Cost Effective Optical Millimeter Wave Generation for Radio Over Fiber System

Abhishek Ranjan, Nilima

Abstract ***- There is continuous growth in demand of internet traffic among end users for various applications. This results in overcrowding and interference of data at microwave region. Numerous research is being carried out in the field of broadband technology to achieve high performance and high data rate, as with the increase in demand of application and various high bandwidth application at the end user terminal is a stress over data rate. Increased interference leads to deterioration in network performance. A promising solution to this problem, is integration of network evolved from wireless and optical fiber network at very high frequency in millimeter (mm) wave range such as 60GHz - 70GHz to cope up the need of bandwidth which result in increased mobility and provide large instantaneous bandwidth. There is a need of shifting frequency of operation to high frequency region in mm. As the propagation characteristics such as reflection, refraction and scattering are less at high frequency, high frequency of operation at mm wave can be proved to be a promising solution to provide high data rate with enhanced performance. In this project four technologies for increasing the bandwidth of network with decrease in cost of system were reviewed .Including photonic mm wave generation using based on external intensity modulation and non-linear effects in fiber using principal of frequency quadrupling and sextupling. From all these four different proposed techniques we conclude that dual-parallel MZM is the most cost effective and promising solution for frequency quadrupling and copes with the increasing frequency demand in the market.***

Index Terms- Fiber, Frequency, Optical, LED, BER, Performance, Photonic, modulator.

I. INTRODUCTION

In this project, we aim to compare and analyze between the performances of the various proposed techniques for cost effective generation of optical millimeter wave for radio over fiber system. We will make an attempt to design and simulate various proposed techniques which might be implemented in the near future in the field of optical communication and enhance the performance of the existing system and decreasing the cost of the network. In the existing system, at central office signals from various sources are received, processed and are modulated, then it is sent to the base station through distribution network (optical fiber). At base station these signals from different sources are again processed and are up-converted separately for each channel. After all these processing the signal is then sent to the user using antenna for wireless signal or using cables for wired signal.

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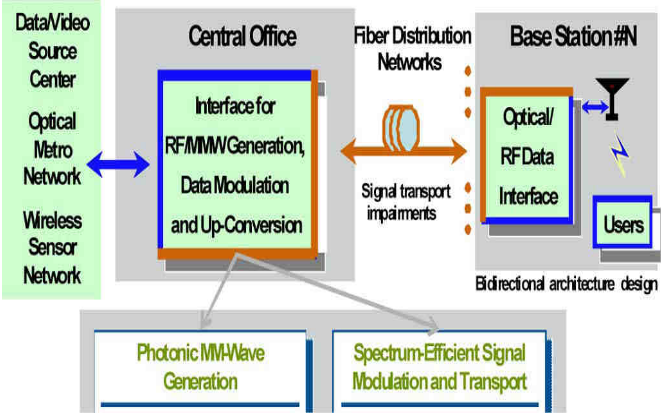

Figure 1.1 Basic Network Architecture

In optical millimeter wave technologies (Figure 1.1), the received signal at the Central Office are processed, modulated and are up-converted for all the channels together. Then it is send to the base station using distribution network for further transmission to the intended user.

Actually in the entire process RF signals are generated at the central office itself which is being distributed to the user without need of anymore up-conversions and processing whereas in the existing system the signal transmitted from Central office to Base Station are not in RF form hence it requires up-conversions and signal processing for each channel separately. This process makes the system costly and complex.

A. Need for Optical millimeter-wave generation

Despite of number of works being carried out in field of broadband technology , to achieve high performance and high date rate , but with the increase in demand of application at the end user terminal and increase demand of various high bandwidth application there is a stress over data rate and increased interference leads to decrease of network performance.

A promising solution to this problem is integration of network evolved from wireless and optical fiber network.

B. Advantage

- Availability of high bandwidth
- Mobility

As more number of applications will be demanded by the end users, there will be overcrowding and interference of data at microwave region .Hence there is a need of shifting frequency of operation to high frequency region in mm interference leads to decrease of network performance. A promising solution to this problem is integration of network evolved from wireless and optical fiber network, wave region such as 60GHz - 70GHz.

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High frequency of operation has various advantages: Large instantaneous bandwidth for information transfer. Small antenna and other component size. Offer capability for enhanced imaging and sensing application.

C. Future Demand of Optical mm Wave

As the propagation characteristics such as reflection, refraction and scattering are less at high frequency, high frequency of operation at mm wave can be proved to be a promising solution to provide high data rate with enhanced performance. Exchange of high definition uncompressed baseband audio and video at high rate can be possible wirelessly in rooms or building .These technology will eliminate the use of high definition multimedia wire or connectors (HDMI wires).

Wireless connectivity of video sources and projectors. Communication link between high speed vehicles. High bandwidth wireless link to high capacity or low-power computing device such as camera and hard drive.

D. Challenges

- Limited frequency response of electrical components
- High frequency oscillation at optical and electronic domain

These limitation results in use of optical techniques for mm wave generations create these components, incorporating the applicable criteria that follow.

II. METHODOLOGY

A. Overview:

High attenuation of millimeter-wave signals in the air numerous antenna BSs are needed in millimeter-wave fiber systems. In order to make the system economically viable it has to be simplified, consolidated, and cost effective. So, it will be critical for ROF systems to shift the complexity away from the RN and BS toward the CO, where the number of expensive millimeter-wave signal processing elements can be reduced greatly by sharing among multiple end users. For enabling simple architecture, easier installation, and low-cost operation and Maintenance we can consolidate most of the expensive components at the CO. Not only this the Processing centralization at the CO also provides a number of system performance advantages like the feasibility of implementing efficient multiple input multiple output (MIMO) techniques and smart antennas array, centralized control of media access layer, and radio sources management. Clearly the BS needs to perform optoelectronic conversion, amplification and broadcast functions only.

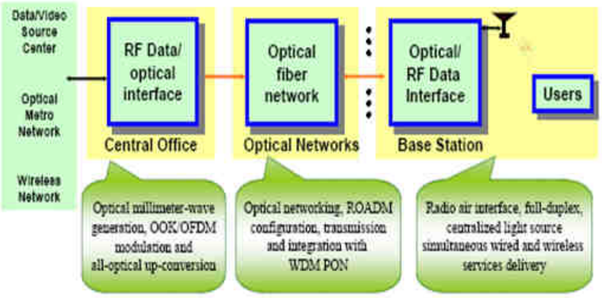

Figure II.1: Key Technology of wireless optical network

The above Figure II.1 shows the block architecture of the optical-wireless system and the enabling technologies for symmetric super-broadband optical-wireless networks. Optical millimeter-wave signals are generated and mixed with baseband digital signals using cost-efficient all-optical approaches at the CO. By using all-optical methods we can assure the use of low-frequency electronic devices and seamless integration with the deployed optical transmission systems. For longer transmission distances we can use SMF. Fading effect induced by chromatic dispersion in optical fiber is the major limitation is the RF signals. So we use optical feeder networks which acts as an analogue transmission system and delivers the radio signals with the best fidelity to the remote BSs.

Due to the need for numerous BSs as a result of shrinkages of a BS cell size a low-cost and simple architecture is required for the BS design. We can have an attractive solution if we use a centralized light source in the CO in the full-duplex system. The second goal of this architecture is delivery of wired and multi-band wireless services to serve both fixed and mobile users.

B. Motivation:

The growing popularity of the Internet, IPTV, Video On Demand, Video Conferencing, Gaming are the key factors behind the development of new access method which would meet the bandwidth requirement. Access network based on copper has distance and bandwidth limitation and will start running out of capacity in near future. The access methods based on the optical fiber are getting more and more attention as they offer the ultimate solution in delivering different services to the customer premises.

C. Architecture:

Numerous works are being carried out in the field of optical for mm wave generation. Here are the proposed techniques for mm wave generation:

1. Based on external intensity modulation
2. Cascade external intensity modulation and use of highly non linear fiber
3. Quadrupling without use of optical filter
4. mm wave generation using freq sextupling

1. Based on external intensity modulation:

In optical communication, intensity modulation (IM) is a form of modulation in which the optical power output of a source is varied in accordance with some characteristic of the modulating signal .This scheme is based on frequency quadrupling technique, to reduce the bandwidth requirement of various optical and electrical component [6]

Principal used: frequency quadrupling

In this technique modulator is being driven by RF generator of frequency f0, and is inputted by laser signal at wavelength lambda 1 .Here the modulator is biased at maximum transmission point to obtain frequency separation between side bands of 4f0. This biasing of modulator at maximum Transmission point results in suppression of 1st side bands, and 2nd sideband is separated from laser spectra by

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2f0.[7],[8] .Figure III.2 explains frequency quadrupling principals

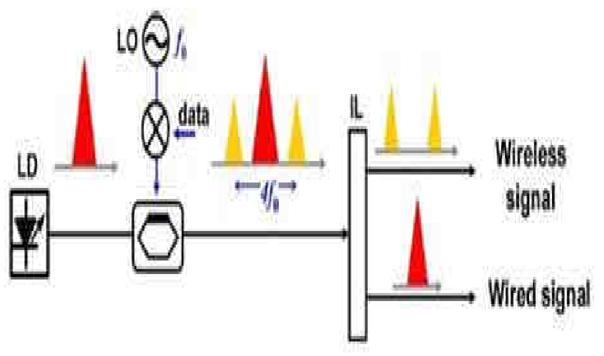

Figure II.2: Frequency Quadrupling principal

Block Diagram and working:

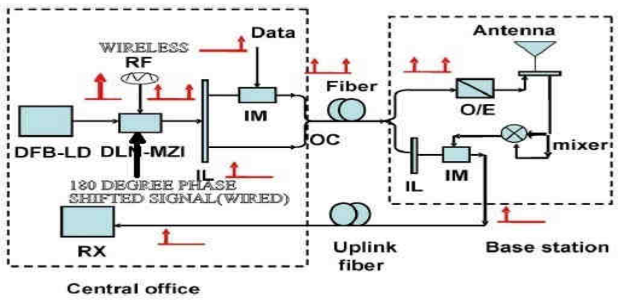

Figure II.3: Block Diagram of mm wave generation using external intensity modulation

AT the Central office Laser signal is generated using DFB-LD laser diode operating at frequency of 193.1THz. RF signal at frequency f0 is modulated with wired and wireless signal at same or different data rate using electrical signal having NRZ encoding at a data rate of 2.5Gbps.

