



A NOVEL SCHEME FOR OPTICAL MILLIMETER WAVE GENERATION USING MZM

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ABSTRACT

This paper proposes a radio-over-fiber system which employs a frequency multiplier scheme to generate optical millimetre wave (MMW) based on external modulation performed using two cascaded Mach-Zehnder modulators. By adjusting the direct current bias voltages of intensity modulator, modulation voltage and phase, the frequency quadrupling optical MMW signal is generated. The performance of the scheme is verified by transmitting the signal along the fiber over a distance of 40 km in terms of bit error rate (BER) performance and received power. The eye diagram is wide open and BER values are low for a data rate of 2.5 Gbps.

Keywords: millimeter wave, intensity modulator, electro-optic modulator.

INTRODUCTION

In the past few years the ever increasing demand for high frequency and broadband mobile applications has resulted in the need for optimal methods to generate MMW and terahertz wave in the field of photonics. Since the topic of MMW and microwave generation finds application in various fields including spectroscopic sensing, radar, medical imaging and modern instrumentation, it has become an active area of research (Seeds and Williams, 2006). The main reason to employ the principle of optics is that it offers wide bandwidth and large tunability when compared to an electrical system for the generation of high frequency electrical signal (Yao, 2009). Moreover MMW radio-over-fiber is a promising technique for data transmission and reception in the broadband wireless communication system. The common photonics methods employed for optical MMW and microwave signal generation includes optical injection locking between a pair of laser diodes (Goldberg *et al.*, 1983), direct beating of dual wavelength source (Sun *et al.*, 2006) and a non linear modulation technique (Li and Yao, 2010a) Among the above photonic wave generation methods, microwave generation based on external modulation offers significant advantages including wide frequency tunability, system reliability and high spectral purity (Li and Yao, 2010b).

PRINCIPLE OF OPERATION

In the proposed method the MMW signal is generated optically using the concept of frequency multiplication assisted by external modulation. It is widely used for various applications such as broadband applications, phase-array antennas, optical sensors, antenna remoting and radars. When compared to conventional electronic approaches, the generation of optical MMW signals offers wide range of frequency tunability. The optical fiber which is used as a medium for MMW signal generation has unlimited bandwidth and very low propagation loss. The advantage of using this approach is that it provides high spectrum purity and low-phase noise MMW when compared to its electrical counterpart. The proposed method generates optical quadruple frequency signal by using two cascaded electro-optic modulators. Moreover generation of millimetre wave signal in optical domain using external modulation is more stable and preferred for long distance data transmission (Anand Prem, *et al.*, 2017).

PROPOSED METHOD AND EXPERIMENTAL SETUP

A schematic view of the optical MMW generation using external modulation scheme is presented in Figure-1 while that of the base station is given in Figure-2. Initially an electrical driving signal is applied to the optical Lithium Niobate Mach-Zehnder modulator (LiNbO_3 MZM), which is biased to suppress both the carrier signal and the even order optical

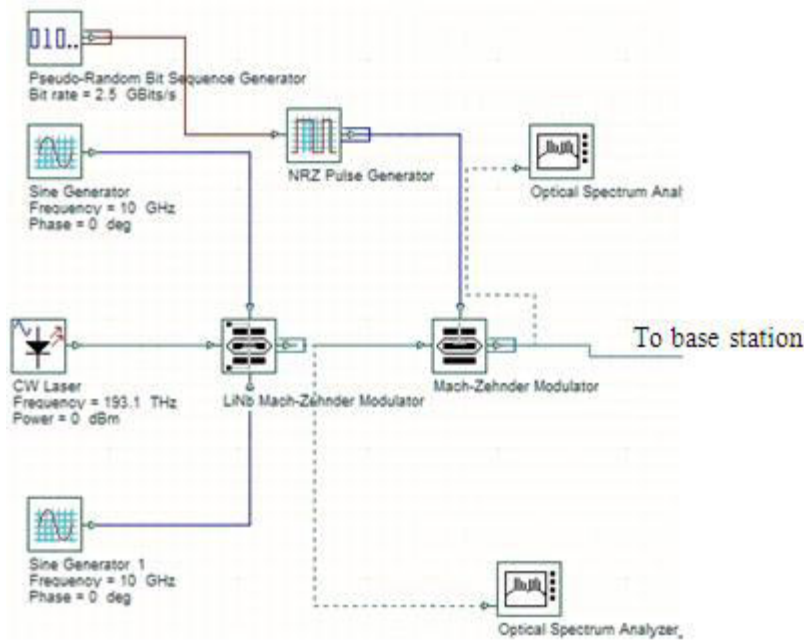


Figure-1. Experimental setup of central station.

