PHASE MODULATED OPTICAL COMMUNICATION SYSTEM

A Thesis Submitted in Partial Fulfillment of the requirements for the Degree of

BACHELOR OF TECHNOLOGY

In

ELECTRONICS & COMMUNICATION ENGINEERING

By

SUDEM DAIMARY (GAU-C-10/222)
BIDU BHUSHAN BARMAN (GAU-C-10/L-324)
GOKUL BORO (GAU-C-10/L-321)
ADITYA KUMAR SINGH (GAU-C-10/237)

Under the supervision of

MR. ARINDUM MUKHERJEE

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

केन्द्रीय प्रौद्योगिकी संस्थान कोकराझार

CENTRAL INSTITUTE OF TECHNOLOGY KOKRAJHAR

(A Centrally Funded Institute under Ministry of HRD, Govt. of India)

BODOLAND TERRITORIAL AREAS DISTRICTS :: KOKRAJHAR :: ASSAM :: 783370

Website: www.cit.kokrajhar.in, www.cit.ac.in

May 2014

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING
केन्द्रीय प्रौद्योगिकी संस्थान कोकराझार
CENTRAL INSTITUTE OF TECHNOLOGY, KOKRAJHAR
(An Autonomous Institute under MHRD)
Kokrajhar –783370, BTAD, Assam, India.

CERTIFICATE BY THE BOARD OF EXAMINERS

This is to certify that the project work entitled **"Phase Modulated Optical Communication System"** submitted by Sudem Daimary (Gau-C-10/222), Bidu Bhushan Barman (Gau-C-10/L-324), Gokul Boro (Gau-C-10/L-321), and Aditya Kumar Singh (Gau-C-10/237) to the Department of Electronics & Communication Engineering of Central Institute of Technology, Kokrajhar has been examined and evaluated.

The project work has been prepared as per the regulations of Central Institute of Technology and qualifies to be accepted in partial fulfillment of the requirement for the degree of Bachelor of Technology.

Project Coordinator **Examiner.**

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

केन्द्रीय प्रौद्योगिकी संस्थान कोकराझार

CENTRAL INSTITUTE OF TECHNOLOGY, KOKRAJHAR

(An Autonomous Institute under MHRD)

Kokrajhar – 783370, BTAD, Assam, India

CERTIFICATE OF APPROVAL

This is to certify that the work embodied in this project entitled **"Phase Modulated Optical Communication System"** submitted by **Sudem Daimary** (Gau-C-10/222), **Bidu Bhushan Barman** (Gau-C-10/L-324), **Gokul Boro** (Gau-C-10/L-321), and **Aditya Kumar Singh** (Gau-C-10/237) to the Department of Electronics & Communication Engineering is carried out under my direct supervision and guidance.

The project work has been prepared as per the regulations of Central Institute of Technology, Kokrajhar and I strongly recommend that this project work be accepted in partial fulfillment of the requirement for the degree of Bachelor of Technology.

To the best of my knowledge the matter embodied in this thesis has not been submitted to any other university/institute for the award of degree or diploma.

26/5/14

Supervisor

(Mr. Arindum Mukherjee)

HOD in-charge, Dept. of ECE

CIT, Kokrajhar

DECLARATION

We hereby declare that the project work entitled **"Phase Modulated Optical Communication System"** is an authenticated work carried out by us under the guidance of **Mr. Arindum Mukherjee**, HOD in-charge, Department of ECE, CIT, Kokrajhar for the partial fulfillment of the award of the degree in Electronics & Communication Engineering and this work has not been submitted for similar purpose anywhere else except to Department of ECE, CIT, Kokrajhar.

Date: 27th of May, 2014

Place: Kokrajhar

Sudem Daimary
Roll No.:- Gau-C-10/222
University Registration No: 67164 of 2010-11

Bidu Bhushan Barman
Roll No.:- Gau-C-10/L-324
University Registration No: 015377 of 2011-12

Gokul Boro
Roll No.:- Gau-C-10/L-321
University Registration No: 015387 of 2011-12

Aditya Kumar Singh
Roll No.:- Gau-C-10/237
University Registration No: 67142 of 2010-11

ACKNOWLEDGEMENT

We wish to express our profound sense of deepest gratitude to our guide and motivator Mr. Arindum Mukherjee, HOD in-charge, Department of Electronics & Communication Engineering, Central Institute of Technology, Kokrajhar for his valuable guidance, sympathy and cooperation and finally help for providing necessary source during the entire period of project.

We wish to convey our gratitude to all the faculties of Department of Electronics & Communication Engineering who have enlightened us during studies. The facilities and cooperation received from the technical staff of Electronics & Communication Engineering Department is thankfully acknowledged.

Lastly, we would like to thank the researches of various articles and book that we referred to.

Date: 27th of May, 2014

Sudem Daimary
Roll No.:- Gau-C-10-222
University Registration No: 67164 of 2010-11

Bidu Bhushan Barman
Roll No.:- Gau-C-10/L-324
University Registration No: 015377 of 2011-12

Gokul Boro
Roll No.:- Gau-C-10/L-321
University Registration No: 015387 of 2011-12

Aditya Kumar Singh
Roll No.:- Gau-C-10/237
University Registration No: 67142 of 2010-11

TABLE OF CONTENTS

CONTENTS

List of Figures

CHAPTER 1

INTRODUCTION

Communication plays an important role in the transmission of information using the communication devices like mobiles, telephone sets and other mediums like internet. Communication may be broadly defined as the transfer of information from one point to another. When the information is to be conveyed over any distance, a communication system is usually required. The information transfer is frequently achieved by superimposing or modulating the information on to an EM wave which acts as a carrier for the information signal. This modulated carrier is then transmitted to the required destination where it is received and the original information signal is obtained by demodulation. Sophisticated techniques have been developed for this process using EM carrier waves operating at Radio frequencies as well as Microwave and millimeter wave frequencies. However, communication may also be achieved using an EM carrier which is selected from the optical range of frequencies. Communication engineers deals with the transmission of various signals from one point to another.

1.1 OPTICAL COMMUNICATION

Optical communication is the communication in which high carrier frequencies are used to carry the information. The use of light for communication has been common for many years such as signal fibers, reflecting mirrors and more recently signaling lamps. However, a renewed interest in optical communication was stimulated in the year 1960s with the invention of the laser. This device provided a powerful coherent light source together with the possibility of modulation at high frequency. In addition, the low beam divergence of the laser made enhanced free space optical transmission a practical possibility. Thus, with the optical communication system several foreseen advantages are considered such as immunity to interference and cross talk, signal security, low transmission loss, system reliability and ease of maintenance, potential low cost etc. Many advantages are therefore provided by the use of a light-wave carrier within the optical communication system.

1.2 OPTICAL HETERODYNING

Heterodyning is a radio signal processing technique in which new frequencies are created by combining or mixing two frequencies. It is useful for frequency shifting signals into a new frequency range and is also involved in the modulation and demodulation. The two

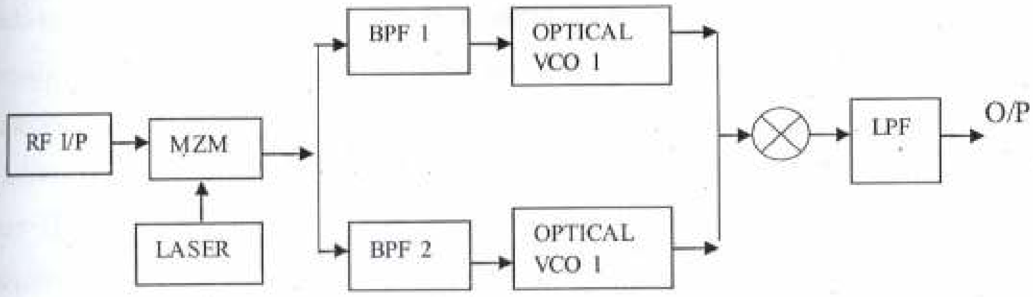

Fig1.1 Block Diagram of Optical Heterodyning Scheme

frequencies are mixed in a signal processing device thereby creating two new frequencies with reference to the principle of sine function i.e. one is the sum of the two frequencies mixed and other is the differences of them. These frequencies are called heterodynes. Typically, only one of the new frequencies is desired (i.e. the higher after modulation and lower after demodulation). Optical heterodyning is an extension of the heterodyning process for higher frequencies in which two different wavelengths of light illuminate the detector so that the oscillating electrical output corresponds to the difference between their frequencies. This allows precision measurements of phase and frequency of a light signal relative to a reference light source.

1.3 PHASE MODULATION

A method of Phase Modulation technique is used in modem optical communication system since it demands higher and higher bandwidth. The process of phase modulation which is a type of angle modulation consists of varying the phase angle of the carrier linearly in proportion to the modulating signal such that maximum phase shift occurs during positive and negative peaks of the modulating signal. This means that in Phase Modulation the instantaneous value of the phase angle is equal to the phase angle of the un-modulated carrier plus a time varying component which is proportional to modulating signal.

1.4 OPTICAL GENERATION OF MILLIMETER WAVE

Optical generation of microwave or millimeter wave is a promising scheme of low cost and high transmission performance in ROF (Radio-Over Fiber) systems. The major advantage of generating such wave signal is that THz signals can be obtained. Basically, generation of such wave signals can be achieved through optical phase locking or injection locking of two laser sources, external modulation of a laser diode and direct beating of dual-longitudinal or multi-longitudinal modes of a laser in a photo detector. Most of the RF Engineers' have already proposed some schemes regarding generation of optical millimeter wave but the generation of the same via external optical modulator is comparatively low cost since its high reliability and is being employed in such transmission of optical signal. In our first case, band pass filter of Gaussian type is used simply to observe the modulated signal at some particular frequency and then fed to photo detector for detection of the desired baseband signal. In our second case, we have considered also injection locking of two slave lasers to the two side bands of the master laser. The injection-locked of two slave lasers signals followed by Photo detector results in faithful detection of the baseband signal or the desired microwave signal with low phase noise.

In the third case, PLL (Phase Lock Loop) is designed which is a negative feedback control system that forces the slave- laser (I_Q VCO) to track the frequency and phase of the reference signal when in lock.

1.5 INJECTION LOCKING

Injection locking is a method which is applied mainly to continuous wave single frequency laser sources when a high output power needs to be combined with a very low intensity noise and phase noise. Such low noise performance or even just single frequency operation is significantly more difficult to achieve in high power lasers. Another advantage of optical injection locking is that the locking oscillator is electrically isolated from the locked oscillator, eliminating the need for impedance matching between the oscillators.

1.6 BRIEF INTRODUCTION OF DIFFERENT BLOCKS

BAND PASS FILTERS (BPF): A filter separates different components of a mixer. An electric filter is a four terminal network which is designed to pass signals of certain frequencies to the load, rejecting other frequencies. A BPF transmits a band of frequency between two cut off frequencies centered around the resonance frequency.

PHOTO DETECTOR: Since, the detector is an essential component of an optical communication system which dictates the overall system performance. Its function is to convert the received optical signal into an electrical signal, which is then low pass filtered (perhaps amplified) before further processing. Therefore, when considering signal attenuation along the link, the system performance is determined at the detector. The role of the detector plays, demands that it must satisfy very stringent requirements for performance and compatibly such as high sensitivity at the operating wavelengths, high fidelity, minimum noise introduced by the detector etc.

