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Photonic Generation of Microwave Signals Using Single Laser Technique

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***Abstract*—photonic generation methods of microwave signal employing single LASER (light amplification by stimulated emission of radiation) technique and Mach-Zehnder modulator (MZM) are presented in this paper. The impact of the finite extinction ratio (ER) of MZM and fiber dispersion on the generated microwave signal is discussed. This system is compared with other reported microwave generation schemes. The results of the system are simulated using OptiSystem12 software.**

***Keywords* — Optical generation of microwave signal, Mach-Zehnder modulator (MZM), LASER, dispersion, Optisystem 12.**

I. INTRODUCTION

Photonic generation of microwave (PGM) signal is very attractive for applications such as in ultra-wide-band and multiple-access communication systems, pulsed radar systems as well as in radio-over-fiber, remote imaging applications, software defined radio, and modern instrumentation [1,2,10,13]. The PGM signal offers many advantages as compared to electronic solutions. To name a few of the advantages are low power consumption, low cost and high reliability, high stability and low noise, low and constant attenuation over the entire microwave modulation frequency range, immunity to electromagnetic interference, and high data-transfer capacity. There are several techniques have been proposed and demonstrated in the last few years to generate low-phase-noise microwave signals [1-11]. One of the simple and popular methods of microwave generation is the process of beating of two optical carriers at THz frequency, followed by a photodiode (PD), however the major problem of this scheme is that a probability of high phase noise is there when the two beating optical carriers are not correlated. Similarly, methods of PGM employing Mach-Zehnder modulator (MZM) effected by the impact of the finite extinction ratio (ER) of MZM [4]. Besides this, the fiber dispersion is also one of the most important limiting factors in PMG. The dispersion effects spread the optical signal as it is transmitted through optical fiber. Methods for photonic generation of microwave signals are presented along with their pro and cons. In this paper, we have presented the effect of dispersion and finite extinction ratio of MZM in generating the microwave signal. The present study was conducted using Optisystem 12 software. The major objective of the simulation is to find the best configuration of the system that can operate at optimum performance. PGM methods were simulated by varying a set of design parameters. The performance of each of the schemes is characterized by the radio spectrum (RF) power spectrum, and the achievable SNR.

II. THEORY

The proposed microwave signal generation system employing single laser and MZM is presented in Fig. 1. A RF drive signal is applied to the MZM. An erbium doped fiber amplifier is connected at the output of the MZM. At the output of the photo detector, a filter is connected to remove the carrier. A beat signal with the scaled frequency of the RF drive signal is generated at a PD. An optical carrier of 193.1 THz and a RF drive signal of frequency 10 GHz is applied to the MZM. We have used standard single mode fiber of length 50 km for calculation and simulation.

The generated microwave signal is very stable with a spectral width of less than 1 Hz. The generated microwave signal was characterized by using an RF spectrum analyzer through a photo detector and an optical spectrum analyzer. After transmission through the 50 km of standard single mode fiber (SMF), the signal is detected by a PIN detector. The modulator used in our work is a MZM, which can be configured as a dual drive or as a single drive configuration. The major difference between these two is that in dual-drive configuration the modulating signal is applied to both arms of the interferometer and a phase changes of $\pi/2$ in the arms of the interferometer will be observed. However, for the single drive configuration which is otherwise known as an unbalanced configuration the modulating voltage is applied to one of the arm of the interferometer and a phase change of 'π' will be observed. Since the signal propagated over a fiber the dispersion effect comes into play. This causes each spectral component to experience different phase shifts depending on

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the fiber-link distance L, dispersion parameter D [ps/nm.km] and the modulation frequency (f_{Rf}).

$$E_R \cong E_T \exp\left\{-\alpha L + j\left[\left\{\beta(\omega_0) + \left.\frac{\partial\beta}{\partial\omega}\right|_{\omega_0}(\omega-\omega_0) + \frac{1}{2}\frac{\partial^2\beta}{\partial\omega^2}(\omega-\omega_0)^2 + \ldots\right\}\right]L\right\} \tag{1}$$

Here, E_R *and* E_T represents the received and transmitted signal respectively. Considering that the phase constant changes slowly, we have used a Taylor polynomial to express $\beta(\varpi)$. Here the dispersion effect is modeled as a relation between β and ω. Besides the impact of dispersion on the microwave generation, we have also simulated the proposed system to establish the effect of the finite extinction ratio on the microwave generation. We have used multi-parameter optimizations to address the probes due to finite extinction ratio and dispersion. In our performance analysis activities, we have reported the results of the single drive and dual drive based photonics microwave generation system.