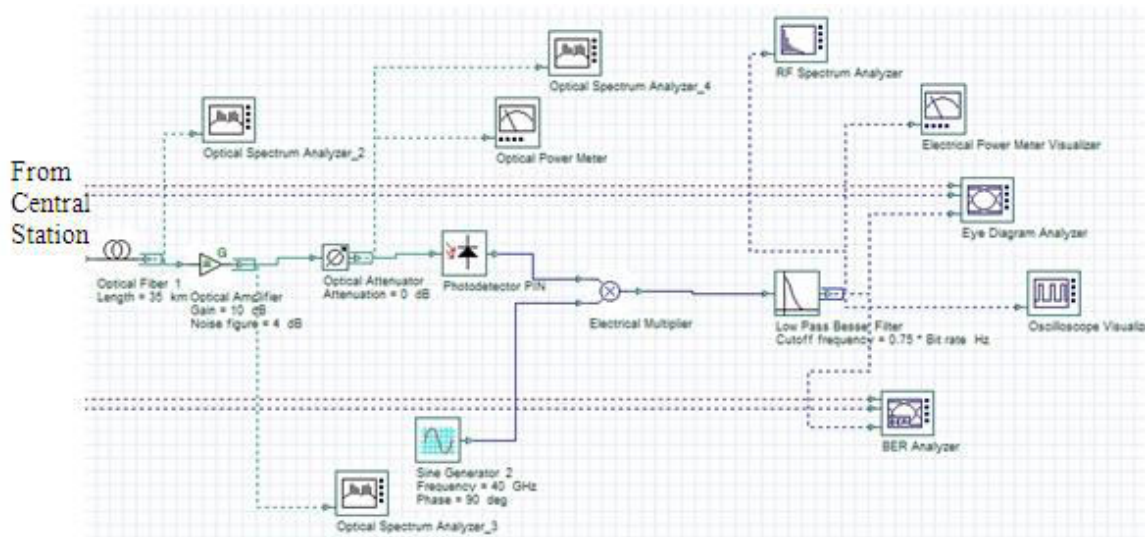


Figure-2. Experimental setup of base station.

sidebands such that the resultant signal possesses the difference which is four times the electrical driving signal. The driving signals having the same frequency but different in phase deviation. The phase deviation of φ is introduced in second driving signal.

A carrier signal with frequency ω_c is applied to an intensity modulator called LiNbO_3 MZM modulator. By varying the bias voltage of the modulator the even order optical sidebands and the carrier signal are suppressed so that only the first order sidebands are preserved. The modulated signal having coherent carriers in frequency $\omega_0 - \omega_c$ and $\omega_0 + \omega_c$, where, $\omega_0 - \omega_c$ is the frequency of laser source.

The electric field applied as input to the modulator is given as

$$E_{in}(t) = E_0 \cos(\omega_0 t)$$

While the voltage of the MM wave signal can be expressed as,

$$V_1(t) = V_e \cos(\omega_c t + \varphi_1)$$

Where E_0 , is the electric field amplitude while V_e and φ_1 are amplitude and phase of the electrical signal respectively. After varying the bias voltage value of the modulator in order to suppress all the even order optical sidebands, the electric field output of the modulator can be expressed by,

$$E_{out1}(t) = E_0 \cos(\omega_0 t) \cos \left[\frac{\pi}{2} + \beta_1 \cos(\omega_c t + \varphi_1) \right]$$



$$\approx J_1(\beta_1)E_0\{\cos[(\omega_0 - \omega_c)t - \varphi_1] + \cos[(\omega_0 + \omega_c)t + \varphi_1]\}$$

Where $\beta_1 = \frac{V_e}{V_{\pi 1}} \cdot \frac{\pi}{2}$, is the phase modulation index of the first MZM

J_1 is the first order Bessel function of the first kind, β_1 is the phase modulation index,

φ_1 and φ_2 is the initial phase of the microwave signal applied to the first and second modulator respectively. V_{e1} and $V_{\pi 2}$ are the amplitude and half-wave voltage of the second modulator.

$V_{\pi 1}$ is the half wave voltage of the modulator. The signal from the first modulator is modulated by the next modulator by a millimeter wave signal with the frequency ω_c and phase of φ_2 . The phase shift between the two signals is $\varphi_2 - \varphi_1$. Also the second intensity modulator is biased to completely suppress the carrier signal, so that the two first order sidebands with centre frequency $\omega_0 - \omega_c$ and $\omega_0 + \omega_c$ are preserved.