VCO (VOLTAGE CONTROLLED OSCILLATOR): A voltage controlled oscillator (VCO) is an oscillator whose frequency is controlled by the modulating voltage. The frequency of the VCO is varied in accordance with the modulating signal (by shunting a voltage variable capacitor with its tuned circuit). When the control voltage is zero, VCO has been adjusted to satisfy the frequency of it has to set precisely at an un-modulated carrier frequency and the VCO output is in phase quadrature with the un-modulated carrier wave.

BUTTERWORTH LOW PASS FILTER: This filter exhibits a monotonically decreasing transmission with all the transmission zeros at central frequency $\omega = \infty$, making it an all pole filter. However, the maximum deviation in passband transmission (from the ideal value of unity) occurs at the passband edge only.

CHAPTER 2

MACH-ZEHNDER MODULATOR

Since, the direct modulation of a laser is a cheap and also easy to adapt to low cost applications for modulated distances or transmission rates; however, for advanced applications involving high data rates or long distance links, resorting to external modulation is a good solution. That's why, the most typical external modulator is the Mach-Zehnder modulator (MZM) which modulates the light generated in a laser operating in continuous wave mode. The material for the MZM has electro-optical properties by which the phase of the optical wave propagating inside it receives a phase modulation proportional to the applied electric field. Hence, Mach-Zehnder Modulator (MZM) may be defined as an electro-optic modulator that is widely used in Radio over Fiber (RoF) systems to generate millimeter-waves (mm-waves).

In our work we have realized working of Mach-Zehnder modulator (MZM) using two softwares, namely, MATLAB/ SIMULINK and Optisystem11. In this report we begin with the realization using MATLAB/SIMULINK and then proceed to realization using Optisystem11.

2.1 TRANSFER FUNCTION OF MZM

The transfer function for MZM is given by:

$$T = K\,[1+\sin\{(\pi V_{RF})/V_\pi\}]=I_0/I_{in} \quad \text{------------} (2.1)$$

where, K=constant, V_π=phase shift when the voltage V_{RF} is applied.

Now, assuming,

$I_{in}= A\sin(\omega_L t)$, $V_{RF}= B\sin(\omega_m t)$, $V_\pi=\pi$

where, ω_L and ω_m are the laser frequency and RF frequency respectively.

$$I_0=K'\sin(\omega_L t)\;[1+\sin(B\sin(\omega_m t))] \quad \text{------------} (2.2)$$

We have, Jacobi-Augen series as-------

$$\sin(m\sin\omega_m t) = 2J_1(m)\sin\omega t+2J_3(m)\sin 3\omega t+2J_5(m)\sin 5\omega t+\ldots\ldots \text{--------} (2.3)$$

Comparing equation (2) with equation(3), we get:

$$I_0=K'\sin(\omega_L t)+K''\sin(\omega_L t)\{2J_1(m)\sin\omega_m t+2J_3(m)\sin 3\omega_m t\}$$

$$I_0=K'\sin(\omega_L t) + K''J_1(m)[\cos(\omega_L-\omega_m)t-\cos(\omega_L+\omega_m)t] + K''J_3(m)[\cos(\omega_L-3\omega_m)t -\cos(\omega_L+3\omega_m)t]$$

2.2 IMPLEMENTATION OF MZM USING MATLAB/SIMULINK

Based on equation (2.1), we can design the Mach-Zehnder modulator (MZM). We have implemented this in MATLAB/SIMULINK. The designed block is shown below.

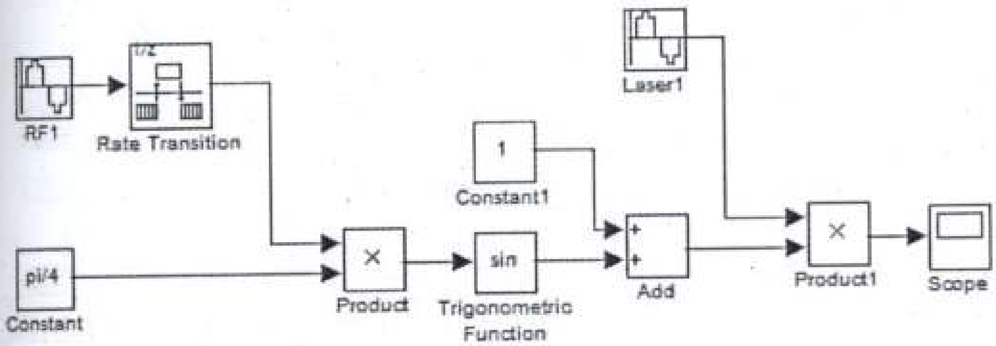

Fig 2.1 Mach – Zehnder Modulator (MZM)

Now, the carrier (Laser1) of higher frequency is modulated with a modulating signal (RF1) with lower frequency compared to that of the carrier. On observation, with some specifications, the modulated signal is obtained as shown in figure (2.2) given below.

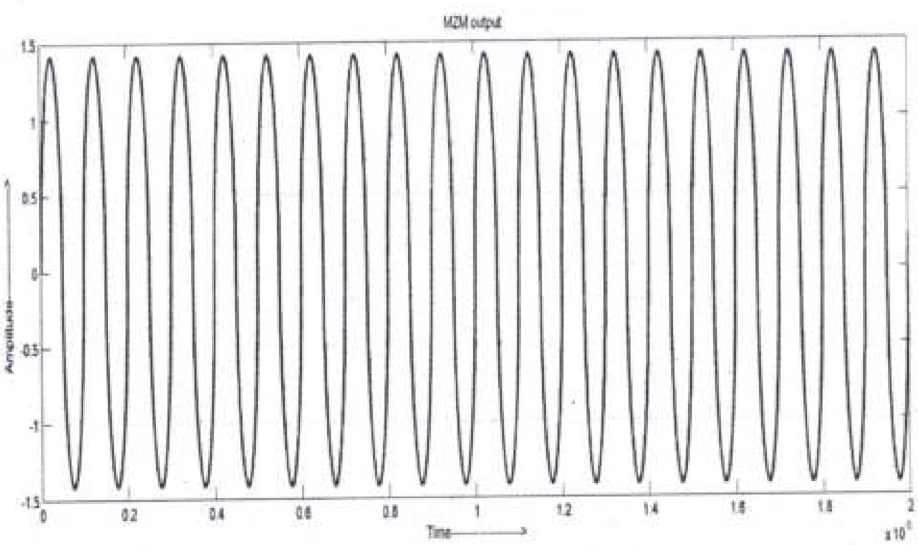

Fig 2.2 Modulated Signal

2.3 SPECIFICATIONS OF MZM REALISATION

Different specifications that were considered while modulating the carrier with the RF signal are given below. The modulated signal obtained in Fig. 2.2 is based on these specifications.

RF1 PARAMETERS:

(1) Amplitude = 2

(2) Frequency (rad/sec) =2*π*50e^4

(3) Sample Time= 1/100 e^4

LASER1 PARAMETERS:

(1 Amplitude = 2

(2) Frequency (rad/sec) = 2*π*0.5e^6

(3) Sample Time =1/100 e^6

RATE TRANSITION PARAMETERS:

Output Port Sample Time = -1

AXIS PROPERTY:

(1) Frequency Range= +F_S/2, -F_S/2

(2) Y-axis scaling→MAGN-SQUARD

2.4 REALISATION OF DETECTION TECHNIQUES

2.4.1 DIRECT DETECTION

The direct detection optical communication system essentially consists of a photo-detector plus an amplifier with possibly additional signal processing circuits. Therefore, the receiver initially converts the optical signal, which is then amplified before further processing to extract the information carried by the optical signal.

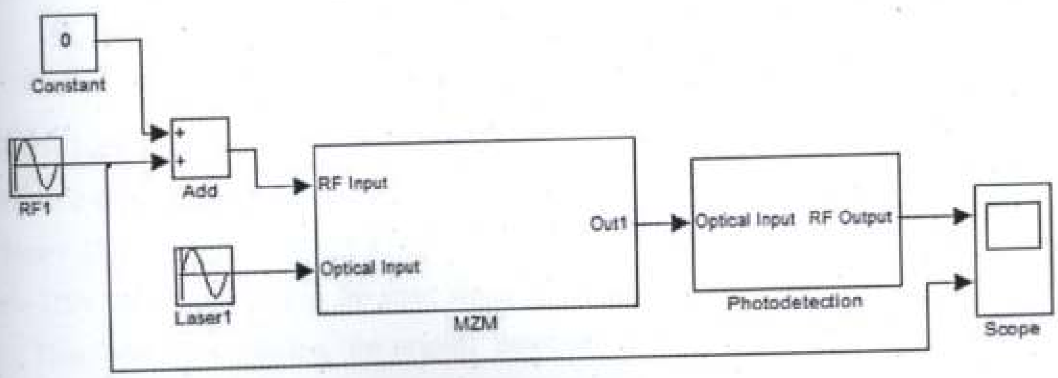

Fig 2.3 Realization of Direct detection

If the output of MZM is $\sqrt{1+f(t)}\cos(\omega_0 t)$; where f(t) is the input signal and ω_0 is the carrier frequency.

After squaring (i.e., photo-detection) $= [\sqrt{1+f(t)}\,]^2 \cos^2(\omega_0 t)$

$$= [\frac{1+f(t)}{2}]\,[1+\cos(2\omega_0 t)]$$

Therefore, after low pass filtering, yield the baseband RF $= K\,[1+f(t)]$

Direct detection can only retrieve signals modulating the intensity of light.

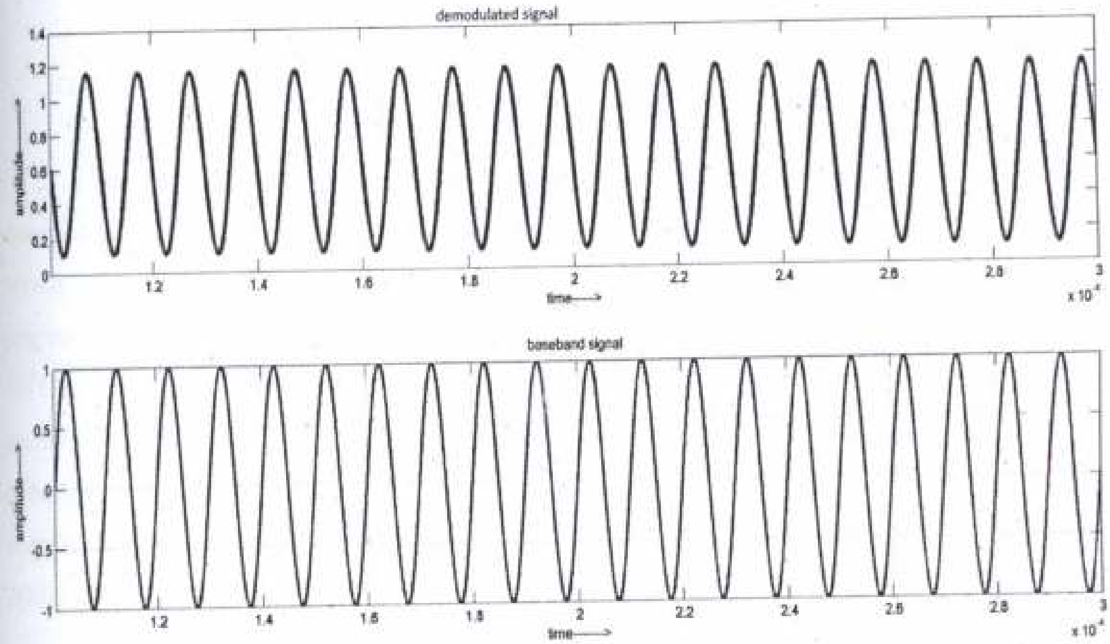

Fig 2.4 Demodulated signal after Direct detection

RESULTS:

For one complete cycle:

Time= $(3.7-3.6)*10^{-4}$ sec= $0.1*10^{-4}$ sec

F= 1/T= 100 KHz; which is the input signal frequency.

