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Tunable Millimeter Wave Full Duplex Radio Over Fiber System Based on Optical Modulators using Low Frequency Local Oscillator

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ABSTRACT

A duplex radio over fiber link (RoF) with a scheme to generate 60GHz millimeter wave using 15GHz local frequency oscillator by exploiting the high nonlinearity of EAM is proposed and simulated. The generation of 40GHz and 60GHz millimeter wave carriers using 20 GHz and 30GHz local oscillators via optical phase modulator is also presented. By exploiting the π out of phase nature of first order harmonics of phase modulator without suppressing the carrier we have successfully double the beating frequency and also up convert 2.5Gb/s and 622Mb/s data in mm wave band over these carriers through $LiNbO_3$ MZM modulator. Since the frequency response of the modulator and the local oscillator frequency are greatly reduced, the bandwidth requirements of the optical and electrical components in the transmitter are significantly decreased. The simulation results show that the generated optical mm-wave signal maintains good performance even after being transmitted over 50 km standard single-mode fiber. Millimeter wave generation and data up conversion is analyzed bout in electrical and optical domain.BER for different length of fibers and immunity of system against dispersion is also simulated.

Keywords: Radio over fiber, Millimeter wave, Phase modulator(PM),Electro absorption modulator (EAM), Mach-Zehnder modulator(MZM), Bit error rate, Mode beating, Fiber Brag gratings.

1. INTRODUCTION

As we are facing explosive demands of high channel capacity, wider service coverage and broadband mm wave access system needs a technology that can meet those requirements in the coming future[1][2][4]. Radio over fiber technology is the most promising solution for enhancing the capacity and mobility with less cost of the base stations (BSs) where most of signal processing such as RF generation, coding, multiplexing and modulation can be done at the central station (CS)[3][5].Due to the limited RF bands availability, The mm-wave bands would be utilized to meet the requirement for higher signal bandwidth and overcome the frequency congestion problems in the future RoF-based optical-wireless access networks[6]. By using RoF, the capacity of optical networks can be combined with the flexibility and mobility of wireless access networks [3][5].There are numerous techniques for generation of millimeter wave signals including external modulation, optical heterodyning, frequency and phase loop locking, but there is numerous research to find cast effective and reliable solution to generate these signals with reduced frequency local oscillators with low cost optical filters. Generating high frequency signals using low frequency local oscillators by exploiting some fundamental properties of modulators is one the hot topic of today's research in field of radio over fiber.

2. MILLIMETER WAVE GENERATION USING ELECTRO ABSORPTION MODULATOR

Millimeter wave (MMW) generation is very important factor for Radio over fiber photonic systems [1]. An electro absorption modulator (EAM) has many advantages over that based on a Mach-Zehnder (MZ) modulator. These include low-voltage operation with high extinction ratio, stable operation without DC bias drift, high-frequency capability over 60GHz, wide operating wavelength range, and the possibility of integration with other electrical and optical devices [5]. The nonlinear transfer characteristics of the EAM also allow for frequency multiplication into the MMW

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region, which can be used for creating tunable high-frequency MMW sources controlled by lower frequency inputs or for high-frequency clock generation or clock recovery with lower-frequency injection. By exploiting the nonlinear operation of external modulators, high frequency millimeter wave signals can be generated with low frequency oscillators and widely used to implement electro optical generation and mixing schemes. In this paper, we have designed and simulated duplex radio over fiber system with the scheme of 4th order 60Ghz harmonic generation via 15GHz local oscillator and also up converted 622-Mb/s PRBS signal modulated impressed over 15GHz (first harmonic) by exploiting inherent nonlinear transfer characteristics of EAM modulators that can generate multiple harmonics which are multiple of fundamental frequency by mode beating at high speed photo detector. This architecture may benefit from the higher nonlinearity inherent in EAMs modulated with the local oscillator (LO) tone. The inherent nonlinearity of the EAM may improve the efficiency of harmonic photonic-mixing schemes as conversion losses can be reduced due to highly efficient generation of the LO-signal harmonics when an EAM is used. The figure 1 and 2 shows the nonlinear effect of bout EAM and MZM modulators when 15GHz local oscillator is applied to bout. It is clear from figures that EAM generates more number of harmonics which are multiple of fundamental frequency than MZM. These modes can be beated at high speed photo detector by mode coupling effect to generate tunable millimeter wave system.

