Broadband RF Photonic Channelization

A Dissertation submitted towards the partial fulfillment of
the requirement for the award of degree of

Master of Technology

In

Microwave and Optical Communication Engineering

Submitted By

Preeti Chauhan
2K11/MOC/10

Under the supervision of

PROF. R. K. SINHA

Department of Electronics and Communication Engineering

&

Department of Applied Physics

Delhi Technological University

(Formerly Delhi College of Engineering)
JUNE-2013

CERTIFICATE

This is to certify that the dissertation title ***“Broadband RF Photonic Channelization”*** is the authentic work of **Ms. Preeti Chauhan** under my guidance and supervision in the partial fulfillment of requirement towards the degree of Master of Technology in ***Microwave and Optical Communication Engineering***, jointly run by the Deptt.of Electronics and Communication Engineering and Deptt.of Applied Physics in ***Delhi Technological University.***

Prof. R. K. Sinha
Supervisor
Deptt. of Applied Physics
Delhi Technological University

Prof. S. C. Sharma
HOD
Deptt. of Applied Physics
Delhi Technological University

Prof. Rajiv Kapoor
HOD
Deptt. of ECE
Delhi Technological University

ACKNOWLEDGEMENT

I am indebted to my thesis supervisor **Prof. R.K Sinha**, Department of Physics, for his gracious encouragement and very valued constructive criticism that has driven me to carry the project successfully.

I am deeply grateful to **Prof. Rajiv Kapoor**, Head of Department (Electronics and Communication Engineering), Delhi Technological University for his support and encouragement in carrying out this project.

I wish to express my heart full thanks to my branch coordinator **Dr. Ajeet Kumar & Dr. Priyanka Jain** and and my friend **Rahul Mishra** for their goodwill and support that helped me a lot in successful completion of this project.

I express my deep sense of gratitude to my mother **Mrs. Saroj Rani Chauhan**, My sister **Neelima Chauhan** for their time to time supports and encouragements.

Finally I would like to thank **God** for his blessings without which nothing is possible in this world.

Preeti Chauhan

M.Tech (MOCE)

2K11/MOC/10

Table of Contents

Chapter 1: Introduction

Chapter 2: System component description

Chapter 3: Methodology and channelization model

Chapter 4: Simulation Result and Discussions

List of Figures

ABSTRACT

A Microwave frequency channelization scheme has been proposed and demonstrated with the help of Optical frequency comb, Mach-zhender modulator, Fabry Parot Filter, Optical Demux. In the proposed channelizer an incoming wideband is multicast by Optical Frequency comb, spectrally sliced by Fabry perot filter and physically separated by demux.

In comparison to previous proposals we have used OFC for channelization to have more uniform, noise immune and simple channelization. We have used SSB-SC Modulation instead of DSB-SC modulation so that we can channelize our signal to 40-50 GHz range than 19.5 proposed in previous paper. As precision of measurement and range to which we can process our Microwave signal depends on number of equally spaced line, we have designed a 36 line OFC and used in our proposal which is much greater than 6 lines used by previous proposal. As an illustration only we have used only 15 line OFC in our experiment but we can also use 36 line OFC wherever required.

As an application multiple frequencies can be processed and measured simultaneously so that our processing is fast, efficient and easy to handle by our premature electronics devices.

Chapter 1

Introduction

1.1 Introduction

Now a days there are various applications which require wide bandwidth to operate like HDTV, Video on demand,interactiveMultimedia, Movie on demand etc. such kind of applications leads bandwidth requirement to several tens of GHz.This requirement of more bandwidth causes spectral congestion at lower microwave frequencies.Especially, future Military RF systems are increasingly being driven toward higher and higher frequencies so to larger bandwidth (as carrier frequency increases bandwidth increases) by user requirements[1]. For example, available communications spectrum used is already congested as the number of users and the bandwidth per user intensify, due to extra services required, which forces communications links to work on ever higher carrier frequencies. Other requirements such as low probability-of-intercept (POI) links are leading the frequencies of communicationssystems out to 60 GHz and beyond. Likewise, modern missileseekers and imaging radars are also moving to frequenciesapproaching 100 GHz to achieve antenna directivity (as directivity is proportional to frequency) and higherresolution from small-aperture systems. For such wideband signal the processing and to analyze the spectrum by conventional electronic circuitry is quiet difficult.

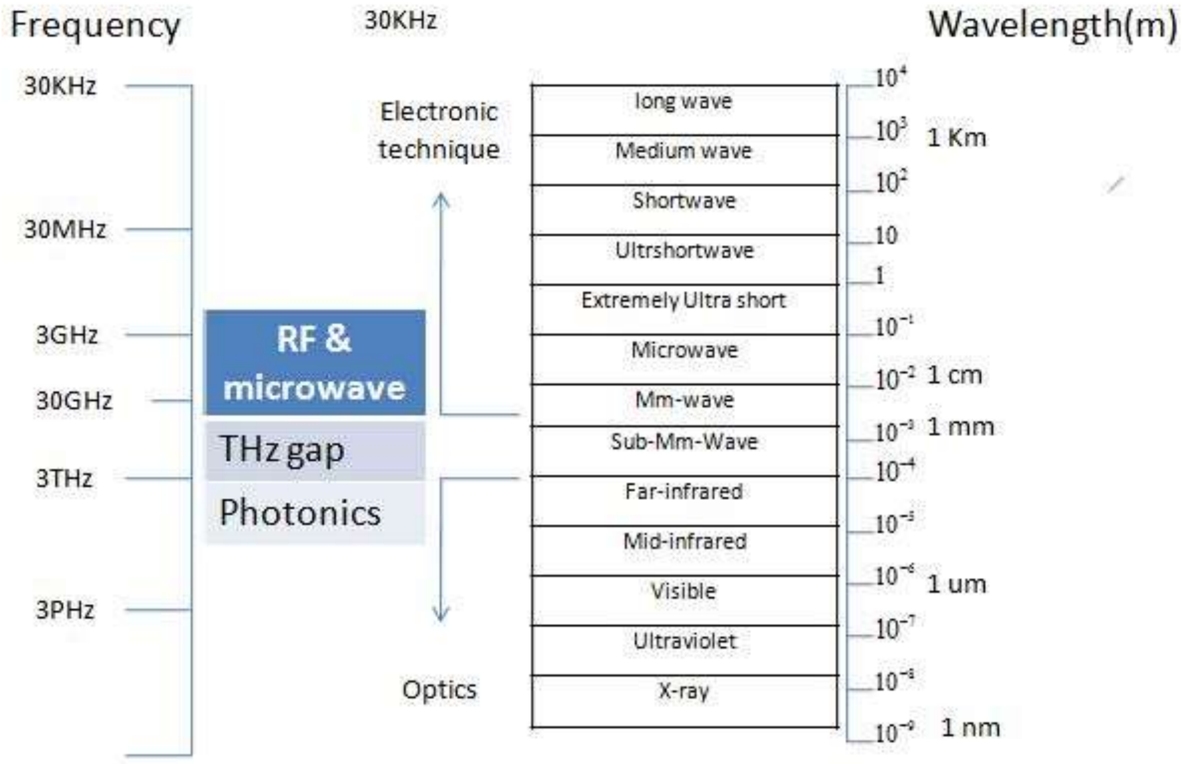


Fig 1.1: RF Spectrum

Conventional electronic spectrum analyzer analyzes the spectrum by scanning whole wideband spectrum with the help of narrow band pass filter serially, this performing a serial scan over entire frequency band. Serial scan is very slow for wideband signals so not able to do real time scanning which is an essential requirement.

Real-time and high-resolution monitoring of the entire RF spectrum in electronic domain is not feasible currently due to the conventional hardware size and power consumption [1]. Currently, the most advanced receivers for processing this signal environment utilize digital electronics and their bandwidths are restricted by the state-of-the-art for electronic analog-to-digital converters to about 1 GHz. **Therefore, it is essential to provide a means to channelize the extremely wide-band signal spectrum into frequency channels with bandwidths that are compatible with digital electronics.**

Channelization refers to a process whereby entire frequency band is divided into small sub bands, which is easy to process and very fast also, compared to serial scanning. Channelized receiver for RF uses this process as in it a number of band pass filter which is connected in parallel to divide the frequency band into small sub bands and then routed to separate detector. The performance of Microwave receiver is much dependent on the quality of the channelization.

But now the problem is that for such GHz range wideband signal channelization by conventional electronics is quit tough, as at this frequency channelization by electronics is complex, having low reliability, more power dissipation and also impractical for large number of channel.

As we know that today there are many applications like HFC, CATV, RF over Fiber etc. using optical carrier transmission and many of the remaining next-generation RF systems will also use optical carrier transmission of RF signals, which will eliminate the very high transmission losses and the sheer bulk attendant with conventional RF cabling and waveguides. It is possible only by Microwave Photonics (MWP) which is a theory or technique to facilitate generation, processing, control and distribution of microwave and millimeter-wave signals with the help of optoelectronic devices or systems[2].

As Photonic RF signal transmission is already relatively well established. There are alsoavailability of optical modulators and detectors approaching 100-GHz bandwidths with low noise and distortion. If the RF signal can be impressed on an optical carrier for distribution, then it certainly then makes sense to exploit the analog functionality offered by optics in electronic processing, which will reduce the burden on electronics counterpart and also gives speed due to ultra-high bandwidth of photonics. Thus, we can have analog processing of wide-band signals in the optical domain. There is also a well-developed research in the area of optical processor.

Therefore due to low loss and high bandwidth offeredby photonics, photonics is used to channelize the entire spectrum.

1.2 Advantages of photonic channelization

1. It can process ultra-wideband signals efficiently so can process large number of channels.
2. High sensitivity
3. High precision
4. High speed due to parallel processing
5. Can process or detect short duration burst signal
6. Low loss
7. Lightweight
8. Potential for the implementation of compact subsystems with low prime power requirements
9. Immunity to electromagnetic interference
10. Offering analogue processing of wideband signals.

1.3 Channelization techniques

A photonic channelizer receiver includes anoptical source with multiple optical signal lines at spaced wavelength, then RF signal received by antenna or waveguide will be multicast on optical carrier lines with the help of optical modulator then sliced by optical filter into subbands by departing a different frequency component or subband from each multicast copy after that we will separate physically each subband and then these can be detected by an optical detector [3].

