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100 GHz RoF System Based on Two Free Running Lasers and Non-coherent Receiver

Ramin Khayatzaeh, Hamza Hallak Elwan, Julien Poette and Beatrice Cabon

Abstract—A 100 GHz radio over fiber (RoF) system based on two free running distributed feed back (DFB) lasers at the transmitter and a non-coherent receiver is proposed and experimentally demonstrated. Different modulation techniques such as QPSK, 16QAM and OOK for the data rate of more than 1 Gbps have been demonstrated for this RoF system. At the central station, one of the two modes is intensity modulated using external modulator and then the two modes propagate through single mode fiber to the base station. The millimeter wave at 100 GHz is produced by heterodyning of two optical modes at a pin photo-diode. At the receiver, an envelope detector (ED) has been used in order to down-convert data to intermediate frequency (IF). The experimental results show that the impact of phase and frequency instability of the system based on two free running lasers on Error Vector Magnitude (EVM) for the communication system based on non-coherent detection is completely vanished.

Index Terms—Envelope detector, Error Vector Magnitude (EVM), Distributed Feedback Laser (DFB), phase noise, Radio-over-Fiber (RoF).

I. INTRODUCTION

FUTURE wireless communication systems will utilize carriers at millimeter wave (mm-wave) frequencies to overcome the saturation of different frequency bands in combination with very high bit rates. In this field, W frequency band is attracting more attentions due to its wide available bandwidth (75-110 GHz). There are many applications using W frequency band such as; satellite communication, W band radar research, radar targeting and tracking and also non military applications for high data rate systems ([1]-[3]).

Mm-wave signal's generation and delivery difficulties bring research works to use microwave-photonics systems such as RoFs. RoF system suggests optical fiber as a solution for loss and bandwidth limitations of the other propagation mediums at mm-wave frequencies. In RoF systems, the two or more optical modes with the frequency distances equal to mm-wave frequency range are produced at the central station (CS) using lasers, and then transmitted through the optical fiber to the base stations (BS) where utilizing heterodyne receiver the mm-wave carrier is generated. Then, from the BSs the wireless delivery of the mm-wave signal to the mobile stations is performed. One of the main issues of the mm-wave frequency generation using heterodyning technique is the phase noise and frequency instability of the generated carrier signal. In order to remove this problem many techniques have been developed. These techniques can be divided into two main groups. The techniques in group one are those that focus on stabilizing the lasers or the transmitter by using phase locked loops at the

transmitter to stabilise the lasers' modes frequency distance [7] or by using phase mode locked lasers such as passively mode locked lasers [8]. The techniques of the second group are those using which one can remove the impact of phase noise from the received signal, for example, by using a non-coherent down-conversion technique [9] or phase recovery techniques [10].

In this paper, a 100 GHz RoF system based on two free running DFB lasers and a non-coherent detector are presented. Many RoF systems based on coherent detection at W band have been studied recently ([4]-[6]) but few works contributed to RoF in W band using non-coherent receiver, to our acknowledge. Using a non-coherent receiver at the receiver side, we could successfully overcome the phase fluctuations caused by two free running lasers in this communication system. Furthermore, using non-coherent receiver the down-conversion is done without utilizing any local oscillator at 100 GHz which highly reduces the cost and complexity of the system.

This paper is organized into four sections. Following section I, the experimental setup is given in section II. In section III, the obtained results are under discussion. And Finally, the paper is concluded in section IV.

II. EXPERIMENTAL SETUP

Experimental setup of the proposed RoF communication system based on two free running DFB lasers and non-coherent receiver is illustrated in Fig. 1. In order to generate the signal at 100 GHz in the system presented in this figure, two DFB lasers (# 1 and # 2) are used and the frequency distance between the two modes is controlled by two temperature controllers (TC1 and TC2). An Mach-Zehnder modulator (MZM) is used to modulate the light at the output of laser # 2 externally. The data at IF is applied to the MZM using an Arbitrary Waveform Generator (AWG) that is able to generate signals with different modulation schemes such as; 16QAM, QPSK and OOK. A variable optical attenuator (VOA) is placed before the photo-diode, so that total input optical power of the photo-detector and the electrical power at the input of envelope detector (ED) can be controlled. The optical mode beating is done using a pin photo-diode of 100 GHz bandwidth, which also acts as a filter for higher order mode beatings. The IF is set at 4.5 GHz so the beating between the laser # 1's mode and the upper side band of the signal at the output of MZM will generate a frequency at 95.5 GHz at the output of the photo-diode. At the receiver, a zero bias ED (75-110 GHz), utilizing schottky barrier beam lead diode, is used to down convert the signal from mm-wave frequency to IF. Before the ED a W-band low noise amplifier (LNA) is used to increase the signal level so that the ED can detect the signal.

