25 Gbit/s Error-Free Wireless On-off-keying Data Transmission at W-band using Ultra-Fast Photonic Transmitter-Mixers and Envelop Detectors

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Abstract: By combing ultra-fast photonic-transmitter-mixers and envelop detectors with record-high modulation (26 GHz) and video bandwidths (37 GHz), respectively, error-free on-off-keying wireless transmission at W-band with data rate as high as 25 Gbit/sec can be achieved.

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I. Introduction

To boost the data rate for wireless transmission at carrier wave frequency up to hundreds of GHz attracts lots of attention [1] due to that it is a possible way to release the great famine of spectrum for wideband wireless communication [1,2]. By use of photonic technique, error-free on-off-keying (OOK) wireless data transmission with data rate as high as 20 and 16 Gbps have been demonstrated at W-band (75-110 GHz) [3] and 300 GHz [4], respectively. This data rate is limited by the modulation speed of photonic-transmitter-mixer (PTM) [3] or the bandwidth of millimeter-wave (MMW) envelop detector [3,4]. In order to further improve the total data capacity in the limited bandwidth, the complex modulation format is required. Recently, some research groups have demonstrated around 40 Gb/s data generation and de-modulation by use of the advanced modulation formats and photonic techniques at W-band (but without wireless transmission) [5] or at 60 GHz [6]. However, the bit-error-rate (BER) of de-modulated data in these previous works [5,6] is very-high, which means that the additional fast and complex real-time signal processing circuits are necessary to correct these errors and the true available date rate in the user-end should be reduced. In this paper, we demonstrate a photonic remotely up-converted [3] error-free 25 Gbit/s wireless OOK data transmission link at W-band by using novel photonic transmitters-mixer (PTM) and receivers both with state-of-the-art performances. By considering both the bandwidth and heat-sinking characteristics in our passive circuit design of PTM [7] and employing a collector thinning near-ballistic uni-traveling carrier photodiode (NBUTC-PD) [8], it simultaneously exhibits a ultra-wide intermediate frequency (IF) (26 GHz) and O-E bandwidths (68-128 GHz) with a high-saturation current (>18mA). Regarding with the envelope detector at W-band, it is composed of a miniaturized Schottky barrier diode (SBD) with an improved device package for wide video bandwidth. Under zero-bias operation, this detector exhibits a record video bandwidth as wide as 37 GHz and very-high sensitivity (~2500 mV/W) at W-band. By use of these two novel devices in transmitting and receiving ends and a simple two-laser heterodyne-beating MMW light source, we successfully demonstrate remotely up-converted error-free linking at W-band with record-high OOK data rate as 25 Gbps [4].

II. Measurement Setup and Device Structure

Figure 1 (a) and (b) shows the backside view and top view of our novel PTM module [7]. As can be seen, the demonstrated device is mainly composed of a diced NBUTC-PD with a 64 μm^2 active area and a dipole based radiator. Here, the epi-layer structure of integrated active NBUTC-PD is different from our previous work [1] and has been demonstrated in [8]. The collector layer in such new device is scaling down to 155 nm, which can greatly reduce the IF driving voltage during bias modulation, increase the extinction ratio of data, and enhance the output saturation power with a smaller DC bias voltage. In order to realize a fully integrated PTM module with both wide O-E and simultaneous up-conversion IF modulation bandwidth (IMB), we incorporated an additional W-band band stop filter (BSF) and band pass filter (BPF) with the dipole based radiator [3]. The simulated frequency responses for the scattering (S) parameters of the dipole based radiator, BPF, and BSF, are given in the insets to Figure 1. Compared with our previous work [3], there are two major differences in the new demonstrated passive structure. One is the backside metal on AlN substrate for better thermal sinking as discussed latter and the other is the improvement in the IF bandwidth of BSF. As shown in the inset to Figure 1 (b), the IF pass band bandwidth of our new designed BSF is much larger (30 vs. 10 GHz) than that of in our previous work [3], which indicates a significant improvement in the modulation bandwidth of our new demonstrated device [7]. Regarding with the MMW envelop detector (VDI diode, G-series), its picture is shown in Figure 3 (a). As can be seen, the whole packaged module is very compact and the input/output ports of launched MMW power and detected MMW envelop is WR-10 waveguide and K-connector, respectively. Compared with the commercial available model (VDI diode, WR-10 ZBD), our new design has a special designed housing to more compactly include the K-connector for minimizing the RC-delay time during envelop detection.