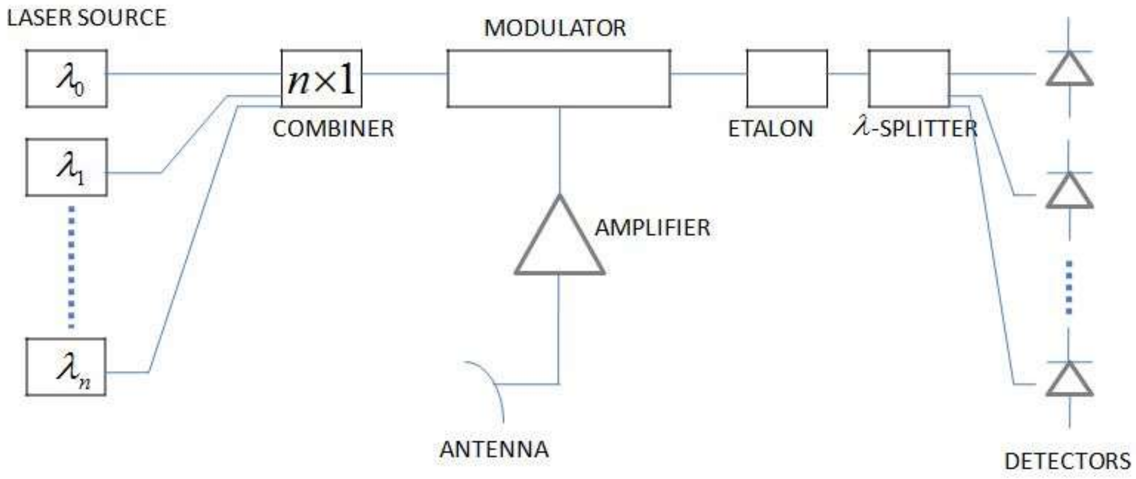


Fig 1.2 A Microwave photonic channelization scheme

Recently, several pioneering photonic methods have beenpresentedfor RF signal channelization. These are based onup conversion-and-split technique,where the RF signal was first modulated on an optical carrier,and then was fragmented*N* ways to *N* physically distinct filters [1].

It could be realized by:

1. Fabry-Perot etalons
2. Acousto-optic crystals
3. Fiber-grating-based parallel filter bank
4. Diffraction gratings
5. Integrated photonic devices
6. AWG

Acousto-optic(AO) systems have been made that are either incoherent, giving a power spectrum of the input signal, or coherent, in which the output retain both the amplitude and phase of the input signal. Generally, AO systems are limited in bandwidthto a few GHz and, thus, are not suitable for the ultra-wideband applications [4].

In fiber Bragg gratingbased channeliserthe receiveruses a parallel bank of progressively incrementedtransmission notches generated by phase-shifted chirpedgratings. This system is capable of processing or determining signals in the 2-18 GHz range into 2 GHz bands and alsomaintaining a high probability of intercept. It can be extended to higher frequencies also. Thistechnique is simple, low cost, of higher resolution,can be packaged into compact,lightweight receiver modulesandstable. In addition, the performance can readily beextended beyond 40 GHz with high resolution throughthe addition of further gratings [5].

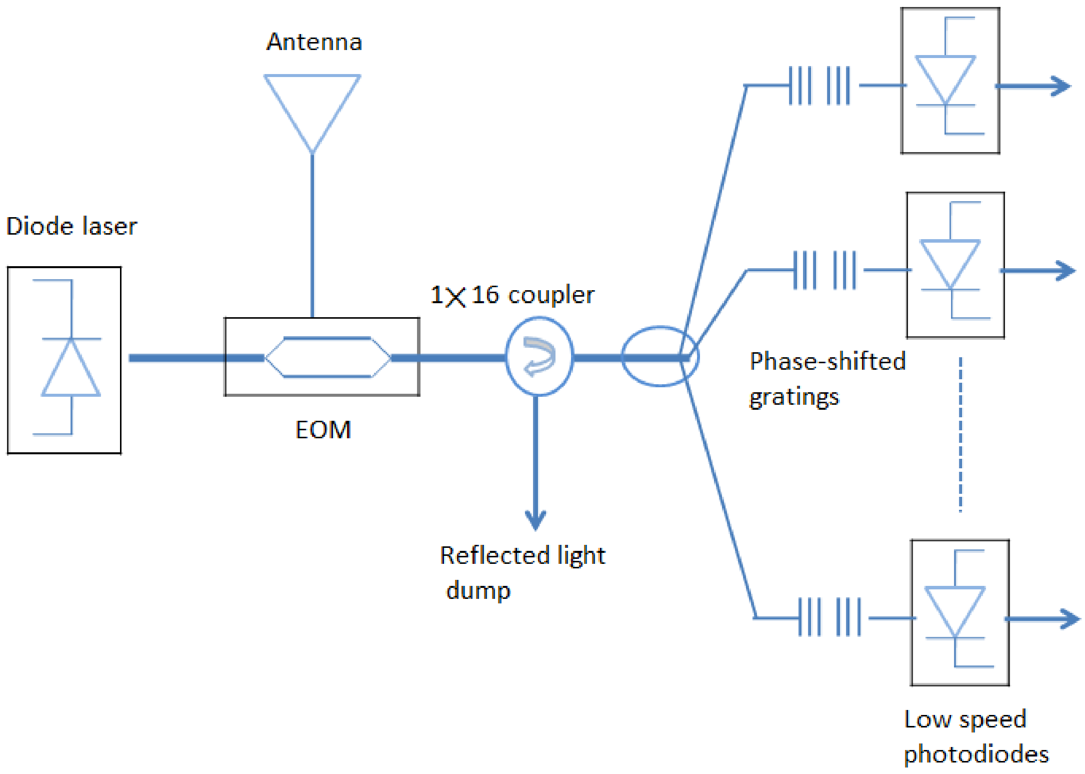


Fig 1.3 Channelization by diffraction grating

By diffraction gratings a coherent optical RF channelizer has been constructedand characterized also. The optical channelizer is based on free-space optical diffraction grating, and utilizes coherentoptical heterodyne detection to translate all of the frequencychannels to a common intermediate frequency (IF). The designedoptical channelizer has a 1-GHz channel spacing, and a nominal5-GHz IF [6].

Note that thebandwidths of the split sub-channels are realistically limitedby electronic hardware. So a large set of narrow, spectrallydense, and precisely centered filters are desired, which is very complex for even few number of channels, so not well suited for ultra-wideband signal [1].

To avoid thecomplicated filter design, a technique come, in which the RF signal was copiedto spectrally sliced incoherent source (SSIS) generated bya FPF. A second FPF with slightly different free spectrumrange (FSR) then sliced different sub-bands from each copy.Then an optical de-mux separated the sub-bands into differentchannels [7]. Since every carrier of SSIS is incoherent with widelinewidth, which results in large amplitude and phase noise,SSIS-based scheme can only achieve frequency estimationother than channelization. Meanwhile, coherent receiver isprecluded. Such scheme could be improved by modulating theRF signal on multiple free-running lasers [3]. But it will require precise spectral alignment where Noperations are needed to align N lasers with the second FPF,which increases the difficulties of practical operation.

A novel photonic channelization scheme for awideband radio-frequency (RF) signal based on an opticalfrequency comb (OFC), a comb filter, and an optical de-muxis proposed,in which, theinput broadband RF signal is multicast by the OFC, spectrallysliced by a Fabry–Pérot filter (FPF) and then channelized bya regular optical de-mux [1]. Compared to previous proposals, theOFC can provide uniform and low-noise channelization andsimplify the spectral alignment to the FPF. In it a 39-GHz-spaced OFC is used to multicast RF signal.

Theproposed OFC consists of flat and multiple frequencylines with high signal-to-noise ratio (SNR) as wellas strictly periodic interval, which can provide both alow-noise channelization and a simplified spectral alignmentto the following passive filters. The frequency response andcharacteristics of the OFC-based channelization are analyzedin theory. This technique can process up to the maximum sensible RF frequencyof 19.5 GHz with the help of 6-channel channelizercentered at 8∼13 GHz and stepped by 1 GHz.

Our work mainly based on the same paper described above based on OFC. As we have used OFC as a tool to optically multicast our received RF signal.There are several paper based on only OFC generation as design of OFC in channelization plays a vital role, that's why there is great concentration on design of OFC [].

There are several parameters on which OFC can be characterized:

1. Spacing between Optical spectrum lines
2. More number of Optical spectral lines
3. High SNR
4. Low complexity
5. Stability
6. High correlation
7. Low frequency deviation

In all the previous proposals we have used DSB modulation which limits the bandwidth of incoming RF signal, for example for a 39 GHz we can determine or process a maximum RF signal upto only 19.5 GHz due to double sideband generation. As the information is repeated on sidebands, only one of the sideband is enough to process our information RF signal and half of the bandwidth is wasted.

In our work we have taken SSB modulation, we have also designed SSB-SC modulation so that the carrier power is not wasted and the photo detector will not go into saturation, but to visualize RF lines with respect to optical carrier we have used SSB modulation only in this work.

Due to SSB modulation used in our work we can process or analyze 50 GHz RF signal by 50 GHz spaced OFC, as bandwidth required by modulated RF is only f_m , where $f_m$is the maximum frequency of RF signal, so bandwidth is not wasted rather utilized in an efficient way.There are also various paper presented on SSB modulation itself too.

In our work we have designed very stable OFC exploiting properties of MZM, we have used less number of component compared to previous proposal and designed a 36 line comb compared to previous proposal which is using 6 line channelizer, so sensitivity and precision is better for our work compared to previous. Even 1 GHz subband is little bit tough to process in electronics so we have done our channelization to produce subbands of 500 MHz, so sensitivity is increased and we have lighten the burden on electronics by doing this.

1.4 Project Objective

The main objective of this project is to design and demonstrate channelizationof broadband RF with the help of OFC, MZM- to generate SSB modulation, FPF- to slice multicast modulated signal. Channelization is done by Microwave Photonic Technique which is nothing but a combination of Microwave and Photonic Technique to complement each other so that we can overcome disadvantage of one by the advantage of another.

