Volume 3, Issue 3
June 2014

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X

Design and Simulation Of Various Millimeter Wave Generation Techniques For Radio Over Fiber System

[1]Asim Shahzad, [2]M Zafrullah, [3]Rizwana Shahzadi

[1]Department of Computer Engineering University of Engineering And Technology Taxila Pakistan

[2]Department of Electrical Engineering University of Engineering And Technology Taxila Pakistan

[3]Department of Telecom Engineering University of Engineering And Technology Taxila Pakistan

asim.shahzad@uettaxila.edu.pk,dr.zafrullah@uettaxila.edu.pk,rizwana.shahzadi@uettaxila.edu.pk

ABSTRACT

Millimeter-wave (mm-wave) generation is currently hot area of research due to the demand of the mm-wave unlicensed band for future broadband communication access systems. In this chapter two different approaches for generation of mm wave carriers ranging from 40GHz to 100GHz are designed and simulated. First by generating DSB+C and DSBSC external modulation schemes through dual arm MZM modulators using low frequency local oscillators by exploiting the nonlinear behavior of these modulators and secondly using Optical injection based Heterodyne technique. The 2.5Gb/s NRZ format PBRS data is also up converted into mm wave band over these carriers. Bout electrical and optical domain analysis is carried out for mm wave generation and data up conversion. The data distribution over these carriers for different length of standard SMF-28 fibers links is also carried out. From simulation results we have demonstrated our system simplicity, efficiency in terms of bit error rate and received signal power for various lengths of fiber.

Keywords: Radio over fiber, Millimeter wave, Optical heterodyne, Intensity Modulation, Double side modulation(DSB),Double side suppress carrier modulation (DSBSC),Single side modulation(SSB) ,Mach-zander modulator, Optical injection locking

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][8]. 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 [7][9][10].

2 . Millimeter wave signal Generation through MZM modulator

One of the most simple method for generating and optically distributing RF signals is to directly modulate the intensity of the light source(laser) with the RF signal itself by driving the laser with the desired mm-wave frequency and filtering the carrier and then use direct detection at the photo detector to recover the RF signal[6][7][8]. The second option is to operate the laser in continuous wave (CW) mode and then use an external modulator such as the LiNbO3MZM modulators to

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X

modulate the intensity of the light. Figure 1 and 2 shows both these setups.

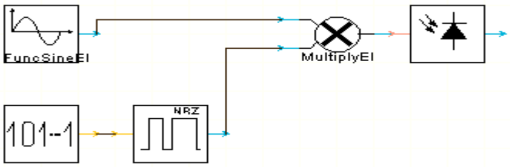


Fig.1: Direct laser modulation process

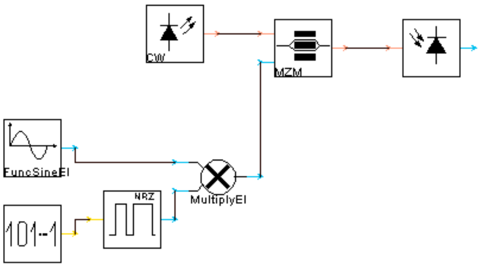


Fig.2: External modulation through MZM

Both methods are considered simple and cost effective for generation of such signals, but there are also some limitations. To generate higher frequency signals such as mm-waves, the modulating signal (RF signal) must also be at the same high frequency. For direct laser modulation, this is not possible due to limited bandwidth, and laser non-linearity, which lead to inter-modulation product terms that cause distortions. The External modulators such as the MZM can support high frequency RF signals and can be used for generation of these signals. The electrical field at dual electrode MZ modulator output is given as

$$E\ (t) = Ein(t)\left[\exp\left\{j\pi \frac{d1(t)}{V\pi}\right\} + \exp\left\{\frac{j\pi d2(t)}{V\pi}\right\}\right] \qquad (1)$$

$Ein(t) = \sqrt{2Po}\,\exp\,(jwt)$ is the optical field that is applied at input of MZM modulator with angular frequency w and average power Po,Vπ is switching voltage. d1 and d2 are derive voltages which are applied to two arms. By controlling these two drive voltages we have analyzed the performance of DSBSC, DSB+C and SSB+C modulation for generation of 40GHz and 60GHz millimeter waves based on BER ,received optical power and maximum immunity against dispersion and also up stream our 2.5 Gb/s PBRS NRZ data in mm wave band under different lengths of fiber to simulate bit error rate and dispersion effects. Full duplex radio over fiber system is also proposed based on double side band suppressed carrier (DSBSC) modulation because of its best results.