III.Measurement Results

Figure 2 (a) shows the measured optical-to-electrical (O-E) frequency responses of our PTM module. Here, the 0 dB reference point of all frequency responses shown here is defined as the output power from an ideal photodiode (i.e., infinite bandwidth) with a 50 Ω load, under an ideal sinusoidal optical source excitation (100% modulation depth), and with the same output photocurrent (4 mA) as that of the PTMs during measurement. The measured 3-dB O-E bandwidth of our device covers from 68 to 128 GHz, which covers all the available bandwidth of W-band (75-110 GHz) and the corresponding fractional bandwidth in our design is as wide as over 60% with a low coupling loss (<-3.5 dB). To the best of author's knowledge, this number should be the best among all the reported photonic transmitters [3,4]. Although there is around 2.6 dB peaking at 72.5 GHz, it is below the lower bound of W-band (75 GHz) and thus should not have a significant influence on the wireless data transmission. Figure 2 (b) shows the measured IF modulation frequency response of device under optimum DC bias voltage (-1.3 V). The simulated IF modulation frequency response is also shown here for reference. During measurement, the optical local oscillator (LO) frequency is fixed at 77 GHz and generated by the two-laser heterodyne beating technique. The output up-converted RF frequency (77 GHz + IF) is measured by a RF spectrum analyzer, which is connected with a down-convert mixer (OML, M10HWD). As can be seen, the measured 3-dB IF modulation bandwidth is around 26 GHz. Such value is near two (26 vs. 14 GHz [3]) times larger than our previous record of PTMs [3] due to the increase in its IF bandwidth of BSF as discussed in Figure 1. Figure 2 (c) shows the photo-generated MMW power versus photocurrent of our new PTM with backside metal. The measured MMW frequency is fixed at 93 GHz and the measurement result of PTM without backside metal [3] is also shown here for reference. The ideal line of photo-generated RF power from an ideal photodiode with a 50 Ω load is shown for reference. We can clearly see that with the backside metal, which can improve the heat-sinking of active PD, the saturation current can be significantly increased from 14 to >18 mA. Furthermore, compared with our previous work [3], because that the integrated NBUTC-PD in our new PTM has a much thinner collector layer (155 vs. 450 nm), it can achieve a higher saturation current under a lower reverse bias voltage (-2 vs. -4V). Figure 3 (a) shows the setup for the video bandwidth measurement. During such measurement, we inject two MMW signal; one is LO signal with a frequency fixed at 75 GHz and the other is radio-frequency (RF) signal with a frequency ranging from 75 to 110 GHz. Two input signals are combined in a W-band 3-dB coupler and the down-converted IF signal output from envelop detector is recorded by the RF spectrum analyzer. Figure 3 (b) shows the measured IF frequency responses of our new device (G-series) and the commercial available device (VDI diode, WR10 ZBD) for reference. As can be seen, the measured video bandwidth of our new device (G-series) is as wide as 37 GHz, which is much wider than that of commercial device (37 vs. 15 GHz). To the best of author's knowledge, the achieved video bandwidth should be the largest among all the reported MMW envelop detectors [4]. During our wireless transmission experiment, in order to simultaneously get the maximum bandwidth for double side-bands OOK signal, the optical LO frequency is chosen at the center of W-band (93 GHz), which corresponds to 17.5 GHz bandwidth for upper or lower side-bands. The extremely wide O-E and modulation bandwidths in our transmitting and receiving ends, as discussed, promises the maximum date rate of double side-band OOK signal can reach 25 Gbps. Figure 4 (a) shows the –log (BER) at 20 and 25 Gbit/s (PRBS: 2^{15}-1) versus transmission distances measured under a fixed output photocurrent at 15 mA. The corresponding error-free (BER < 10^{-12}) 20 and 25 Gbit/sec eye-patterns are given in Figure 4 (b). Here, we adopted a two-laser heterodyne beating system to generate optical LO signal and the detail measurement setup can be referred to our previous work [3]. Due to the limited bandwidth of W-band low-noise-amplifier in our receiver end, such component has been removed during 25 Gbps measurement. As can be seen, error-free 20 and 25 Gbit/sec operations are achieved for a 2.5 m and ~0.3 m wireless transmission distances, respectively.