1.5 Scope of Project

As in future networks there is ever increasing requirement of higher frequency, due to bandwidth hungry services for example real time video or Video on demand, and high quality internet, for which very high bit rate is required which can only be accomplished by higher bandwidth. According to Cisco Visual Networkingforecasts, almost 66 percent of the world'smobile data trafficwill be video in 2014. So there is always a need of precise and fast channelization so that multiple frequencies can be processed and measured simultaneously.

1.6 Organization of the Thesis

First of all in **chapter 2nd**we would like to introduce operating principle and component description.

In **Chapter 3** we would like to give Methodology and channelization model.

In **Chapter 4** we will see simulation and resultdiscussion.

In **Chapter 5** we would like to give summery and recommendation for future work.

Chapter2

System Component description

2.1 Introduction:

In this section we will describe main optical and electrical component which we have used in our experiment to channelize the RF broad band data. the main component used are listed below as,

1) Continuous laser source
2) Mach-Zender modulator
3) Optical frequency comb
4) Fabry-perot filter
5) demultiplexer

2.2 Continuous laser source

Continuous laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The term "laser" originated as an acronym for Light Amplification by Stimulated Emission of Radiation. Lasers differ from other sources of light because they emit light coherently. Its spatial coherence allows a laser to be focused to a tight spot. In our experiment we use laser to generate optical carrier signal.

The field equation for the laser output can be given as,

$$E(\mathrm{t}) = \mathrm{E}_0 \exp(\mathrm{j}\,\omega_c\, \mathrm{t}),$$

Where,

E_0 is the amplitude of laser output field, and ω_c is the optical carrier frequency.

2.3 Mach-Zehnder modulator

A modulator will be used to modulate the RF data. For design of High performance systems, external modulation is usually used. The Mach-Zehnder Interferometer Modulator (MZIM) is described here due to superior and flexibility in use as compared with the Electro Absorption modulator or direct modulation technique. This is due to the change in the refractive index of some materials when an electric field, usually via a bias and a travelling RF wave is applied to the electrodes. This affects the material almost instantly the light waves passing through the modulator. Hence the electro-optic refractive index change is proportional to the voltage applied to the material. Delaying the light phase causes interference effects that modulate the output intensity constructively or destructively.

In our experiment we MZM will be used in two mode of operation, so it will be biased such that,

1) To generate SSB SC
2) To generate equal power level for carrier and first side band.

The first mode of operation will be used in modulation block to modulate RF broad band data which we have to slice, while second one will be used in designing of optical frequency comb.

2.3.1 Single sideband suppressed carrier scheme for MZM.[24]

The technique of the SSB modulation has been widely used in electrical domain for up-conversion circuits. It consists of the summation of two double-sideband signals with carriers and modulation signal in quadrature (90° phase shift). This combination results in the suppression of one of the modulation sidebands of the carrier, as schematically shown in Fig 2.1.

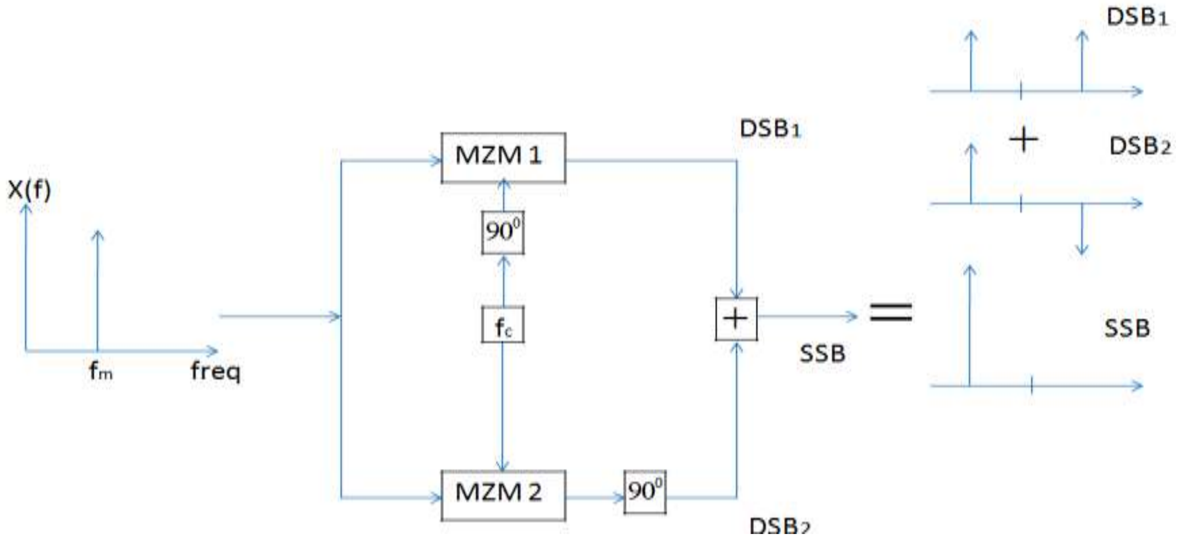


Fig. 2.1 -generation of SSB-SC signal

The demonstration of the optical SSB-SC modulator is done with a combination of classical Mach Zehnder modulators arranged in a configuration shown in Fig.. This configuration was designed by using guided-phase modulators and phase shifters. These modulators are divided into two pairs of phase modulators. Both pairs are operated as balanced modulators by setting the phase shifters to obtain an optical phase difference corresponding to one half-wavelength between the two input light waves in each pair of phase modulators. Also, the applied drive voltages are connected in such a way that they induce phase modulations of opposite signs. In other hand, a π/2 phase shift is introduced between the two balanced modulators. An example of this modulator was designed using a z-cut LiNbO3 optical waveguides and tested at 0.63-μm with a 2 GHz command signal. The result of this modulation consists of the recovery of the third low harmonic band and the first high harmonic band with a reasonable rejection.

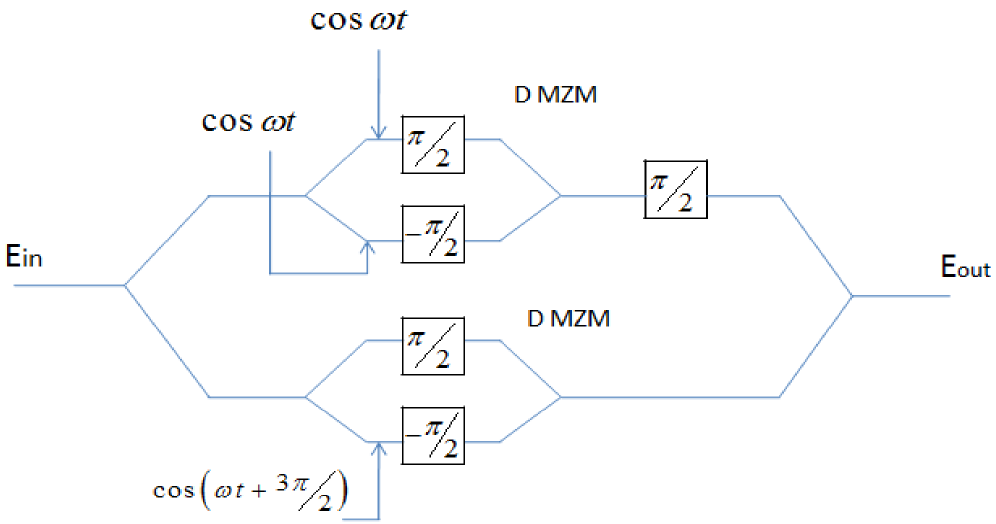


Fig. 2.2- SSB-SC generation

The another configuration can be integrated optical SSB-SC modulator consists of two parallel D-MZM intensity modulators coupled at entrance and exit by Y junctions. Electrical signals applied to each of the four arms of the D-MZMs are respectively cos(ωt), cos(ωt+π), cos(ωt+π/2), cos(ωt+3π/2). Unlike the first modulator, the optical phase shifts of π and π/2 are controlled externally by the electrical signals. Also, this modulator was supposed to be realized on a z-cut LiNbO3 substrate, tested with 1.55 µm DFB-LD laser and a 10GHz frequency of the signal modulation.

2.3.2 To generate equal power level for carrier and first side band.

This configuration will be use full in designing of optical frequency comb**.** if we use mzm modulation index so, for that particular value the carrier power and sideband power is same. Then we will be able to generate three comb line of almost equal power from a single carrier, so from on carrier we will generate three carrier lines and so by increasing the number of laser source we be able to generate triple number of comb lines.

The schematic diagram for given design is given below

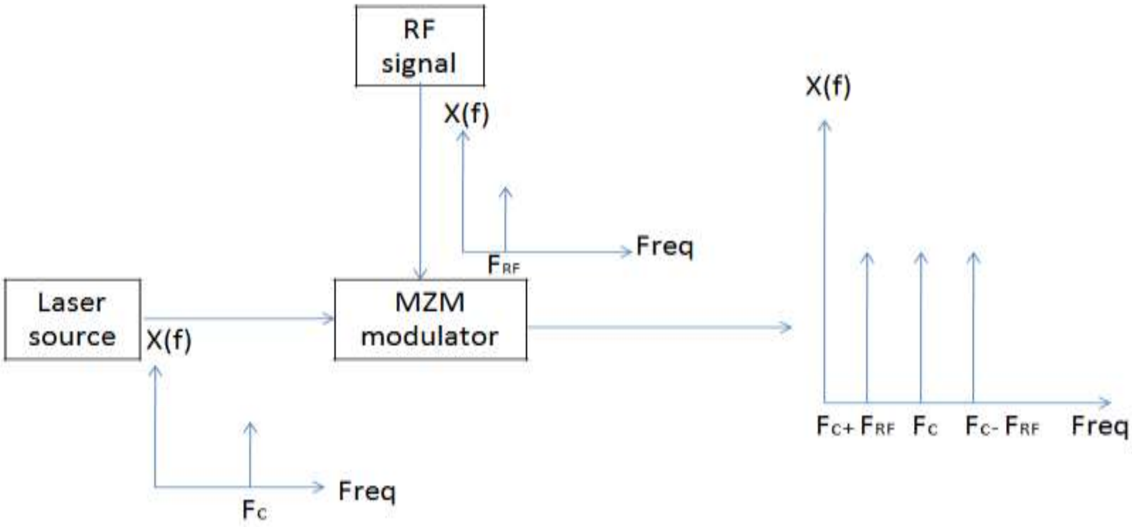


Fig.2.3-power equalization process

Let output of laser source expressed by equation

$$E(\mathrm{t}) = \mathrm{E}_0 \exp(\mathrm{j}\omega_c \,\mathrm{t}), \qquad \text{.............. (1)}$$

