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2.5 Gbps Millimeter-Wave Radio over Fiber Transmission based on Dual Octupling of RF Local Oscillator

K. Esakki Muthu* and A. Sivanantha Raja**

ABSTRACT

A 2.5 Gbps Millimeter wave Radio over Fiber (MMW-RoF) system based on a novel dual octupling the local oscillator frequency is proposed and demonstrated. Two cascaded Mach-Zehnder Modulators (MZM) and an optical 1x4 WDM-Demultiplexer are used to select the desired frequency for the generation of dual-octupling frequency. Dual octupling allows the central station (CS) to use single laser source for transmitting data for the two base stations. Thus requirement of the CS is simplified with independent data rates. In this work a 5 GHz RF local oscillator frequency is octupled and 2.5Gb/s data is transmitted over 100 km SMF. The simulation results shown better BER performance with less than 0.3 dB dispersion induced power penalty.

Keywords: MM-Wave Generation, Radio over Fiber, Mach-Zehnder Modulator.

1. INTRODUCTION

Use of Millimeter Wave bands resolves the spectral congestion issues in the microwave band and provides 270 GHz bandwidth. An optical fiber is an excellent transmission medium with numerous benefits such as huge bandwidth, no EMI and low loss. An integration of Millimeter wave and optical fiber network is very essential to realize high speed and high performance communication networks to support increasing bandwidth needs from both wired and wireless customers. However, MM-Wave generation above 30 GHz is costlier with limited stability due the poor frequency response of the conventional electronics [1] [2]. Hence optical generation of MM-Wave has been proposed. Several techniques have been demonstrated for the generation based on direct modulation and external modulation. In spite of its simplicity, the direct modulation suffers from lower modulation bandwidth and frequency chirping effect [3]. The external modulation based frequency multiplication is found attractive due to its higher modulation bandwidth, stability, less phase noise and tunability [4] [5]. Several frequency multiplication techniques have been demonstrated such as frequency doubling [5], quadrupling [6], [7], [8], sextupling [9-11], octupling [12], [13] and so on. However, a cost effective design of Central Station is a major challenge. To achieve this, a dual quadrupling proposed in [14], dual sextupling in [15] and dual octupling in [16] serves two base stations simultaneously. But the use of too many FBGs and Interleavers involved in selecting the desired sidebands make the system complex and costlier. In this paper, we propose a novel dual octupling technique with the help of two cascaded MZMs and WDM De-multiplexer. This technique utilizes less number of components and allows the CS to serve two BS simultaneously with independent data rates. And thus reduces the cost and complexity of the system.

Structure of the paper is as follows, section II describes the mathematical principle of the proposed scheme, section III demonstrates the transmission performance of the proposed scheme and section IV presents the conclusion.

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* University VOC. College of Engineering, Thoothukudi–628008, India, *Email: esaionly@gmail.com*

** A.C. College of Engineering & Technology, Karaikudi–630003, India.

2. PRINCIPLE

Fig. 1 shows the block diagram of the proposed scheme for the generation of dual octupling. A continuous wave DFB laser light $E_o(t) = E_o e^{j\omega ct}$ is injected in to the MZM1 which is biased at the null point. E_o is the field amplitude and ω_c is the angular frequency. The transfer function of MZM the can be written as,

$$E_{MZM}(t) = \frac{Eo}{2} e^{j\omega_c t} \left[e^{j\frac{\pi V_{rf}}{V_\pi} + j\frac{V_{b2}}{V_\pi}} + e^{-j\frac{\pi V_{rf}}{V_\pi} + j\frac{V_{b1}}{V_\pi}} \right] \tag{1}$$

where V_{rf} is the RF amplitude, V_π is the switching bias voltage, V_{b1} and V_{b2} are the bias voltage of the upper and lower arms respectively. The output of the MZM1 is sent in to the MZM2 which is symmetrically biased as MZM1. Both MZM1 and MZM2 are driven by a RF local oscillator with 180 degrees phase shift between the electrodes. The output after the MZM2 can be expressed as,

$$E_o(t) = E_{MZM1}(t) * E_{MZM2}(t) \tag{2}$$

The output optical field of the MZM1 can be shown as,

$$E_{MZM1}(t) = \frac{Eo}{2} e^{j\omega_c t} \begin{bmatrix} e^{jm\sin(\omega_m t)} \\ -e^{-jm\sin(\omega_m t)} \end{bmatrix} \tag{3}$$

where $m = \square\pi V_{rf}/V_\pi$ is the modulation index. Using Bessel function, eqn. (3) can be expressed as,

$$E_{MZM1}(t) = E_0 e^{j\omega_c t} \sum_0^\infty J_{2k+1}(m) \sin(2k+1)\omega_m t \tag{4}$$