Thus, after demodulation, the original baseband signal of 100 KHz has been obtained but with difference in amplitude.

2.4.2 COHERENT DETECTION REALISATION

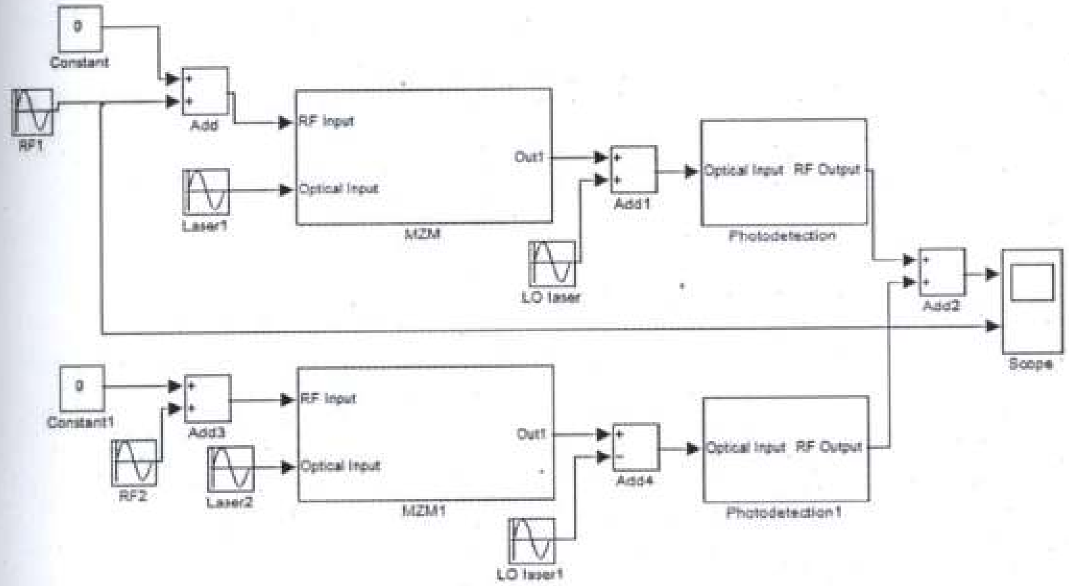

Fig 2.5 Realization of Coherent detection

Unlike Direct detection, in which the optical signal is converted directly into a demodulated electrical output, Coherent optical receivers first add incoming signal from a locally generated optical wave prior to detecting the sum. The photo current is a replica of the original signal which is translated down in frequency from the optical domain (around 10^5GHz) to the radio domain (up to several GHz) and where conventional electronic techniques can be used for further signal processing and demodulation. It is noted that coherent detection provides the greatest benefit for high speed systems operating at longer wavelengths. A potential improvement in receiver sensitivity using Coherent detection of upto 20dB can be obtained.

If the output of the 3d-coupler is given by $\sqrt{P1[1+f(t)]}\cos(\omega_0 t) + \sqrt{P2}\cos(\omega_0 t)$

Therefore, $PD1 = [E_1\sqrt{1+f(t)}\cos(\omega_0 t) + E_2\cos(\omega_0 t)]^2$

$$= E_1^2[1+f(t)]\cos^2(\omega_0 t) + E_2^2\cos^2(\omega_0 t) + 2E_1E_2\sqrt{1+f(t)}\cos(\omega_0 t)$$

And , $PD2 = [E_1\sqrt{1+f(t)}\cos(\omega_0 t) - E_2\cos(\omega_0 t)]^2$

$$= E_1^2/2\,[1+f(t)] + E_2^2/2 - E_1E_2\sqrt{1+f(t)}$$

Thus, $PD1 + PD2 = (E_1^2 + E_2^2) + E_1^2 f(t)$

$$= [1+f(t)]\,E_1^2 + E_2^2$$

Thus, Coherent detection can retrieve optical signals modulating the amplitude.

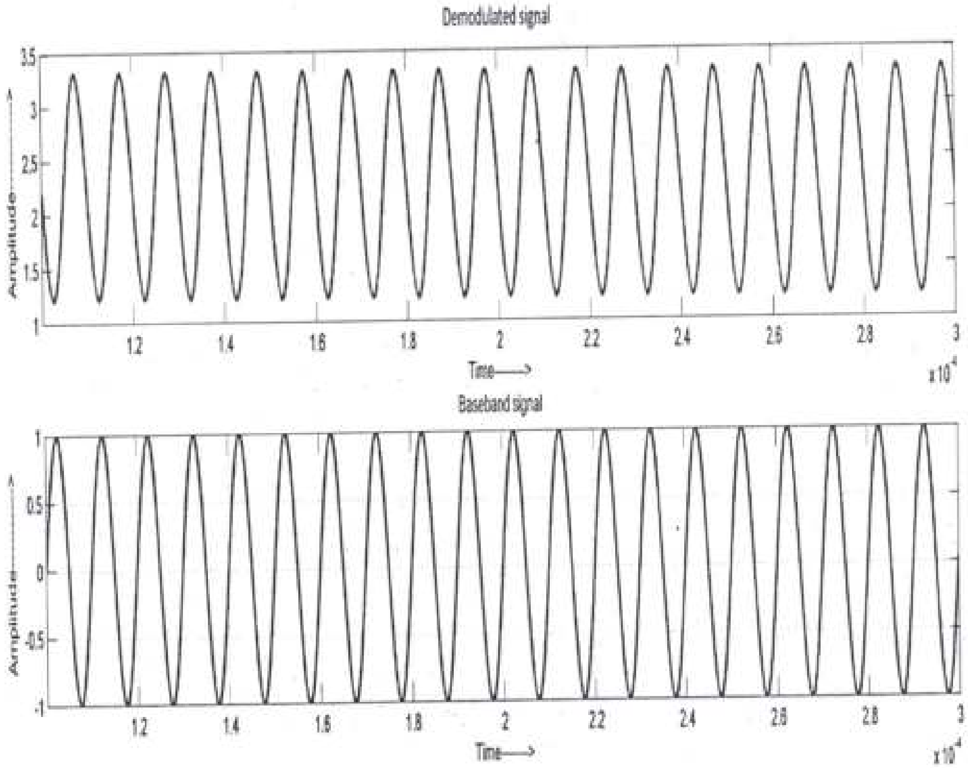

Fig 2.6 Demodulated signal after Coherent detection

RESULTS:

For one complete cycle:

T= $(1.6 - 1.5)*10^{-4} = 0.1*10^{-4}$

F= 1/T= 100 KHz; which is the input signal frequency.

Here, also the baseband signal has been obtained after faithful detection of 100 KHz with small difference in amplitude.

CHAPTER 3

REALISING MZM USING OPTISYSTEM

In the previous chapter we have done the MZM realization using MATLAB/SIMULINK software. This software cannot work on the signals in THz range, i.e. the millimeter waves, so to observe the performance of MZM we used the software Optisystem11. This is very sophisticated software which is generally used for high frequency signal experimentation.

3.1 IMPLEMENTATION OF MZM USING OPTISYSTEM

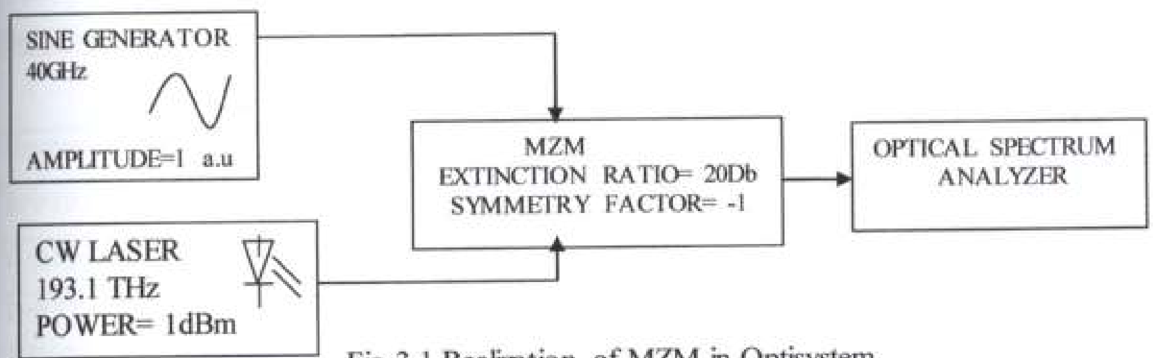

Fig 3.1 Realization of MZM in Optisystem.

A sine wave of 40 GHz frequency is used as an input via the sine wave generator to the MZM. The CW laser is used as the carrier with 193.1 THz frequency. After being modulated with the input signal, the output or the modulated signal through the optical spectrum is obtained as----

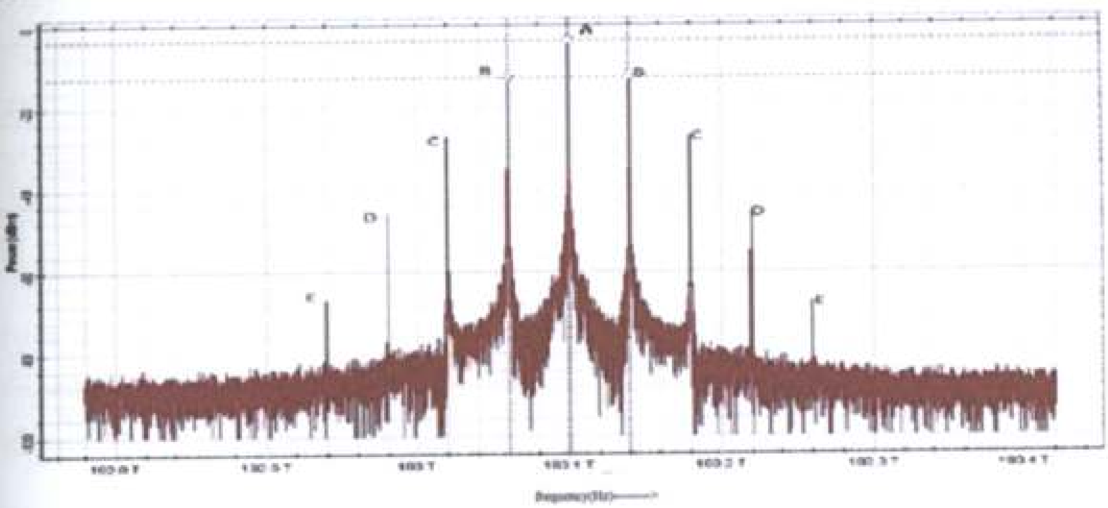

Fig 3.2 Modulated signal obtained using Optisystem

From the graph, it has been observed that the carrier signal is properly modulated with its central frequency at 193.1 THz.

3.2 OBSERVATIONS

Along X-axis → Frequency in THz; Along Y-axis→ Power in dBm.