3. *2f and 4f method*

There are two modulation side band techniques dubbed 2f and 4f methods. These techniques generate high order harmonics by relying on the non-linear transfer characteristic of the Mach -Zander modulator (MZM). The output of the MZM in terms of the E-field can be described by [11]:

$$\mathrm{Eout(t)} = \mathrm{Ein(t)}\cos\frac{\pi}{2}\frac{\mathrm{Vmod(t)}}{\mathrm{V\pi}} \qquad (2)$$

Where Vmod(t) is th voltage applied to input terminal of modulator, Ein(t) is the optical field applied to the input of the modulator, and Vπ is the modulating voltage required to totally suppress the output. If the modulating voltage Vmod(t) is sinusoidal, it can be shown that the output field may be written in the form [11]:

$$\begin{aligned}\mathrm{Eout(t)} &= \frac{1}{2}\mathrm{Jo}(\alpha\frac{\pi}{2})\cos\left[\frac{\pi}{2}(1+\varepsilon)\right]\cos(\Omega t)\\ &-\frac{1}{2}\mathrm{J1}(\alpha\frac{\pi}{2})\sin\left[\frac{\pi}{2}(1+\varepsilon)\right]\cos(\Omega t \pm \omega t)\\ &+\frac{1}{2}\mathrm{J2}(\alpha\frac{\pi}{2})\cos\left[\frac{\pi}{2}(1+\varepsilon)\right]\cos(\Omega t \pm 2\omega t)\\ &-\frac{1}{2}\mathrm{J3}(\alpha\frac{\pi}{2})\sin\left[\frac{\pi}{2}(1+\varepsilon)\right]\cos(\Omega t \pm 3\omega t)\end{aligned}$$

(3)

Where ε is the normalized bias, Ji is the ith Bessel function of the first kind, and α is the drive level. Equation (2.12) shows that by adjusting the bias to appropriate levels ε=0, or ε=1, the 2nd or 4th order harmonics of the drive signal may be generated.

4: The 2f METHOD

When the MZM is biased so that ε = 0 (at Vπ), the optical carrier is suppressed collectively with the even modulation

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X

sidebands at Ω ± 2ω, Ω ± 4ω, etc. What remain are two strong components separated by 2ω and centered on Ω , plus higher order odd terms. The higher order terms have lower amplitudes and can be reduced to 15dB below the two major components by careful control of the bias point [43]. The modulated optical signal is transported across the fiber length to the RAU. When the two strong components separated by 2ω impinge on the photodiode, they are heterodyned to generate a microwave signal with angular frequency equal to 2ω. In other words, the drive frequency is doubled, or fmm = 2fmod .The doubling in frequency is what leads to the name 2f method. Adding data modulation to the generated mm-waves is achieved by filtering one of the optical sideband components and then modulating it with the data before combining and transmitting both sidebands.

5. 4f METHOD

The 4f method is similar to the 2f method as explained above, except that in this case ε= 1 is used. The spectrum then comprises the optical carrier at the center with sidebands at 2ω on either side. By carefully choosing the drive voltage α, the central component at Ω can also be suppressed. The resulting optical spectrum now consists of two main components separated by four times the drive frequency of the modulator. Heterodyning at the photodiode produces a signal at frequency, fmm = 4fmod – hence the term 4f method.

6.MM wave signal generation by injection locking based heterodyning technique

A different but attentive technique for optical mm-wave generation can be realized by using optical heterodyne technique in which two phases correlated optical carriers from two different light sources are generated at the central station (CS) with a frequency offset equal to the desired mm-wave. The generated carriers are then transmitted over the fiber and beat together at a high speed photo detector (PD). The use of this technique can greatly reduce the bandwidth of the optical components required as now we are actually dealing with offset between two light sources and can also eliminate the power fading effect due to fiber transmission. But one of the big drawback associated with this technique is the production of two perfectly phase correlated light sources because slight mismatch in their correlation can lead to significant degradation in performance. We have designed and simulated a new set which optical injection locking for generation of highly correlated optical signals to overcome dispersion effects. By using this technique, very high frequencies can be generated, limited only by the photo detector bandwidth. Furthermore, higher carrier-to-noise ratio (CNR) is achieved through this technique.