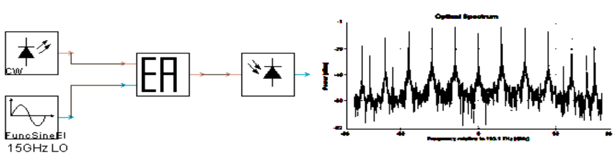

Figure 1: Optical spectrum of EAM modulator when drived by 15GHz LO

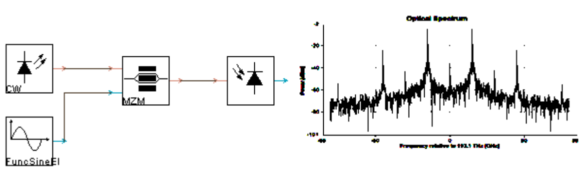

Figure 2: Optical spectrum of MZM modulator when derived by 15GHz LO

3. SIMULATION SETUP AND RESULTS

Figure 3 presents the duplex optical mm-wave link main block diagram. The light source considered in the simulation is an ideal CW laser, with 1 mW of emission power centered at 1550.1nm and line width of 6MHz. This light signal is fed to a polarization controller to match the state of polarization before entering into the modulator. The 2.5 Gb/s data is filtered by a 100% roll over square root raised cosine filter. This baseband data signal is first modulated via a single arm MZM. Then, the resultant signal is modulated by via a electro absorption modulator (EAM) with inherent high nonlinear property. This modulator is driven by 15GHz local frequency oscillator. The modulator is capable for generating multiple fundamental frequency harmonics which can be beated at high speed photo detector to get tunable millimeter waves. The modulated optical signal is amplified by an ideal EDFA and filtered by

TOF with 0.5nm bandwidth to suppress any AES noise before O/E conversion process starts. The filtered signal is transmitted through various lengths of standard single mode fiber, operating at the third transmission window, with 0.2 dB/km loss and 17 ps/(nm·km) . At this point a 3dB splitter is used to split the incoming optical signal into two streams. One stream goes to input of fiber brag grading which filters the undesired sidebands from optical signal and then it is used to drive MZM modulator along with 2.5Gb/s data for uplink connection .The other stream goes to the 3 port circulator for the extraction of baseband data through low pass filter and multiple harmonics at 30Ghz and 60GHz at base station (BS) using two FBG filters centered at 30GHz and 60GHz .After transmission over the same length SMF-28 as the downlink channel, a low-pass filter is employed to detect2.5-Gb/s data signal and filter out the residual part of the high-frequency millimeter-wave signal. For the uplink, it is modulated by a symmetric 2.5-Gb/s PRBS electrical signal with a word length of $2^{31}-1$.Compared with the downlink millimeter-wave signals, the uplink signals might be transmitted a longer distance because most of the components of high frequency are already removed by the FBG filter before they are sent back to the CO. The emission spectrum of CW laser is shown in figure 4 which is used to modulate ideal MZM modulator with 2.5Gb/s for uplink and downlink transmission. Figure 5 shows the output optical spectrum of MZM clearly show the modulated data on both sides.

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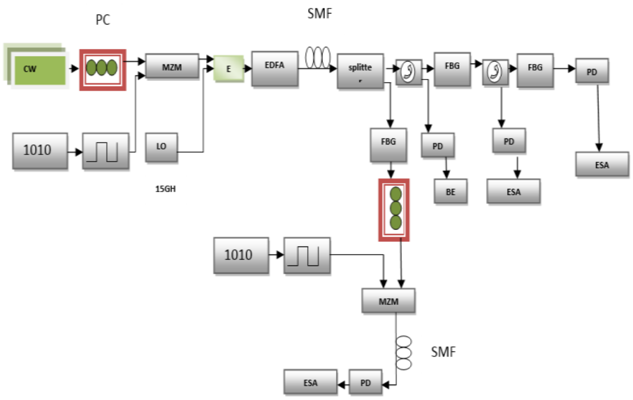

Figure 3: Block diagram of EAM based duplex millimeter wave Radio over fiber link