The voltage of the second modulator driving signal can be expressed as

$$V_2(t) = V_{e1} \cos(\omega_c t + \varphi_2)$$

The electric field at the output of second modulator can be expressed as,

$$E_{out2}(t) \approx J_1(\beta_1)J_1(\beta_2)E_0 \cos[(\omega_0 - 2\omega_c)t - \varphi_1 - \varphi_2] + J_1(\beta_1)J_1(\beta_2)E_0 \cos[(\omega_0 + 2\omega_c)t + \varphi_1 + \varphi_2] + 2J_1(\beta_1)J_1(\beta_2)E_0 \cos(\varphi_2 - \varphi_1) \cos(\omega_0 t)$$

Where $\beta_2 = \frac{V_{e1}}{V_{\pi 2}} \cdot \frac{\pi}{2}$, is the phase modulation index of the second MZM.

The phase deviation introduced by the electrical phase shifter is $\frac{\pi}{2}$. The electric field of the optical signal at the output of the second modulator can be expressed as,

$$E_{out2}(t) \approx J_1(\beta_1)J_1(\beta_2)E_0 \cos[(\omega_0 - 2\omega_c)t - \varphi_1 - \varphi_2] + J_1(\beta_1)J_1(\beta_2)E_0 \cos[(\omega_0 + 2\omega_c)t + \varphi_1 + \varphi_2]$$

Thus the second order sidebands are present and having a frequency separation of four times the driving signal frequency. At the output of photodiode, an electrical signal has four times the frequency of the driving signal will be generated. The generated signal can be written as,

$$V_{out}(t) = RJ_1^2(\beta_1)J_1^2(\beta_2)E_0^2 \cos(4\omega_c t + 2\varphi_1 + 2\varphi_2)$$

The above theoretical analysis focuses on the conditions and methods employed for achieving frequency multiplication factor. The proposed approach is verified by experiments which perform investigations on the optical and electrical spectrum of the generated MMW signal and the time domain electrical signal after transmitting through a fiber of length 40 km. The BER performance for different fiber length, and received power are also experimentally investigated.

EXPERIMENTAL RESULTS AND DISCUSSIONS

In order to verify the proposed method of frequency quadrupling optical MM wave generation, radio-over-fiber link is constructed using the Optisystem tool. The operating laser source has a wavelength of 1552.5 nm that is 193.1 THz, line width of 10 MHz and power of 0.7 dBm. The 2.5 Gbps pseudo random bit sequence is first modulated onto 10 GHz radio frequency local oscillator with a voltage of 6 V.

The resulting signal and binary data are combined to drive the integrated nested MZM, which is biased at the minimum transmission point. The phase shift of the first and second signals are zero and $\frac{\pi}{2}$ respectively. Thus the frequency quadrupling optical MMW with first order sidebands are generated. The data is transmitted over the fiber length of 40 km. At the base station the frequency quadrupling optical MM wave is detected by a photodiode (PD) and RF harmonic signal is filtered by a band pass filter centered at 40 GHz. So that the 40 GHz RF signal is down converted to the base band by coherent demodulation. After passing the RF signal through a low pass filter the down converted data is evaluated by a BER analyzer. By varying the attenuation, the corresponding BER values are calculated for different fixed lengths and also the Q factor and eye diagrams are calculated. From Figure-3 it is clear that only two sidebands at ± 2 order is generated and all other sidebands are suppressed. While Figure-4 displays the electrical spectrum of the signal at the output of PD, due to complete suppression of other sidebands the power due to other harmonics is almost negligible.

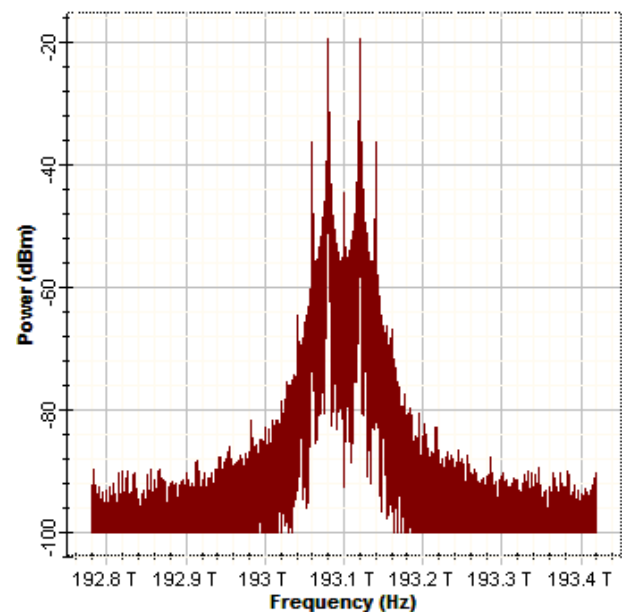


Figure-3. Optical spectrum of the generated 40 GHz MM wave.