7. SIMULATION AND RESULTS

DSB,SSB, DSBSC modulation based millimeter wave generation through dual arm MZM modulator

The Figure 3 illustrates the three simulation setup for the generation of mm waves in 40 and 60 GHz bands with three different modulation formats. .A CW light carrier tuned at 1550.1nm is driving one input of single arm MZM modulator while the other input is driven by NRZ format pseudorandom sequence word length of 2^{31}-1 data which will be up converted in millimeter wave band. An erbium doped fiber amplifier and polarization controller is used to compensate the insertion loss and polarization mismatch before modulated data signal is input to dual arm MZM modulator. In order to obtain an optical modulated signal with double side band format, it is necessary to reduce the power of upper side bands with negligible power so that we are left with only the first upper and lower sideband. This is accomplished by means of external modulation with a MZM biased at quadrature point. It generates an optical field whose spectrum consists of an optical carrier at W0 frequency with the upper and lower sidebands located at W0+Wm and W0-Wm frequencies, respectively; where W0 corresponds to the MMW radio modulation frequency while to generate OSSB modulation one of the sidebands is eliminated when a phase difference of π/2 is applied in the two RF electrodes of the MZM biased at quadrature. To accomplish this one input of dual arm MZM modulator is driven by 20GHz and 30GHz sinusoidal local oscillators whose frequencies are set to half of the desired mm wave frequencies (fmm/2) to generate 40Ghz and 60Ghz millimeter waves respectively while the bias voltage of 1.02 v

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X

is applied to other arm while in case of SSB modulation 40Ghz and 60GHz local oscillators are applied to dual arm MZM to generate 40GHz and 60Ghz millimeter wave signals . To generate an OCS signal two RF local carries with a phase difference of π and biased the MZM at the switching voltage v_π is applied .To accomplish this dual arm MZM modulator is set at its minimum bias point to suppress the carrier and shift power of carrier to first order side bands. The bias voltage of 1.02V is applied to its two arms while phase shift of π is applied between two frequency local oscillators that are set at 20 and 30Ghz respectively and driving two arms of MZM .Resultant signals with DSB,DSBSC and SSB modulation formats are propagated through different lengths of SMF-28 fiber with dispersion of 17ps/nm/km . Optical to electrical conversion of the 40 GHZ and 60GHZ signals is carried out by 60GHz PIN photodiode followed by electrical amplifier. The response of PD is set at 1 A/W. Relative Intensity noise of laser is chosen at<-145 dBc/Hz while the line width of laser is set at 5 to 6MHz. The received power at optical spectrum analyzer (OSA)and electrical spectrum analyzer(ESA) for 40GHz and 60GHz is analyzed in terms of distance and modulation depth. The efficiency of modulated data is measured in terms of bit error rate for various lengths of single mode fiber.

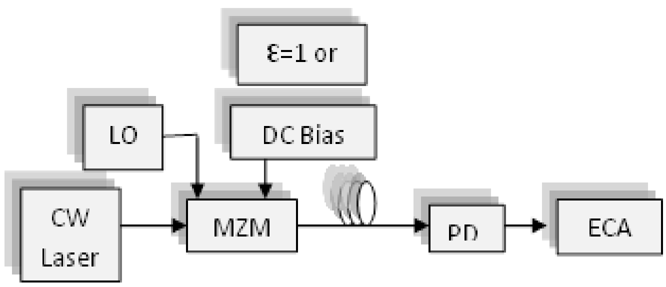


Fig.3 Setup for SSB,DSBSC,DSB modulation based mm wave generation by using dual arm MZM