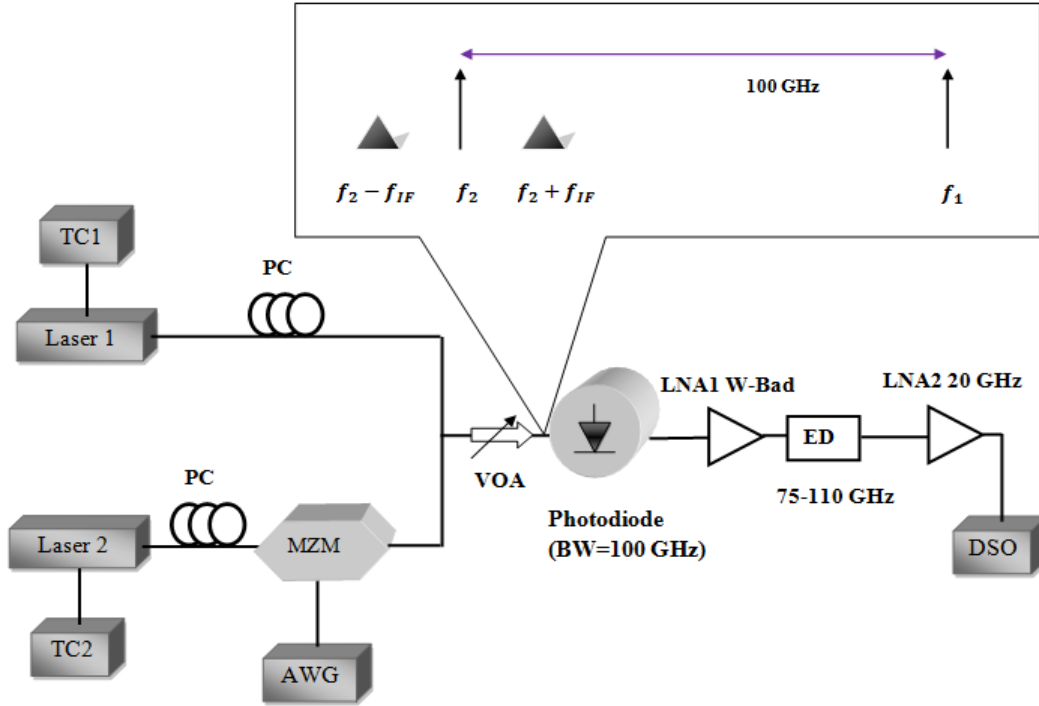


Fig. 1. Experimental setup of RoF communication system based on two DFB lasers and non-coherent receiver, TC: Temperature Controller, PC: Polarization Controller, MZM: Mach-Zehnder Modulator, AWG: Arbitrary Waveform Generator, VOA: Variable Optical Attenuator, LNA: Low Noise Amplifier, ED: Envelope Detector, DSO: Digital Storage Oscilloscope.

EVM values of the down-converted signal are measured using Vector Signal Analyzer (VSA) installed on digital storage oscilloscope (DSO) with sampling rate of 20 Gsps.

III. RESULTS AND DISCUSSION

The system performance is verified for various bit rates and received optical powers. For a fixed length of optical fiber, the received optical power is varied by changing attenuation value of the VOA and the EVM values are monitored by plotting them versus different values of the received optical power. Using this technique, one can determine impact of different noise on the performance of the RoF system under test. This technique is well studied in [11], where we proposed a method to determine the origin of the noise which has the most impact on EVM. This method is based on analyzing the trends of EVM versus received optical power using (1) [12]:

$$EVM = \sqrt{\frac{1}{SNR} + 2 - 2 \exp\left(\frac{-\sigma^2}{2}\right)} \sqrt{\frac{1}{PAPR}} \quad (1)$$

where SNR is signal to noise ratio, σ is rms value of phase noise and PAPR is the peak to average power ratio for the considered modulation scheme. In an RoF system the SNR can be modelled as follows:

$$SNR = \frac{R^2 P_{opt}^2}{\frac{4kTF\Delta f}{R_L} + 2qRP_{opt}\Delta f + 10^{RIN/10} R^2 P_{opt}^2 \Delta f} \quad (2)$$

where k: Boltzmann constant, T: temperature, Δf : received signal bandwidth, F: amplifier noise figure, q: electron charge,

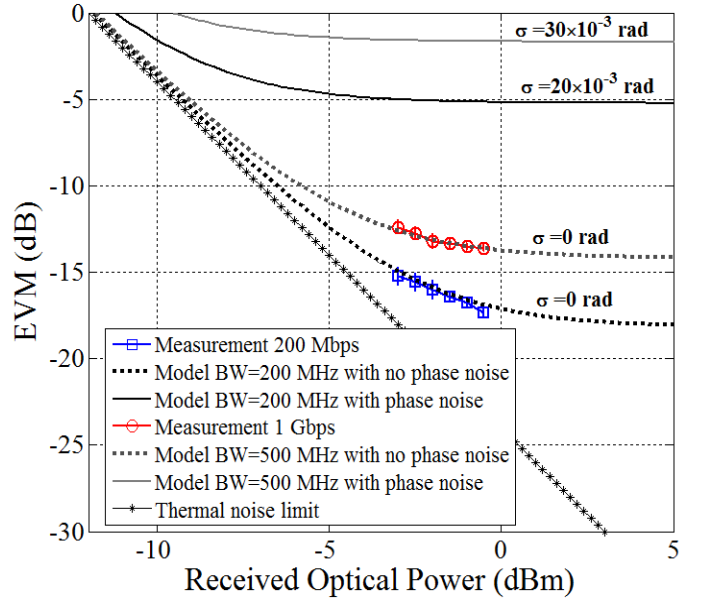


Fig. 2. EVM versus received optical power for RoF system at 100 GHz and 16QAM modulation scheme.