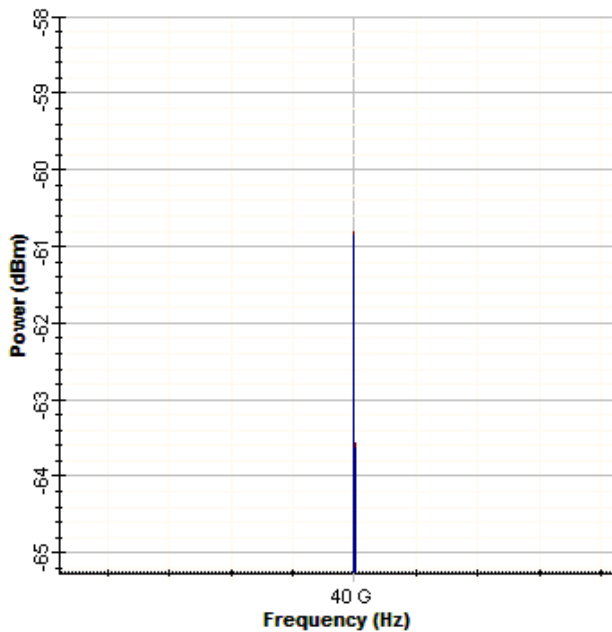


Figure-4. Electrical spectrum of the generated 40 GHz MM wave.

The base band eye diagram of the generated MM wave signal which is coherently demodulated from the 40 GHz photocurrent at a distance of 40 km is shown in Figure-5. Since the resonant photon's average life time is proportional to the Q-factor, Figure-6 presents the Q-factor plot expressed as a function of time. The time domain waveform of the generated 40 GHz MMW signal using a PD after transmission through a 40 km standard single mode fiber (SSMF) is presented in Figure-7. Since the unnecessary sidebands are suppressed and only the desired SB are preserved, no significant distortion is observed in the signal after fiber transmission. It is shown that the eye diagrams are wide open when the MM signal is transmitted over 40 km which is a clear indication that the data symbols are preserved and has no distortion. In order to check the sensitivity of BER to the changes in the modulator extinction ratio, BER curve is plotted as a function of extinction ratio of the MZM in Figure-8. It is evident from the plot that as extinction ratio increases the BER also increases for a fiber length greater than 45 km.

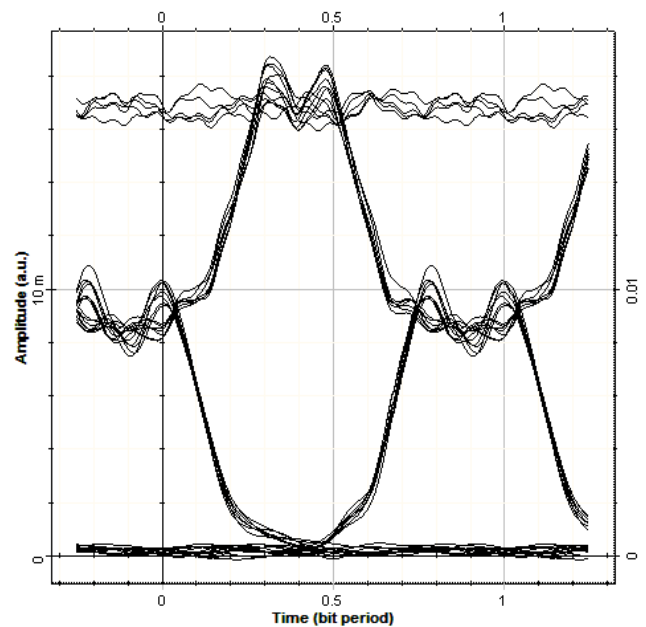


Figure-5. Eye diagram of the baseband signal at 40 km.