Figure 4 shows the emission spectrum of CW laser centered at 193.1THz with average power of 1mW and line width of 5MHz.The resultant DSC+C signal after data modulation is shown in figure 5 which clearly indicates carrier and two first order sidebands 20GHz apart from center frequency .The higher order sidebands are neglected due to negligible power compared to first order sidebands. The Figure 6 shows the resultant beat signal at 40GHz after photo detection. The loss of approximately -20db is observed in received signal when it is transmitted over length of 25km over which we got noisy signal due to the fading effects between two side bands and generate chromatic dispersion. Figure 7 shows different patterns of eye diagrams for received DSB modulation based mm wave signal for various lengths of SMF-28 fiber which shows the loss of approximately -20db is observed when signal is transmitted over length of 25km over which we got noisy signal due to the fading effects between two side bands. Figure 8 shows the DSBSC signal after dual arm MZM modulator that clearly indicated that carrier is suppressed when phase shift of π is applied to two arms and switching voltage of v_π is applied. The resultant signal at 40GHz and 60GHz are shown in figure 9,10 and 11 when 20GHz and 30 GHz local frequency oscillators are applied to dual arm MZM.The eye pattern of DSBSC signal shown in figure 12. Under the requirement of BER of 10^{-9}, we can get that DSBSC signal is able to transmit up to 50km.In this case the signal got noisy at 50km due to the excitation of multiple modes generated by MZM modulator. These side bands can be reduced by biasing MZM with suitable bias or by applying wide band filtering that can suppress these upper sidebands. But we need 20GHz and 30GHz signals to generate 40GHz and 60GHz respectively .Therefore DSBSC acts as frequency doubler which significantly reduce the cost of system as opposed to SSB modulation in which we need s frequency value of local oscillator equal to mm wave that we want to generate.

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X

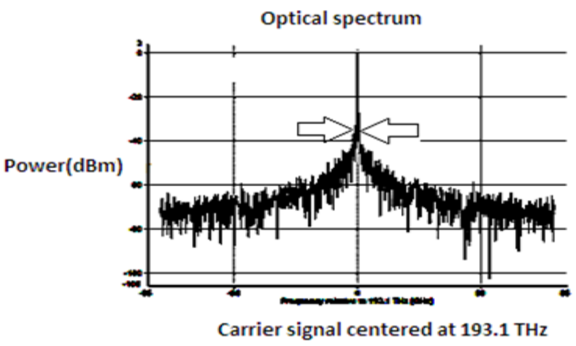
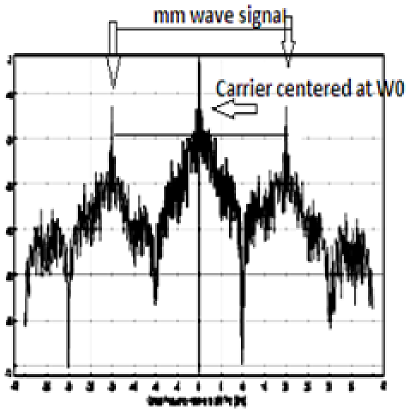


Fig.4 :Emission frequency of emitting laser centered at 193.1 THz



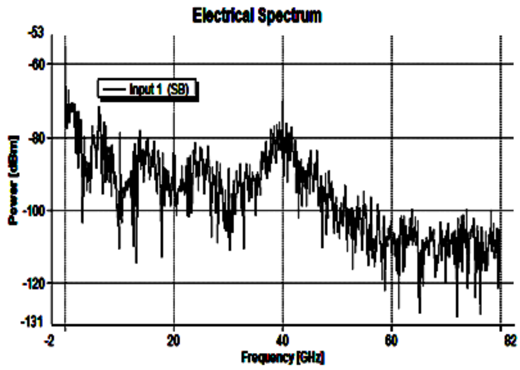


Fig.5 :Resultant DSB+C modulated signal Fig.6 Received Electrical Signal centered at 40 GHz transmitted over 25KM length of fiber