LibNO3 Mach zehnder IM modulator is used, and the modulator is biased at maximum transmission point [2], [7], [8] to achieve frequency quadrupling. Modulator has input from laser (DFB-LD) source and is inputted by wired and wireless signal operating at RF frequency f0. Both wired and wireless signal is 180 degree phase shifted with respect from each other to achieve DSB signal.

Let the RF signal be at 10 GHz ,and data rate of wired and wireless signal be 2.5Gbps the output of modulator will be two side band separated from the central spectra by 20 GHz. Hence both the side bands are separated from each other by 40 GHz.

If the carrier is at 193.1 THz and then two significant side bands are at 193.08THz and 193.12THz. Here the side bands are separated by frequency separation of 40GHz (which is 4 times of RF signal).hence we can see that frequency quadrupling is achieved using the property of modulator. Here we can see that 1st order side band is totally suppressed and power difference between carrier and 2nd side bands are around 14 db .Then after signal is launched into the single mode fiber (SMF)of length 20km. After travelling down the length of 20km it has some attenuation and polarization issues. To compensate losses we use amplifier.

At the Base station ,at the other end of fiber ,there is an interleaver , which function is to separate carrier and side bands .At one port of interleaver it has the side bands (*sub Carrier) and other end it has laser signal (*carrier) , carrier signal will be use as a laser source for back propagation in bidirectional communication. Sub -carrier ,carries the information, is send further for signal detection and processing further the detected signal is measured using BER meter and power is measured.

Here in this technique we are using exploring the property of modulator (frequency quadrupling) this reduces the bandwidth requirement of modulator and interleaver and other component .and reduces the cost of system to large extent.

2. Cascade external intensity modulation and using highly non linear fiber

This scheme is based on generation of polarization insensitive all optical up conversion using co-polarized pump source.

Previous work based on external intensity modulation has a simple architecture for frequency quadrupling but has a disadvantage of polarization issue, hence common external modulator cannot be used for frequency up conversion for baseband signals or multisignal input [9],[10].Numerous of methods has been proposed for polarization sensitive all optical up-conversion. Based on external intensity modulation, phase modulator, and cross absorption [11], [12], [13].However all these proposed scheme has some drawback of conversion loss and polarization sensitivity to optical signal

In the proposed scheme we are using four wave mixing technique (FWM) in highly non- linear fiber, for optical up-conversion, FWM in non-linear provide attractive solution for all optical up-conversion as it provide transparency to the signal bit rate and modulation format, and is insensitive to phase matching and multi wavelength capability added advantage of non–linear fiber is fast non-linear response.

Basic principal of this scheme is FWM in HNLF [14].However only a single pump source is used, so it is polarization sensitive and cannot be use to remove the drawback. Wavelength conversion in non-linear fiber can be polarization insensitive if we are using co-polarized pump source [15], [16].

Principal used: FWM using co-polarized pump source

It works on the principal of FWM using co-polarized pump source. Two pump sources are generated using common laser source and are spaced 2f, when they are driven by RF signal at frequency f. Since these two pump sources are generated using common laser signal hence they are phase locked, and hence they have fixed phase relation. If the phase of pump signal is not phase locked they will not have fixed phase relation and hence will not be used for frequency up conversion of baseband signal.

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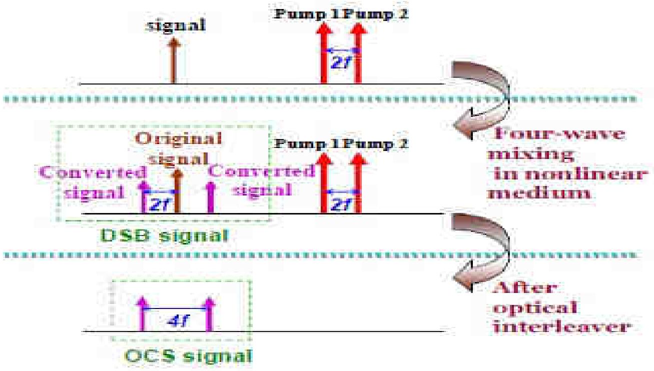

Figure II.4: Four wave mixing in highly non linear fiber

In Figure II.4 we can see the signal and two pump sources, after passing through the HNLF, frequency conversion takes place and converted peak are spaced 4f after FWM in HNLF. Since the pumps sources are phase locked hence all the converted peaks and signal are phase locked with respect to each other. The converted signal include signal and two peaks hence when the signal is removed the peaks will be 4f apart and are OCS. Hence we can see that we have generated DSB-OCS signal. We can use interleaver or filter to remove the signal.

Here we are more focused on OCS as it has high receiver sensitivity and negligible fading effect.

Block Diagram and working:

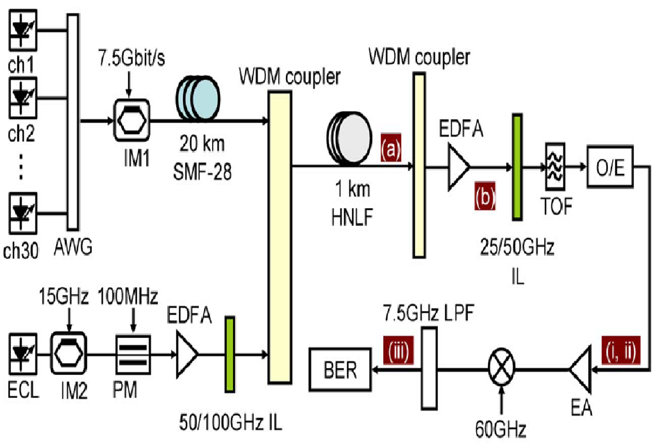

Figure II.5: Block Diagram of mm wave generation using cascade external intensity modulation using highly non linear fiber

We have used 30 WDM channel, these are generated using DFB-LD from wavelength ranging from 1532.81nm to 1555.88nm with channel spacing of 100GHz.all the 30 channels are added using AWG grating or is multiplexed using 30X1 MUX and then is send to intensity modulator .IM1 is being driven by electrical signal at data rate 7.5Gbps.This electrical signal is NRZ encoded and since we have used 30 channel hence date length of 231-1 is needed. This electrical signal will act as On off Key (OOK).Modulated signal is then send down to 20km long fiber to emulate the baseband signal.

Another laser signal operating at 1561.32nm is used to create the co-polarized pump signal. This laser signal is send to IM2 which is being driven by RF signal source of frequency f (15GHz).IM2 is biased at null point to realize OCS .the output of modulator IM2 is two peak signal separated by 30 GHz (2f) and is OCS. This Pump signal is phase locked. Modulator IM2 is followed by phase modulator driven by 100MHz signal whose function is to broaden the spectrum and removing the stimulated brilloum scattering effect.PM is then followed by IL which functions to enhance the carrier suppression function of pump source.

The output of IM1 travelled down 20km SMF is added to output of IM2 using WDM coupler. The output of coupler is passed to HNLF of length 1km.The HNLF is 1Km long, zero dispersion at wavelength of 1561nm has attenuation of 0.4db/km. dispersion slope of 0.02ps/nm^2/km.The spectrum after HNLF with a resolution of 0.02 nm is shown below. We can see that after passing through HNLF up-converted signal is DSB , have 2 peaks each spaced 30GHz from the central peak is created using 7.5Gbps OOK signal the power difference between the peaks of 30GHz converted FWM signal and carrier is29 dbm .

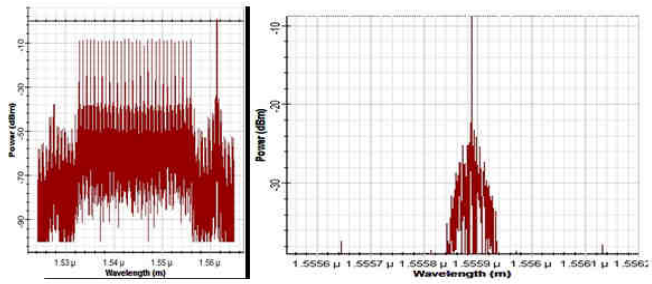

Figure II.6: Four wave mixing explanation

HNLF is then followed by WDM coupler and IL for enhancing the suppression of carrier; at the end of IL we can see that carrier is almost totally removed.IL is then followed by TOF with 3db b/w to select a channel. This particular signal is then photo detected and send further for signal processing and BER estimation.

3. Quadrupling without use of electrical filter:

As freq up-conversion above 40GHz is challenging, many work has be shown above and in past using LibNO3 MZM for frequency up-conversion around 40GHz.however higher conversion require cascade modulation scheme which increase the cost of the system, additionally electrical component above 26GHz is costly compare to below 26 GHz in addition to these component electrical filter makes the system complex and costly.

Using frequency tripling and quadrupling techniques, optical millimeter-wave signals can be generated using low-frequency RF components and equipment without using electrical filter, which reduces the entire system costs. Here we have proposed the technique to use two parallel Mach-Zehnder Modulators to get frequency quadrupling .In addition to Radio over fiber techniques, simultaneous transmission of wired and wireless signals for low-cost quad-play services (wireless, telephone, television and internet) over the passive optical networks (PON) is possible. The proposed architecture supports both wireless and wired services [17], [18].