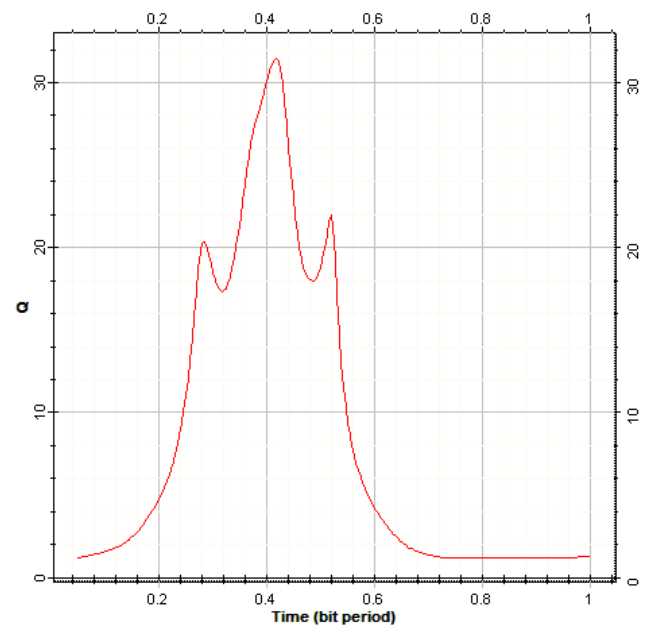


Figure-6. Q factor.

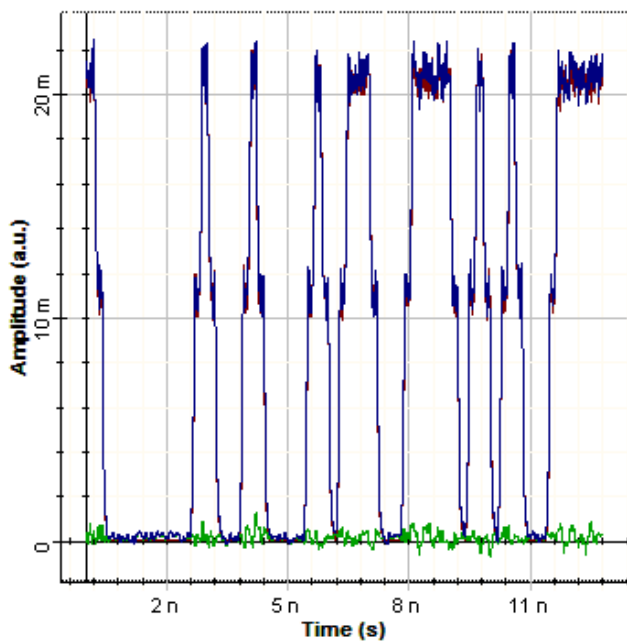


Figure-7. Time domain waveform of the generated MMW signal.

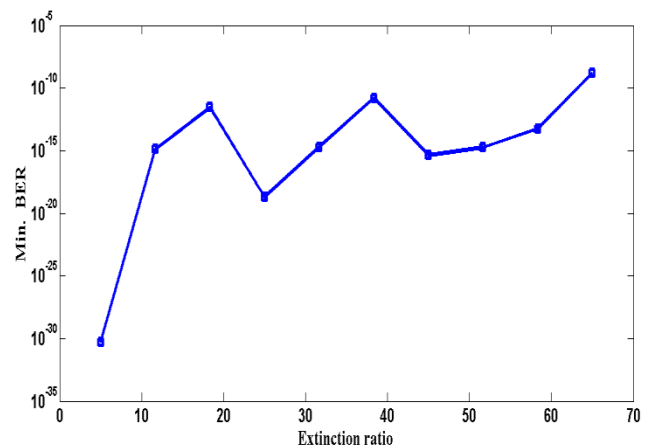


Figure-8. BER versus non ideal extinction ratio.

The variation of BER with respect to the length of the fiber is presented in Figure-9. The plot shows that the BER is negligible for the fiber length less than 65 km and implies that the proposed method is more suitable for data transmission between 40 and 65 km. While Figure-10 shows the plot for minimum BER expressed as a function of received power of the generated MMW signal. The main advantage of the proposed external modulation approach is the simple frequency tuning