Carrier Frequency (THz): A→193.1

Carrier Amplitude (dBm): A→-3.46912

Positive side band:

Frequency (THz)	Amplitude (dBm)	Frequency Separation (GHz)
B→193.*14*	*-12.2219*	*B-A →40*
C→193.*18*	*-27.4885*	*C-A →40*
D→*193.22*	*-46.0119*	*D-A →40*
E→193.26	*-67.5886*	*E-A →40*

Negative side band:

Frequency (THz)	Amplitude (dBm)	Frequency Separation (GHz)
B→193.06	*-12.2219*	*A-B→40*
C→193.02	*-27.4885*	*A-C→40*
D→192.98	*-46.0119*	*A-D→40*
E→192.94	*-67.5886*	*A-E→40*

From the observations, it is observed that the frequency separation of the peak signals of frequency 40 GHz has been obtained which is the input signal frequency i.e, the carrier signal is modulated with the input signal.

3.3 REALISATION OF FILTERING SIGNALS

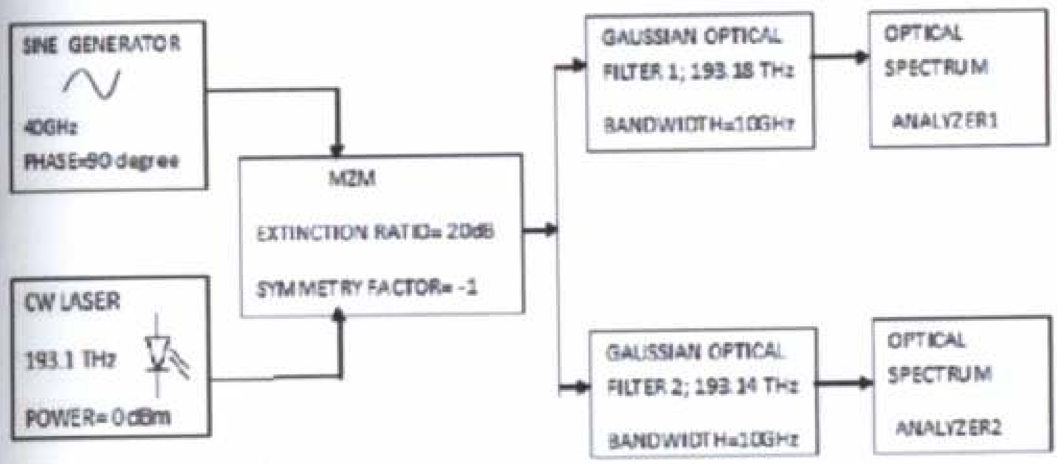

Fig 3.3 Realization of filtering signals

Here, the resultant modulated signal is fed to Gaussian optical filter with frequency selection of 193.18 THz and 193.14 THz frequency respectively to the positive side only.

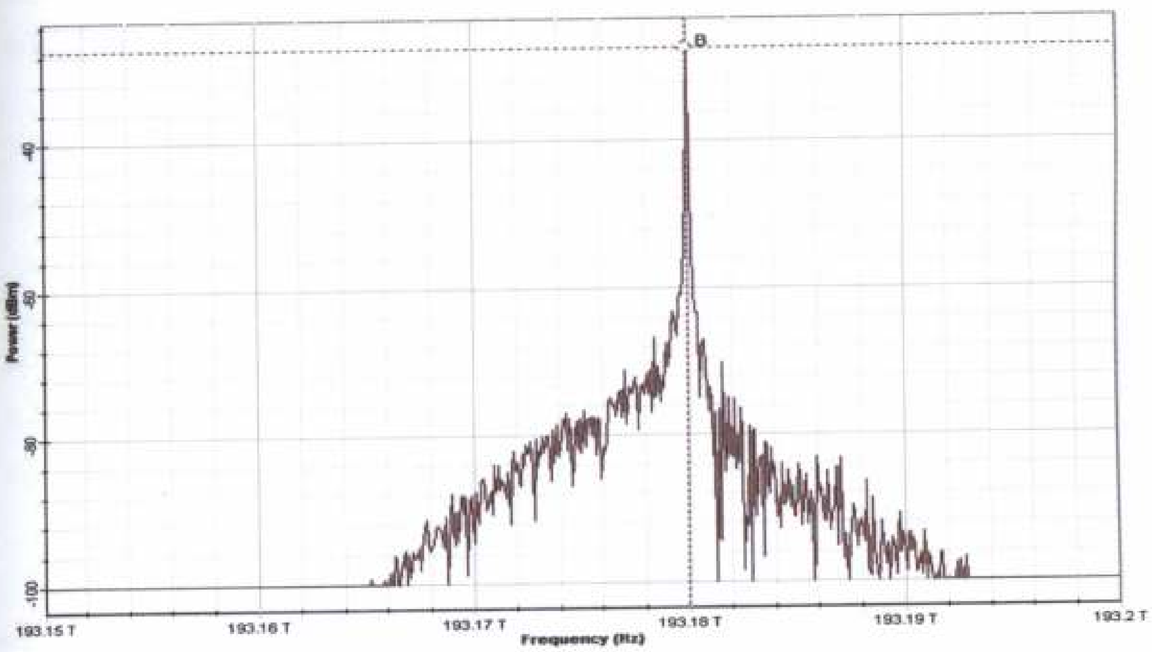

Fig 3.4 Positive 3rd Side Band at 193.18 THz.

After the modulated signal is passed through the frequency selective filter, a positive 3rd side band is obtained at 193.18 THz of frequency, which is shown in figure 3.4 given above.

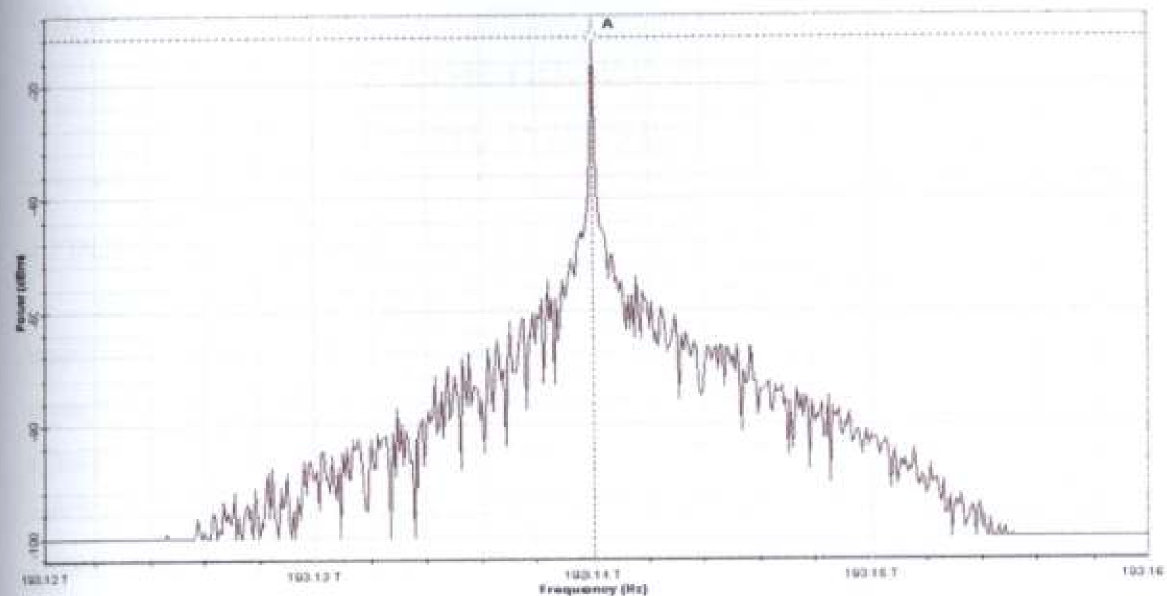

Fig 3.5 Carrier sideband at 193.14 THz

After the modulated signal is being fed to the frequency selective filter with its frequency tuned to the carrier frequency, the signal is obtained properly at 193.14 THz, which is shown in figure 3.4 given above.

<u>SCALES OF GRAPH</u>

For the above two graphs:

Along X-axis→Frequency in THz

Along Y-axis→ Power in dBm

A→(Carrier frequency) 193.14 THz; Amplitude→-12.306(dBm)

B→(3^{rd} side band) 193.18 THz ; Amplitude→-27.4647(dBm)

Frequency separation (GHz): B-A→40

Thus, from the above calculations, it is observed that 40 GHz of frequency as the input given to the optical modulator (MZM) is obtained after being filtered.

CHAPTER 4

MILLIMETRE WAVE SIGNAL GENERATION USING INJECTION LOCKING SCHEME

4.1 INJECTION LOCKING

In injection locked laser systems, a master laser injects light into a slave laser thus modifying the characteristics of the slave laser. The modulated master laser (A master laser is a single frequency laser) via MZM is injection locked by the two slave lasers (A slave laser is a laser which emits on an optical frequency which is dictated by an external master laser via injection locking). The desired output is obtained at the Photo detector. Thus, Injection locking is a method which is applied mainly to continuous wave single frequency laser sources when a high output power needs to be combined with a very low intensity noise and phase noise. Such low noise performance or even just single frequency operation is significantly more difficult to achieve in high power lasers. Another advantage of optical injection locking is that the locking oscillator is electrically isolated from the locked oscillator, eliminating the need for impedance matching between the oscillators.

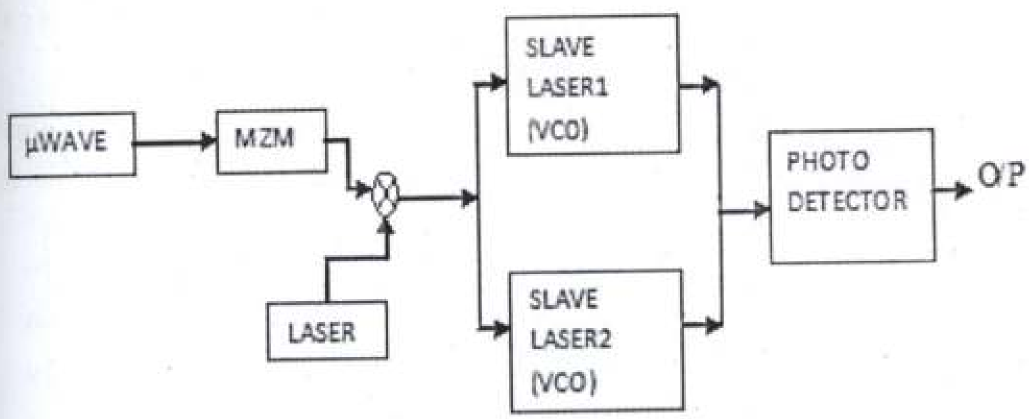

Fig 4.1 Block diagram of Modulation using Injection Locking Scheme

The injection voltage-controlled oscillator is of the type which can be set to oscillate in the vicinity of a desired frequency by simple adjustment of a controlled unidirectional voltage level so applied, the injection oscillator is capable of locking stably on the nearest frequency signal of the array of signals injected into it. Thus, the oscillator behaves like a filter, selecting the desired component of the output.