Similarly, the output of the MZM2 can be written as,

$$E_{MZM2}(t) = \frac{Eo}{2} e^{j\omega_c t} \begin{pmatrix} e^{jm\sin(\omega_m t + \pi/2)} \\ -e^{-jm\sin(\omega_m t + \pi/2)} \end{pmatrix} \tag{5}$$

Using Bessel function eqn. (5) can be expressed as,

$$E_{MZM2}(t) = E_0 e^{j\omega_c t} \sum_0^\infty J_{2k+1}(m) \sin(2k+1)\omega_m t + \frac{\pi}{2} \tag{6}$$

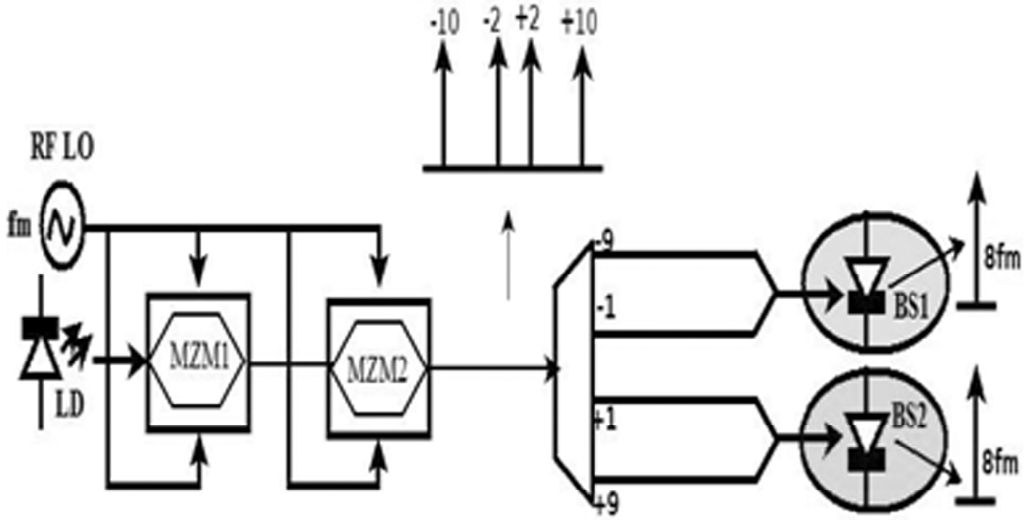

Figure 1: Block diagram of the proposed model

where *J*(*) is the Bessel function of the first kind. Finally the output can be expressed as,

$$\begin{aligned} E_o(t) &= E_0 e^{j\omega_c t}\sum_0^\infty J_{2k+1}(m)\sin(2k+1)\omega_m t \\ &*\sum_0^\infty J_{2k+1}(m)\sin 2k+1\left(\omega_m t+\frac{\pi}{2}\right) \end{aligned} \tag{7}$$

Simplifying the above equation results,

$$E_o(t) = E_0 e^{j\omega_c t}\begin{Bmatrix} -J_1^{\,2}(m)\cos(2\omega_m t+\pi) \\ -J_3^{\,2}(m)\cos(6\omega_m t+3\pi) \\ -J_5^{\,2}(m)\cos(10\omega_m t+5\pi) \\ -J_7^{\,2}(m)\cos(14\omega_m t+7\pi) \end{Bmatrix} \tag{8}$$