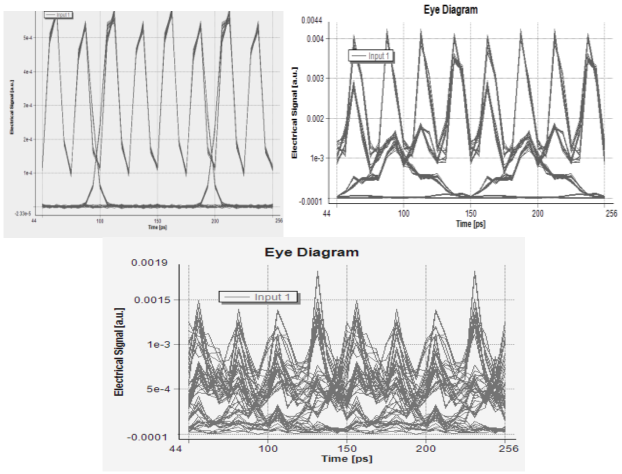


Fig.7: Eye diagram pattern for received mm wave signal

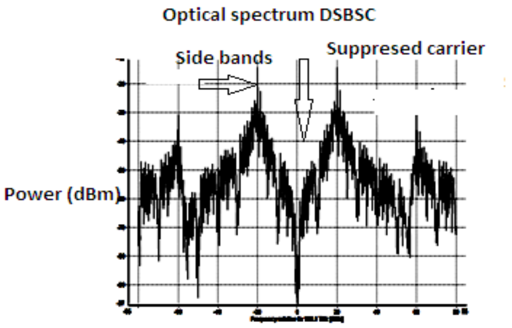
SIMULATION PARAMETERS

Parameters	Values
CW laser emission frequency	193.1THz
CW laser Average Power (Po)	1mW
Laser Line width	5MHz
Local Oscillator Frequency (f)	20Ghz,30Ghz
Data bit rate	2.5Ghz
MZM Extinction	30 dB
BPF central Frequency	193.1THz
Fiber length	25km
Responsetivity of PD	1.0 A/W
Small signal gain for electrical amplifier	30db

Volume 3, Issue 3
June 2014

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X



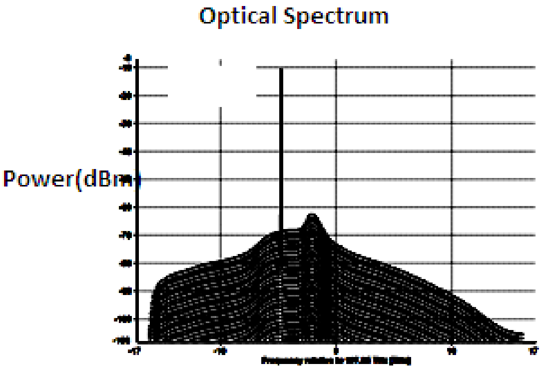
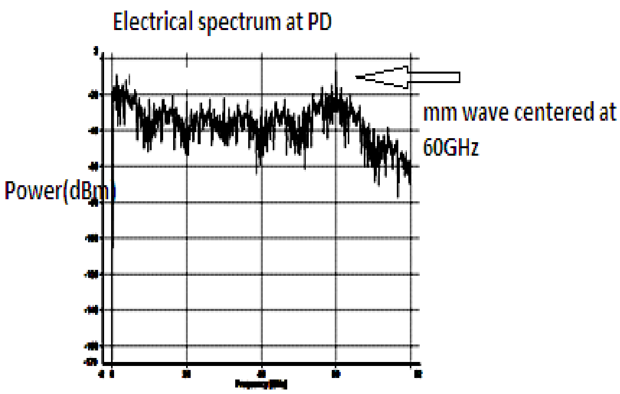


Fig.8: Resultant DSBCS modulated signal after filtering
Fig.9 Received Optical signal before photo detection



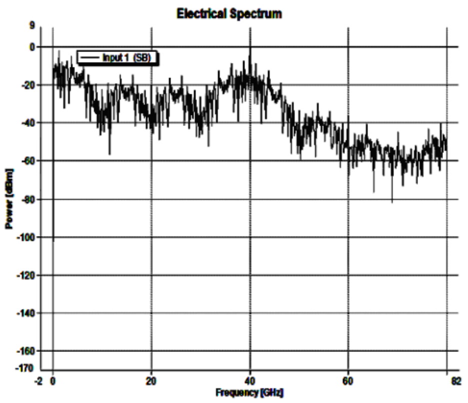


Fig.10 Detected electrical signal at PD Centered at 60GHzFig.11 Detected Electrical signal centered at40GHz

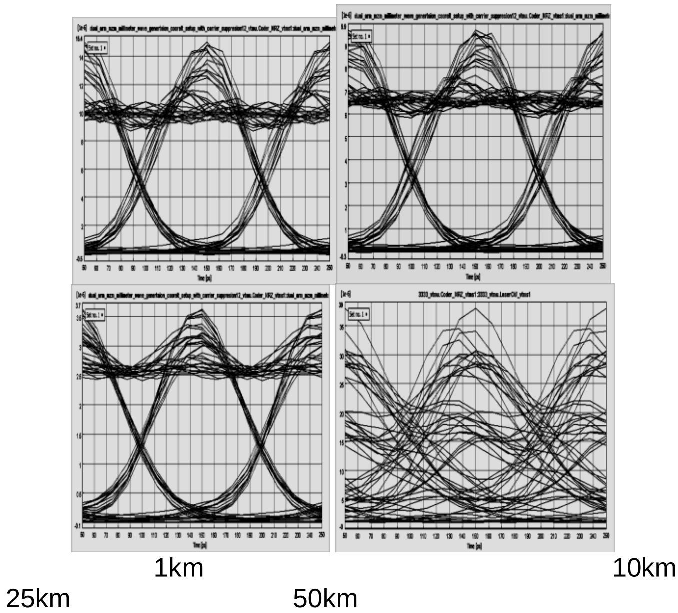


Figure 12: Eye diagram of the received up converted baseband data in mm wave band (100 ps/div)

