INVESTIGATION OF DISPERSION ORDER ON CHIRP MICROWAVE
GENERATION USING MICROWAVE PHOTONIC LINK WITHOUT
OPTICAL FILTER

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Abstract:

In this work, we investigate the influence of the second order-(2OD) and third
order-(3OD) dispersion terms on chirp signal generation and transmission
through RF photonic link without optical filter. Dispersion equations are
formalised using Taylor series and Bessel function to study the link
performance. Our result (Eye diagrams) shows that the 2OD+3OD have
significant impact on chirp mm-wave propagating through fiber of different
lengths. In this paper chirp mm signal is controlled at photo detector by
individual phase term of external modulators. Moreover, we also demonstrated
experimentally that the chirp rate can be significantly controlled by properly
choosing the type of fiber in the experiments. We discussed the RF photonic
link performance in terms of Optical Sideband Suppression Ratio (OPSSR),
Radio Frequency Spurious Suppression Ratio (RFSSR), Bit Error Rate (BER).
Theoretical results are verified using MATLAB Software.
**Keywords:** RF Photonics, Triple Parallel-Intensity Modulators (TP-IM), Fiber Dispersion, RoF, Optical Sideband Suppression Ratio (OPSSR), Radio Frequency Spurious Suppression Ratio (RFSSR)

1. INTRODUCTION

RF Photonics is an excellent technology for modern RoF systems, due to its advantages like reduced size, low cost, large ultra-wide bandwidth, immunity to electromagnetic interference, no electrical-optical conversion etc [1-4]. Over the last few decades, RF Photonics generation methods such as optical injection locking [5, 6], optical phase lock loop [7], and external modulation [8, 9] were reported. Wangzhe Li et. al successfully demonstrate frequency octupling using two cascaded optical modulators with Optical Sideband Suppression Ratio (OSSR) of 26.79 dB [8]. Jian Zhang et. al used optical carrier suppression modulation scheme to generated frequency quadrupler scheme with OSSR of 20 dB [10]. Sextupling optical mm-wave signal with cascaded MZM [both at different transmission point] is obtained with OSSR of 16 dB [11]. Optical chirp mm-wave generation with external modulation (using cascaded or parallel MZM) has attracted many research groups [8-12]. Peiming Shi et. al reported the novel two parallel sub-MZM in nested configuration to get sextupling microwave signal with OSSR of 26 dB [12]. In [13], a dual-parallel MZM configuration is also studied to obtain frequency octupling with OSSR of 17 dB. Moreover, an optical octupling mm-wave with 20 dB OSSR is also proposed
using 4-MZMs [14, 15]. Recently, Raghuwanshi et. al [16], showed the application of chirped arbitrary microwave generation in the field of remote sensing application. In this work, we advocated the impact of higher order dispersion (HOD) on mm-wave traveling through optical fiber of different lengths without any electrical and optical filter.

The work is presented as follows: Section 2 includes the principle of proposed photonic link (without any electrical or optical filter) along with mathematical formulation of dispersion equation. Experiment details are described in section 3. Results are discussed in Section 4. Finally, section 5 includes conclusion.

2. THEORETICAL MODEL

Fig. 1 represents the schematic of proposed RF photonic link. We have used the OPTISYSTEM SOFTWARE (VERSION 13) to model our proposed link [17]. An optical carrier (expressed as $E_0 \cos \omega_0 t$, where $E_0$ and $\omega_0$ are the amplitude and angular frequency of the optical carrier, respectively) from a CW laser is injected into Triple Parallel-Intensity Modulators (TP-IMs) (all operating at Maximum Transmission Points [MTP]). The key advantage of using 3-parallel MZM in proposed link as compare to cascaded configuration is more frequency multiplication, improved OSSR and improved RFSSR. Due to the absence of optical filter in proposed photonic link, the system experience more frequency tunability and stability.
The generalized electric field expression at the output of fiber (by adding the transmission phase delay \([\beta(\omega_0 \pm 2n\omega_{RF})L]\) to sidebands) is expressed as \([18-22]\):