Principal used: Principal of Frequency Quadrupling without

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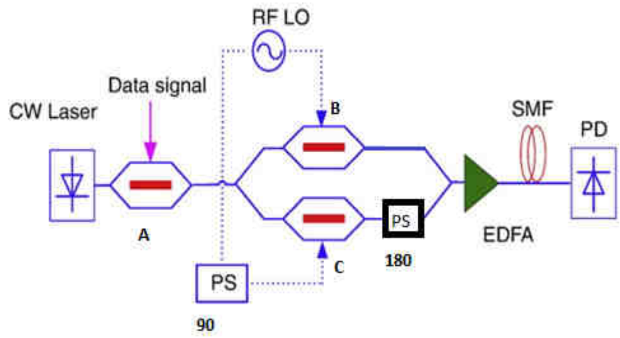

Figure II.7: Use of electrical filter

As illustrated above Figure II.7, In the Central unit we are using array of DFB-LD as a source of laser, these laser signals are then modulated using NRZ encoded electrical signal at 1.5Gbps data rate. Then both signals are use to drive the modulator. The Optical signal is then send for Up-conversion and all the channels are up-converted simultenously.MZM –b and MZM-c are parallel .Two MZM -b and MZM-c are biased at max transmission point for odd band suppression and the MZM-a is biased at null point for carrier suppression.

RF signal fed to it is 90 degree phase shifted .This RF signal is modulated by NRZ encoded electrical signal .Output of these MZM is DSB signal , whose 1st side band is suppressed and 2nd side band is spaced 2f0 from the carrier .Hence side bands are separated by 4f0 with each other and here we have attain frequency quadrupling.

For the carrier suppression output of one of MZM is 180 degree phase shifted and then added using power combiner. The output of Coupler is DSB-OCS signal.

Assuming that the field of optical source is defined as

$$Ein\ (t) = Eo\cos(\omega o t)$$

Where,

Eo denotes the amplitude of the optical field, and

ωo is the angular frequency of the optical carrier.

Electrical RF driving signals sent into MZ-b and MZ-c are

$$Vb(t)=Vm\cos(\omega RFt)$$

And

$$Vc(t)=Vm\cos(\omega RFt+90)$$

Respectively, where, ωRF is the angular frequency of the electrical driving signal.

The optical field at the output of the dual-parallel MZM can be expressed as

$$Eout(t)=-Eo\sum J4n\text{-}2(m)*[\cos\{(\omega o+(4n-2)\omega RF)t\}+\cos\{(\omega o-(4n-2)\omega RF)t\}]$$

Where, the phase modulation index m is = πVm/2 Vπ and J4n-2 denotes the Bessel function of the first kind of order 4n-2. Due to the properties of Bessel function, the optical sidebands with the orders exceeding J2 can be ignored without generating considerable error. Therefore, the output optical field can be simplified as

$$Eout(t)=-Eo[J2(m)\cos\{(\omega o+2\omega RF)t\}+J2(m)\cos\{(\omega o-2\omega RF)t\}]$$

After square-law detection using a photo diode, only the electrical signal with a frequency four times that of the electrical driving signal, ωRF, will be detected.

Optical side band suppression ratio:

$$OSSR=10\log\left[\frac{(1-\cos(3\Delta)}{(1-\cos(7\Delta)}\right]$$

It can be found from that the OSSR is identical and both equal to 31.09 dB for Δ = /2 and Δ = although the third-order sideband has different power for two cases.

Block diagram and working:

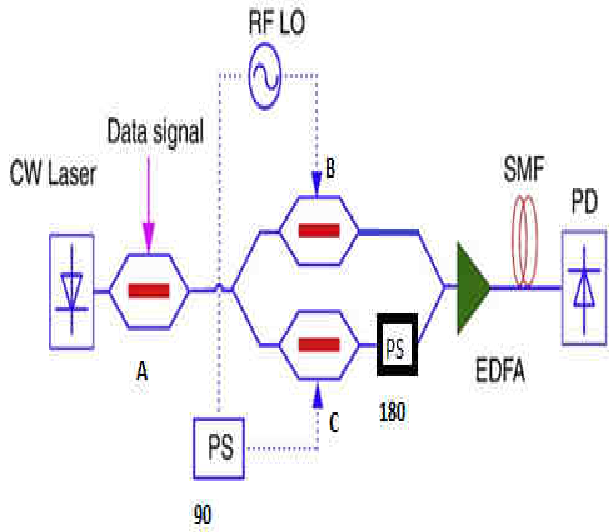

Figure II.8: Block diagram of frequency quadrupling without use of electrical filter

An array of CW laser is used as four channels with frequency 193.1 THz to 193.4 THz. These signals are multiplexed and modulated with a simple Mach-Zehnder Modulator-A driven by RF signal which is NRZ encoded .The output of this MZM –A is power splitted using splitter and send to MZM-B and MZM-C.MZM –b and MZM-c are parallel .Two MZM -b and MZM-c are biased at max transmission point for odd band suppression and the MZM-a is biased at null point for carrier suppression. MZM-B and MZM-C is also fed by RF signal at frequency f0 which is phase shifted by 90 degree. The output of MZM-B and MZM-C is DSB signal, this DSB signal is 2f0 separated from carrier hence side band is 4f0 separated from each other. Here we have frequency quadrupling.

To attain OCS the output of one of MZM-B, C is 180 degree phase shifted and added using power coupler. The output of coupler is DSB-OCS signal. An extinction ratio of 20dB is used .Both the modulators MZM –B and MZM-C are biased at maximum transmission point in order to cancel even odd sidebands. An EDFA amplifier is used to amplify the signal and send it via optical fiber of 50 Km. The output is detected via PIN photodiode.

This photo detected signal is then BER analyzed.

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4. Millimeter-wave generation using frequency sextupling using three parallel LiNb MZM:

Many different approaches have been proposed to generate high frequency mm-wave. In Ref. [19], two cascaded intensity modulators are used for frequency quadrupling. In Ref. [20], frequency sextupling mm-wave signal is generated with two cascaded intensity MZM. In Ref. [21], we propose an octupling mm-wave generation scheme based on two cascaded MZM. In Ref. [22], a new scheme to generate an optical mm-wave with octupling of the local oscillator via a nested MZM is proposed.

Here in this scheme, we have used three parallel Mach-Zehnder Modulator to achieve frequency sextupling. We have used 10 GHz frequency to get 60 GHz frequency using three parallel LiNb Mach-Zehnder Modulators.

We are proposing this new technique to cope up with the increasing demand of bandwidth.

Principal used: frequency sextupling

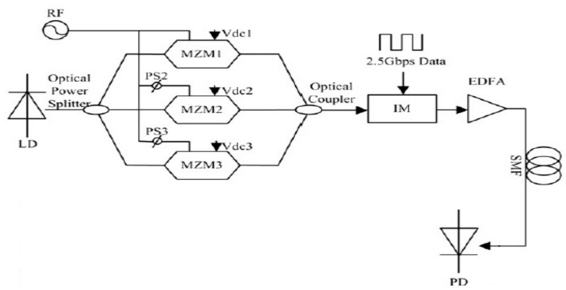

Figure II.9: Principal of mm wave generation using frequency sextupling

Three MZMs are in parallel, and a RF signal is applied to the three MZMs with different initial phases. The light wave centered at ωc emitted from the laser diode (LD) is divided into three equal parts by an optical power splitter and injected into the three MZMs respectively. The phase shifts introduced by PS2 and PS3 are $\Delta\phi 2$ and $\Delta\phi 3$, and the phase differences between two arms of a MZM introduced by DC bias are $\phi 1$, $\phi 2$ and $\phi 3$ respectively, where $\phi i=\pi Vdci/V\pi$ (i=1, 2, 3).

$V\pi$ is the half-wave voltage of the MZM.

If the insertion loss of the MZM is neglected, and the extinction ratio of the MZM is assumed to be infinite, the output optical signal of the optical coupler can be expressed as

$$E(t)=1/6E0\exp(j\omega ct)\{\exp(jm\sin(\omega mt))+\exp(-m\sin(\omega mt)-j\phi 1\}+1/6E0\exp(j\omega ct)\{\exp(jm\sin(\omega mt+\Delta\phi 2))+\exp(-jm\sin(\omega mt+\Delta\phi 2)-j\phi 2)\}+1/6E0\exp(j\omega ct)\{\exp(jm\sin(\omega mt+\Delta\phi 3))+\exp(-jm\sin(\omega mt+\Delta\phi 3)-j\phi 3)\}$$

Where, m is the RF modulation index defined as $m=\pi VRF/V\pi$, VRF and ωm are the amplitude and angular frequency of the RF signal, E0 and ωc are the amplitude and angular frequency of the optical signal, $Jn(\cdot)$ is the nth-order Bessel function of the first kind.

We use modulation index to suppress the third order sidebands. If we do not suppress the third-order sidebands, and set $\Delta\phi 2=120°$, $\Delta\phi 3=-120°$, only two third-order sidebands and two sixth-order sidebands exist. Due to the characteristic of Bessel function, when the modulation index is small, the sixth-order sidebands are much lower than the third-order sidebands. So the two third-order sidebands can be used to generate sextupling mm wave signals.

We set m=1.795 ($VRF=0.571V\pi=2.855$). The frequency of the RF oscillator is 10 GHz. If $\Delta\phi 2=120°$, $\Delta\phi 3=-120°$, $Vdc1=Vdc2=Vdc3=V\pi=5$, and we choose the first zero point of zeroth-order Bessel function as the working point high quality sextupling mm-wave will be generated. The elimination of the sidebands is achieved by adjusting the driving voltage of the RF oscillator, the phase difference between the RF signals applied to the MZMs, and the DC bias.