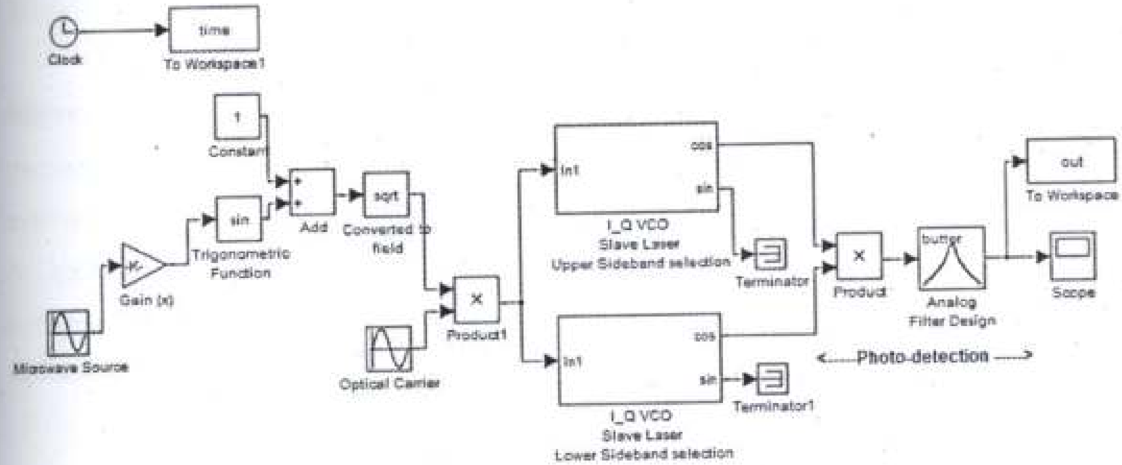

Fig 4.2 Optical Injection Locking of Two Slave Lasers

The slave lasers (I_Q VCO) are injection locked to the sideband signals ($\omega_c+3\omega_m$) and (ω_c-$3\omega_m$) of master laser, where ω_c is the carrier frequency (master laser) and ω_m is the modulating frequency. The injection- locked slave lasers' output is fed to the Photo detector (product of the output of two slave lasers signal followed by a Butterworth type filter) to obtain the desired output at a frequency of 60 GHz.

4.2 OBSERVATIONS

For computer aided analysis, we have applied an input signal i.e. the modulating signal of 10 GHz. The spectrum of the input signal is shown below in fig 4.3.

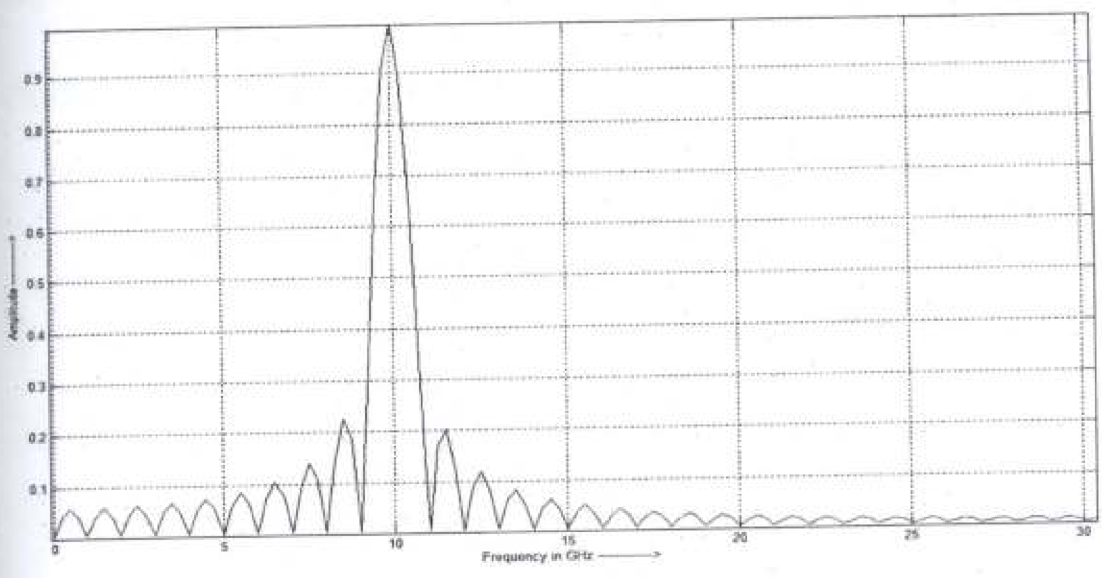

Fig 4.3 Input signal to MZM

MODULATING SIGNAL

The RF signal is applied to one of the inputs of the MZM. The signal passes through different stages of the MZM. The signal at the stage after the adder block in fig 4.2 is observed whose spectrum is shown in fig 4.4. In this spectrum, it is seen that the third harmonics at 30 GHz has the highest amplitude. This is so because the Bessel function has the highest amplitude at the third harmonics i.e. $J_3(3.843)=0.421$. Hence, this is true according to mathematical analysis too.

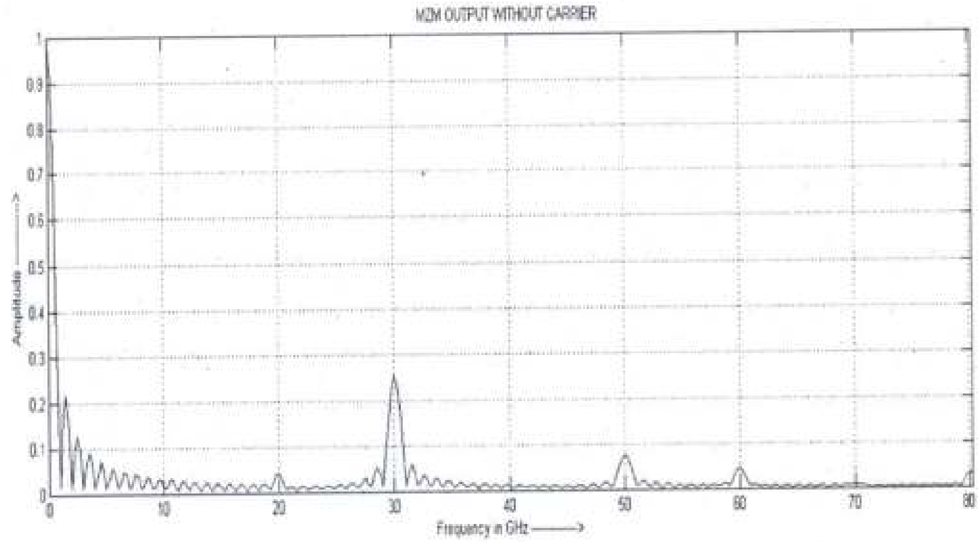

Fig 4.4 Modulating signal

Here, the third harmonics at **30 GHz** has the highest amplitude due to Bessel function since for our purpose we have chosen modulation index as **3.843** for which it has the highest magnitude according to the Bessel table.

CARRIER SIGNAL (MASTER LASER OF 5000GHz)

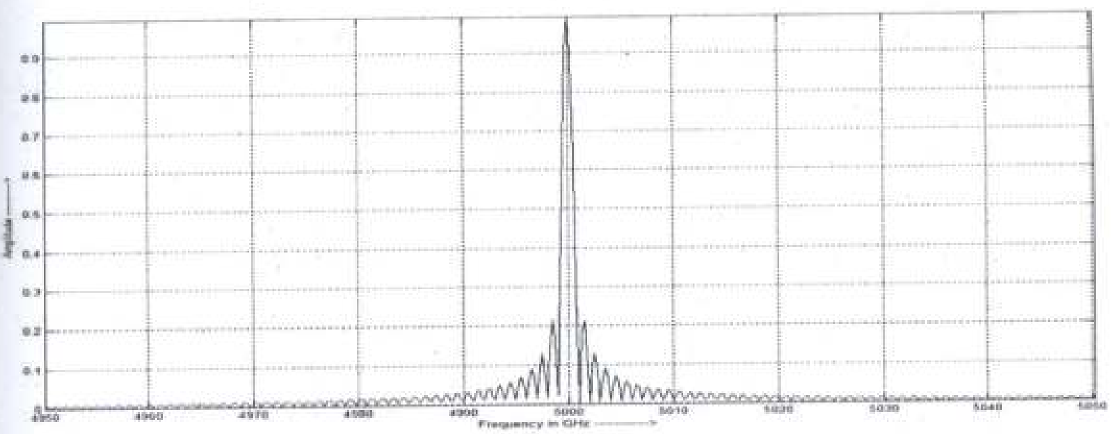

Fig 4.5 Carrier Signal Spectrum

The carrier signal is a single frequency signal i.e. master laser of 5000 GHz. This carrier signal's spectrum is shown in fig 4.5.

.MODULATED SIGNAL

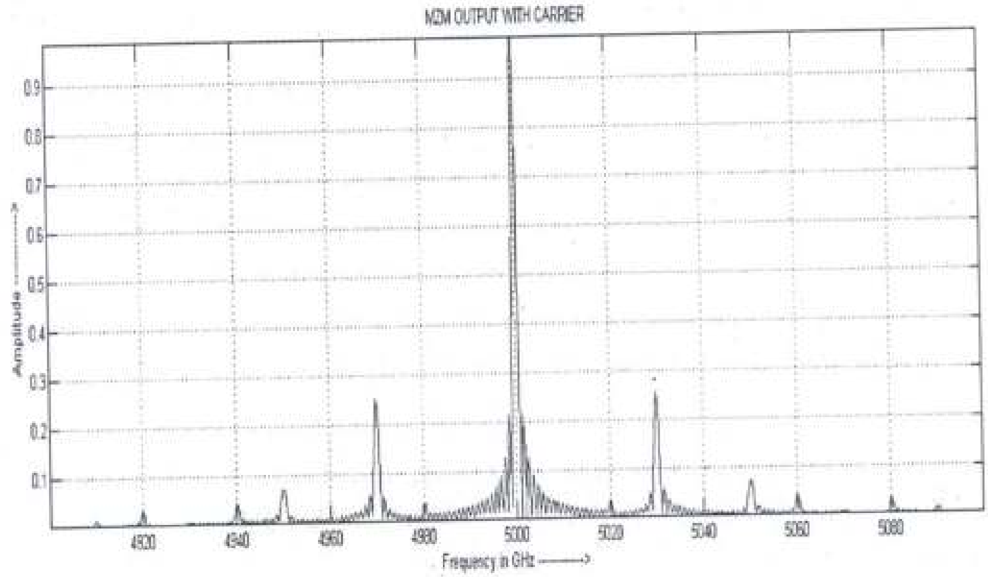

Fig 4.6 Modulated Signal Spectrum

The master laser is modulated with the MZM signal (modulating signal) with its central frequency at 5000 GHz and according to the modulating signal, it has the third (upper and lower) sidebands at 5030 GHz and 4970 GHz respectively. That is, the master laser is properly modulated with the modulating signal for modulation index as **3.843**.

As the third harmonics have the highest amplitude, our aim will be to utilize this sidebands with highest amplitude. To obtain this sideband we have to design VCOs which selects these sidebands. The various experiment carried out on the sidebands using VCOs (which are termed Slave Laser in our work) is discussed in the next section.