And input rf voltage applied to the MZM is given by

$$V_i(\mathrm{t}) = V_{dci} + V_{RF} \cos(\omega_{RF} \,\mathrm{t}) \qquad \text{............ (2)}$$

Then output Field of MZM is given by

$$E_{mzm} = E_0 \exp(\mathrm{j}\phi_d) \sum_{n=-\infty}^{n=+\infty} \left\{ 2J_n(\mathrm{m}) \cos(\phi_v) \times \exp(\mathrm{j}(\omega_c + \mathrm{n}\,\omega_{RF})\,\mathrm{t}) \right\} \text{.............. (3)}$$

For carrier component n=0, so

$$E_{mzm} = E_0 \exp(\mathrm{j}\phi_d) \times 2J_0(\mathrm{m}) \cos(\phi_v) \times \exp(\mathrm{j}\omega_c \,\mathrm{t}) \qquad \text{................ (4)}$$

For first side band n=1, so

$$E_{mzm} = E_0 \exp(\mathrm{j}\phi_d) \times 2J_1(\mathrm{m}) \cos(\phi_v) \times \exp(\mathrm{j}(\omega_c + \omega_{RF})\,\mathrm{t}) \qquad \text{...........(5)}$$

From equation (1) & (2) it is clear that carrier component and first sideband component will be equal if

$$J_0(\mathrm{m}) = J_1(\mathrm{m})$$

Using mat lab tool we can find the points where we can achieve carrier power and first side band power equal. Plot given below shows, points to find equal power level points,

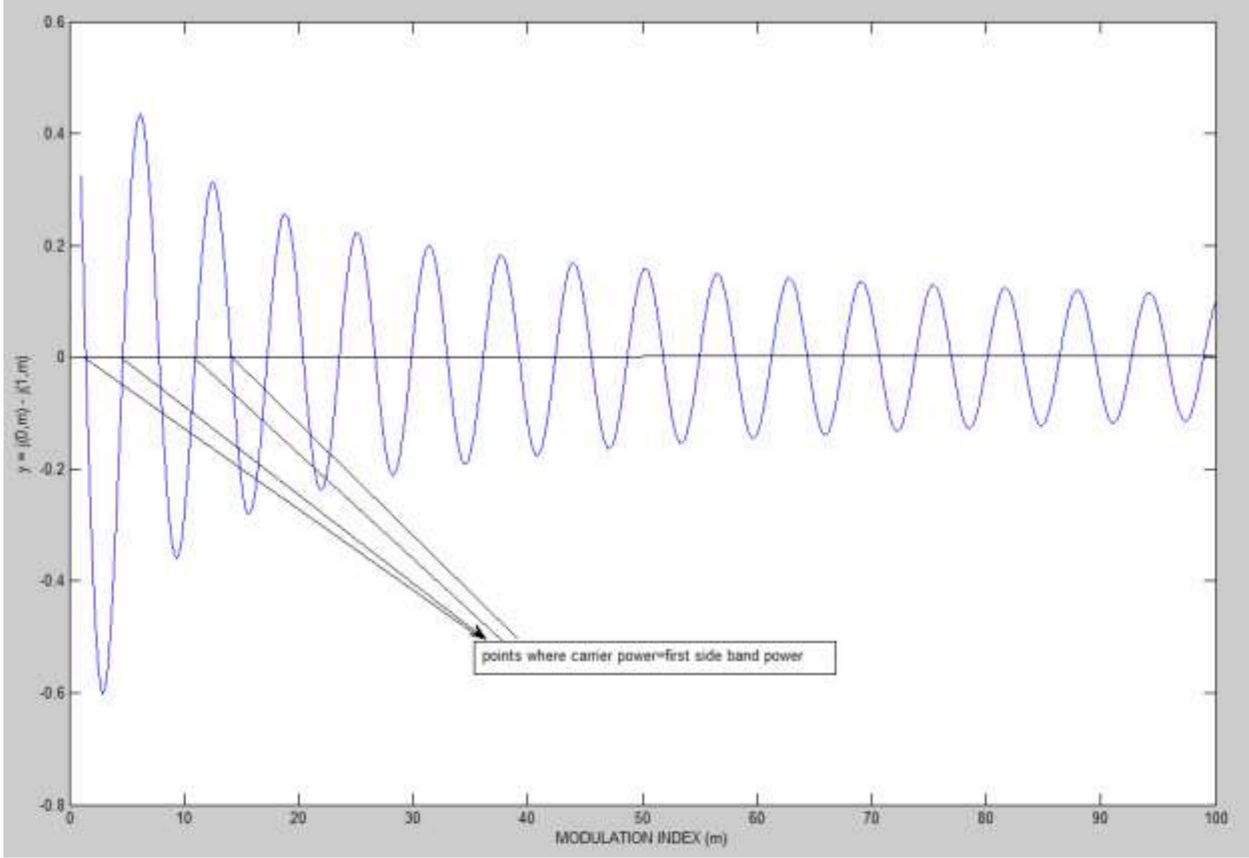


Fig.2.4 - graph shows the points where $J_0(\mathrm{m}) = J_1(\mathrm{m})$

So by taking the points shown, we calculate the modulation index value and by finding corresponding biasing voltage we can archive the power level equalization. The relation between modulation index and the biasing is given below.

Where, modulation index

$$m = \pi V_{RF} / V_{\pi}$$

2.4 Optical frequency comb:

A frequency comb is a light source whose spectrum consists of a series of discrete, equally spaced elements. Frequency combs can be generated by a number of mechanisms, including amplitude modulation of a continuous wave laser or stabilization of the pulse train generated by a mode locked laser.

Much work has been devoted to the latter mechanism, which was developed around the turn of the twenty first century and ultimately leads to one half of the **Nobel Prize in Physics** being shared by **John L. Hall**and **Theodor W. Hänsch**in 2005.

The frequency domain representation of a perfect frequency comb is a series of delta functions spaced according to

$$f\,(\mathrm{n}) = \mathrm{f}_0 + n f_r$$

Where, n is an integer, f_r is the comb tooth spacing and f_0 is the carrier offset frequency, which is less than f_r.

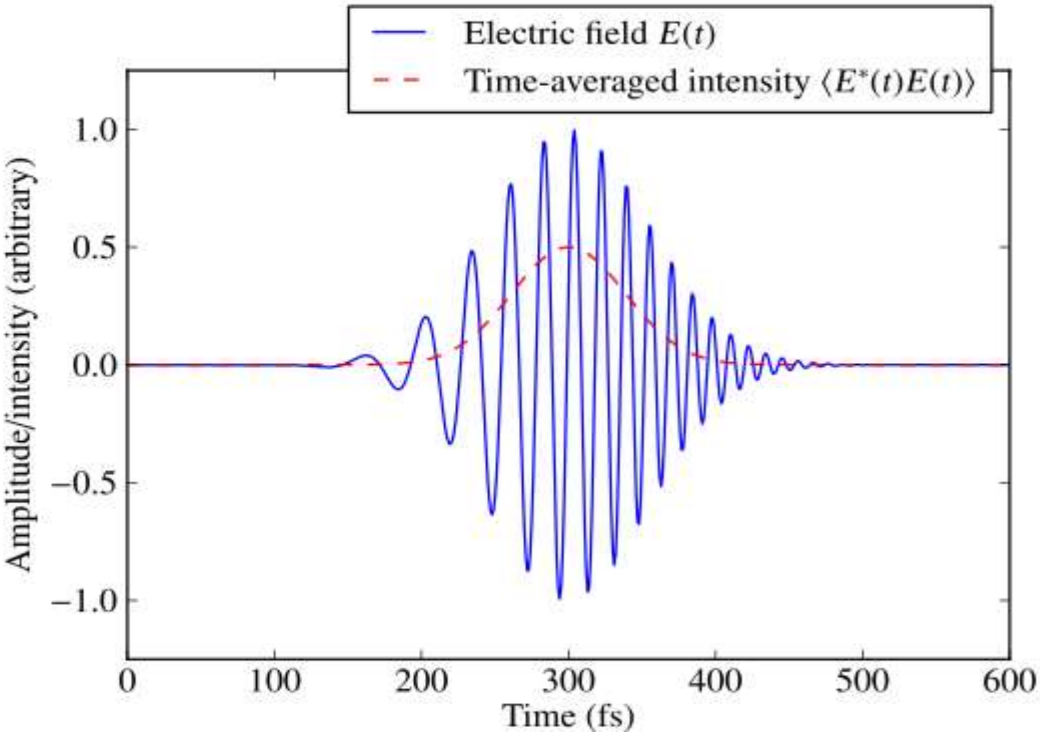


Fig. 2.5- Time domain representation of optical frequency comb[29]

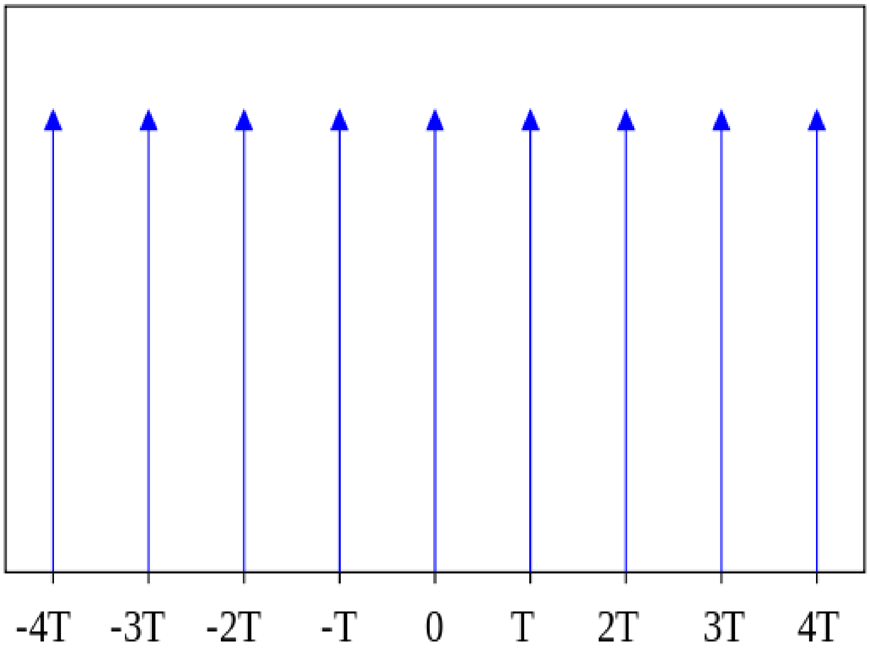


Fig 2.6-frequency domain representation of optical frequency comb[29]

In given experiment frequency comb will used to generate optical carrier signals.

