an uni-travelling carrier photodiode (UTC-PD) as the photomixer and a bias stabilizer circuitry for the UTC-PD. The mm-wave generator is the conventional DSB-SC scheme with an amplitude shift keying (ASK) modulation block. The signal processing block of the mm-wave transmitter converts a RGB parallel data to a serial data of HDMI data formats. That is for transmitting a HD video with the blue ray player. The mm-wave detector is composed of a schottky barrier diode (SBD) as an envelope detector, pre-/post-amplifier, and a bias circuitry.

Figure 7 shows dynamic performances of the wireless link such as an eye diagram and bit-error rates are measured with 3 m long between the mm-wave transmitter and the mm-wave receiver [5]. With non-return-to zero (NRZ) pseudorandom binary sequence (PRBS) 223-1 data, the eye diagram and the BER are measured. A good eye opening is shown in Figure 7(a). In Figure 7(b), black squares with black lines and red circles with red lines are the BER results for 3 Gbps data rates (3 Gbps) and 10 Gbps data rates (10 Gbps), respectively. Without some error corrections, the receiver sensitivity at the case of 3 Gbps and 10 Gbps are -41 dBm and -37 dBm at BER $= 10^{-12}$, respectively. Accordingly, the photonic-based mm-wireless link is a potential technology for a fixed wireless access with up to and over 10 Gbps.

3. CONCLUSION

In this paper, various continuous wave (CW) millimeter wave (mm-wave) generation schemes based on photonics were presented. To overcome an electronic dependency, an optical feedback loop was adopted to a conventional double sideband suppressed carrier scheme and to reduce implementation cost, a scheme of eliminating an optical source, which emits a single wavelength optical signal, was evaluated. According to the measurement results, our proposed schemes were verified. Also, a high-speed wireless link using mm-wave generated using photonics-based technology was designed and demonstrated to achieve the feasibility of mm-wave wireless links. To verify a high-speed wireless link, the dynamic performances such as an eye diagram and bit-error rate (BER) are measured for a back-to-back test and a link test with a link distance of 3 m. From our measurement results, the receiver sensitivity for a link test with a link distance of 3 m is -37 dBm (@ BER $= 10^{-12}$) with 10 Gbps non-return-to-zero (NRZ) pseudorandom binary sequence (PRBS) 2^{31}-1 data. With some error corrections and a precise alignment algorithm between the transmitter and the receiver, the wireless link distance can be extended. The results in this paper can provide helpful data to researchers for realizing a CW generator operating in mm-wave bands and a high-speed wireless link using a carrier frequency in mm-wave bands to achieve a seamless connectivity between wired and wireless networks, and high quantity/quality transfer systems.

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