III. Simulation

The proposed system as shown in *Fig. 1* is designed and simulated in Optisystem 12 environments. The Table-I shows the parameters and its value for the single drive and dual drive based MZM setup. The same parameters are also used for the pulse-repetition rate multiplication (PRRM) based scheme of microwave signal generation.

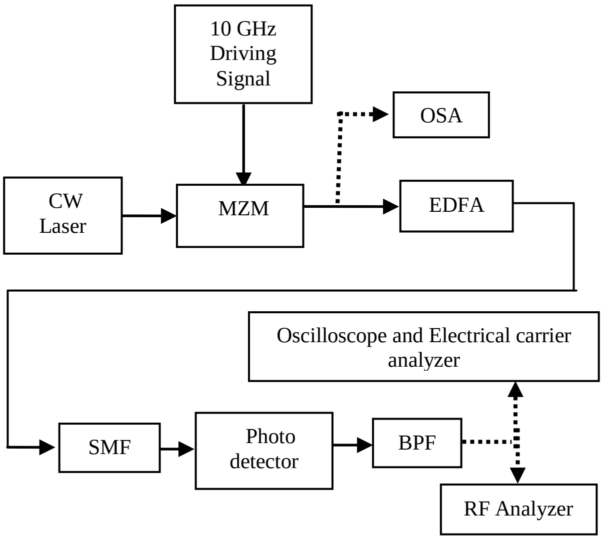

Figure 1. Block diagram of the proposed system

TABLE I: SIMULATION PARAMETERS

Parameter	Value
Input power level	10 dBm
Line width of laser	0.1 MHz
Driving signal frequency (Sinusoidal)	10 GHz
EDFA length	5 m
Length of optical fiber	50 km
Sequence length	2048
Samples per bit	32
Data rate	5 GHz
Filter bandwidth	10 Hz

IV. Results and Discussion

In this paper different methods for optical generation of 40 GHz microwave signals have been presented along with their features. *Fig. 2* shows optical spectrum at the output of single drive MZM of the proposed setup. From *Fig. 2*, it is clear that the modulated output optical signal has power level of 6 dBm. The spectral properties of the generated 40 GHz microwave signal are measured by a RF spectrum analyzer which is shown in *Fig. 3*. The signal power level of the generated 40 GHz microwave is -32.003 dBm. It is less noisy compared to other schemes [12-14] with SNR of 40.009 dB and found to be very stable. The waveform of the generated microwave signal using a single drive MZM is shown in *Fig. 4*.

Fig. 5 shows the output optical spectrum of the dual drive MZM. It shows that the modulated signal is at 0 dBm, which is 6 dBm less than the signal generated by a single drive MZM. The waveform and its RF spectrum of the generated 40 GHZ microwave signal, using dual drive MZM are shown in *Fig. 6* and *Fig. 7* respectively. The generated microwave signal of 40 GHz has a power level of -44.391 dBm with SNR of 25.007 dB. Hence the method of microwave generation using single drive MZM is advantageous over dual drive MZM.

We have also compared our proposed work with the work done by Kostko et al. [12], where they have generated the 40 GHz signal based on PRRM scheme using lattice-form Mach-Zehnder interferometer (LF-MZI). *Fig. 8* shows the optical spectrum at the output of MZM based on PRRM scheme, which uses a LF-MZI. The corresponding RF spectrum and waveform are shown in *Fig. 9* and *Fig.10* respectfully. It shows that the microwave signal power level generated in PRRM scheme employing LF-MZI is -49.590 dBm. The SNR found for this scheme is 26.440 dB. From *Fig. 3* and *Fig. 9*, it is observed that the generated signal power level of single drive MZM based scheme is high or less noisy comparing to PRRM based scheme. Again from *Fig. 3* and *Fig. 9*, it is also observed that the power level of the side lobes of the proposed system is very less comparing to the system proposed by Kostko et al. From *Fig. 3*, *Fig. 6* and *Fig. 9*, it is clear that the 40 GHz microwave generated using single drive MZM is free from ground noise and is very stable.