\[
E_z(0,t) = \frac{\alpha}{3} E_0 \{3J_0(m)e^{i\alpha t + \beta(\alpha_0)L} + J_2(m)\left[e^{j(\alpha t - 2\omega_{RF}t) + \beta(\alpha t - 2\omega_{RF})L}(1 + e^{-j2\Delta\phi} + e^{j2\Delta\phi}) + e^{j(\alpha t + 2\omega_{RF}t) + \beta(\alpha t + 2\omega_{RF})L}(1 + e^{-j2\Delta\phi} + e^{j2\Delta\phi})\right] + J_4(m)\left[e^{j(\alpha t - 4\omega_{RF}t) + \beta(\alpha t - 4\omega_{RF})L}(1 + e^{-j2\Delta\phi} + e^{j2\Delta\phi}) + e^{j(\alpha t + 4\omega_{RF}t) + \beta(\alpha t + 4\omega_{RF})L}(1 + e^{-j2\Delta\phi} + e^{j2\Delta\phi})\right] + J_6(m)\left[e^{j(\alpha t - 6\omega_{RF}t) + \beta(\alpha t - 6\omega_{RF})L}(1 + e^{-j2\Delta\phi} + e^{j2\Delta\phi}) + e^{j(\alpha t + 6\omega_{RF}t) + \beta(\alpha t + 6\omega_{RF})L}(1 + e^{-j2\Delta\phi} + e^{j2\Delta\phi})\right] \}
\]

(1)

where \(m = \frac{V_{RF}}{V_z} \cdot \frac{\pi}{2}\) is a modulation depth, \(\alpha\) is the optical loss within the IM, \(V_{RF}\) is the amplitude of applied low frequency RF signal, \(\omega_{RF}\) is the angular frequency of RF signal. Now, expanding the propagation constant \(\beta(\omega)\) for each optical sideband using Taylor series around the angular frequency of the optical carrier \([18]\):

\[
\beta(\omega_0 \pm 2n\omega_{RF}) = \beta(\omega_0) + \frac{d\beta}{d\omega}(\pm 2n\omega_{RF}) + \frac{1}{2} \frac{d^2\beta}{d\omega^2}(\pm 2n\omega_{RF})^2 + ...
\]

(2)

where,

\[
\beta_2(\omega_0) = \frac{d^2\beta}{d\omega^2} = 2OD = \text{group delay dispersion}; \beta_3(\omega_0) = \frac{d^3\beta}{d\omega^3} = 3OD = \text{dispersion slope};
\]

We followed the ITU G.655 fiber manual for dispersion parameters values \([23]\).

In order to suppress the optical carrier the term \(" J_0(m)e^{i\alpha t + \beta(\alpha_0)L} \) \([\text{in eq.}(1)]\) must
be equal to zero. The output intensity of photodiode (at the end of the fiber, i.e $z=L$) is given by:

$$I_{pp}(0,t) = \frac{\alpha}{9} \mu |E_z(0,t)E_z^*(0,t)|$$

(3)

where $\mu$ is the responsivity of the photodiode.

3. EXPERIMENT SETUP

The experiment is setup according to Fig. 1. An optical carrier with wavelength of 1554.7 nm is generated from a laser (Yokogawa AQ2200-136) and intensity-modulated via Triple Parallel-Intensity Modulators (TP-IMs). The half voltages of the modulators are 3 V and ER above 22 dB. The signal from three IM’s are combined by OC and transmitted over fiber of different lengths [as in Fig.2]. The eye diagrams are measured using oscilloscope with a 60-GHz bandwidth. The signal is detected by PD (UTMPDV1120RA) with a 3dB cutoff frequency of 30 GHz and responsivity of 0.6 A/W. Then the generated electrical signal is analysed by an electrical spectrum analyser [ESA] (FSQ26). Experimentally generated chirped microwave waveform (using Digital Storage Oscilloscope [DSO]) due to continuous wave laser is shown in Fig. 3.

4. RESULTS AND DISCUSSION
The optical link performance is studied theoretically using both OPTISYSTEM SOFTWARE (VERSION 13) [17] and MATLAB SOFTWARE. The simulation model is setup according to Fig. 1. Radio Frequency Spurious Suppression Ratio (RFSSR) for fibers of lengths 10 km, 20 km, 30 km and 40 km is calculated to be 20 dB, 18 dB, 17 dB and 15 dB, respectively (follow FIG. 4). Moreover, OSSR for the proposed RF photonic link without optical filter is noted nearly to 30 dB. The Maximum Q-factor from eye pattern for fiber of lengths 10 km under the effect of (a) no dispersion parameter, (b)2-OD, (c)3-OD, and (d) 2OD+3OD comes out to be 115.848, 86.115, 54.3729, and 30.7302, respectively (as in FIG. 5). Similarly, Eye height for the above mention cases are: 2.099E-3, 1.042E-4, 5.116E-5 and 1.3633E-7, respectively. Clearly, the eye pattern height is reduced with 2OD+3OD, as compare to 2OD. Moreover, simulation shows that BER for 10km, 20 km, 30 km and 40km are nearly: 8.24E-65, 6.12E-30, 0.000824 and 0.000326, respectively.