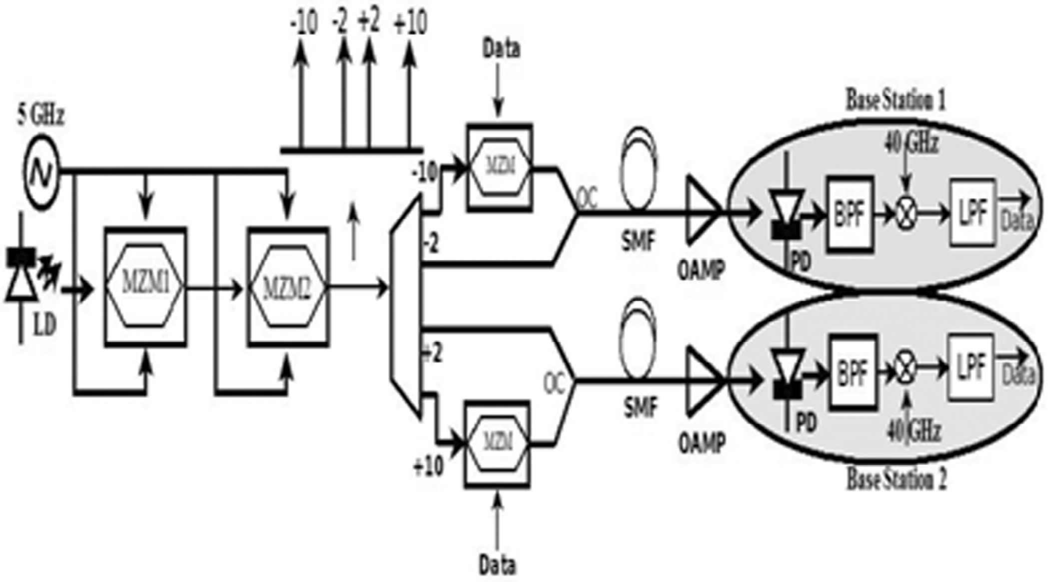

Figure 2: The simulation experimental setup

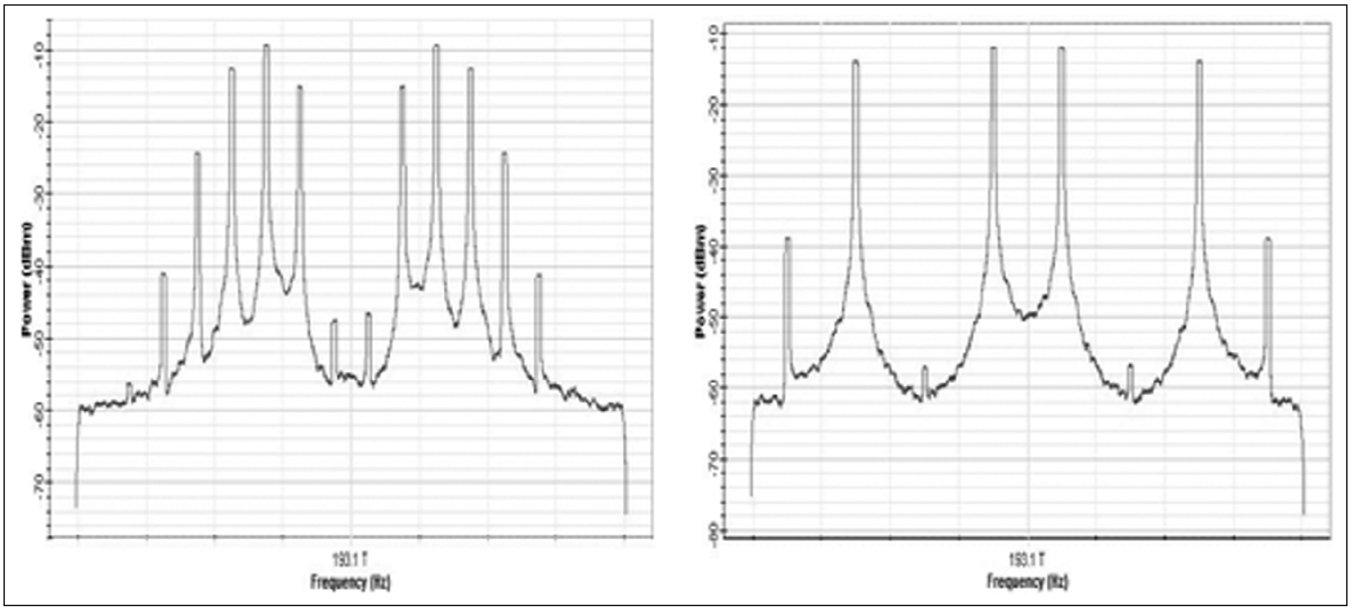

Figure 3: optical spectra after a) MZM1 and b) MZM2

The above eqn. (8) clearly shows that, there are only second, sixth, tenth and fourteenth order terms. The proper selection of the modulation index maximizes the second and Tenth order sidebands and suppresses other sidebands. The positive second and tenth order sidebands are selected to beat at the photo-detector to generate octupling at the BS1. Negative second and tenth order sidebands are allowed to beat at the photo-detector to another octupling at the BS2.

