20-Gb/s Error-Free Wireless Transmission Using Ultra-Wideband Photonic Transmitter-Mixer Excited with Remote Distributed Optical Pulse Train

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Abstract: Photonic transmitter-mixers with ultra-wide O-E/modulation bandwidths excited by remote-distributed pulse trains for 20Gbps error-free wireless transmission is presented. The S/N ratios and output power are greater than sinusoidal excitation.

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I. Introduction

In recent years, the developments of photonic wireless data transmission linking in sub-THz regime are very attractive for its ultra-wide transmission bandwidth [1-3]. However, the demonstrated maximum data rate in these photonic-wireless systems with extremely high carrier frequencies (200~500 GHz) is still limited by the speed of necessary active/passive components in their front-end [1]. One of the avenues for increasing the data rate is to further increase the available optical-to-electrical (O-E) bandwidth of the (near) W-band (75-110GHz) photonic transmitter as shown in [4]. In this paper, we successfully demonstrated a 20 Gbit/sec error-free on-off-keying (OOK) wireless data transmission at W-band by use of an ultra-wide band near-ballistic uni-traveling-carrier photodiode (NBUTC-PD) based photonic transmitter-mixer (PTM). The NBUTC-PD is bias modulated [4] with a high-performance photonic MMW source at W-band [5]. The adopted NBUTC-PD based PTM has the state-of-the-art performances including an extremely-wide 3 dB O-E (67-120, 53 GHz), as well as up-conversion modulation bandwidths (15 GHz), high saturation power, and a small WR-10 waveguide coupling loss (~2 dB). As for the photonic MMW source for the PD excitation, it is generated from a line-by-line pulse shaper, which can deliver a pre-compensated 1ps optical pulse train with a ultra-high repetition rate (~100GHz) for remote-distribution (>25km) optical local oscillator (LO) signal without using any dispersion compensator during fiber transmission [5,6]. Compared with the single-frequency sinusoidal signal at 100 GHz, the used 100 GHz short optical pulse train achieve a 4 dB enhancement in the photo-generated MMW power under the same PD operation current, which indicates a larger optical modulation depth, a higher signal-to-noise (S/N) ratio, and a lower bit-error-rate (BER) during wireless transmission.

II. Device Structure and MMW Photonic Source

Figures 1(a) to (c) respectively shows the top-view of our novel PTM, the measured and simulated coupling loss and O-E responses of the PTM, and the intermediate-frequency (IF) modulation responses of our PTM under a fixed optical local oscillator (LO) frequency at 93 GHz. As shown in Figure 1(a), the demonstrated device is mainly composed of a diced NBUTC-PD with a 144 μm^2 active area and a dipole-based waveguide feed. The 3-dB O-E bandwidth of the NBUTC-PD is around 120GHz with around 30mA saturation current under a 50Ω load. In order to realize a fully integrated PTM module with both wide O-E bandwidth and simultaneous up-conversion IF modulation bandwidths (IMB), an additional W-band band-pass filter (BPF) is employed between the bandstop filter (BPF) and the dipole-based feed, as shown in Figure 1 (a). With the inclusion of the BPF, an excellent isolation between the IF signal input and MMW source output is achieved. Specifically, with a low insertion loss (<1dB) at the passband, the stopband rejection is greater than 20dB at W-band for the BSF, and greater than 10dB from DC to 10GHz (IF band) for the BPF, which leads to a good IMB [7]. More details of these components and process of design can be found in our previous work [8]. Figure 2 shows the schematic of our experimental setup for data transmission, which includes our MMW light source. A phase-modulated continuous-wave (CW) laser frequency comb is generated by injecting a narrow-linewidth CW laser into of a low-V_π $LiNbO_3$ phase modulator. A 31GHz sinusoidal signal from an ultra-low phase noise RF signal generator, amplified to +33 dBm, is used to drive the phase modulator. The phase modulation frequency of 31 GHz equals the resulting frequency comb line spacing. The details of our line-by-line shaper are described in Ref. [5]. By utilizing this setup, ~1 ps optical pulse trains with 31 to 496 GHz repetition-rates suitable for high modulation-depth photonic MMW generations have been demonstrated [6]. As compared to using pure optical sinusoidal waveform as photonic MMW source, short optical pulse excitations could offer a ~4 dB enhancement in the resulting MMW power given the same averaged operation photocurrent, as well as achieving a higher maximum saturation current due to reduced device-heating [5,6,9]. Furthermore, the line-by-line shaper can simultaneously provide dispersion pre-compensation required delivering the short optical pulses for remote (> 25 km) MMW signal generations without the need for additional dispersion management within the fiber link [6]. Figure 2 (a) shows the optical spectrum of 93 GHz two-line sinusoidal signal, and 93 GHz short-pulse (~1ps) signal with 11 comb lines. Figure 2(b) shows the corresponding experimental intensity autocorrelation traces for the sinusoidal and short-pulse signals. As can be seen, the 11-comb lines provide a shorter duration of optical power than that of sinusoidal signal, thus a higher MMW output power and an improved signal-to-noise (S/N) ratio from our PT can be anticipated under the same operating current [5,9]. Figure 2 (c) shows the measured MMW output power from our PT versus different numbers of comb lines under a fixed output photocurrent (~5mA) and different reverse bias voltage. As can be seen, the photo-generated MMW power increases significantly with the number of comb lines and saturates when it reaches 4. Under the optimized bias voltage (-3V), the maximum enhancement in MMW power is around 4 dB with a number of 10 comb lines, which corresponds to around 1 ps pulse-width.