2.5 Fabry-perot filter[26]

The fabry-perot filter is an optical resonator that confines and stores light energy at selected frequencies. this optical transmission system incorporates feedback, whereby light is repeatedly reflected within the system and thus circulates without escaping the system. A simple fabryperot filter comprises of two parallel planner mirrors spaced a fixed distance apart.the rays travelling between the mirrors are kept perpendicular to plane of the mirrors via two-lencesystem.the lenses are placed outside the mirrors to serve two purposes: firstly to establish parallel rays inside the resonance cavity between the mirrors; and secondly to focus the output of light on to the detector following the fabry-perot filter. So the FPF will provide a periodic pass band for the signal at its input. The important parameter for FPF is Free spectral range which is describes as:

Free spectral range (FSR): it is the spacing between two successive modes i.e. spacing between frequencies corresponds to maximum transmission it is given by the expression

$$\Delta f_{FSR} = \frac{c}{2nd}$$

Where, n is the index of refraction, and d is the physical mirror separation

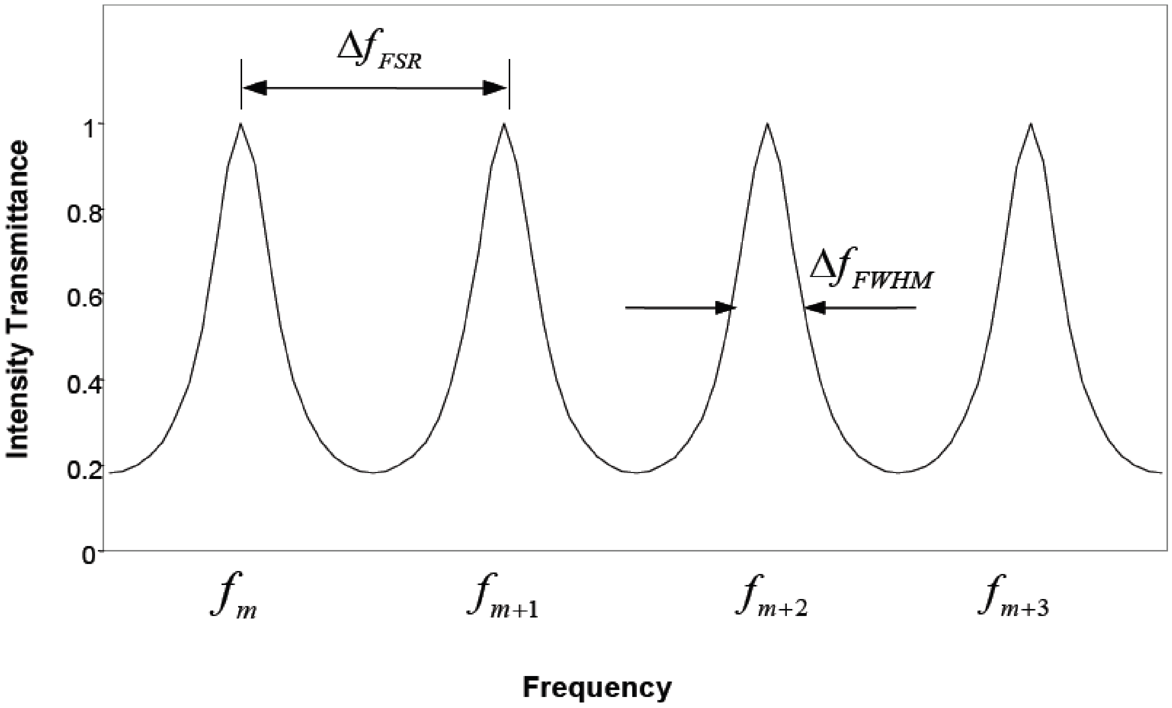


Fig.2.7 transmission pattern of FPF, indicating free spectral range and bandwidth resolution as a function of frequency

Source- [26]

2.6 Optical demultiplexer:

The main function of an optical demultiplexer is to receive from a fiber a beam consisting of multiple optical frequencies and separate it into its frequency components, which are coupled in as many individual fibers as there are frequencies.

There are two classifications of optical demultiplexer devices, passive and active. Passive demultiplexers are based on prisms, diffraction gratings, and spectral (frequency) filters. Active demultiplexers are based on a combination of passive components and tunable detectors, each detector tuned to a specific frequency. Arrayed waveguide grating as demultiplexer is described here.

Arrayed waveguide grating (AWG):

Arrayed waveguide gratings (AWGs) are based on the principle of interferometry.Let a fiber F carrying a multiplicity of wavelengths $\lambda_1, \lambda_2, \lambda_3, ... \lambda_n$ .Let the light of all wavelengths from F shine in cavity S1, which is coupled to an array of waveguides, W1 ....Wn . The optical length difference of each waveguide introduces wavelength-dependent phase delays in cavity S2 where an array of fibers is coupled. The phase difference of each wavelength interferes in such a manner that each wavelength contributes maximally at one of the output fibers.

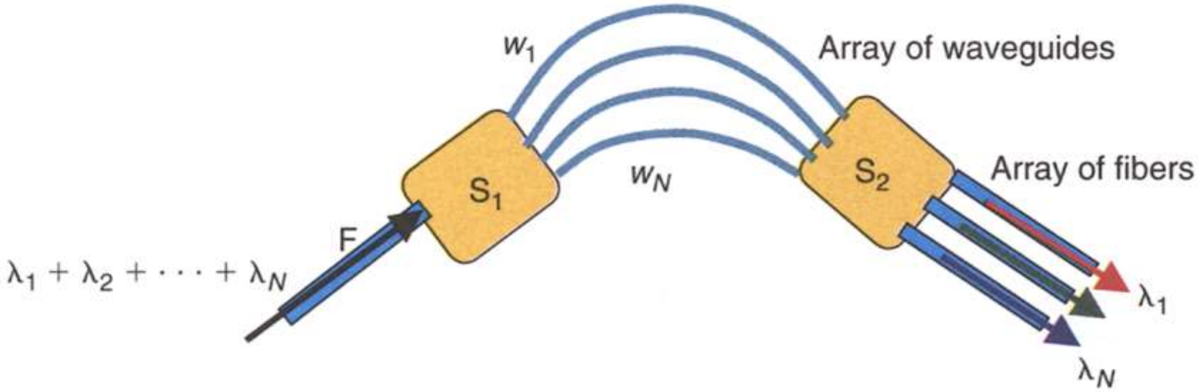


Fig.2.8 array waveguide grating

AWGs for 128 channels (wavelengths) with 250-GHz channel spacing have been already designed, also InP AWGs for 64 channels with 50-GHz channel spacing.

Chapter 3

Methodology and channelization model

3.1 Introduction:

In this section we will present a discussion on the basic module used in process of channelization. We discuss the previous design and its comparison with the proposed design model. in process of channelization the two main modules are optical frequency comb generation and modulation technique used. So in section 4.2 we present discussion on comb design and in section 4.3 we will discuss the modulation technique. After that in section 4.4 we will discuss the proposed model.

3.2 optical frequency comb design:

In channelization process the comb design have very important value. As output of comb should be stable, the frequency separation should be fixed and it should be maximum, if frequency separation is not fixed we not be able to slice data properly, also it should be maximum so that we can maximise the RF data to slice, the power level should be almost same at output improved SNR. Several design for frequency comb are proposed previously, firstly we will discuss some previous and then we will discuss our proposed model.

3.2.1 Previous comb design analysis:

Here we will discuss some previously design frequency comb system, mainly two type of comb design can be given as:

I. Comb design using cascade of modulators:
II. Comb design by recirculating frequency shifting (RFS)

I. Comb design using cascade of modulators[28]:

In this technique, two cascaded Mach-Zenher modulators (MZ) are driven by sinusoidal electrical waves. In this technique, not just MZ modulators may be cascaded, the set up may comprise a cascade of phase modulators (PM), or a combination between PMs and MZs.

Here each modulator will produce a set of side bands shifted by the RF frequency applied on the modulators. Another important aspect to be observed is that the amplitude of all subcarriers must be equalized by a special scheme. In Fig., the optical comb with 10 lines, generated by two MZs, are separated by a WDM demux that allows the use of variable attenuators for adjusting the amplitude of each channel. Once the comb lines are flat, they are modulated and, then, combined in a WDM mux before being launched into the transmission fiber.

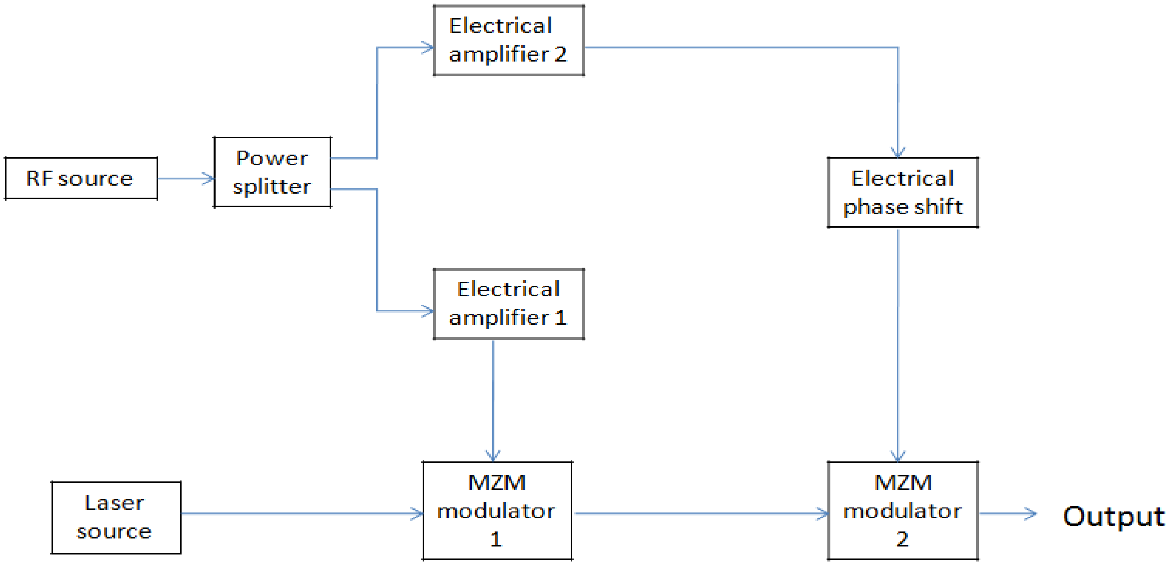


Fig.3.1 block diagram for the modulator cascade technique.