8. Millimeter wave generation through optical heterodyne Technique

The Figure 13 proposes the Optical injection based heterodyning setup for generation of mm wave signal and upstream of data in mm wave band. A light signal is generated from a CW lasers tuned at 1550.1nm .The 622Mb/s NRZ data with pseudorandom sequence word length of 2^31-1 is mixed with sinusoidal wave of 2.5 GHz to up convert it to mm wave band (Optical subcarrier multiplication) .This signal along with light source is used to drive the MZM modulator extinction ratio of 30dB .The detected signal after MZM modulation is shown in figure 14. The resultant signal is passed to Optical filter to suppress ASE noise and amplified through ideal amplifier. A second light source set at 1550.2nm and perfectly correlated to first light source is launched into system through 50/50 coupler which is used to couple the signals from two lasers .In second setup and the resultant signal is sent to 10km,25 km,50km and 75km length SMF before detection at photo detector. The resultant signal centered at 100GHz is shown in figure 15 which is the offset of two light sources and in this setup photo detector acts as mixer and generate signal that is the offset of frequency between two laser sources. The eye pattern of detected signal at high speed photo detector is shown in figure 16. Under the requirement of BER of 10^{-9}, we can get that resultant signal is able to transmit up to 50km.At 75km signal becomes noisy due to non-perfection of correlation between two light sources .Figure 17 shows the BER vs received power for bout light sources which clearly shows almost negligible BER up to 25km but start increasing due to lack of correlation between two light sources .

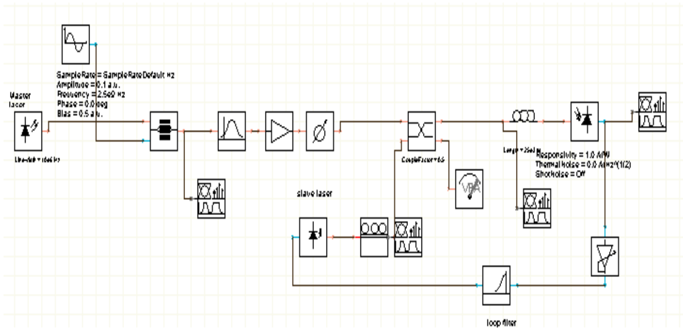
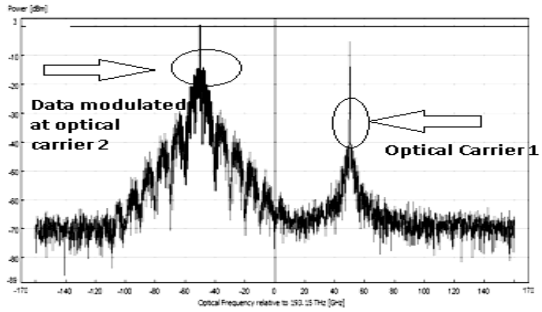


TABLE II

Parameters	Values
CW laser 1 emission frequency	193.1THz
CW laser 2 emission frequency	193.2THz
CW lasers Average Power (Po)	1mW
Lasers Line width	5MHz
Data bit rate	622Mb/s

Fig.13:Setup for mm wave generation using Optical injection based heterodyne technique for more phase correlation