We have also optimized the fiber length of all the above setups for improving the desired signal power level and minimizing the dispersion. After optimization the signal power level and the SNR observed are -8.041 dBm and 51.324 dB respectively for single drive MZM scheme. The corresponding fiber length found is 15.426 km. Similarly, for dual drive MZM scheme the signal power level and the SNR observed are -18.060 dBm and 39.457 dB respectively at a fiber length of 19.618 km. However, for PRRM technique the optimized signal power level and the SNR observed are -30.126 dBm and 29.77 dB, at fiber length of 8.149 km. We also considered the effect of extinction ratio on generated microwave signal power level and SNR. In our proposed system, we optimized the extinction ratio of the single drive MZM scheme after the fiber length optimization to get an improved quality microwave signal at 40 GHz. The optimized extinction ratio and SNR found are 40 dB and 51.646 dB respectively at the optimized fiber length of 15.426 km. Table II shows the achievable SNR for the above three systems. Table III shows the SNR for the above system after fiber length optimization. Table IV shows the SNR for different schemes of microwave generation after both fiber length and extinction ratio optimization.

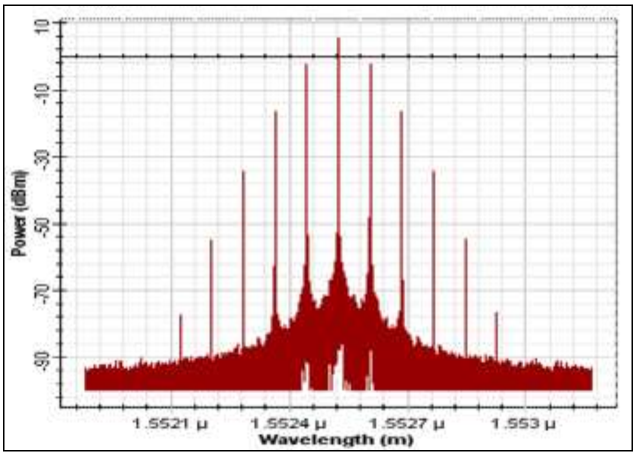

Figure 2. Optical spectrum at the output of single drive MZM (50 km fiber)

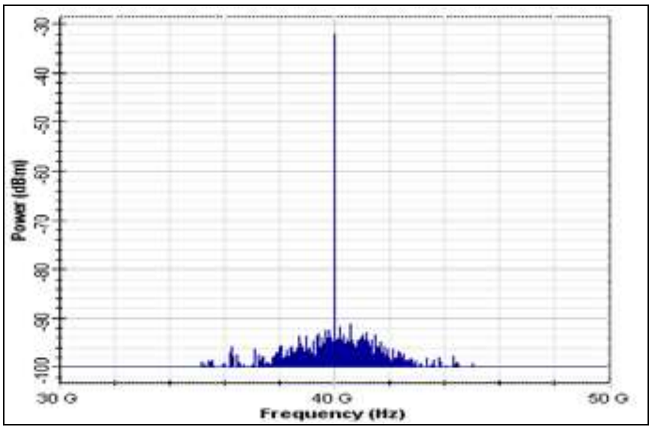

Figure 3. RF spectrum of the 40 GHz microwave signal using single drive MZM (50 km fiber)