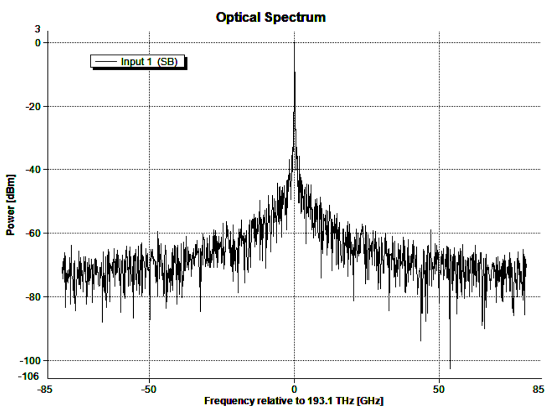

Figure 4

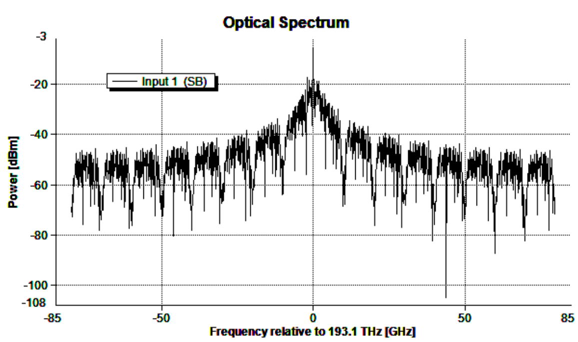

Figure 5

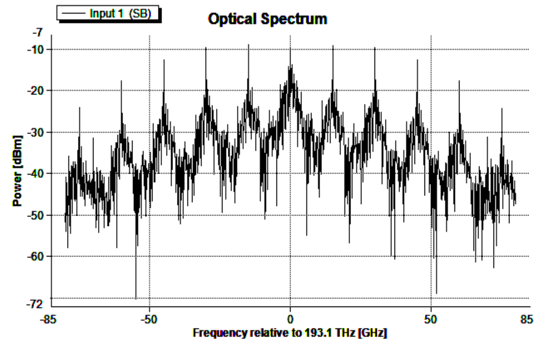

Figure 6

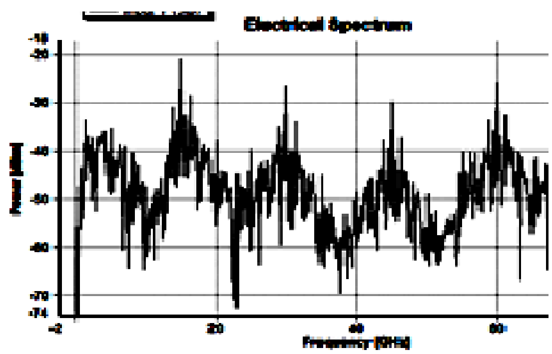

Figure 7: Electrical Spectrum of Multiple Harmonics

The resultant signal is modulated by EAM modulator which is driven by 15GHz local frequency oscillator which produce harmonics at center frequency Fo,2F0,3F0 and 4Fo as shown in figure 6. These harmonics are selected through fiber brag grating and beated at high speed photo detector. The resultant electrical spectrum of generated signal clearly shown harmonics set at 15GHz, 30GHz, 45GHz, 60GHz shown in figure 7 to 10.

Figure 4 shows the Laser Emission Spectrum of CW laser centered at 193.1THz, The modulated 2.5Gb/s data after MZM modulation is shown in figure 5, Figure 6 shows the generated multiple harmonics and modulated data after EAM is drived by 15GHz local oscillator

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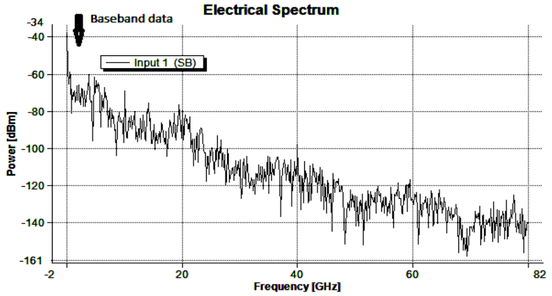


Figure 8: Retrieved based band data at receiver

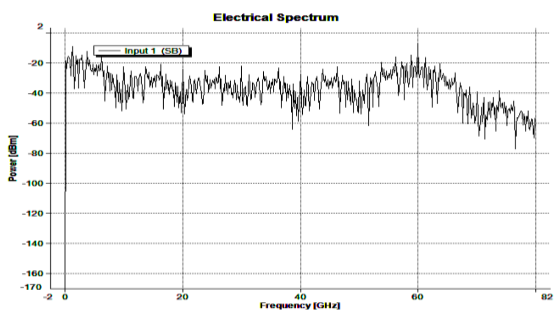


Figure 9: Detetectd 4th Harmonic 60GHz signal

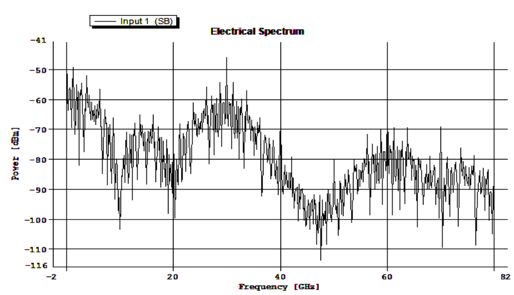
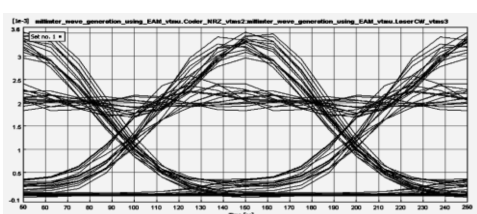