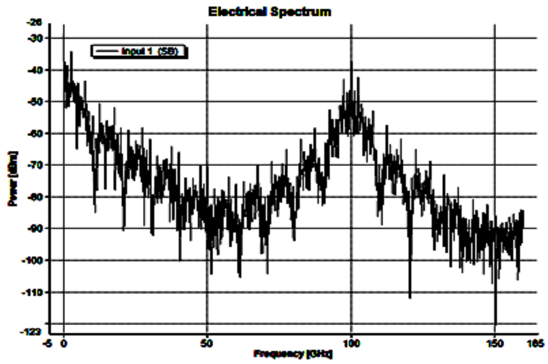


Fig.14 Detected Signal after modulation

Fig. 15 Detected Electrical Signal detection

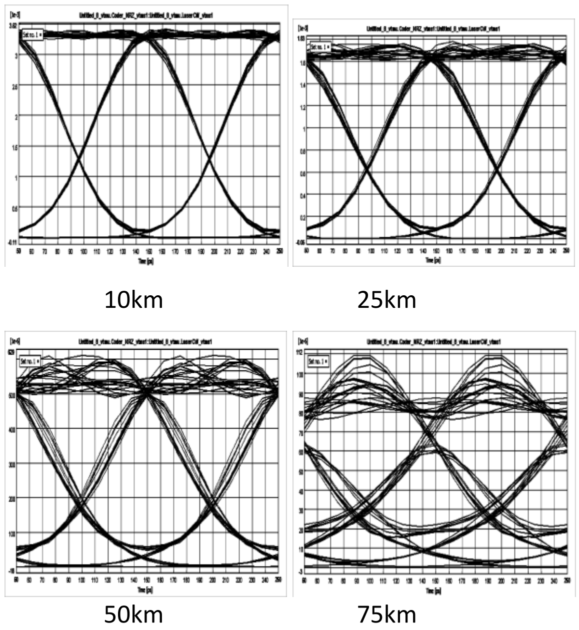
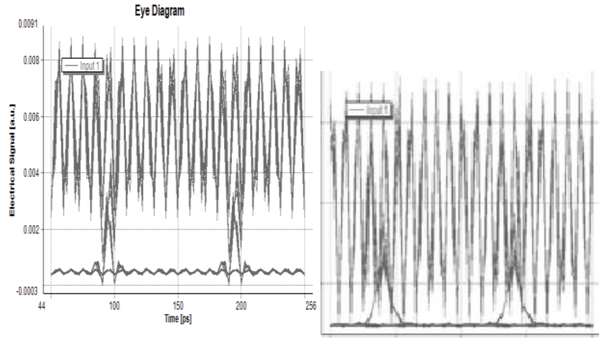


Fig.16 Eye Diagram of received base band signal after propagating through 10km, 25km, 50km and 75km of SMF

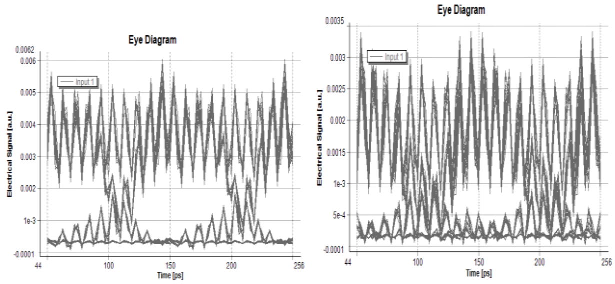
Volume 3, Issue 3
June 2014

ITEE Journal
Information Technology & Electrical Engineering

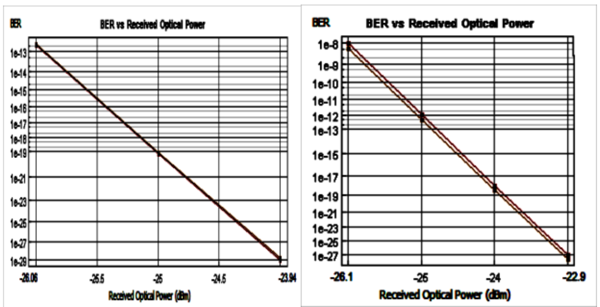
ISSN: - 2306-708X



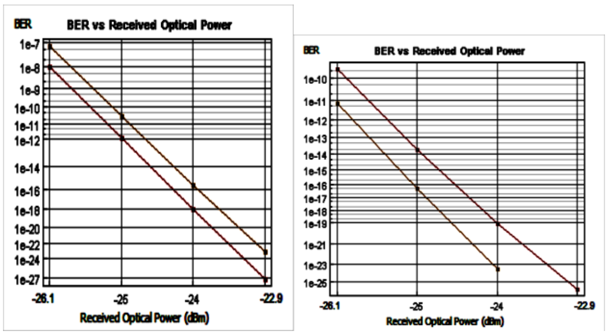
10km 25km



50km 75km



10km 25km



50km 75km

Fig.17 :BER vs. received optical power for bout light sources used in heterodyne setup 2 centered at1550.1nm and 1550.2nm