II. Comb design by recirculating frequency shifting, (RFS) [27]:

In the RFS technique, the optical signal, generated by a laser source, is shifted, in frequency, within a recirculation loop. This Comb-Generator (CG) consists of a single mode laser, a 2x2 optical coupler, a double Mach-Zehnder (MZ) optical modulator, an optical amplifier (Erbium-doped fiber amplifier, EDFA), to compensate for the loop losses, and an optical filter, for limiting the number of generated carriers and the level of amplified spontaneous emission noise within the loop, as illustrated in Fig.. According to the Fig., an optical signal (coming from a laser source), is continuously injected into the loop through one of the coupler input ports, and circulates on the loop. After each round trip part of the signal outputs the loop and part returns to it.

In the loop, the optical modulator is optically controlled by a polarization controller and electrically driven by two RF sine waves. Its biasing points are adjusted in such a way to generate a single side-band suppressed carrier signal (SSB-SC), which is than amplified and filtered. The action of the filter is crucial as it limits the optical noise and cuts off the optical carriers that exceed its bandwidth. Here filter output is added to the signal coming from the laser and inputs the loop again. At each round trip, the optical modulator shifts the signal spectrum in a frequency equal to the RF frequency applied to it. After many round trips, the circulating signal spectrum is shifted to outside of the filter bandwidth, thus limiting the Number of comb lines at the generator output. The block diagram is shown in Fig.

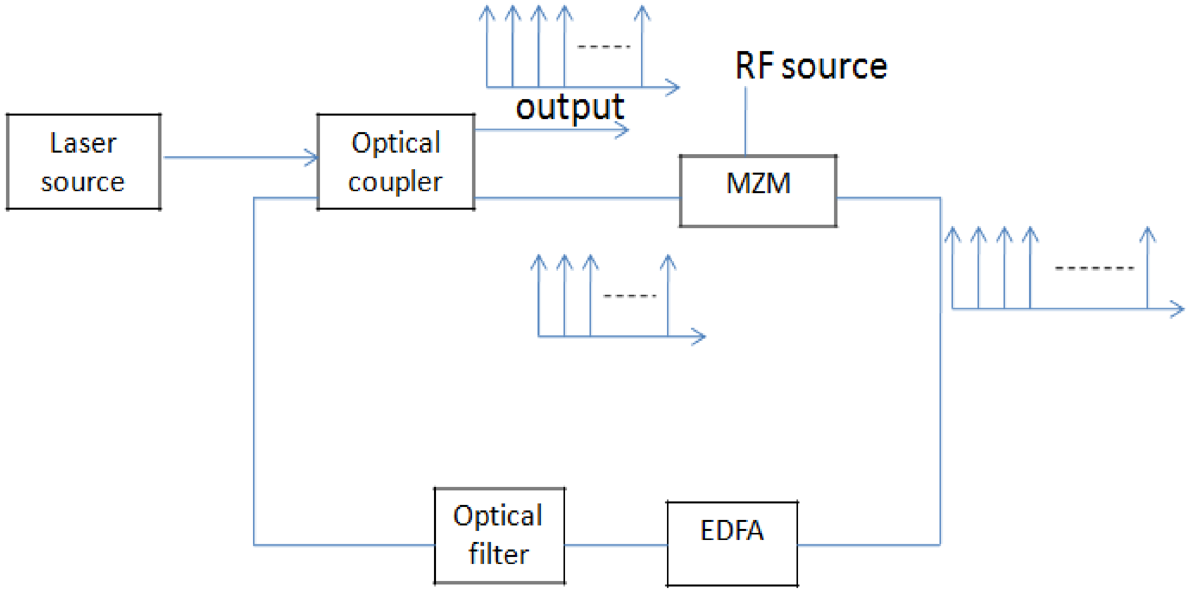


Fig.3.2 -Comb generator based on the recirculating frequency shifting

Technique

3.2.2 Proposed comb design

Here we are presenting the comb design using the arrayed laser source. This is highly stable and having a fixed spacing of 40GHz between its Spectral components.

Block diagram given below shows the 36 channel optical frequency comb.

BLOCK DIAGRAM

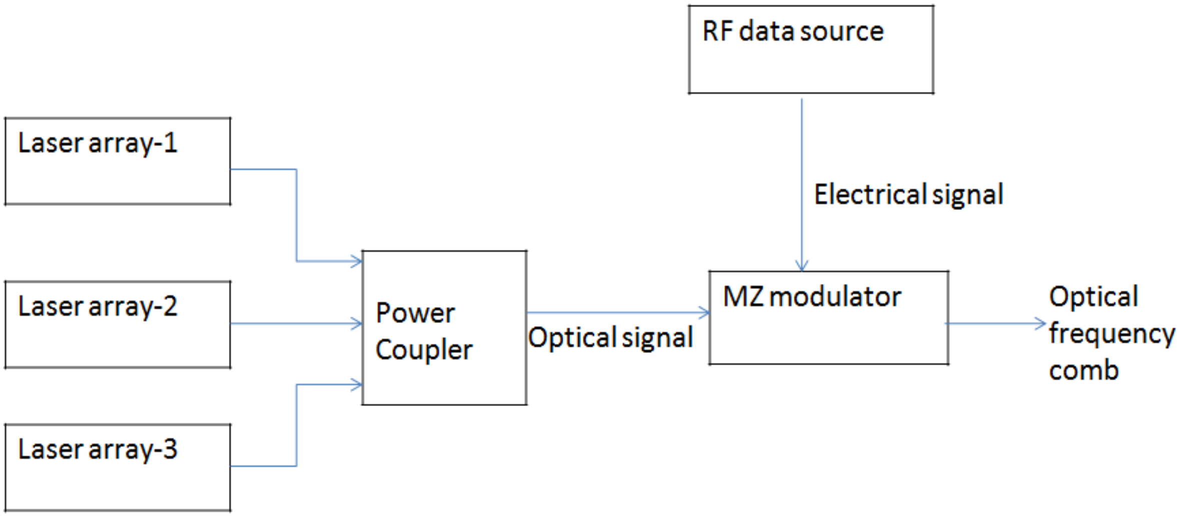
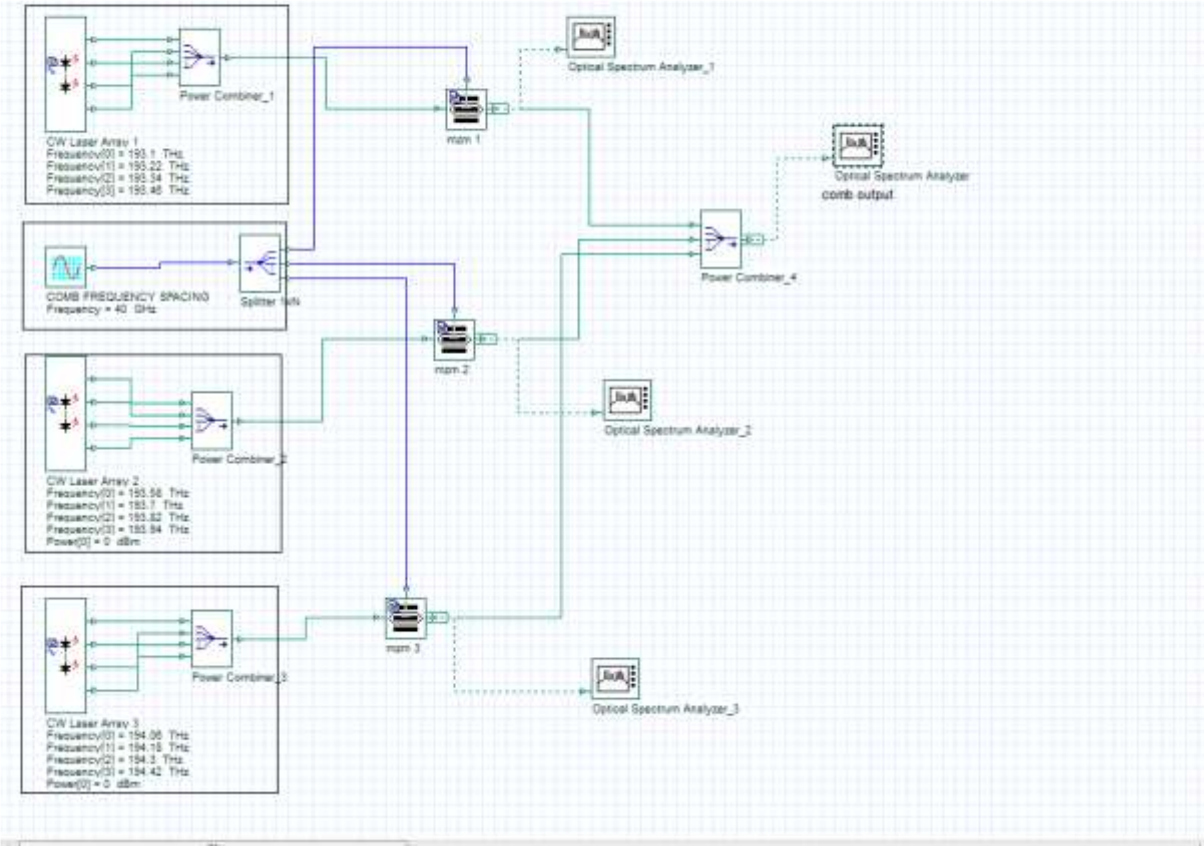


Fig.3.3 – block diagram to generate OFC

Description:

Here diagram shows 4 laser arrays, each array is consisting of four continuous laser sources. Each laser is radiating at a different frequency so that the frequency difference between two consecutive lasers is of 120 GHz. The concept to fix this frequency difference is that, after modulation through MZ modulator at 40GHz of RF data the difference between the consecutive spectral peaks is kept fixed at 40GHz, to produce stable frequency comb spacing. So here we can channelize RF data of maximum 38 GHz.