3. SIMULATION EXPERIMENT AND RESULTS.

The schematic of the proposed technique for the dual octupling is shown in Fig. 2. The entire system is simulated using Optisystem^{TM} 12 simulation tool. A continuous wave laser of 193.1 THz with 10 MHz spectral width is injected into the MZM1 whose electrical input arms are is driven by a 5 GHz RF local oscillator with 180^{o} phase shift between it. The MZM is biased at the null point by setting a switching RF voltage to 4V and the half wave voltage to 2V. The modulation index is set to 7.0293. Output of the MZM1 is shown in fig. 3a. It contains only odd order sideband such as ±1, ±3, ±5, ±7 and ±9. Then the resultant field is applied to the MZM2 which is symmetrically biased as MZM1. Due to symmetrical biasing conditions, the output of the second all sidebands are well suppressed except ±2 and ±10 order sidebands. The output spectrum of the MZM2 is shown in the fig. 4b. The lower sideband field component appears at 193.09 THz and 193.05 THz with a frequency difference of 40 GHz, which the eight fold of the input local oscillator. In the same manner, the higher sideband peaks at 193.10 THz and 193.15 THz. A 4x1 WDM de-multiplexer is used to separate the desired sideband as described. In the upper sideband spectrum the data is modulation over +10 order sideband. In the lower sideband spectrum the data is over -10 order sideband the corresponding optical spectra are shown in fig. 4a and 4b. The data modulated signals are then transported to the two different BSs over a 100 km Single Mode Fiber with 0.2 dB/km attenuation and 17.5ps/ (nm-km). An optical amplifier is used to compensate the fiber losses at the link. At the BS, a PIN photo detector with 0.7 A/W is used to detect the signal. After the detection, the signal is passed through a electrical band pass filter to remove unwanted spurious spectra. The filtered signal is then passed through a mixed, where a 40 GHz local oscillator is mixed with. The down converted signal is low pass filtered and sent to the BER tester.

The BER performance of the proposed scheme is shown in fig. 6 and 7. The received power is varied using a variable attenuator and the corresponding variations in the BER are noted down. Performance of the both the BSs are remarkable since the data is modulated over only one of the sidebands of the dual