Block Diagram and working:

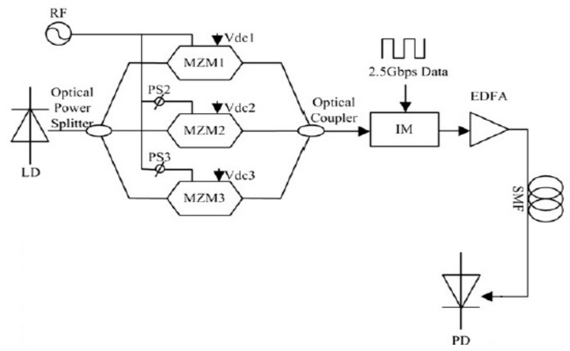

Figure II.9: Block diagram of mm wave generation using frequency sextupling using 3 parallel MZM

Three MZMs are in parallel, and a RF signal is applied to the three MZMs with different initial phases. The light waves centered at ωc emitted from the laser diode (LD) is divided into three equal parts by an optical power splitter and injected into the three MZMs respectively. The phase shifts introduced by PS2 and PS3 are $\Delta\phi 2$ and $\Delta\phi 3$, and the phase differences between two arms of a MZM introduced by DC bias are $\phi 1$, $\phi 2$ and $\phi 3$ respectively, where $\phi i=\pi Vdci/V\pi$ (i=1, 2, 3).

$V\pi$ is the half-wave voltage of the MZM.

If the insertion loss of the MZM is neglected, and the extinction ratio of the MZM is assumed to be infinite, the output optical signal of the optical coupler can be expressed as

$$E(t)=1/6E0\exp(j\omega ct)\{\exp(jm\sin(\omega mt)) + \exp(-jm\sin(\omega mt)-j\phi 1)\}+1/6E0\exp(j\omega ct)\{\exp(jm\sin(\omega mt+\Delta\phi 2)) + \exp(-jm\sin(\omega mt+\Delta\phi 2)-j\phi 2)\}$$

$$+1/6E0\exp(j\omega ct)\{\exp(jm\sin(\omega mt+\Delta\phi 3)) + \exp(-jm\sin(\omega mt+\Delta\phi 3)-j\phi 3)\}$$

Where

M is the RF modulation index defined as $m=\pi VRF/V\pi$,

VRF and ωm are the amplitude and angular frequency of the RF signal,

E0 and ωc are the amplitude and angular frequency of the optical signal,

$Jn(\cdot)$ is the nth-order Bessel function of the first kind.

We use modulation index to suppress the third order sidebands.

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If we do not suppress the third-order sidebands, and set Δϕ2=120°, Δϕ3=−120°, only two third-order sidebands and two sixth-order sidebands exist. Due to the characteristic of Bessel function, when the modulation index is small, the sixth-order sidebands are much lower than the third-order sidebands. So the two third-order sidebands can be used to generate sextupling mm wave signals. We set m=1.795 (VRF=0.571Vπ=2.855). The frequency of the RF oscillator is 10 GHz.

If Δϕ2=120°, Δϕ3=−120°, Vdc1=Vdc2=Vdc3=Vπ=5, and we choose the first zero point of zeroth-order Bessel function as the working point high quality sextupling mm-wave will be generated. The elimination of the sidebands is achieved by adjusting the driving voltage of the RF oscillator, the phase difference between the RF signals applied to the MZMs, and the DC bias.

III. RESULTS AND ANALYSIS

1) Based on External Intensity Modulation:

Figure III.1 shows the modulated signal and Figure III.2 shows the modulated output. We can clearly see that the carrier has a frequency of 193.1THz in figure III.1. After being modulated we can clearly visualize the frequency quadrupled signal in Figure III.2.

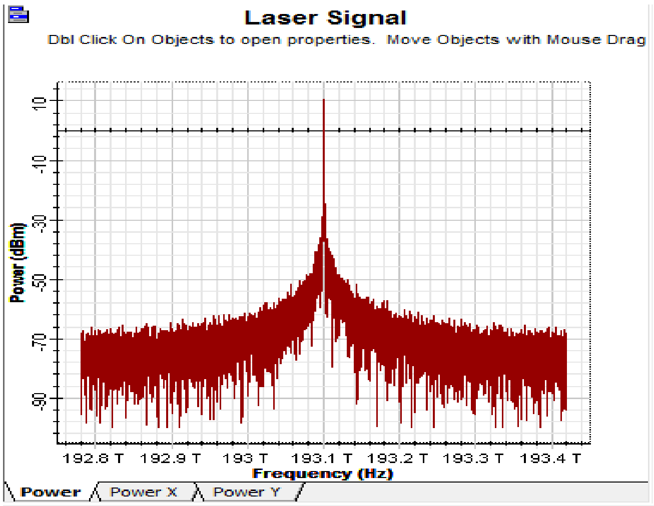

Figure III.1: Laser signal

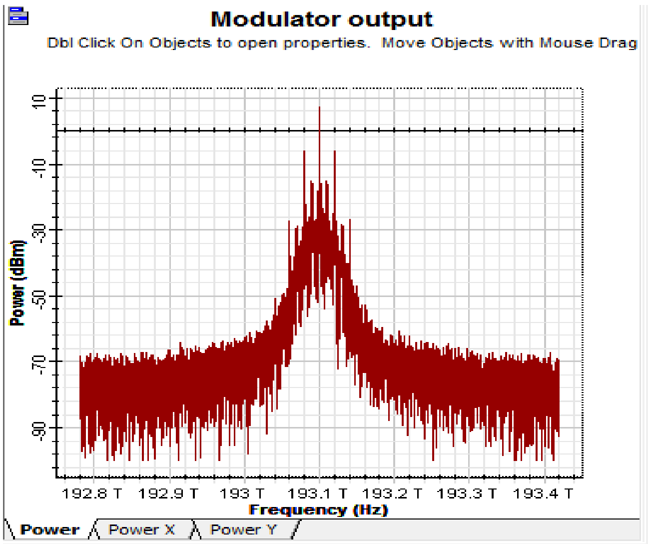

Figure III.2: Modulated signal

The output of Interleaver is shown in Figure III.3 and Figure III.4.

Figure III.4 shows OCS signal, we can see that the carrier is suppressed in Figure III.4.

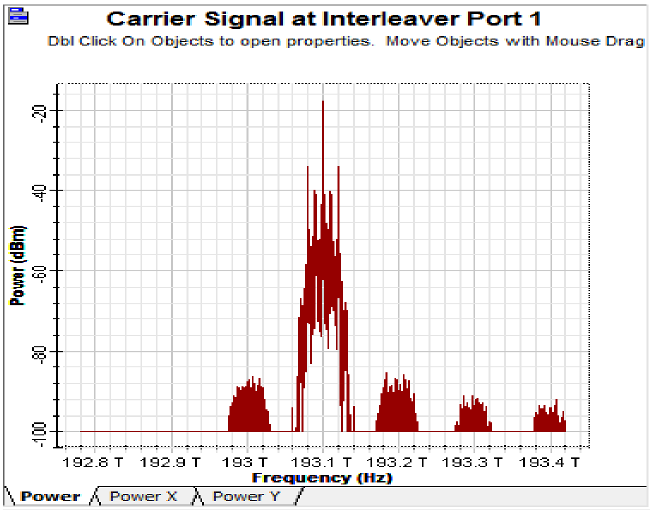

Figure III.3: Carrier Signal at Interleaver port1

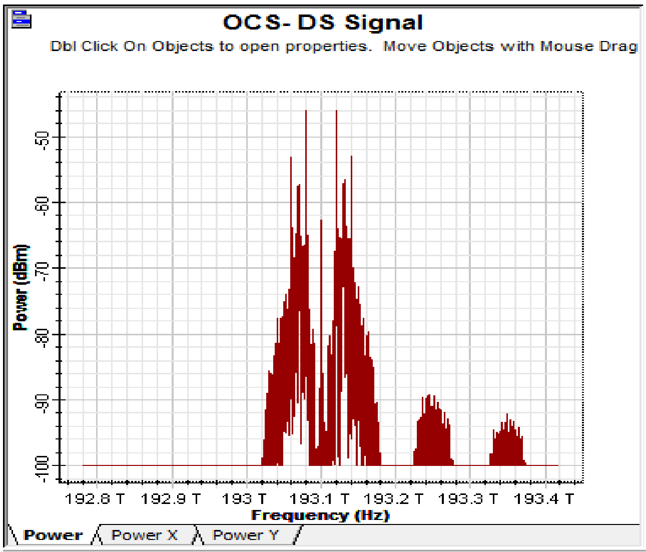

Figure III.4: OCS-DS signal

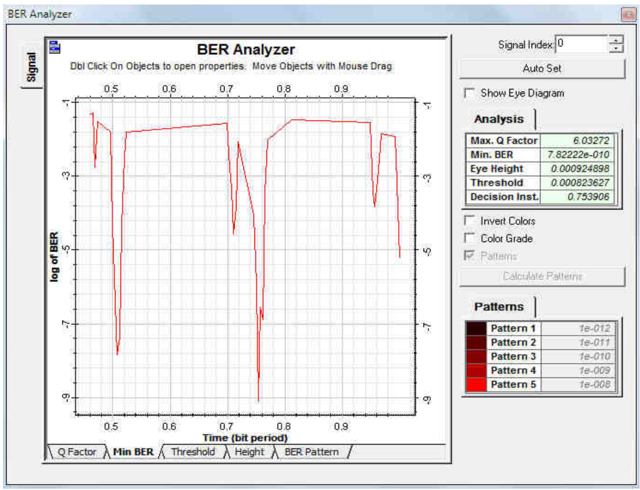

Figure III.5: BER analyzer

Figure III.5 shows BER which is equal to 7.8222e-010.

2) Based on Cascaded External Modulator and Nonlinear Fiber

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Figure III.6 shows the modulated signal of all 30 channels ranging from the frequency range from 192.683 THz to 195.583 THz, each channel having a difference of 100GHz. Figure III.7 shows OCS signal, we can clearly see that the carrier is suppressed.