IV.Summary

By using the transmitter and receiver both with state-of-the-art performance, we can successfully achieve error-free 25 Gbit/sec OOK wireless data transmission at W-band. Such data rate is limited by half of the maximum available bandwidth (17.5 GHz) at W-band (75-110 GHz) for double side-band OOK data transmission.

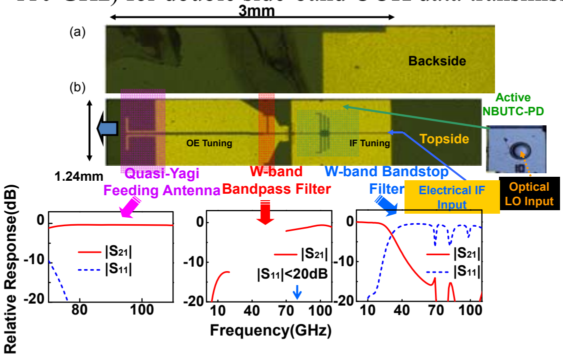

Figure 1. (a) Backside view of our PTM module; (b) Top-view of the novel NBUTC-PD based PTM. The insets give the simulated frequency responses of the scattering (S) parameters of the band-pass filter (BPF), band-stop filter (BSF), and dipole-based feeding antenna (FA).

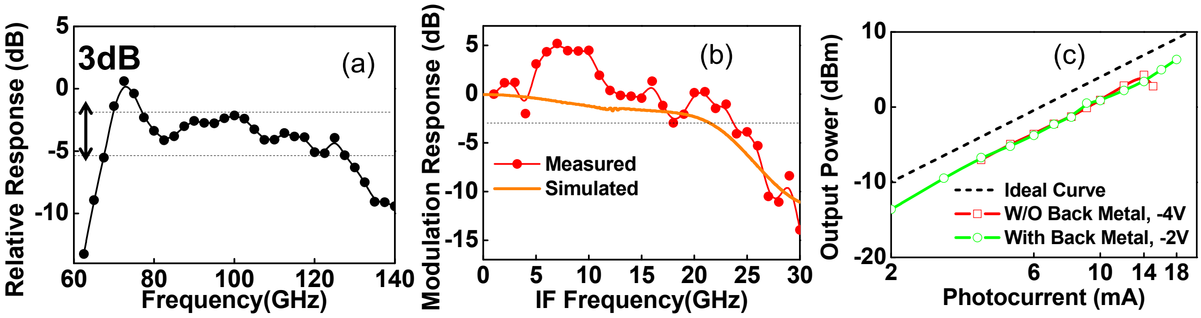

Figure 2. (a) Measured O-E response of our PTM module, (b) Measured/simulated IF (bias) modulation frequency response, and (c) Measured photo-generated MMW power at 93 GHz versus photocurrent from PTM modules with and without backside metal under -2 and -4 V bias, respectively.

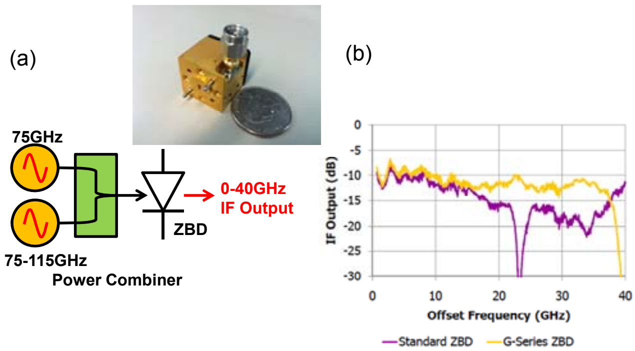

Figure 3. (a) The measurement setup for video bandwidth of fast power detector. The inset shows the picture of demonstrated G-series power detector; (b) The measured IF frequency response of commercial available device (WR-10 ZBD) and demonstrated device (WR-10 G-series)