III.Measurement Result:

Figure 1 (b) shows a plot of the simulated/measured O-E responses of our full PTM module and the simulated/measured coupling loss from planar circuit to WR-10 waveguide. During measurement, the dipole-based radiator of both devices is inserted into the WR-10 waveguide to feed into the photo-generated MMW power. The other end of the waveguide is connected to a power sensor to record the frequency response. The frequency of the injected optical local-oscillator (LO) signal is swept from 60 to 130GHz and generated by the two-laser heterodyne beating system. As can be seen, an ultra-wide 3-dB O-E bandwidth (67-120GHz, 53GHz), which covers V, W, and D bands, and an extremely large fractional bandwidth (~57%) with a small coupling loss (<2dB) can be achieved simultaneously. Here, the coupling loss is defined by subtracting the measured power from PT, which has de-embedded around 1.5 dB high-frequency roll-off of NBUTC-PD chip at around 100 GHz, from the ideal photo-generated MMW power under a 100% optical modulation-depth and a 50 Ω load resistance close to the input impedance of our dipole-based feed. As can be seen, the measured coupling loss is even larger than 0 dB at a certain frequency range (100-110 GHz). This indicates a good impedance matching characteristic of our passive MMW circuit, which can over-compensate the high-frequency roll-off of NBUTC-PD chip. Furthermore, as compared to the reported taper-slot antenna coupled UTC-PD PT [10], our demonstrated device exhibits a much higher fractional bandwidth (57% vs. 24.2%). Figure 1 (c) illustrates the bias dependent IF modulation responses of our PTM under a fixed photocurrent (5mA) with different optical excitations (pulse and sinusoidal). We can clearly see that the measured 3-dB IF modulation bandwidth is the same around 15 GHz, which is large enough for 20 Gbps wireless data transmission. Figure 3 shows the measurement setup for 20Gbit/s OOK wireless data transmission. During this experiment, an optical MMW LO pulse or sinusoidal signal at 93GHz is transmitted through a 25 km single-mode fiber and injected onto our device by use of a lensed fiber. Meanwhile, the electrical IF data-stream (20-Gb/sec) is fed into the IF input port of the device through an on-wafer probe for bias modulation of the NBUTC-PD, and up-converted RF signal then fed into the WR-10 waveguide based horn antenna. The receiver end is composed of another W-band horn antenna and a fast power detector (VDI diode) with an 11GHz 3-dB bandwidth for detecting the envelope of received MMW power. The down-converted data-stream is then further amplified, recorded, and analyzed by an IF amplifier, high-speed sampling scope, and error-detector, respectively. Figure 4 (a) shows the measured –log (BER) at 20 Gbit/s (PRBS: 2^{15}-1) versus transmission distances under two different optical excitations (pulse and sinusoidal) and (b) shows the corresponding error-free 20 Gbps eye-patterns for pulse excitation. As can be seen, error-free 20 Gbps operation is achieved under a 20 cm wireless distance, a 25 km fiber transmission distance, and pulse excitations. Furthermore, the short pulse excitation offers a lower BER compared with the sinusoidal signal excitation due to that the improved MMW output power performance, as discussed in Figure 2. Compared with our previous work [11], the significant improvement in 20 Gbps BER performance can be attributed to the increase in the bandwidth of receiver (fast power detector) and output power performance of our PTM under pulse excitation.

IV.Summary:

In conclusion, we have demonstrated a NBUTC-PD based photonic transmitter-mixer with extremely wide O-E bandwidth (67-120 GHz) and very-high IMB (15 GHz). By use of this novel device and a short optical pulse (~1ps) train with an ultra-high repetition rate (93 GHz), 20 Gbps error-free OOK wireless data transmission has been successfully demonstrated for the first time.