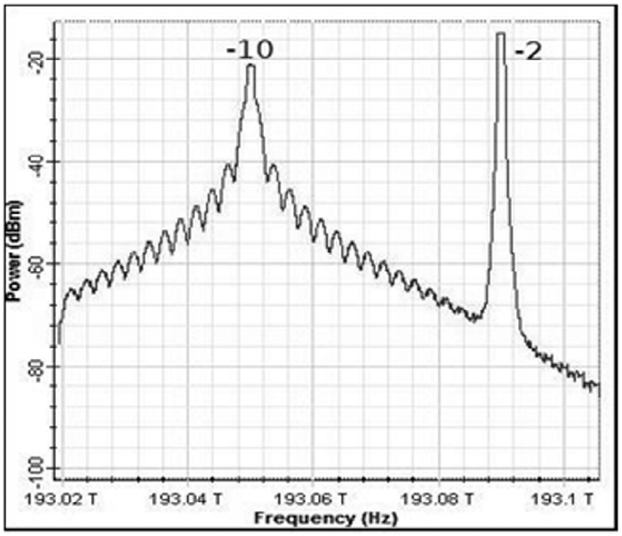

Figure 4: Data Modulation over lower octupled optical MM-Wave Spectrum

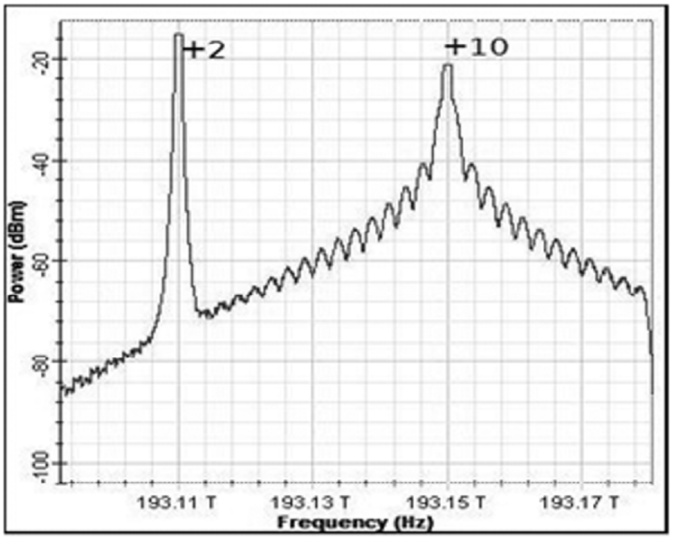

Figure 5: Data Modulation over upper octupled optical MM-Wave Spectrum

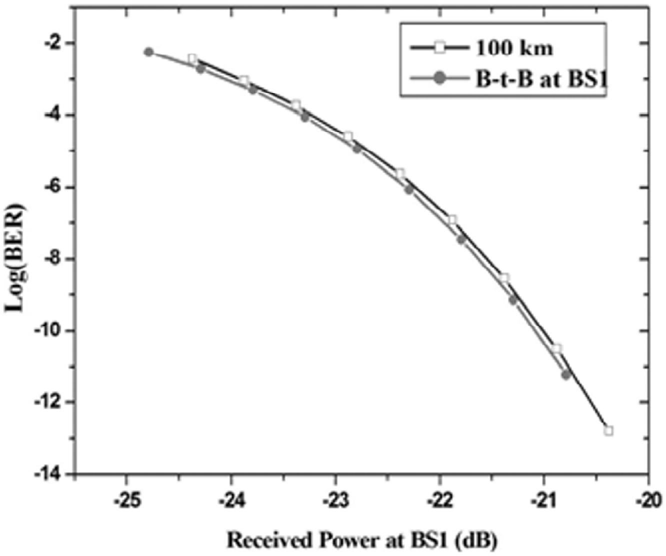

Figure 6: BER performance at the Base Station1

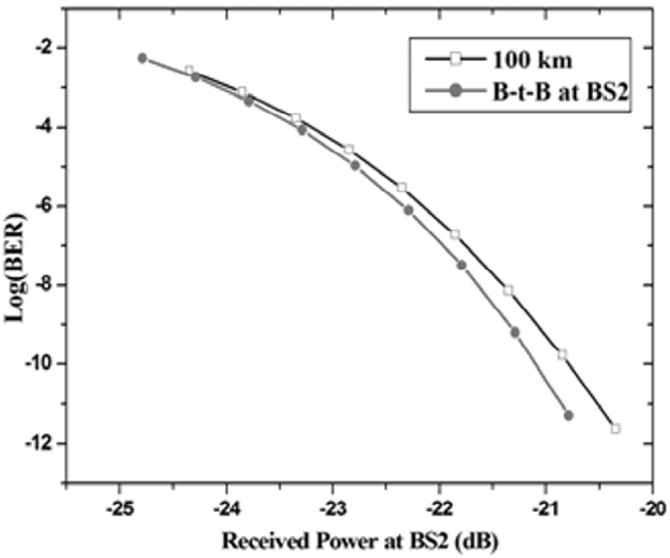

Figure 7: BER performance at the Base Station 2

octupled MM-Wave signal. Hence the dispersion induced power fading as well as the bit walk-off effects are eliminated. The power penalty due to dispersion is about 0.3 dB for both the BSs.

4. CONCLUSION

In this paper, we have proposed a novel frequency dual octupling technique using two cascaded MZMs. Both the MZMs are biased at the null point. With the proper adjustment of the phase, amplitude and MZMs biasing parameters the dual octupling is generated. The BER performance of the scheme is better even after 100 km with very low dispersion induced power penalty. This technique allows us to transmit independent data rates to the two different BSs using the same infrastructure. Hence the CS is greatly simplified in-terms of cost and complexity.

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