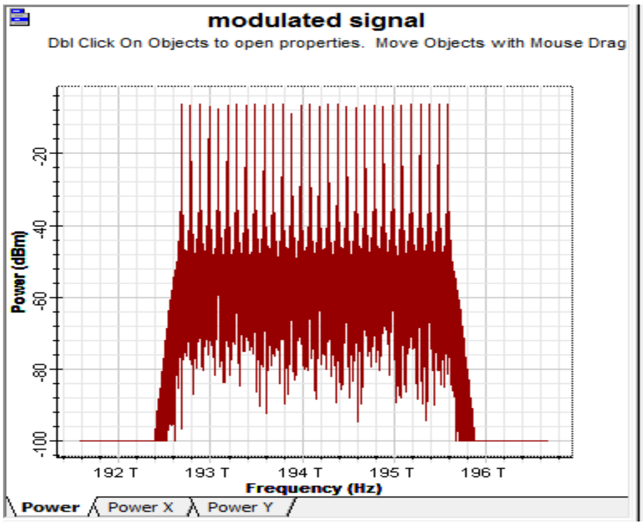

Figure III.6: Modulated signal

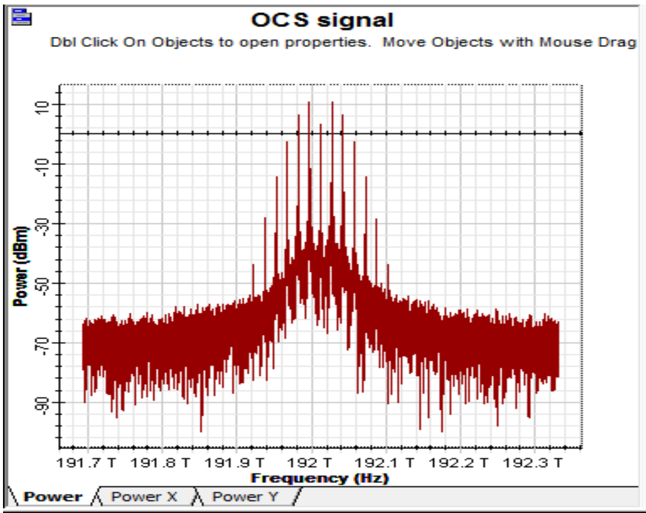

Figure III.7: OCS signal

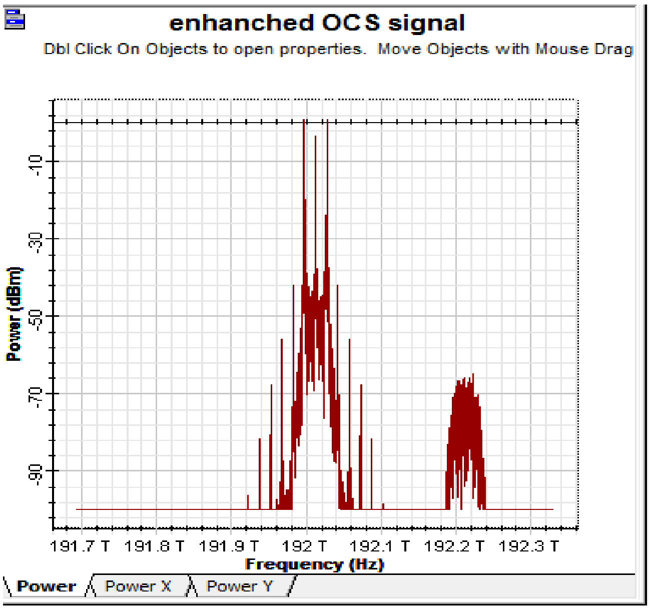

Figure III.8: Enhanced OCS signal

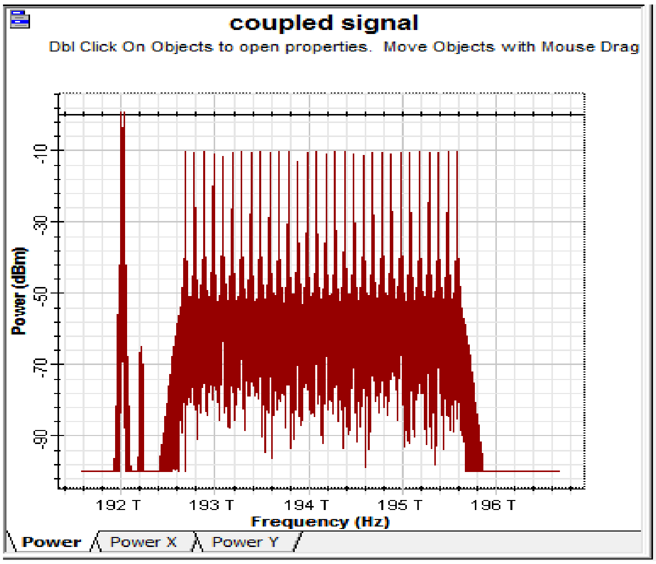

Figure III.9: coupled signal

Figure III.8 shows the enhanced OCS signal which is the output of Interleaver. The coupled signal is shown in Figure III.9.

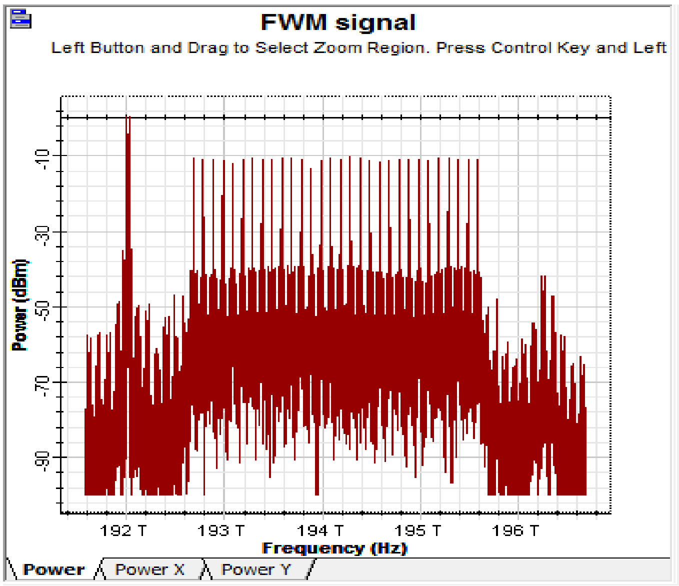

Figure III.10: FWM signal

Figure III.10 shows four wave mixed signal which is generated in highly nonlinear fiber, which can be seen clearly in Figure III.11.

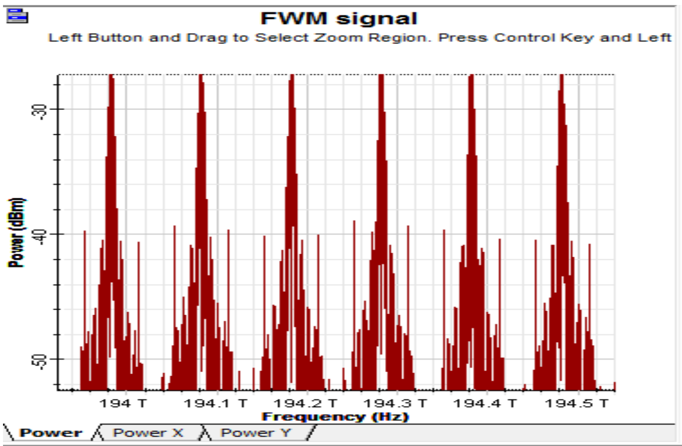

Figure III.11: FWM signal (shown clearly)

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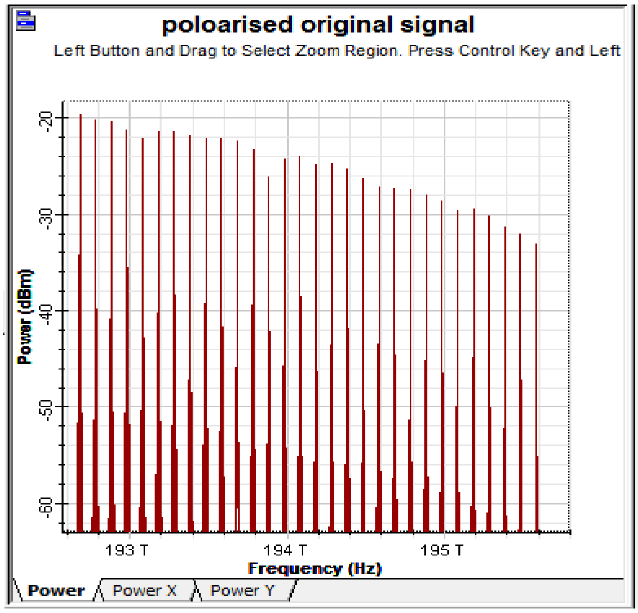

Figure III.12: polarised original signal

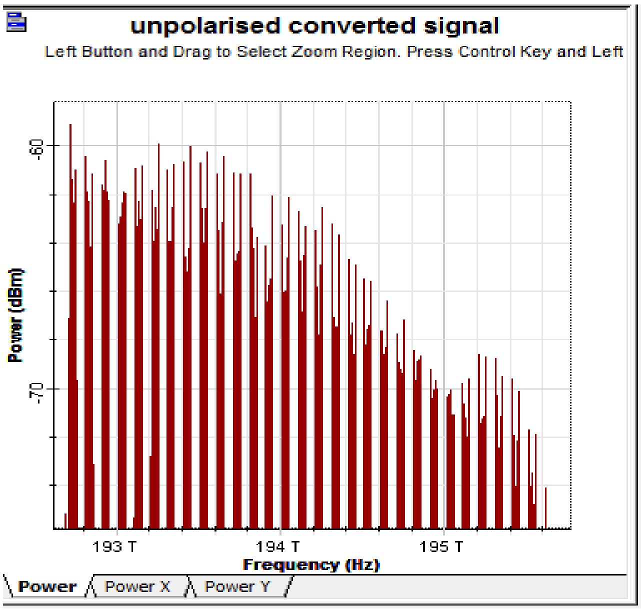

Figure III.13: unpolarised converted signal

The output of Interleaver can be seen in Figure III.12 and Figure III.13. The unpolarised signal which is four wave mixed signal can be seen in Figure III.13.