P_{opt} : received optical power, RIN: relative intensity noise and R_L is the load resistance. By substituting SNR to (1), one can model the EVM for an RoF system.

Fig. 2 shows the trend of EVM values versus received optical power for different scenarios. The EVM values are measured at 200 Mbps (square points) and 1 Gbps (circle

points) for 16QAM modulation scheme and IF of 4.5 GHz. It can be seen that for the same received optical power, the EVM value for 200 Mbps (-17 dB for -0.5 dBm optical power) is much lower than the EVM value for 1 Gbps (-14 dB for -0.5 dBm optical power). The reason the EVM value increases is that for measuring EVM for the signals with higher data rates we need to increase the bandwidth of the VSA while receiving the same optical power which reduces SNR. For example, for data rate of 200 Mbps the VSA's bandwidth is set to 200 MHz while for 1 Gbps its bandwidth is set to 500 MHz. As can be seen in this figure, the models with no phase noise impact (phase noise variance $\sigma = 0$) well match the measurement results for both 200 Mbps and 1 Gbps data rates. By setting σ to 20×10^{-3} rad and 30×10^{-3} rad, which correspond to rms phase jitter of a signal generator with broadband phase noise equals -120 dBc/Hz over 200 MHz and 500 MHz bandwidths [13], one can see that for the same received optical power the EVMs are increased to much higher values, especially for large values of received optical power. This shows that using the non-coherent receiver in this RoF system we could successfully overcome the phase noise impact on performance of the system. In this figure, the star point line shows the EVM evolution versus the received optical power when there is no phase and no optical (RIN, shot) noise impact on the received signal. In this case, the only noise that impacts the performance of the system is the receiver thermal noise.

The constellation diagram of the detected signal is presented in Figure 3 (A) for 16QAM modulation scheme with 200 Mbps and (B) QPSK modulation scheme with data rate of 1 Gbps. Observing the constellation diagram, we can see that the phase noise impact on the received symbols are vanished using non-coherent receiver, as it is expected. The system performance is also tested for OOK modulation scheme. The eye diagrams of the detected signal are presented in Figure 4 for different data rates (A) 100 Mbps (B) 400 Mbps (C) 1 Gbps (D) 2 Gbps. The results are showing well open eye upto 1 Gbps. By increasing the data rate to 2 Gbps, the eye opening is reducing which is caused by the limited bandwidth of the ED.

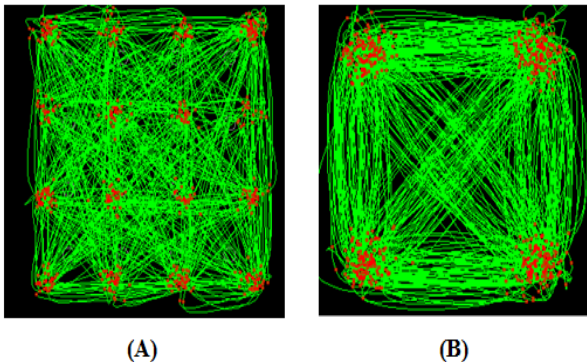


Fig. 3. Constellation diagram of the detected signal (A) 200 Mbps 16QAM (B) 400 Mbps QPSK.

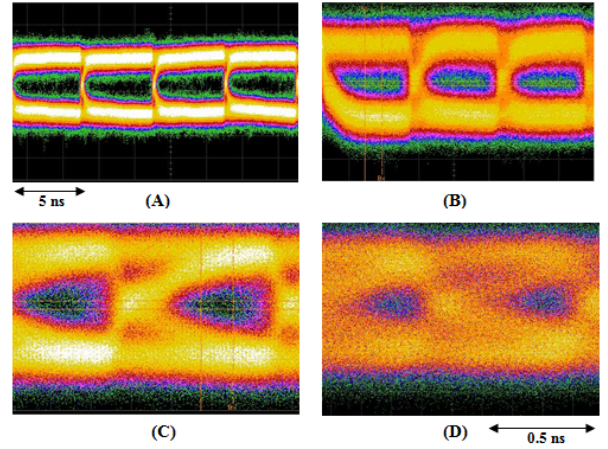


Fig. 4. Eye diagram of the detected signal (A) 200 Mbps (B) 400 Mbps (C) 1 Gbps (D) 2 Gbps.

IV. CONCLUSION

In this paper, we propose a 100 GHz RoF communication system based on two free running DFB lasers and a non-coherent receiver. Different digital modulation schemes such as 16QAM, QPSK and OOK are successfully tested for the data rates of more than 1 Gbps using the proposed communication system. The phase noise impact on the performance of the system is completely vanished using non-coherent receiver. The simplicity of the proposed communication system comparing to the systems based on coherent detection, in which different stabilisation techniques are needed to stabilize the mm-wave carrier, is a further strength point of this system.

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