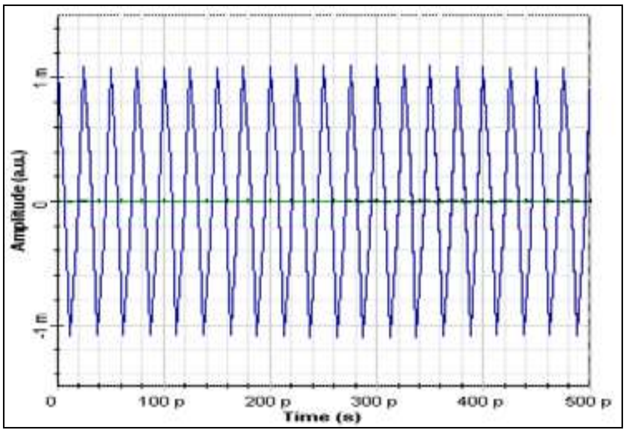

Figure 4. Waveform of the 40 GHz microwave signal (50 km fiber)

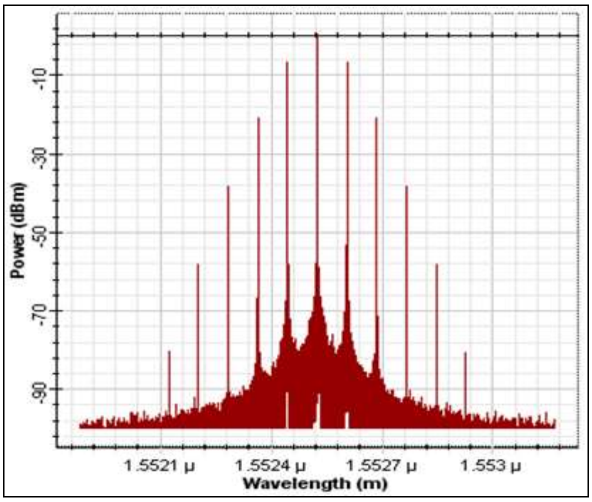

Figure 5. Optical spectrum at the output of dual drive MZM(50 km fiber)

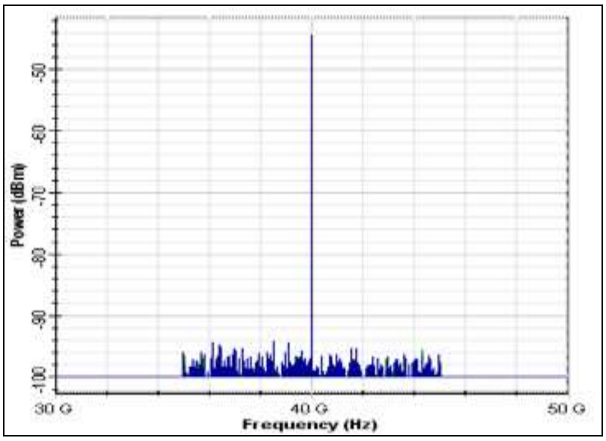

Figure 6. RF spectrum of 40 GHz microwave signal using dual drive MZM(50 km fiber)

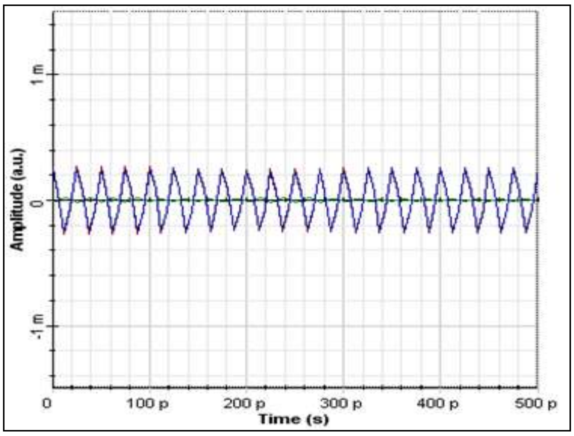

Figure 7. Waveform of the generated microwave signal using dual drive MZM (50 km fiber)