Figure III.14 shows the filtered signal which we get upon using Bessel optical filter

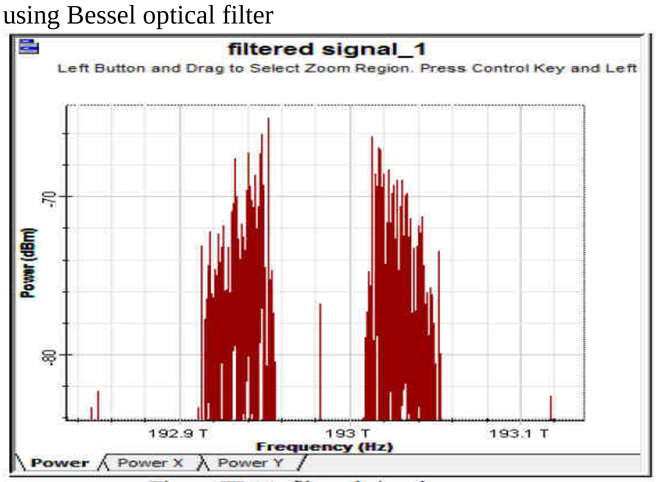

Figure III.14: filtered signal

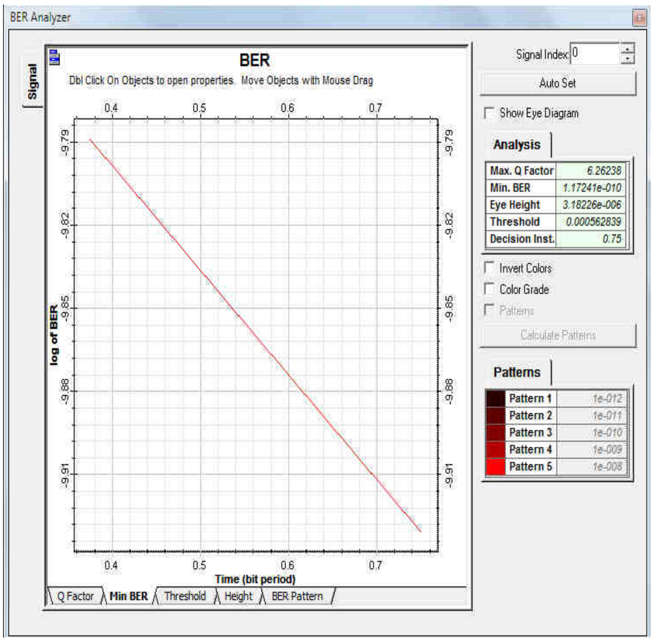

Figure III.15: BER analyser

BER is shown in Figure III.15. The BER is 1.17241e-010 which is satisfactory.

1) Based on dual-parallel Mach-Zehnder modulator

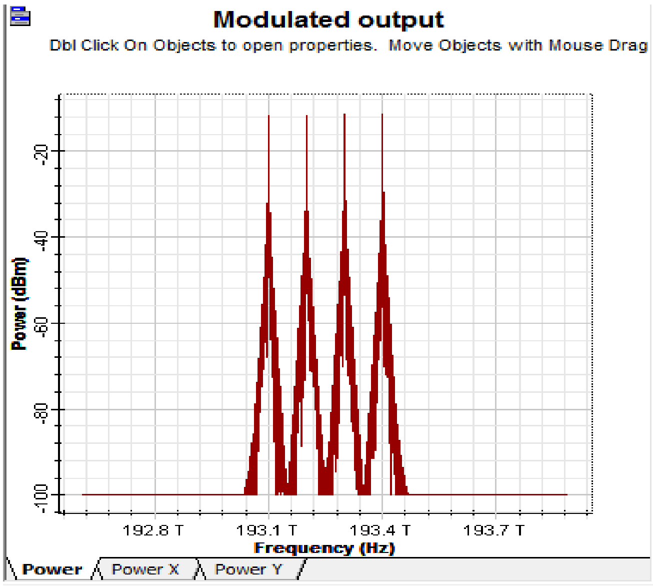

Figure III.16: Modulated output

Since we have used four channels with frequencies ranging 193.1 THz to 193.4 THz, they can be clearly visualized with their respective power in Figure III.16.

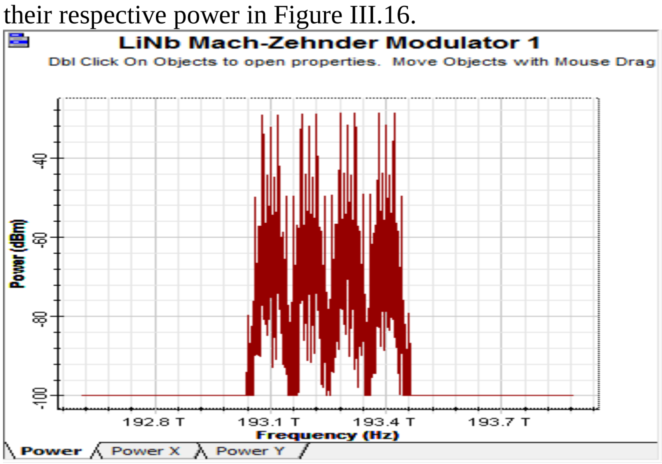

Figure III.17: LiNb MZM 1 output

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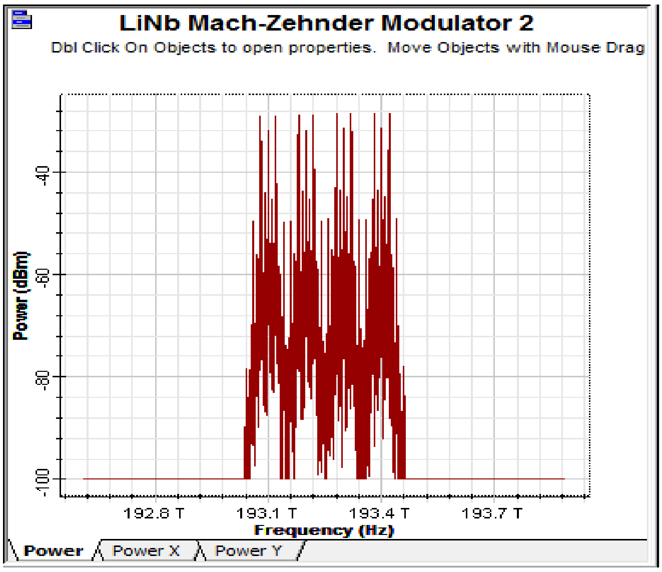

Figure III.18: LiNb MZM 2 output

The output of both LiNb Mach-Zehnder Modulators are shown in Figure III.17 and Figure III.18 respectively. We can see that it is DSB signal with carrier.

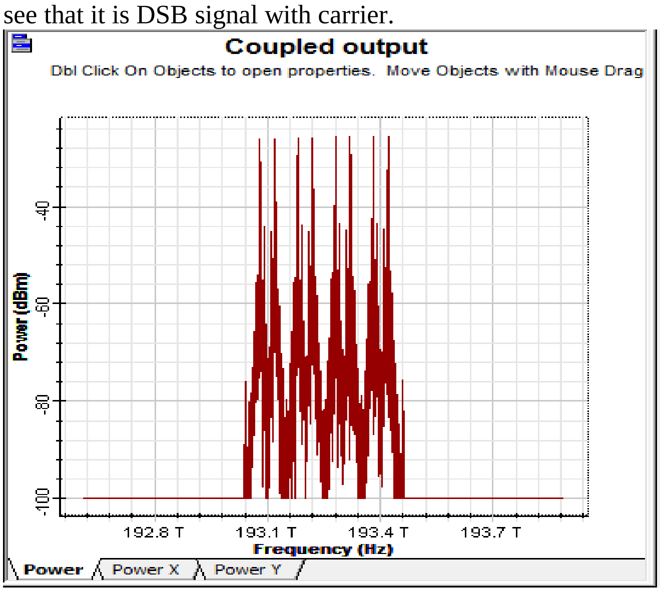

Figure III.19: Coupled output

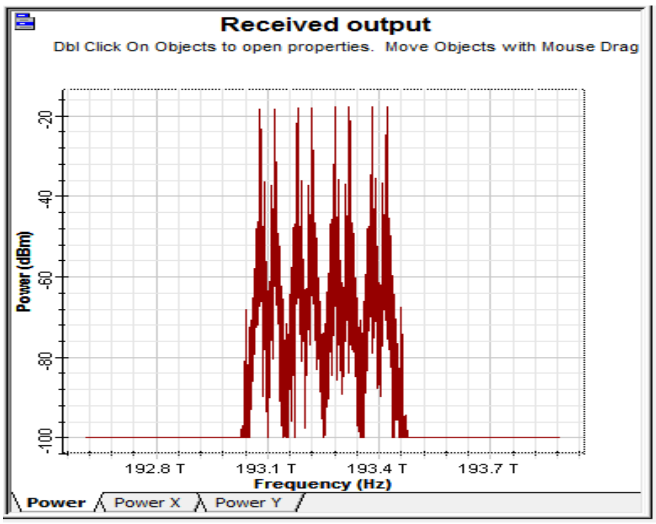

Figure III.20: Received output

The frequency quadrupled signal can be seen in Figure III.19, and it is DSB-OCS signal whereas Figure III.20 shows the received output.

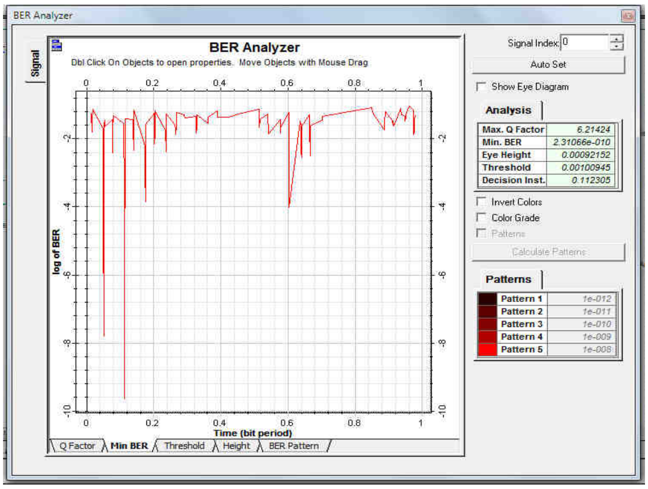

Figure III.21: BER analyser

BER can be seen in Figure III.21. The BER is about 2.31066e-010 which is satisfactory.