MATLAB results also shows that better performance occur for 10 km fiber and worst performance is shown by 40 Km fiber (refer FIG.6). The reason for this is that influence of both individual (2OD, 3OD) and combined (2OD + 3OD) increases as the fiber length increases.

Finally, we presents the influence of 2OD, 3OD and 2OD+3OD in Table I. Hence, numerical study (using MATLAB) verified that 3OD together with 2OD impact the optical transmission through proposed TP-IMs proposed link.
5. CONCLUSION

In summary, this study reveals that higher order dispersion (HOD) terms has an effect on chirp mm-wave generation. The chirp rate can be effectively controlled by using properly selecting the type of fiber viz dispersion compensation fiber (DCF), dispersion shifted fiber (DSF), Dispersion flattened fiber (DFF) etc. We also demonstrate that combined HOD terms [2OD+3OD] shows significant effect on mm wave propagation through fiber of different length. For 10 km fiber, RFSSR comes to be 20 dB and OSSR is nearly 30 dB. Moreover, Proposed Triple Parallel-Intensity Modulators (TP-IMs) based optical link without optical filter exhibits more frequency tunability and stabilty.

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REFERENCES


[17] OPTI SYSTEM-user’s manual, OPTIWAVE Inc (VERSION 13)


**FIGURE CAPTIONS**

FIG. 1: Representative operation of optical chirp mm-wave generation RF photonic link without optical filter. CW: continuous wave laser, PC: power splitter, IM: intensity modulator, OC: optical coupler, G.655: International Telecommunication Union’s standardized fiber, PD: photo diode.

FIG.2 Experimental setup as per the proposed model. OSA: Optical spectrum analyser; EDFA: Erbium Doped Fibre Amplifier; DSO: Digital Storage Oscilloscope; LC-FBG: linearly chirped fiber Bragg grating; MZM: Mach-Zehnder Modulator; ESA: Electrical spectrum analyser.

FIG 3: Digital Storage Oscilloscope (experimentally) output of generated chirped microwave waveform due to continuous wave laser.

FIG. 4. RF spectrum at the output of photodiode (a) 10 km, (b) 20 km, (c) 30 km, and (d) 40 km.

FIG. 5. Eye diagram at the output of photodiode (with 10 Km fiber) under the effect of (a) no dispersion parameter, (b) 2OD, (c) 3OD, and (d) 2OD+3OD.

FIG. 6: Plot of intensity at the output of the photodiode versus modulation depth (m) under the effect of (a) 2OD, (b) 3OD, and (c) 2OD+3OD.

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TABLE I. Summary of the individual and combined dispersion parameter with fibers of different lengths.

<table>
<thead>
<tr>
<th>Dispersion order</th>
<th>Fiber length (km)</th>
<th>Experiment</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I_{PD} (dB)</td>
<td>m= 1</td>
</tr>
<tr>
<td>(\beta_2) only</td>
<td>10</td>
<td>-1.8</td>
<td>-3.8</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>-2.3</td>
<td>-4.7</td>
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<tr>
<td></td>
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<td>40</td>
<td>-4.6</td>
<td>-7.3</td>
</tr>
<tr>
<td>(\beta_3) only</td>
<td>10</td>
<td>-5.2</td>
<td>-9.8</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>-6.4</td>
<td>-14.6</td>
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<td>-24.6</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>-8.5</td>
<td>-13.8</td>
</tr>
<tr>
<td>(\beta_2 + \beta_3)</td>
<td>10</td>
<td>-8.9</td>
<td>-12.9</td>
</tr>
<tr>
<td></td>
<td>20</td>
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</tr>
<tr>
<td></td>
<td>40</td>
<td>-12.3</td>
<td>-9.8</td>
</tr>
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</table>

Biography of Authors

Mandeep Singh obtained a B.Tech. degree in Electronics & Comm. Engineering from Beant college of Engineering and Technology, Gurdaspur- India, in 2010, an M.Tech. degree in Electronics & Comm. Engineering from IIT (ISM Dhanbad)-INDIA, in 2013, and pursuing his PhD degree in ECE from IIT Roorkee-INDIA. His area of research is optical fiber communication and Plasmonics. He is doing ISRO
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