4.3 REALISATION OF VCO (SLAVE LASER)

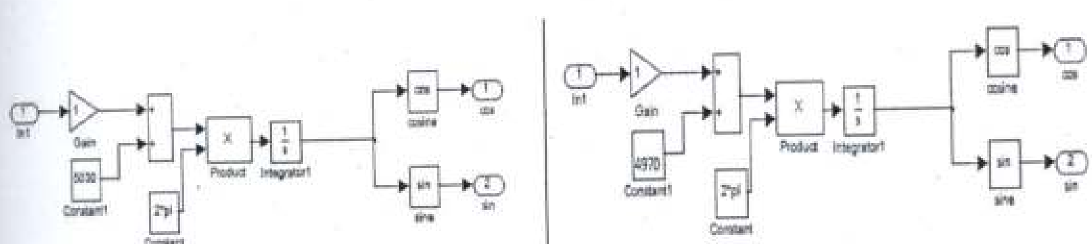

Fig I_Q VCO (UPPER SIDE BAND SELECTION) Fig I_Q VCO (LOWER SIDE BAND SELECTION)

Fig 4.7 Realisation of VCO (Slave Laser)

The VCO is an oscillator whose output frequency is directly related to the input voltage. The VCO supplies signal at its free running frequency if no input is applied. With input signal, it generates an output whose frequency follows the amplitude of the input in accordance with the applied voltage.

In our case, the VCO is termed as Slave Laser because its characteristic depends on the previous stage of modulation, which is the Master Laser. Thus, by choosing the center frequency to be 5030 GHz and 4970 GHz (i.e. the 3rd order sideband) we can select the sideband with highest amplitude. Since, the master laser output is injected into slave laser which are tuned at the center frequencies of the two sidebands with highest amplitude, we can say that this scheme utilizes the injection locking method.

4.4 OBSERVATION FROM VCOs

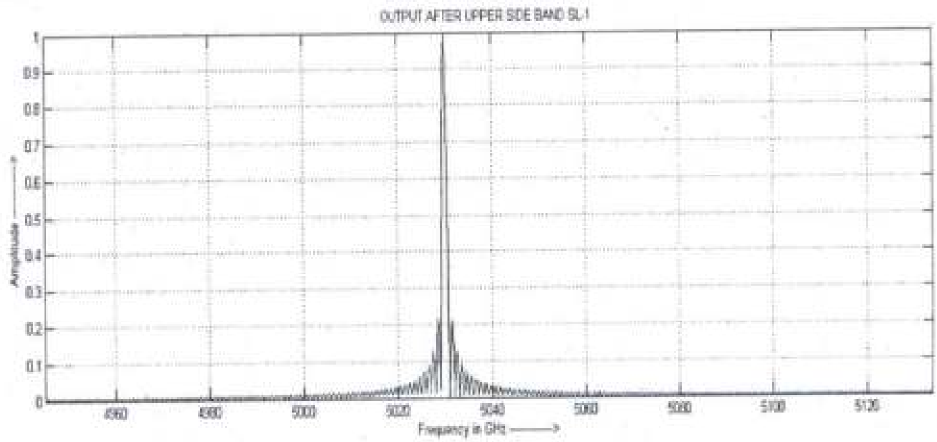

Fig 4.8 Upper Sideband

The upper side band is obtained with injection locking at 5030 GHz from slave laser.

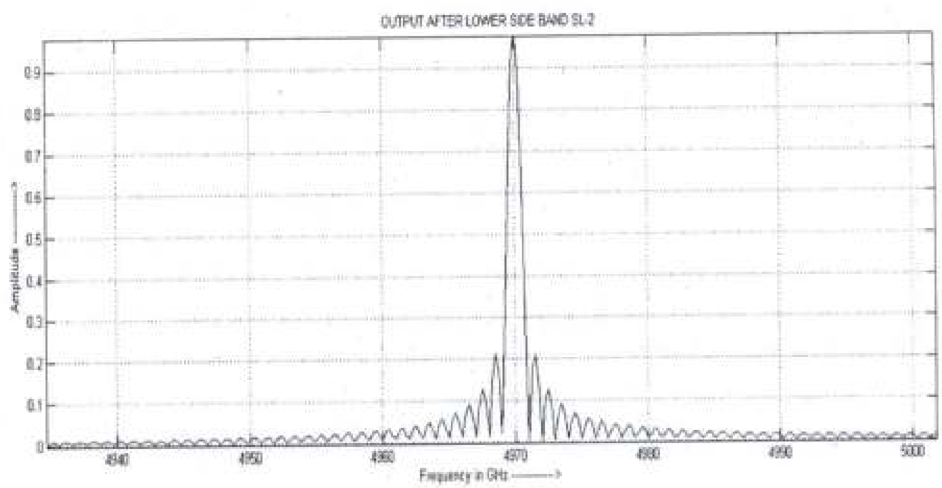

Fig 4.9 Lower Sideband

The lower side band is obtained with injection locking at 4970 GHz slave laser. Thus, the VCO's act as filter generating output signals whose frequencies are directly related to the input signal with upper and lower sidebands respectively. The two slave lasers are phase incoherent. Also, the phase noise is a serious problem as the output of a single-frequency laser is not perfectly monochromatic but rather exhibits some phase noise which leads to a finite line width of the laser output.

Now, by taking the output side bands from the VCO's, it is fed to the Photo-detector (product of the output of VCO's signal followed by a Butterworth type filter) to get the desired output at 60 GHz.

4.5 PHOTO DETECTION

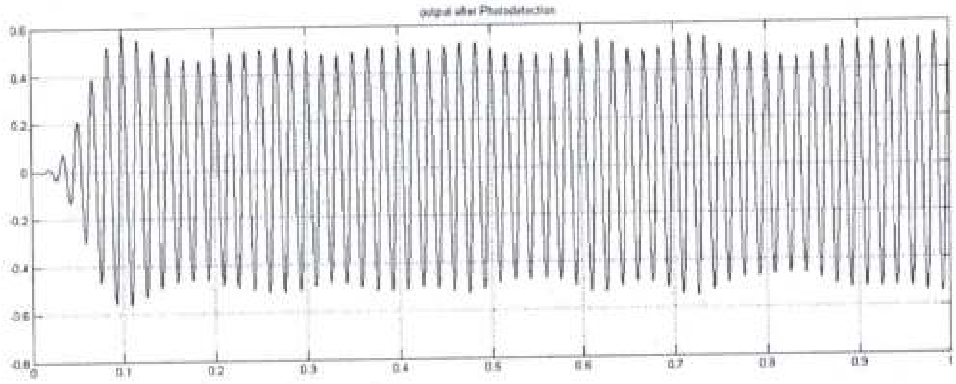

Fig 4.10 Output of Photo Detector in Time Domain

Figure given above shows time domain output of photo detector with no injection locking.

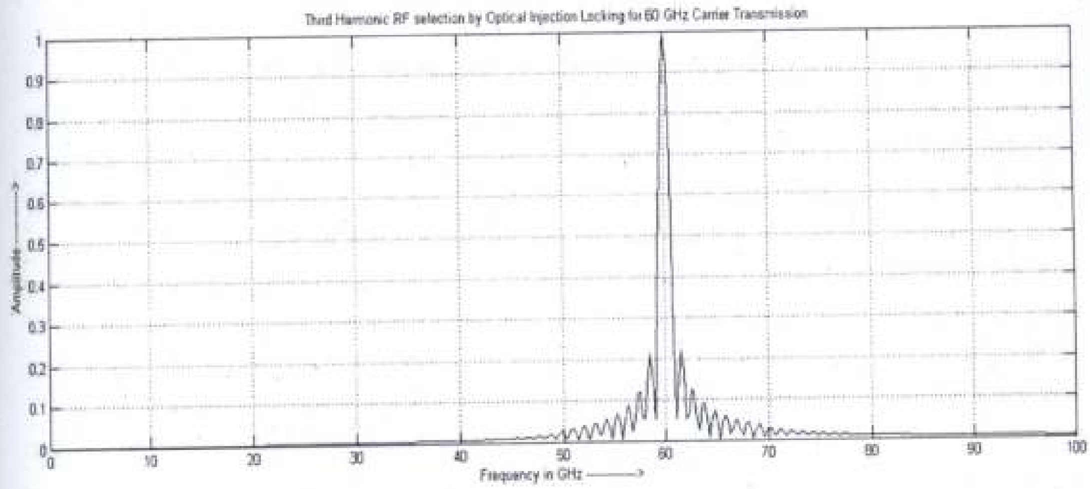

Fig 4.11 Output of Photo Detector in Frequency Domain

Figure 4.11 shows frequency domain output of photo detector with injection locking.

The output of the photo detector results a sharp signal of 60 GHz for carrier transmission. It can be observed that the effect of phase noise of the signals via injection locking significantly reduces the same and results a sharp line width spectrum otherwise the phase noise will be maximum.

Hence, we have successfully generated a millimeter wave having frequency 60 GHz utilizing the optical injection locking scheme.

CHAPTER 5

MILLIMETRE WAVE SIGNAL GENERATION USING OPTICAL PHASE LOCK LOOP (OPLL)

5.1 INTRODUCTION

The PLL is an important part of communication system. It is a negative feedback control system. Traditionally, carrier synchronization has been performed by optical Phase-lock Loop (PLL). However, there exists two disadvantages such as firstly, the sensitivity to propagation delay in optical PLL feedback path. Secondly, the fixed loop bandwidth of the PLL that imposes a tradeoff between acquisition time and steady-state phase tracking performance. Since, PLL is built using less optical components, leading to a smaller loop bandwidth, and with a carrier frequency of THz range, which results in low loop bandwidth to carrier frequency ratio. As such, acquiring locking is less straight forward in an optical PLL as the slave laser must be tuned to the master laser wavelength with high accuracy.

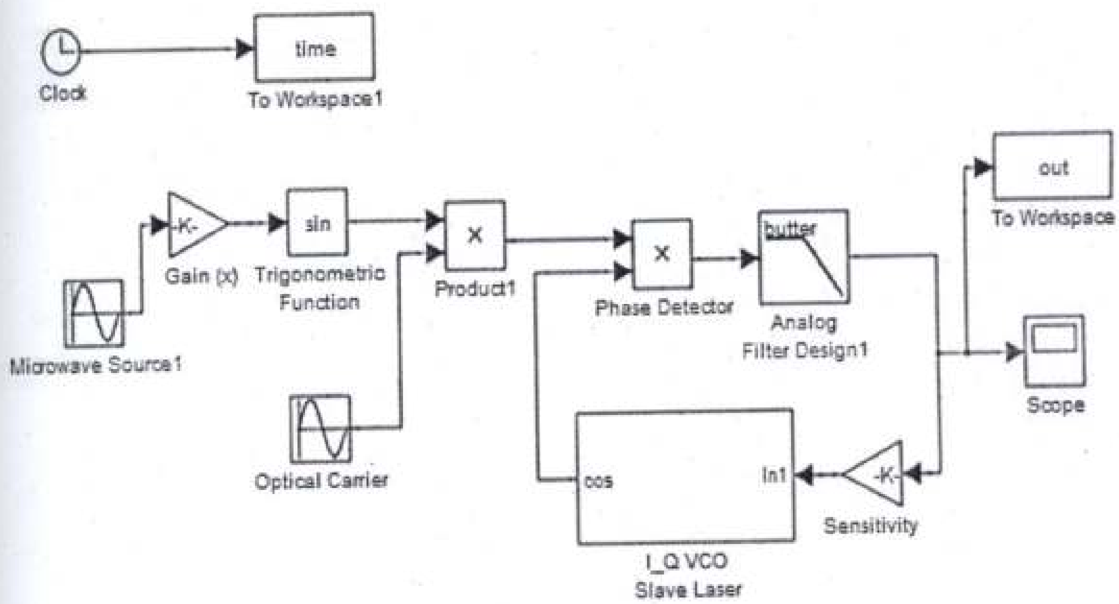

Fig 5.1 Optical Phase Lock Loop (OPLL)

Since, the center of a PLL is VCO which is locked to a reference frequency. The lock is accomplished by the output of phase detector which is amplified and low pass filtered providing the correction voltage for the VCO. The phase detector is simply a multiplier whose output is related to the product of both its inputs.