2) Based on three parallel Mach–Zehnder modulators

The output of the three LiNb Mach-Zehnder Modulators are shown in Figure III.22, Figure III.23 and Figure III.24. The combined output of these three LiNb Mach-Zehnder Modulators is shown in Figure III.25. The combined output is frequency sextupled signal.

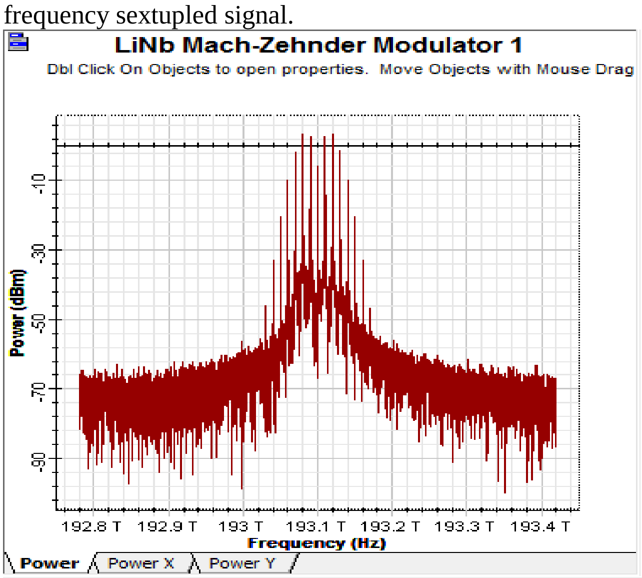

Figure III.22: Output of MZM 1

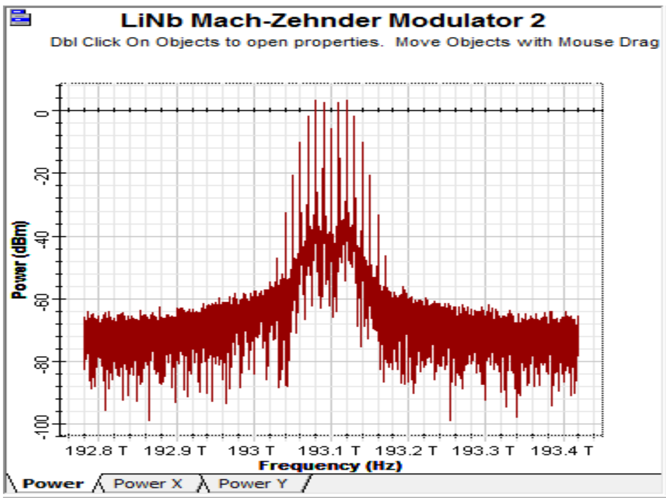

Figure III.23: Output of MZM 2

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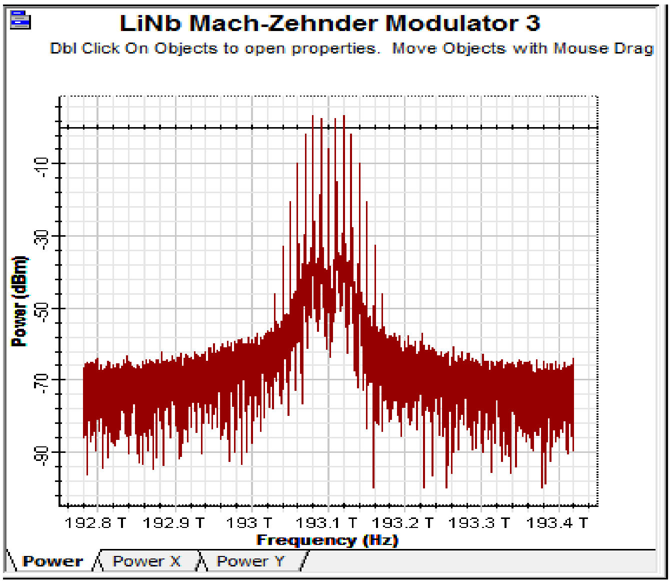

Figure III. 24: Output of MZM 3

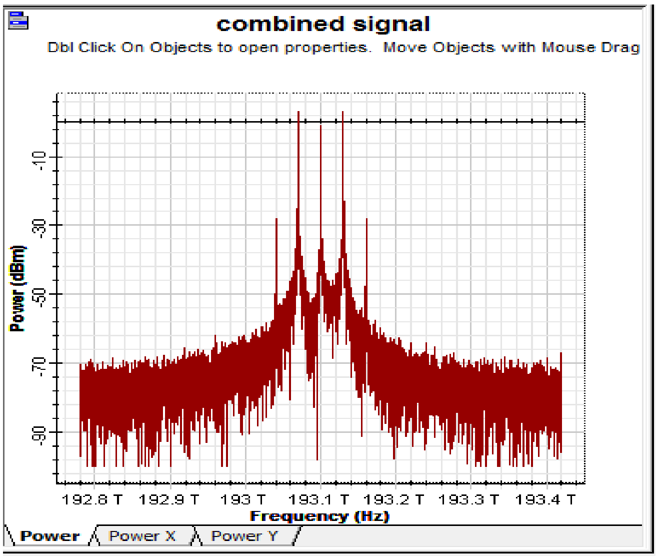

Figure III. 25: Combined output

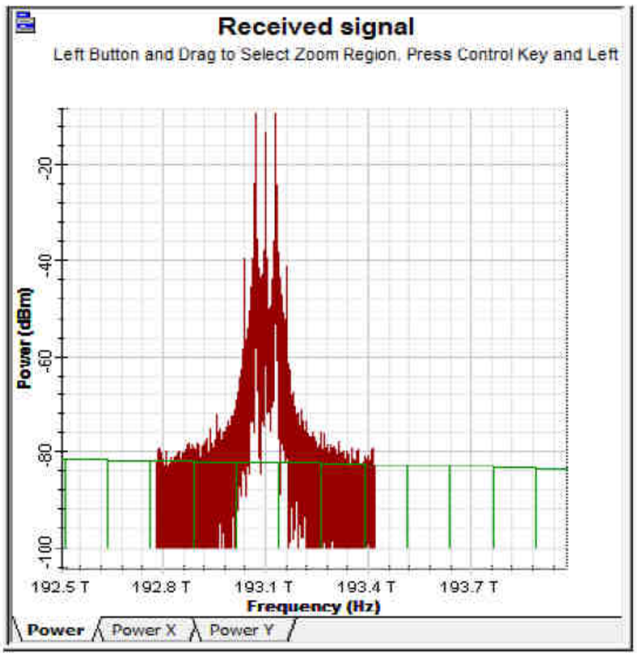

Figure III. 26: received output

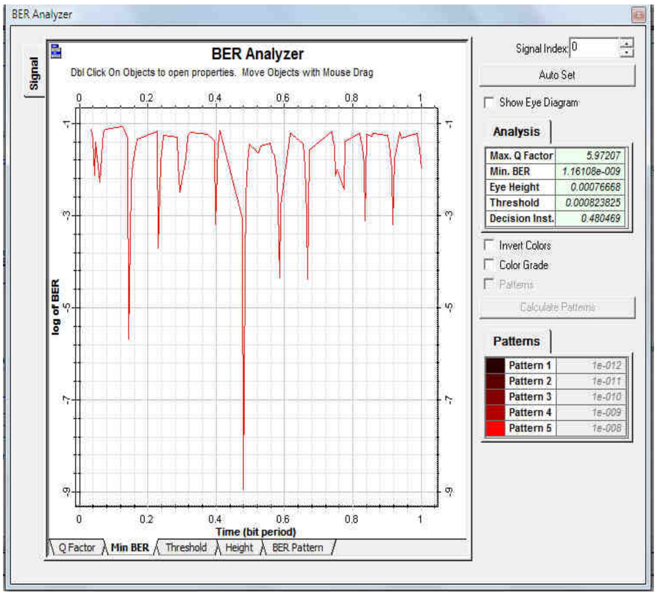

Figure III. 27: BER analyser

BER analyzer is shown in Figure III.27. The BER is about 1.16108e-009 which is satisfactory.