9. CONCLUSION

We have proposed and simulated various techniques for broadband mm-wave signal generation and data up conversion by using different techniques. We have proposed and configured three main configurations for the generations of mm-wave radio over fiber architectures and find that SSB modulation based external modulation is more less immune to dispersion effects but same value of local oscillator as required millimeter wave is required. The DSBSC scheme is more efficient and cost effect in sense that half frequency local oscillator is required to generate required millimeter wave and it acts as frequency doubler .We have achieved mm wave up to 60 GHz and modulated 2.5 Gb/s and 622Mb/s data by our proposed system over various lengths of fiber. One setups is proposed for mm wave generation and carrier up conversion by using injection based heterodyning technique. This setup provides more flexibility than the conventional heterodyne techniques in terms of signal phase correlation and maximum distance that we can cover. By using this technique we have generated RF carriers up to 100GHz that can be detected by commercially available photo detectors. To solve phase correlation problem between two light sources we have simulated optical injection locking setup and achieved RF carriers up to 40GHz range.

REFERENCES

[1]. L. Noel, D.Wake, D. G. Moodie, D. Marcenac, L. D.Westbrook, and D.Nesset, "Novel techniques for high-capacity 60-GHz fiber-radio transmission systems," *IEEE Trans. Microwave Theory Tech.*, vol. 45, pp.1416–1423, 1997.

[2]. 60 GHz Millimeter-Wave Source Using Two-Mode Injection-Locking of a Fabry–Perot Slave Laser Masahiro Ogusu, K. Inagaki, and Y. Mizuguchi "IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, VOL. 11, NO. 3, MARCH 2001"

[3].Review on System Architectures for the Millimeter-Wave Generation Techniques for RoF Communication Link N. Mohamed1, S.M. Idrus2 and A.B. Mohammad" 2008 IEEE INTERNATIONAL RF AND MICROWAVE CONFERENCE PROCEEDINGS December 2-4, 2008, Kuala Lumpur, MALAYSIA"

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X

[4]. Simultaneous Generation of Baseband andcRadio Signals Using Only One Single-ElectrodecMach–Zehnder Modulator With Enhanced Linearityc Chun-
Ting Lin, Wei-RenPeng, Peng-Chun Peng, Jason (Jyehong) Chen, Cheng-FengPeng, Bi-ShiouChiou,
andSien Chi "IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 18, NO. 23, DECEMBER 1, 2006"

[5]. R. Kashyap, J. Yao, K. Wu, and X. Zhang, "Techniques for photonic generation of millimeter-wave signals," in Proc. of IEEE/LEOS Summer Topical Meetings 2007, Portland, Oregan, July 2007, pp. 188-189

[6]. Frequency Quadrupling and Upconversionin a Radio Over Fiber LinkHao Chi and Jianping Yao, Senior Member, IEEE, Member, OSA" JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 26, NO. 15, AUGUST 1, 2008"

[7]. Scheme for a High-Capacity 60 GHzRadio-Over-Fiber Transmission SystemJing Li, TiGangNing, Li Pei, and ChunHui Qi"J. OPT. COMMUN. NETW. /VOL. 1, NO. 4/SEPTEMBER 2009"

[8]. Yu-Ting Hsueh, ZhenshengJia, *Member*, *IEEE*, Hung-Chang Chien, *Member*, *IEEE*,Jianjun Yu, *Senior Member* A Novel Bidirectional 60-GHz Radio-Over-FiberScheme With Multiband Signal Generation Using a Single Intensity Modulator, *IEEE*, and Gee-Kung Chang, *Fellow, IEEE"* IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 21, NO. 18, SEPTEMBER 15, 2009".

[9].Optical Millimeter-Wave Generation andTransmissionWithout Carrier Suppression for Singleand Multi-Band Wireless Over Fiber Applications Hung-Chang Chien, *Member*, *IEEE*, Yu-Ting Hsueh, *Student Member*, *IEEE*, ArshadChowdhury, *Member*, *IEEE*, Jianjun Yu, *Senior Member*, *IEEE*, *Fellow*, *OSA*, and Gee-Kung Chang,
*Fellow, IEEE "*JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 28, NO. 16, AUGUST 15, 2010" IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 58, NO. 11, NOVEMBER 2010

[10].Optical Generation of Modulated Millimeter Waves Based on a Gain-Switched LaserHayman Shams, *Student Member*, *IEEE*, Prince M. Anandarajah, *Member*, *IEEE*, Philip Perry, *Member*, *IEEE*, and Liam P. Barry, *Member*, *IEEE"*IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 58, NO. 11, NOVEMBER 2010".