Let, Reference signal be

$E_i = E_I \{sin(\omega_\lambda + 3\omega_{RF})t - sin(\omega_\lambda - 3\omega_{RF})t\}$

and the slave laser VCO output be

$E_o(t) = E_o cos\ [\omega_o t + \Psi_{VCO}(t)]$

where ω_o= free running frequency, $\Psi_{VCO}(t)$ = phase modulation due to laser VCO frequency modulation.

Therefore, Phase detector output is given by

$v_\phi = \mu\ sin\ \phi(t);$ where $\phi(t) = (\omega_\lambda - 3\omega_{RF} - \omega_o)t - \Psi_{VCO}(t)$

And VCO, frequency deviation is directly proportional to the input signal to the VCO

i.e. $d\Psi_{VCO}/dt = K_{VCO}v_\phi = \mu K_{VCO}F(s)sin\phi(t)$

Now, if the open loop frequency error be $\Omega = \omega_\lambda - 3\omega_{rf} - \omega_o$, then

$d\phi/dt = \Omega - d\Psi_{vco}/dt = \Omega - \mu\ K_{vco}F(s)sin\ \phi(t)$

Thus, Phase governing equation of the system is given by,

$d\phi/dt = \Omega - \mu\ K_{vco}F(s)sin\ \phi(t)$

$s\phi(s) = \Omega - \mu\ K_{vco}F(s)\phi(s)$; using Lplace transform i.e, 1st order linearisation.

Or, $\phi(s) = \Omega\ /[s + \mu\ K_{vco}F(s)] = [\phi_i - \phi_o](s);$

where $\phi_i(t) = (\omega_\lambda - 3\omega_{rf})$ & $\phi_o(t) = \omega_o t - \Psi_{vco}(t);$ $\phi(t) = \phi_i(t) - \phi_o(t) = \Omega t - \Psi_{vco}(t)$

And $d\Psi_{vco}/dt = \mu\ K_{vco}F(s)\phi(s)$

Or $s\Psi_{vco}(s) = \mu\ K_{vco}F(s)\phi(s)$

Or $\Psi_{vco}(s)/\phi(s) = \mu\ K_{vco}F(s)/s$

Or, $\phi(s)/\Psi_{vco}(s) = s/\ \mu\ K_{vco}F(s)$

Now, $d\Psi_{vco}/dt = \mu\ K_{vco}F(s)\ [\phi_i - \phi_o](s);$

When $\Omega = 0$ i.e $\omega_\lambda - 3\omega_{rf} = \omega_o$, the VCO is tuned to the carrier frequency and the input is written as, $E_i = E_I\{ sin(\omega_\lambda - 3\omega_{rf})t + \phi_i(t)\}$ thus $\phi_o(t) = \Psi_{vco}(t)$

And, $d\phi_o/dt = \mu\ K_{vco}F(s)\ [\phi_i - \phi_o](t)$

$s\phi_o(s) = \mu\ K_{vco}F(s)\ [\phi_i - \phi_o](s)$

$\phi_o(s)/\ \phi_i(s) = \mu\ K_{vco}F(s)/[s + \mu\ K_{vco}F(s)] = H(s);$ which is the Loop transfer function.

By appropriate choice of F(s), any order closed loop transfer function can be obtained.

Since, $H(s) = \Psi_{vco}/\ \phi_i(s)$ and $1 - H(s) = H_1 = \phi_o(s)/\ \phi_i(s);$

Therefore, Error function $H1(s) = s/[s + \mu\ K_{vco}\ F(s)]$

It is to be noted that a wideband PLL allows more noise to pass into the loop, which corrupts the phase estimate.

5.2 OBSERVATIONS OF PLL

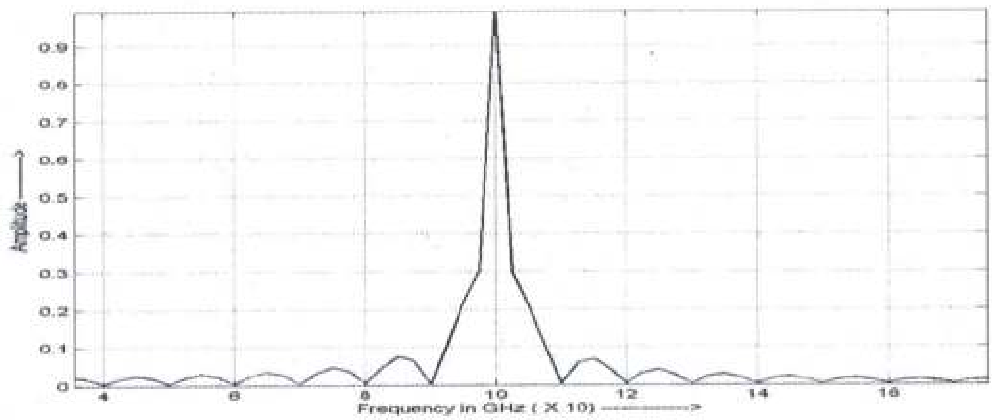

Fig 5.2 Microwave signal input

The baseband signal (microwave) of 10 GHz is given as input to the MZM.

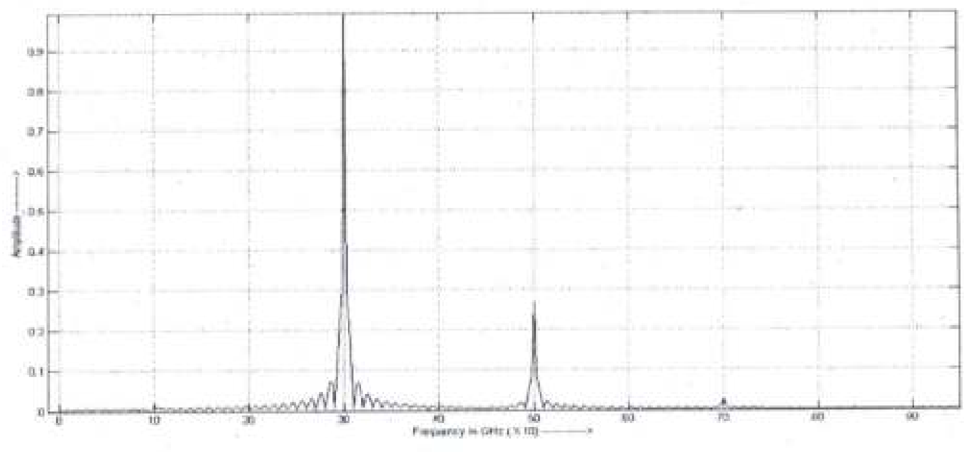

Fig 5.3 Modulating signal

Here, the signal at 30 GHz has the highest amplitude of the MZM followed by a small amplitude at 50 GHz.

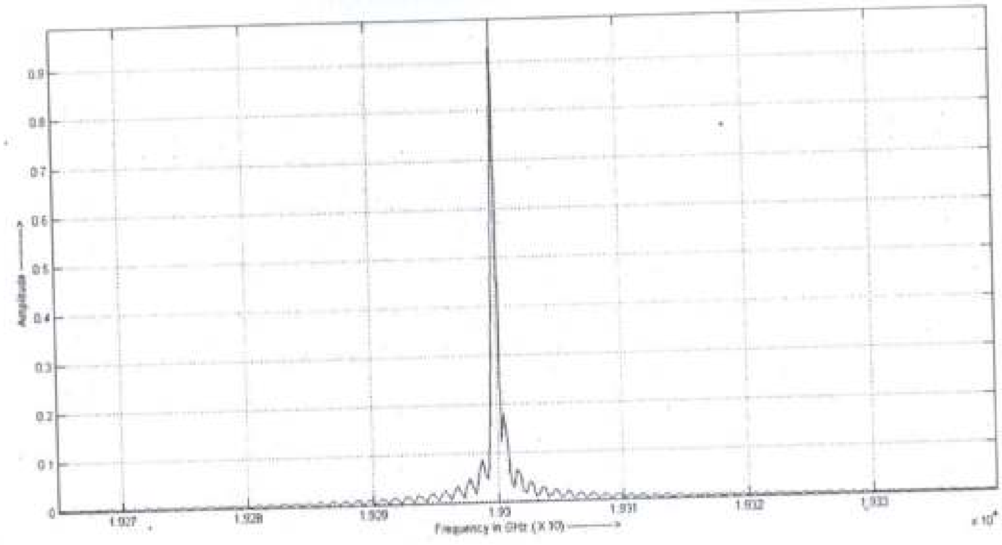

Fig 5.4 Carrier signal (Master Laser)

The carrier signal (Master Laser) of 1.93 GHz is to be modulated with the MZM's signal.

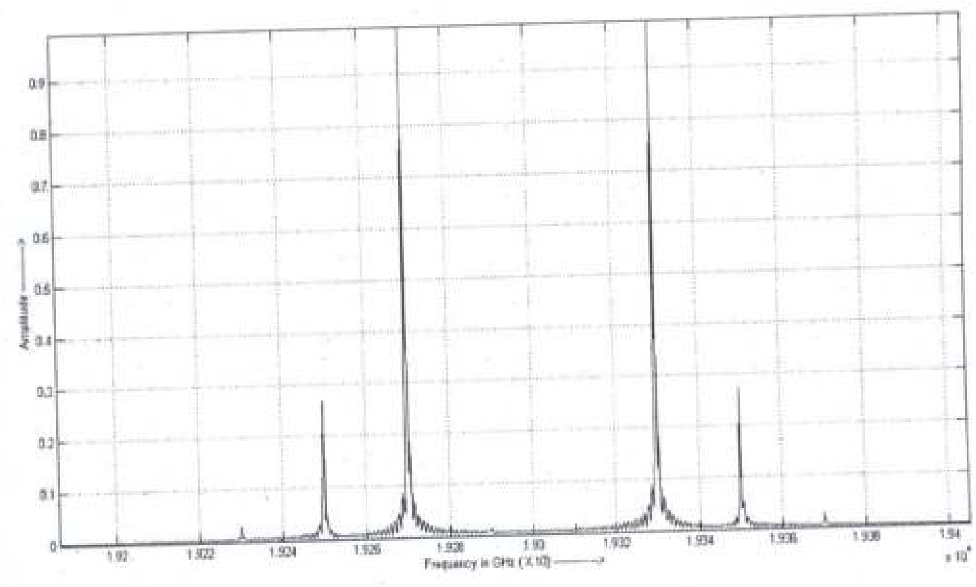

Fig 5.5 Modulated signal

The master laser is modulated with the modulating signal of MZM having upper sideband highest amplitude at 1.933 GHz and lower sideband highest amplitude at 1.927 GHz.

Since, the highest frequency term will be rejected by the low pass filter; so the VCO will correspond to the lower frequency term only.