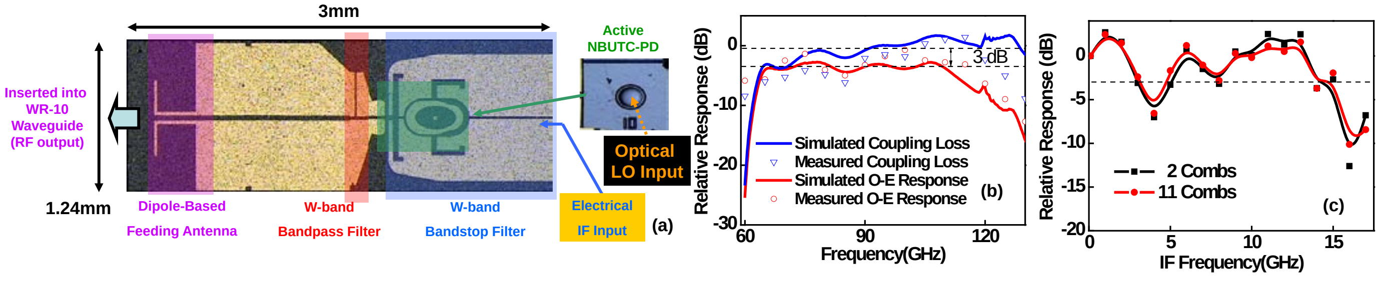


Figure 1. (a) Top-view of the demonstrated PT; (b) The simulated and measured O-E responses of full module and responses of coupling loss from planar circuit to waveguide; and (c) The measured IF modulation response.

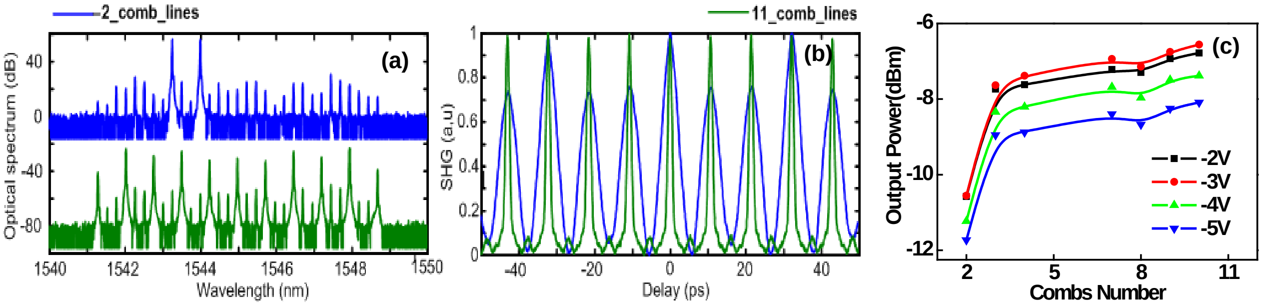
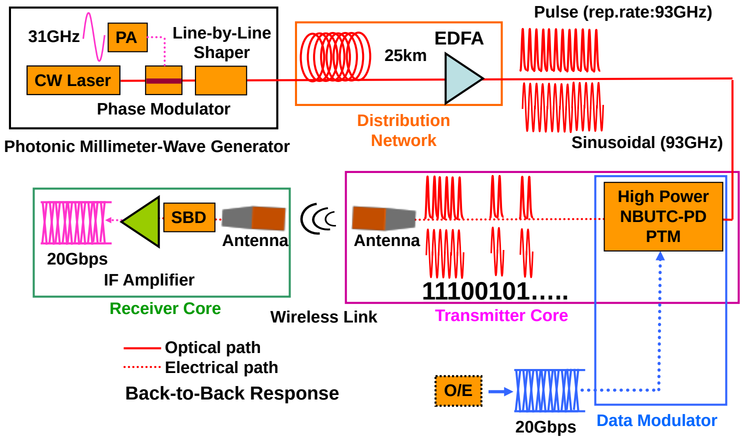


Figure 2. (a) The measured two-line and 11-lines optical spectrum; (b) The measured intensity autocorrelation traces for the sinusoidal (two-line) and short-pulse (11-comb lines) signals; and (c) The measured output MMW power versus different numbers of optical comb lines under different reverse bias voltages and a fixed output current (~5mA).



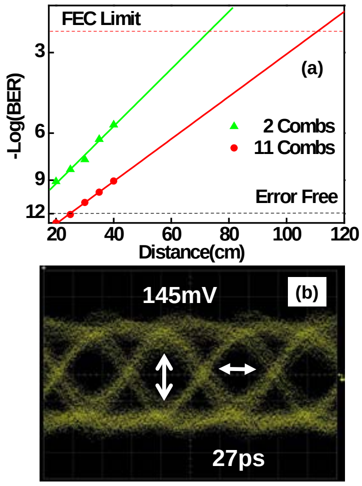


Figure 3. The measurement setup for 20 Gbps wireless data transmission. SBD: Schottky Barrier Diode. PA: power amplifier

Figure 4. (a) –log(Bit Error Rate) vs. transmission distance under different optical excitations (pulse and sinusoidal) during 20-Gb/s OOK data transmission; and (b) Measured 20 Gbit/sec eye-pattern under 12mA photocurrent and 20cm wireless transmission distance.

V. References:

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