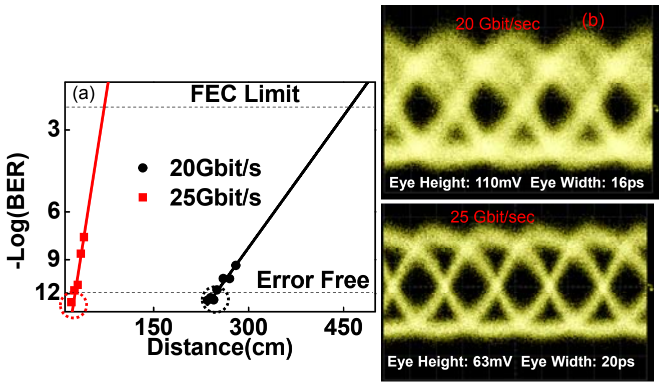

Figure 4 (a) The measured BER at 20 and 25 Gbps vs. wireless transmission distance; (b) The measured corresponding error-free eye-pattern at 20 and 25 Gbps data rate. The W-band LNA has been removed during 25 Gbps measurement. FEC: Forward error correction.

References:

[1] J.-W. Shi, C.-B. Huang, and C.-L. Pan, "Millimeter-wave Photonic Wireless Links for Very-High Data Rate Communication," *NPG Asia Materials*, vol. 3, No. 2, pp. 41-48, April, 2011.

[2] J. Wells, "Faster Than Fiber: The Future of Multi-Gb/s Wireless," *IEEE Microwave Magazine.* vol. 10, pp. 104-112, May, 2009.

[3] F.-M. Kuo, C.-B. Huang, J.-W. Shi, Nan-Wei Chen, H.-P. Chuang, John E. Bowers, and Ci-Ling Pan, "Remotely Up-converted 20 Gbit/s Error-Free Wireless On-off-keying Data Transmission at W-band using an Ultra-Wideband Photonic Transmitter-Mixer," *IEEE Photonics Journal,* vol. 3, no. 2, pp. 209-219, April, 2011.

[4] H.-J. Song and T. Nagatsuma, "Present and Future Terahertz Communications," *IEEE Trans. Terahertz Science Tech.,* vol. 1, pp. 256-263, Sep., 2011.

[5] D. Zibar, R. Sambaraju, A. Caballero, J. Herrera, U. Westergen, A. Walber, J. B. Jensen, J. Marti, and I. T. Monroy, "High-Capacity Wireless Signal Generation and Demodulation in 75- to 110-GHz Band Employing All-Optical OFDM," *IEEE Photon. Technol. Lett.,* vol. 23, No. 12, pp. 810-812, June, 2011.

[6] W. J. Jiang, C. T. Lin, L. Y. Wang He, C. C. Wei, C. H. Ho, Y. M. Yang, P. T. Shih, J. Chen, and S. Chi, "32.65-Gbps OFDM RoF Signal Generation at 60GHz Employing an Adaptive I/Q Imbalance Correction," *36nd European Conference on Optical Communication (ECOC 2010)*, Torino, Italy, Sep. 19-23, 2010, Paper Th.9.B.5.

[7] J.-W. Shi, F.-M. Kuo, Hsuan-Ju Tsai, Y.-M. Hsin, Nan-Wei Chen, H.-C. Chiang, H.-P. Chuang, C.-B. Huang, and Ci-Ling Pan, "High-Power Photonic Transmitter-Mixer with Ultra-Wide O-E (50 GHz) and IF (26 GHz) Modulation Bandwidths for Wireless Data Transmission," to be published in *2011 Int. Topical Meeting Microwave Photon.,* Singapore, Oct., 2011.

[8] J.-W. Shi, F.-M. Kuo, Mark Rodwell, and J. E. Bowers, "Ultra-High Speed (270 GHz) Near-Ballistic Uni-Traveling-Carrier Photodiode with Very-High Saturation Current (17 mA) under a 50 Ω Load," to be published in *IEEE Photonic Society Meeting 2011, Arlington,* VA, USA, Oct., MC 2.