Comparison of all 4 proposed techniques:

1. Based on External Intensity Modulation VS Based on Cascaded
2. External Modulator and Nonlinear Fiber

   i. Signal power vs length :

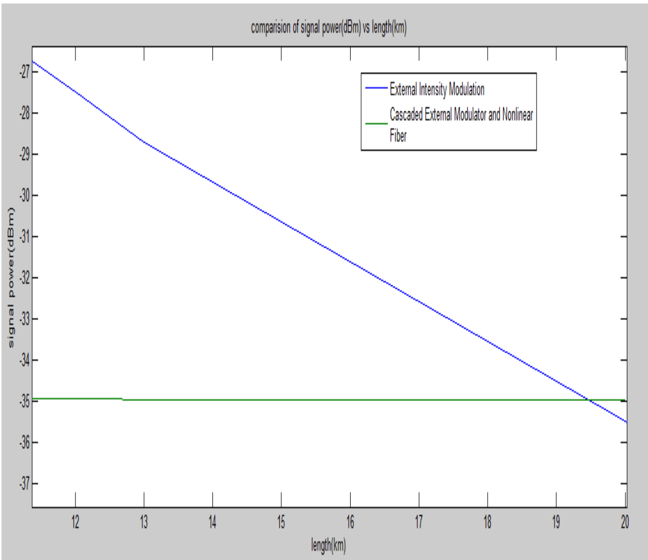

Figure III. 28: Signal power vs length

We can clearly see that the received signal power decreases sharply for External Intensity Modulator but in the case of Cascaded External Modulator and Non-linear Fiber the decrease in very small. So in the terms of received signal power and length we can see that Cascaded External Modulator and Non-linear Fiber provides a better solution.

ii. Log(BER) vs Length :

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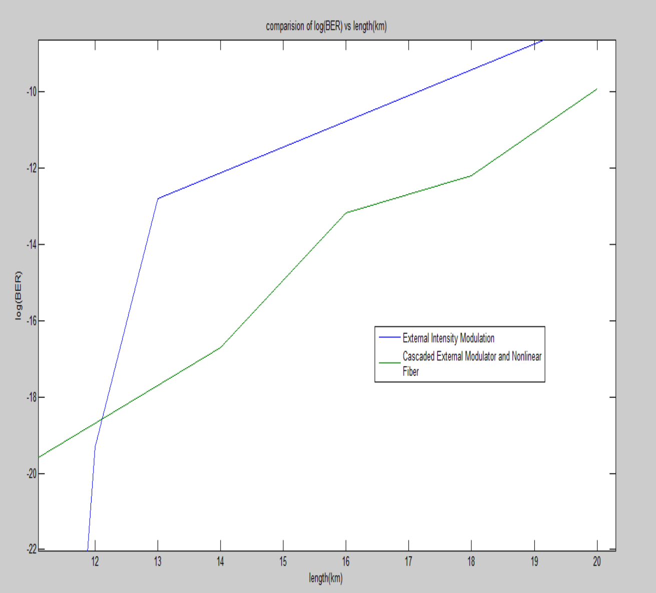

Figure III. 29: Log (BER) vs length

As we can see that External Intensity Modulator shows higher BER increment compared to Cascaded External Modulator and Non-linear Fiber, we can consider Cascaded External Modulator and Non-linear Fiber as a better solution.

iii. -log(BER) vs received power :

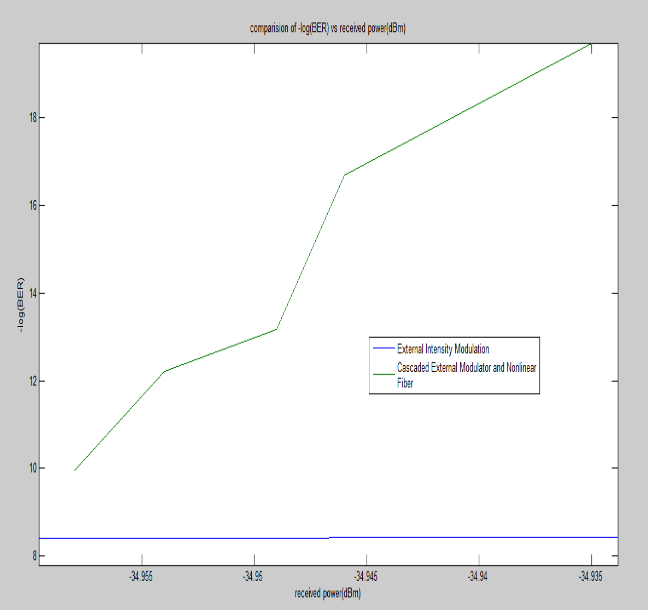

Figure III. 30: -log (BER) vs received power

We can see that to get same BER External Intensity Modulator requires more received power compared to Cascaded External Modulator and Non-linear Fiber. For example in order to get a BER of about 10^10, using Cascaded External Modulator and Non-linear Fiber it can be achieved at power level of -35dBm but it requires much higher received power for External Intensity Modulator.

So, in this case Cascaded External Modulator and Non-linear Fiber provides a better solution.

3. Based on dual-parallel Mach-Zehnder modulator VS Based on three

4. parallel Mach–Zehnder modulators

i. Signal power vs length:

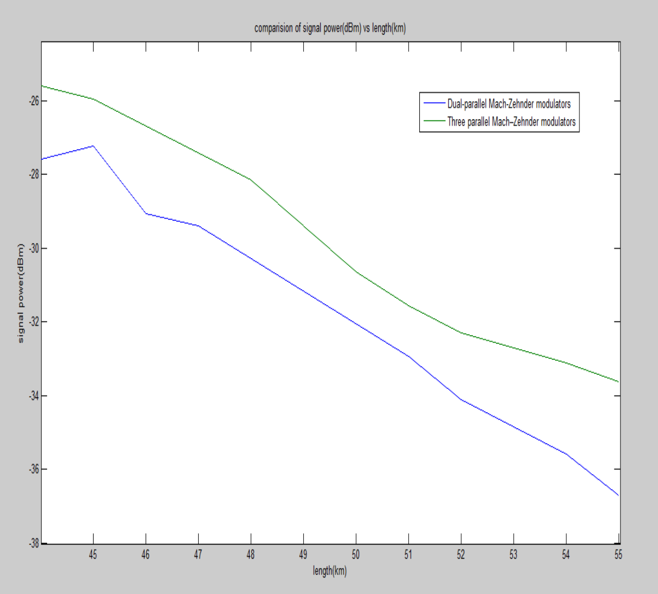

Figure III. 31: signal power vs length

We can clearly see that signal power decreases more rapidly in case of on dual-parallel Mach-Zehnder modulator than three parallel Mach–Zehnder modulators. For the distance of 50Kms we can see that received power dual-parallel Mach-Zehnder modulator is less compared to three parallel Mach–Zehnder modulators.

ii. Log (BER) vs Length:

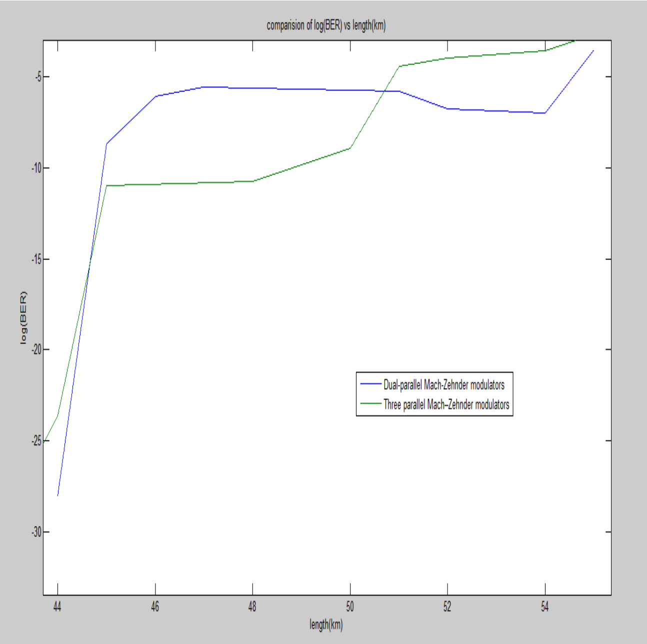

Figure III. 32: log (BER) vs length

We can see that for a distance of 50 Km the BER for dual-parallel Mach-Zehnder modulators is more compared to that of three parallel Mach-Zehnder modulators.

So technique based on three parallel Mach-Zehnder modulators provide a better solution in this case compared to technique based on dual-parallel Mach-Zehnder modulators.

iii. -log (BER) vs received power:

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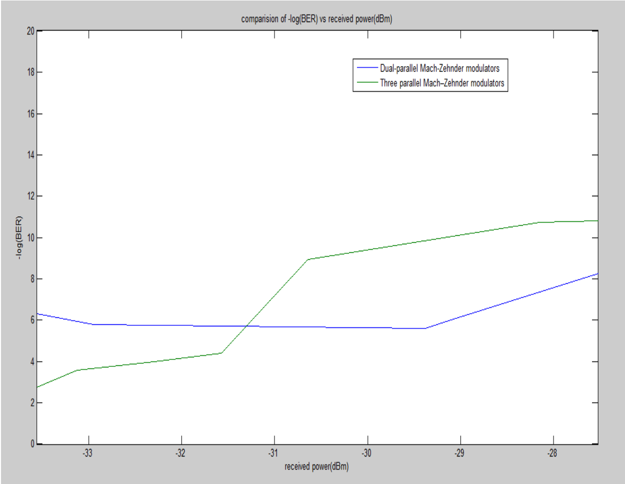

Figure III. 33: -log (BER) vs received power

We can clearly see that in order to achieve a BER of 10^-10, we require more received power for dual-parallel Mach-Zehnder modulators compared to three parallel Mach–Zehnder modulators. So, a lower BER can be achieved at lower received power for three parallel Mach–Zehnder modulators in comparison with dual-parallel Mach–Zehnder modulators

IV. CONCLUSION

Looking at the results obtained by the simulation of different architectures and comparing the results for Radio over Fiber System, we can see that there is valid scope for implementation of these architectures in a real world scenario. The BER obtained are much better than a simple network architecture and it goes to show how these new techniques can be a superior substitute for the existing system.For short distances and only one channel where no polarization issue can occur we can go for the technique based on External Intensity Modulation but in current scenario we have more number of users and more demands for various needs like text, data, video, voice, pictures, etc. So there will be polarization issue at the receiver in order to retrieve the signal, the technique based on Cascaded External Modulator and Nonlinear Fiber provides a better solution for short distances in the range of 20Kms. When we deal with long distance transmission the technique based on Cascaded External Modulator and Nonlinear Fiber does not meet our requirement and so in order to meet our demand at less BER we go for the technique based on dual-parallel Mach-Zehnder modulators. This technique provides us a satisfactory solution for long haul transmission. The technique based on dual-parallel Mach-Zehnder modulators is quite well and cost effective, but in order to meet the demands of higher bandwidth we need to go for frequency sextupling and so a promising solution is provided by using the technique based on three parallel Mach–Zehnder modulators. This technique provides satisfactory solution for long haul transmission and has a low BER and high received signal power.

V. ACKNOWLEDGMENT

I would like to acknowledge contributions by Anand Kumar, Nilima, and G. Aarthi.

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