Figure 10: Detetectd 2nd Harmonic 40GHz signal



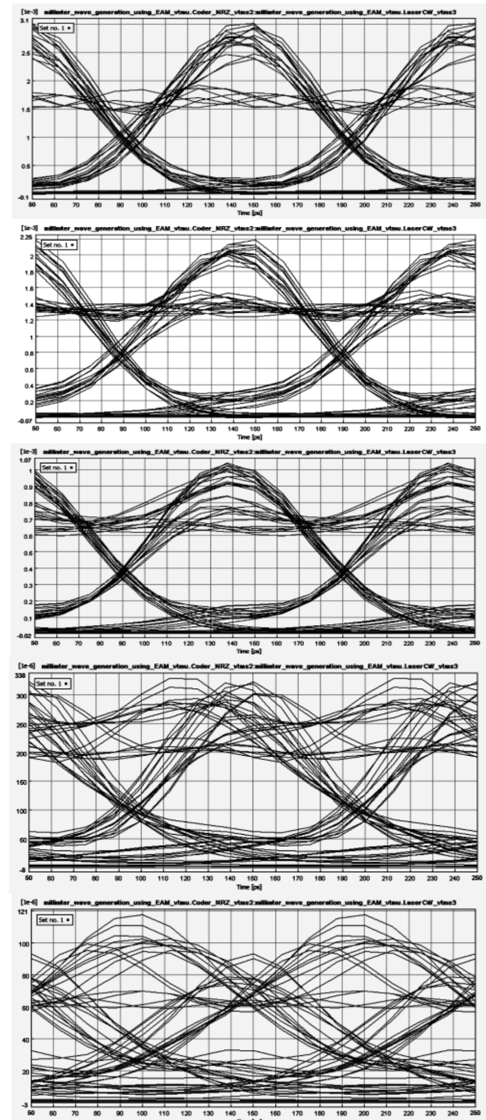


Figure 11: Eye diagram pattern of received baseband data for various lengths of SMF-28

The down- converted 2.5-Gb/s signal is detected by a BER tester. Eye diagrams are recorded by a high-speed oscilloscope and shown in Fig 11 for different transmission distances. It is clearly seen that the eye still remains open despite transmission over 50-km SMF which make this scheme quite comparable with other millimeter wave generation techniques with low frequency local oscillator. The figure 12 shows BER vs received optical power for different lengths of fiber.

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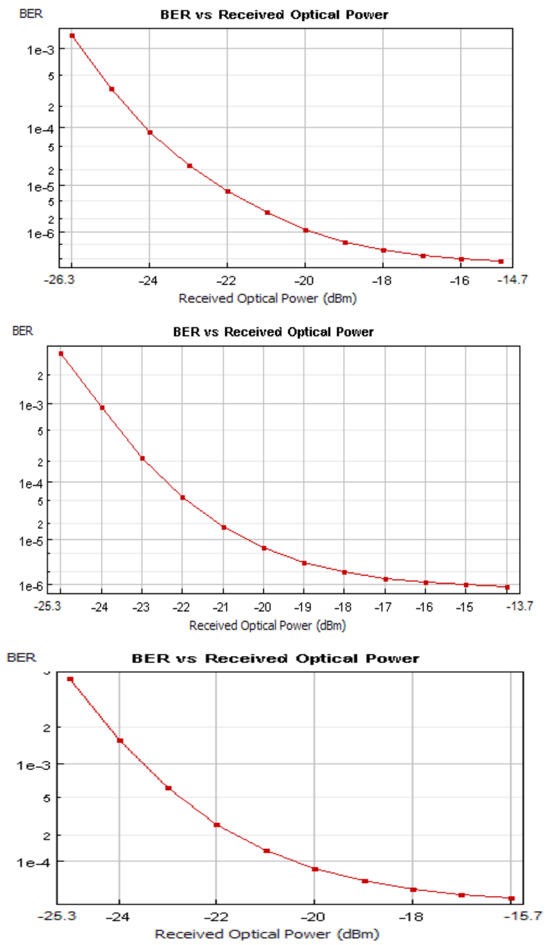

Figure 12: BER vs received optical power for different lengths of SMF-28

4. CONCLUSION

A duplex radio over fiber link (Rof) with a scheme to generate 60GHz millimeter wave using 15GHz local frequency oscillator by exploiting the high nonlinearity of EAM is proposed and simulated. The simulation results show that the generated optical mm-wave signal maintains good performance even after being transmitted over 50 km standard single-mode fiber.

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