We simulated our design in optisystem software, simulation setup is given in diagram below.



CW Laser Array 1
Frequency[0] = 193.1 THz
Frequency[1] = 193.22 THz
Frequency[2] = 193.34 THz
Frequency[3] = 193.46 THz

COMB FREQUENCY SPACING
Frequency = 40 GHz

CW Laser Array 2
Frequency[0] = 193.58 THz
Frequency[1] = 193.7 THz
Frequency[2] = 193.82 THz
Frequency[3] = 193.94 THz
Power[0] = 0 dBm

CW Laser Array 3
Frequency[0] = 194.06 THz
Frequency[1] = 194.18 THz
Frequency[2] = 194.3 THz
Frequency[3] = 194.42 THz
Power[0] = 0 dBm

Fig. 3.4 -Optisystem simulation window

Here the each block of laser array will produce four optical carrier signal, Here MZ modulator is biased so that the power of carrier and first two side bands is same so, after modulation through mach-zehnder four optical carrier will produce12 line, similarly other two will also generate 12 spectral lines. So at the end we will be able to generate 36 comb lines. Here power of all comb lines will be nearly same, and spacing will be fixed at 40GHz, output of frequency comb is shown below

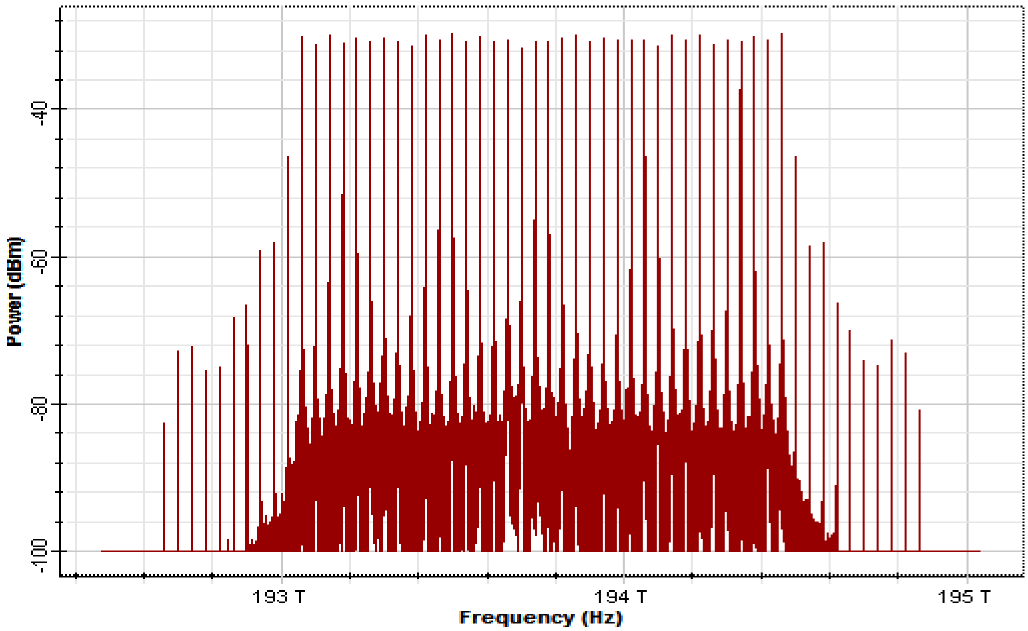
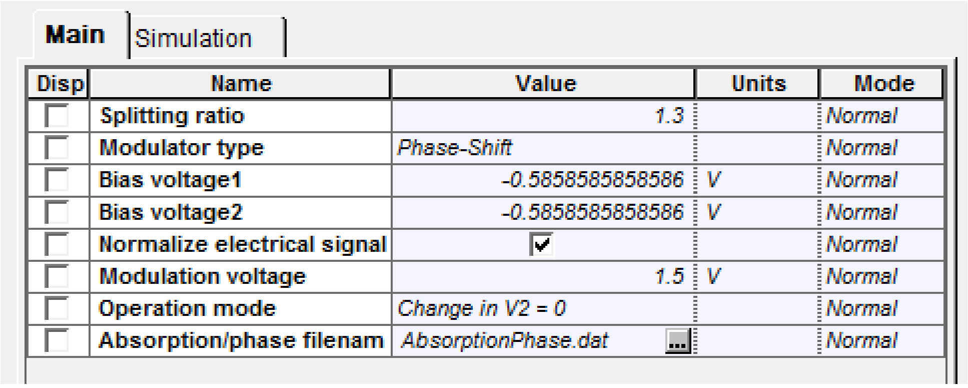


Fig.3.5 shows the output of 36 line frequency comb

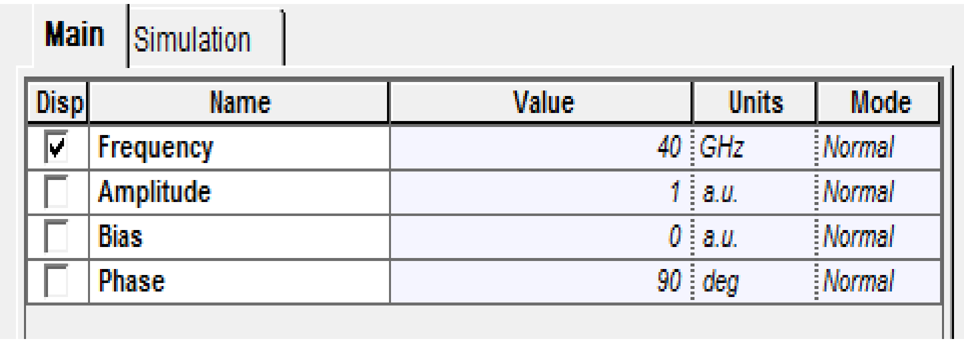
Here we have used three mach-Zehnder modulator, the bias voltage and modulation is kept such that power of carrier and first side bands is same. Fig.3.6 given below shows the bias voltage and parameter setting window.



Disp	Name	Value	Units	Mode
☐	Splitting ratio	1.3		Normal
☐	Modulator type	Phase-Shift		Normal
☐	Bias voltage1	-0.5858585858586	V	Normal
☐	Bias voltage2	-0.5858585858586	V	Normal
☐	Normalize electrical signal	☑		Normal
☐	Modulation voltage	1.5	V	Normal
☐	Operation mode	Change in V2 = 0		Normal
☐	Absorption/phase filenam	AbsorptionPhase.dat		Normal

Fig.3.6 - properties of MZM-1

To set a frequency spacing of 40GHz we used a sinusoidal source, whose parameter setting windows is shown below



Disp	Name	Value	Units	Mode
☑	Frequency	40	GHz	Normal
☐	Amplitude	1	a.u.	Normal
☐	Bias	0	a.u.	Normal
☐	Phase	90	deg	Normal

Fig 3.7 – properties of source

3.3 modulation technique analysis:

Data which we have to channelize is modulated using the MZM modulator, here in previous design MZM is used in DSB configuration, which is discussed in section 3.3.1. but if use SSB-SC configuration we can get better result, as in SSB-SC chromatic dispersion problem will be reduced also now we can slice 2 time more data than the previous design. the SSB-SC configuration scheme is described in section 3.3.2

3.3.1 DSB modulation technique:

Double side band generation technique is very easy to design ,in this technique at output of modulator the amplitude of carrier component will be reduced as compare to the two sidebands amplitude, which are corresponds to the RF data signal. A schematic block diagram can be shown in Fig. given below,

Block Diagram:

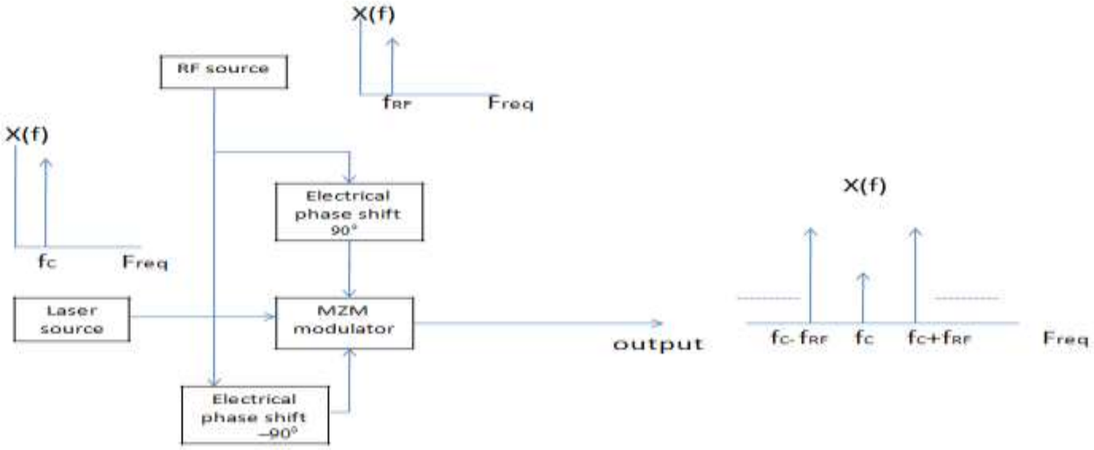


Fig.3.8 generation of DSB modulated signal

The optiwave simulation palate for the generation of the DSB is shown in Fig. below. here MZM is used in dual input mode, RF data is fed in two arm have a phase difference of180 degree.