5.3 REALISATION OF VCO (SLAVE LASER)

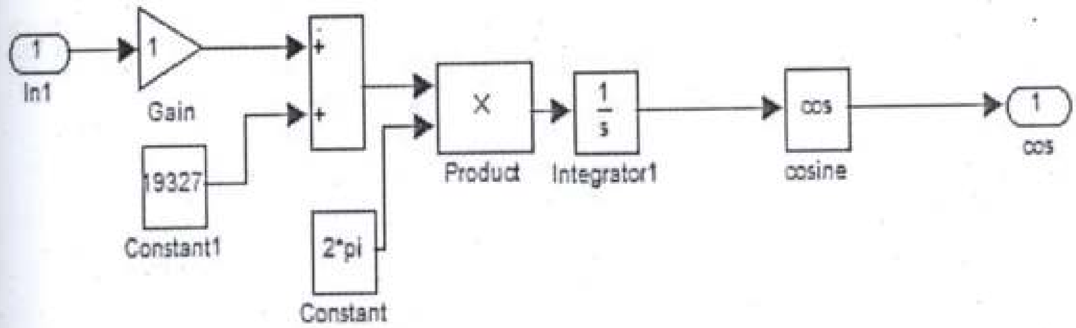

Fig 5.6 VCO (Slave Laser)

Since, the VCO is tuned to the carrier frequency with the lower side band selection, so the output of the VCO is obtained as----

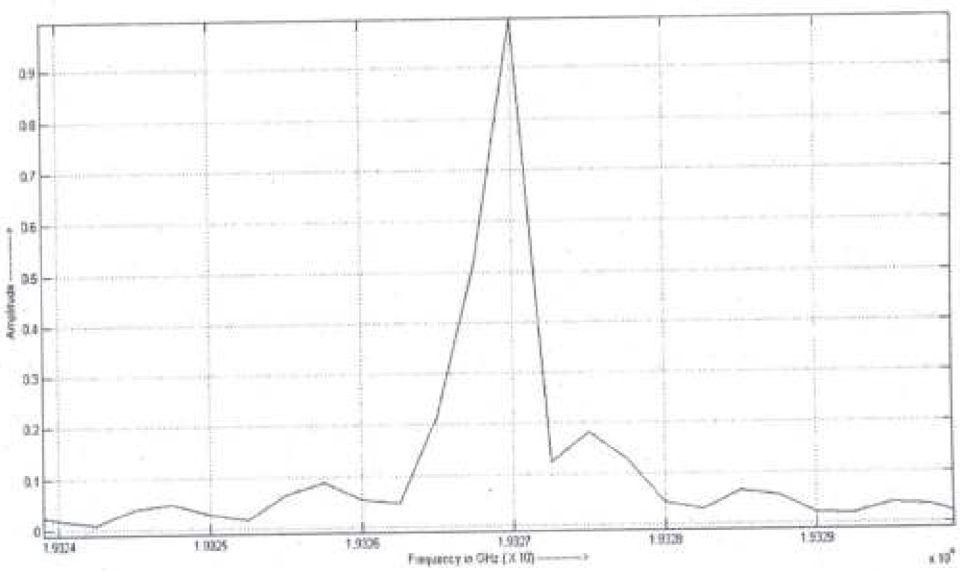

Fig 5.7 VCO Output

It is to be noted that the output of VCO has 90 degree phase shift with respect to the un-modulated carrier frequency. The output is fed to the phase detector together with the modulated signal. The phase detector generates an output signal which is a function of the difference between the phases of the two input signals.

The output of the phase detector is obtained as shown below

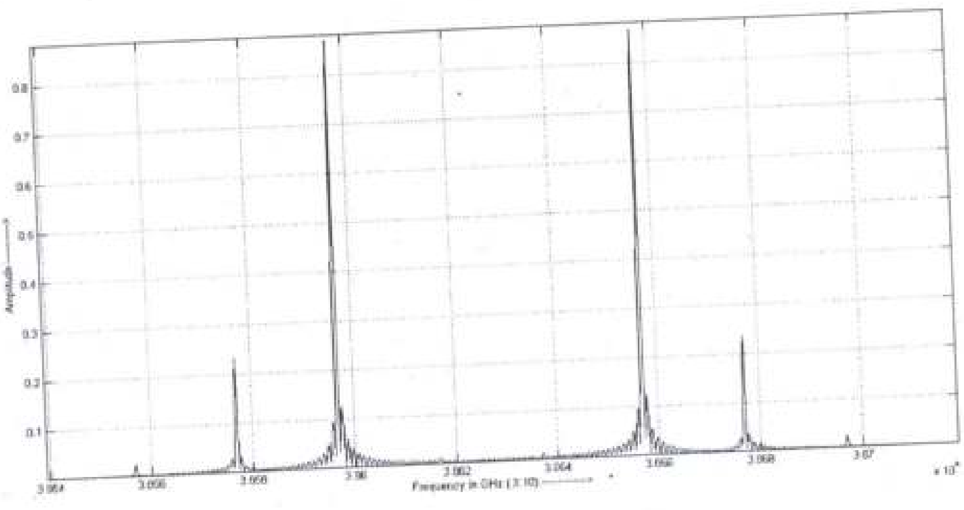

Fig 5.8 Output of Phase Detector

This output of the phase detector is filtered and the error signal is fed to the VCO which is forced to track the master laser at a frequency offset corresponding to the frequency of the reference input signal. The feedback signal is used to lock the output frequency and the phase of the input signal. However, the feedback bandwidth is independent of the desired microwave frequency. The only function of the (butter-worth type) low pass filter used is to remove the second harmonic of the carrier frequency resulting from multiplication.

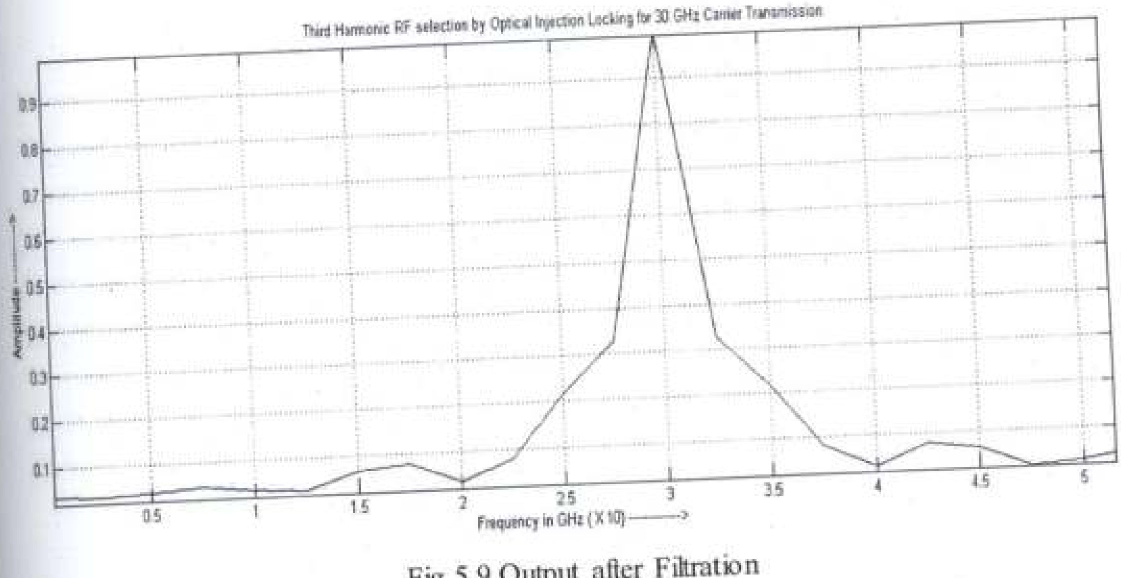

Fig 5.9 Output after Filtration

Therefore, after suppressing the double frequency term by the filter, a 30 GHZ mm wave is generated at the output via injection-locking.

CHAPTER 6

CONCLUSION

The proposed work has been demonstrated using a novel scheme to generate mm-wave signal using optical sideband generation technique. This work uses a phase modulator technique along with optical filtering. In our first case, we consider Gaussian type filter for filtration and then faithful detection of the baseband signal via direct and coherent detection has been accomplished. Next, we have considered linear MZM and slave lasers for injection locking process to generate a 60 GHz mm-wave after photo detection. The 60 GHz mm-wave has been obtain since in most of the communication system at this frequency of optically generated mm-wave, noise is comparatively low such as Phase and relative intensity noise as compared to traditionally generated microwave signal of the same 60GHz range. Lastly, an optical PLL is implemented and a faithful optical mm-wave is generated at 30 GHz frequency via injection locking for carrier transmission. The generated 30 GHz signal can be upconverted to a 60 GHz microwave signal. But the basic philosophy of generating a 30 GHz microwave signal using an OPLL is that this method enjoys the advantage of noise squelching phenomenon of a conventional PLL along with the additional advantage that the generated signal has a very low phase noise which improves the BER and the receiver sensitivity.

CHAPTER 7

FUTURE SCOPE

This work can be further extended to study the dependence of the MZM on the splitting or extinction ratio, dynamic range or the linearity of MZM. The final output can be modulated using different modulation formats like PSK, OFDM and the effect of fiber dispersion on the 60 GHz carrier transmission can be also studied.

REFERENCES

1. Lin Chen, Hong Wen and Shuangchun Wen , " A Radio- Over-Fiber system with a novel scheme for millimeter-wave generation and wavelength reuse for up-link connection", IEEE photonics Tech. Lett.,vol.18.No.19,october1,2006.

2. L.N. Langley, M.D. Elkin, C. Edge, M.J. Wale, U. Gliese, X. Huang, and A. J. Seeds, " Packaged semiconductor Laser optical Phase-locked loop (OPLL) for Photonic generation, processing and transmission of microwave signals", IEEE transactions on microwave theory and techniques, vol. 47, No. 7, July 1999.

3. Y. Li, S. Goldwasser, and P.R. Herezfeld, " Optically generated dynamically tunable, low noise millimeter wave signals using microchip solid state lasers", Center for Microwave/ lightwave Engg, Drexel University, Philadelphia, PA. 19104 USA, yifeili@io.ece.drexel.edu

4. Subal Kar, S. Banerjee, S. Bhattacharyya, D. De Sarkar, and P. Das, " Computer- aided analysis of an Heterodyning scheme for ultra-stable microwave signal generation and its scale-model hardware characterization", Institute of Radio Physics and Electronics, University Of Calcutta, 92,A.P.C. Road, Calcutta-700009, India.

5. John M. Senior, " Optical Fiber Communications (principles and practice)", second edition, Pearson Education.

6. Govind P. Agarwal, "Optical communication system(OPT428)", Institute of Optics, University of Rochester, NY-14627.

7. G.P. Agarwal, "Fibre optic communication system", e-book.

8. Keang PO HO, "Phase modulated optical communication system", Institute of communication Engg, Deptt. Of Electrical Engg., National Taiwan University, Taipei 106, Taiwan.

9. Adel S. Sedra, Kenneth C. Smith, "Microelectronic circuits", fifth edition, Oxford

10. R.P. Singh, S.D. Sapre, "Communication system (analog and digital)", second edition, Tata McGraw Hill.

11. D.C. Tayal , "Basic Electronics", second revised edition 2008, Himalaya Publishing House.

12. Erwin K Lau, "High speed modulation of injection locked semiconductor lasers", Thesis for Ph.D, Electrical Engg. & Computer Sciences, University of California, Barkeley.

13. SasaRistic, AshishBhardwaj, Mark J. Rodwell, Larry A. Coldren, and Leif A. Johansson, " An optical phase- locked loop integrated circuit", Journal of Lightwave Technology, vol. 28, No 4, February 15, 2010.