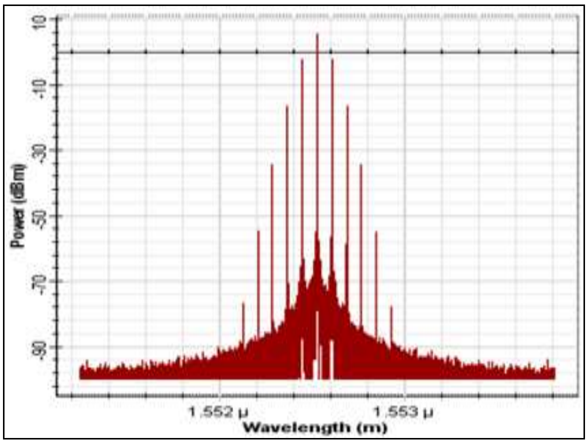

Figure 8. Optical spectrum at the output of MZM (50km fiber) using PRRM scheme

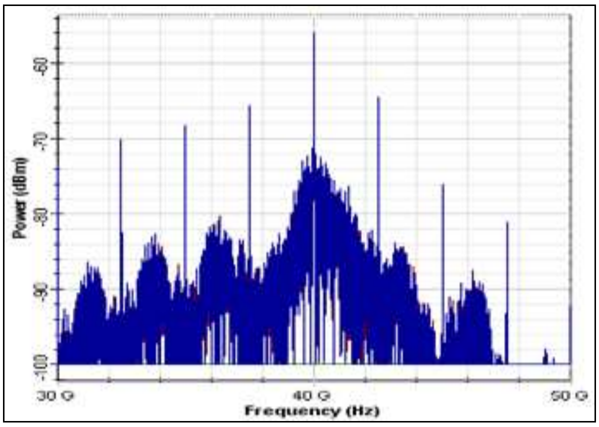

Figure 9. RF spectrum of the 40 GHz microwave signal using PRRM technique

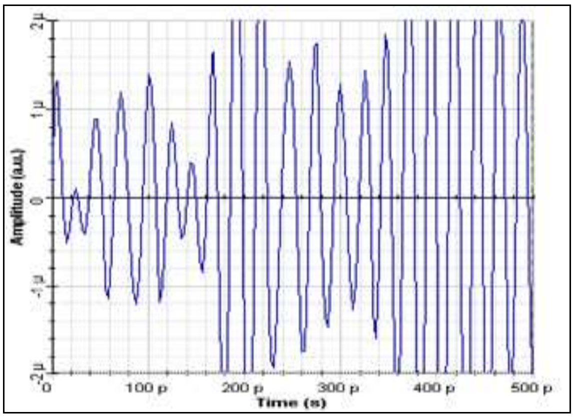

Figure 10. Waveform of the generated microwave signal using PRRM technique (50 km fiber)

TABLE II: ACHIEVABLE SNR FOR DIFFERENT SCHEMES FOR GENERATING MICROWAVE SIGNAL BEFORE OPTIMIZATION (fiber length=50 km, extinction ratio=30 dB)

Microwave generation method	**SNR of microwave before optimization(dB)**
Single drive MZM	40.009
Dual drive MZM	25.007
PRRM with LF-MZI	26.440

TABLE III: SNR AFTER FIBER LENGTH OPTIMIZATION (extinction ratio=30 dB)

Microwave generation method	**SNR (dB) after fiber length optimization**	**Fiber length(km)**
Single drive MZM	51.324	15.426
Dual drive MZM	39.457	19.618
PRRM with LF-MZI	29.777	8.149

TABLE IV: SNR AFTER FIBER LENGTH AND EXTINCTION RATIO OPTIMIZATION

Microwave generation method	**Fiber length (km)**	**Extinction ratio (dB)**	**SNR(dB) after optimization**
Single drive MZM	15.426	40	51.646
Dual drive MZM	19.618	28.541	39.417
PRRM with LF-MZI	8.149	25.708	30.041

IV. CONCLUSION

Methods for generation of 40 GHz signal has been proposed and simulated using Optisystem 12 software. We have shown that the proposed scheme can generate and transmit a 40 GHz signal using a Mach-Zehnder modulator modulated at 10 GHz. We have also optimized the transmission distance and the MZM for achieving an improved quality 40 GHz RF signal. The impact of finite extinction ratio and the dispersion effect has been discussed in this paper.

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