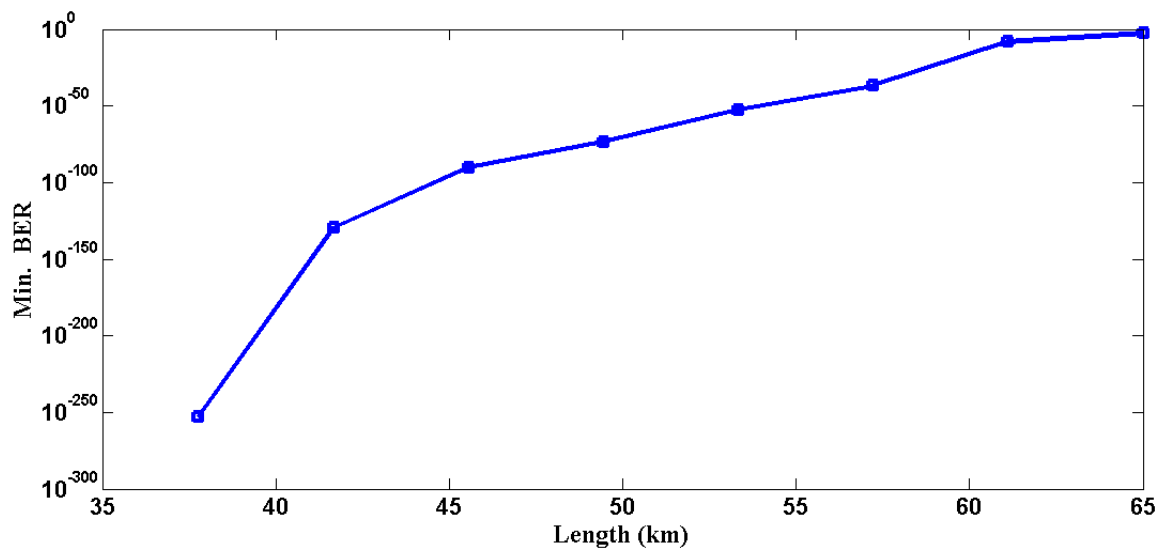


Figure-9. BER as a function of length of the fiber.

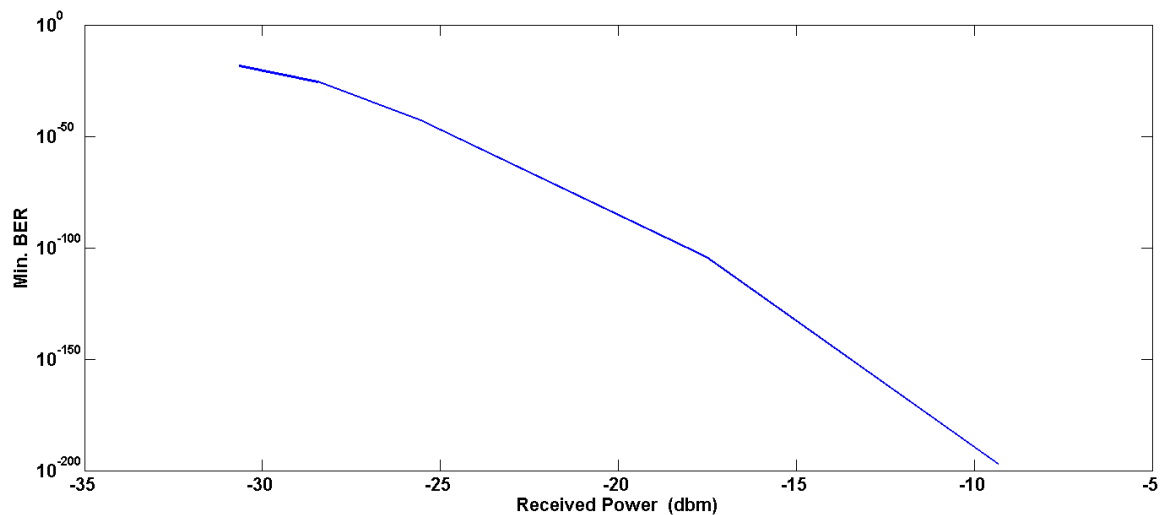


Figure-10. Plot for BER performance and received power for the proposed MMW signal.

and its wide tunable range. The method can be used for generating high frequency electrical signal in the terahertz range if the employed photo detector has its bandwidth extending to terahertz range.

CONCLUSIONS

A novel frequency quadrupling method which generates the MMW signal whose frequency is four times that of the RF driving signal is proposed. The eye diagrams are wide open when the signal is transmitted over the fiber length of 40 km and hence the generated signal is robust to the fiber dispersion effects. The experimental results are shown for the extinction ratio and BER performance by varying the length of the fiber between 35 and 60 km. The BER performance, Q-factor and the time domain signal of the quadrupling method were also experimentally investigated and presented in this article using Optisystem tool.

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