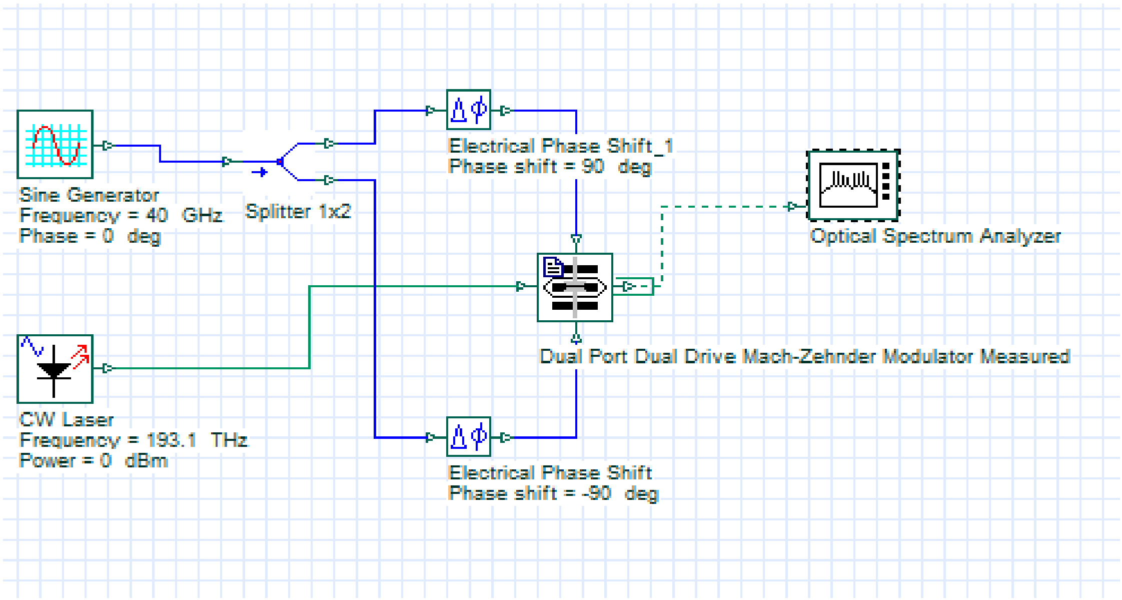


Fig.3.9 optiwave DSB generation

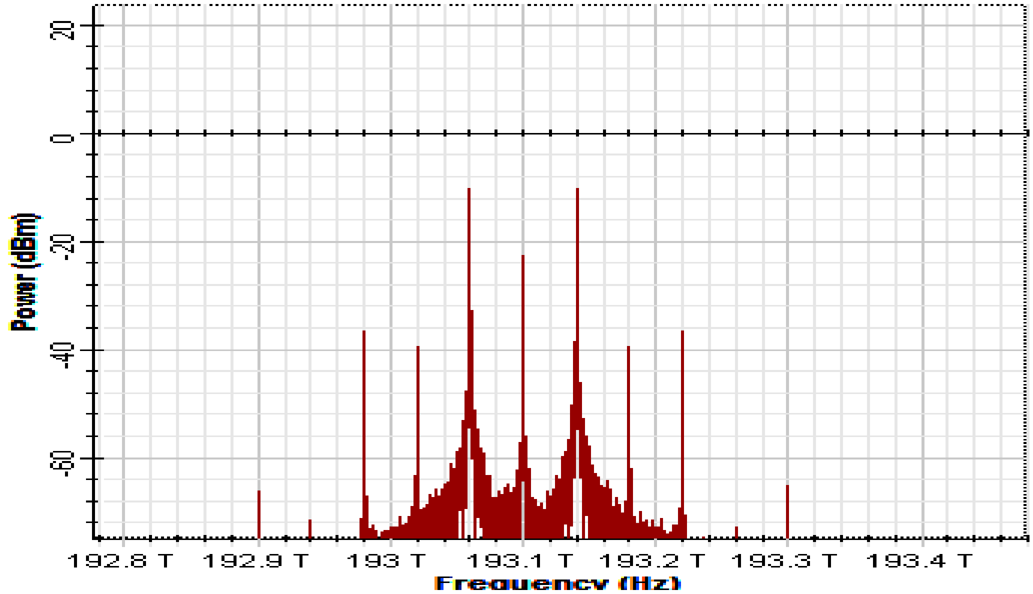
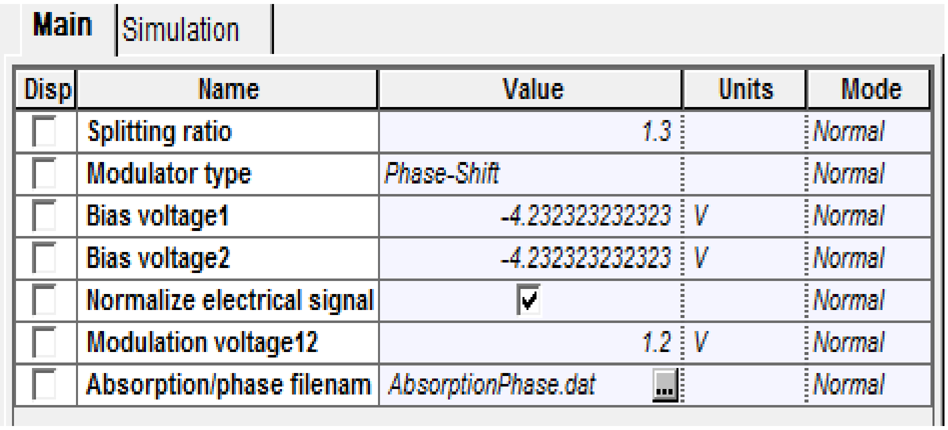


Fig.-3.10 output having two side bands



Disp	Name	Value	Units	Mode
☐	Splitting ratio	1.3		Normal
☐	Modulator type	Phase-Shift		Normal
☐	Bias voltage1	-4.232323232323	V	Normal
☐	Bias voltage2	-4.232323232323	V	Normal
☐	Normalize electrical signal	☑		Normal
☐	Modulation voltage12	1.2	V	Normal
☐	Absorption/phase filenam	AbsorptionPhase.dat		Normal

Fig.3.11 properties of modulator

3.3.2 proposed SSB-SC modulation technique

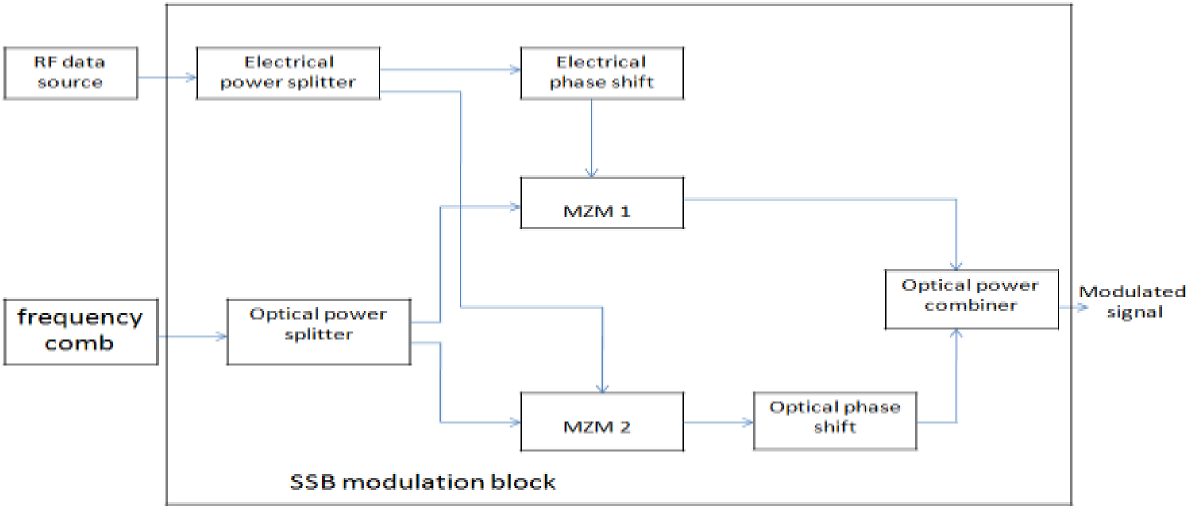


Fig.3.12 SSB-SC generation technique

The generation of SSB-SC signal is already discussed in section 2.3.1

The optisystem simulation model is shown in the Fig.3.13

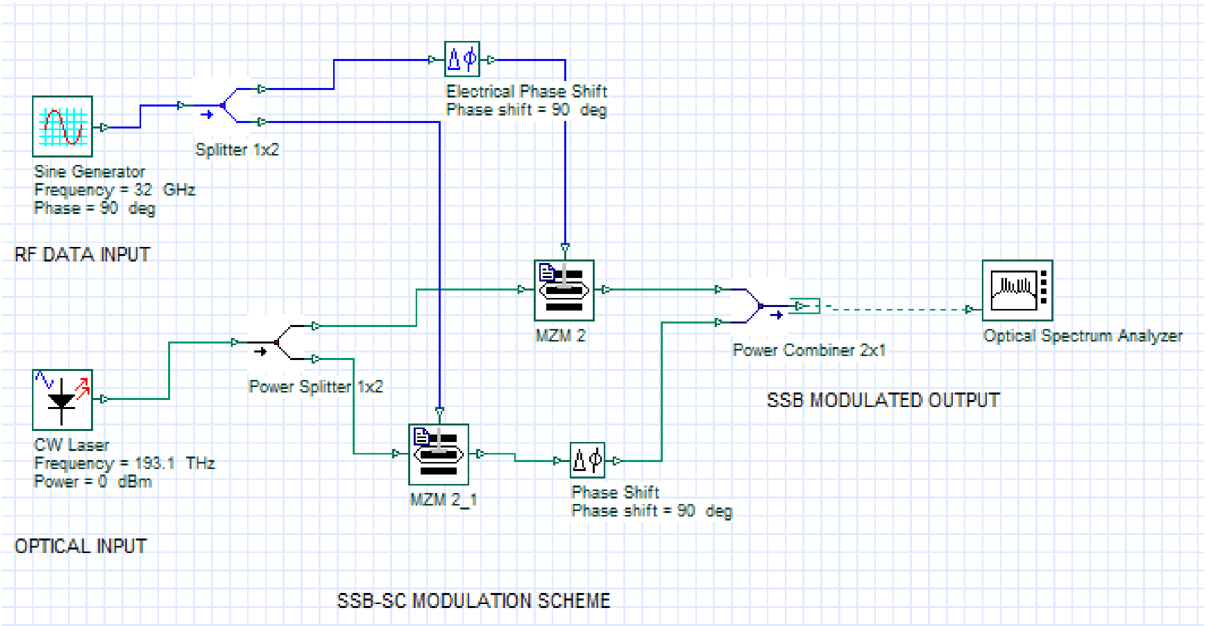


Fig.3.13-optiwave simulation setup

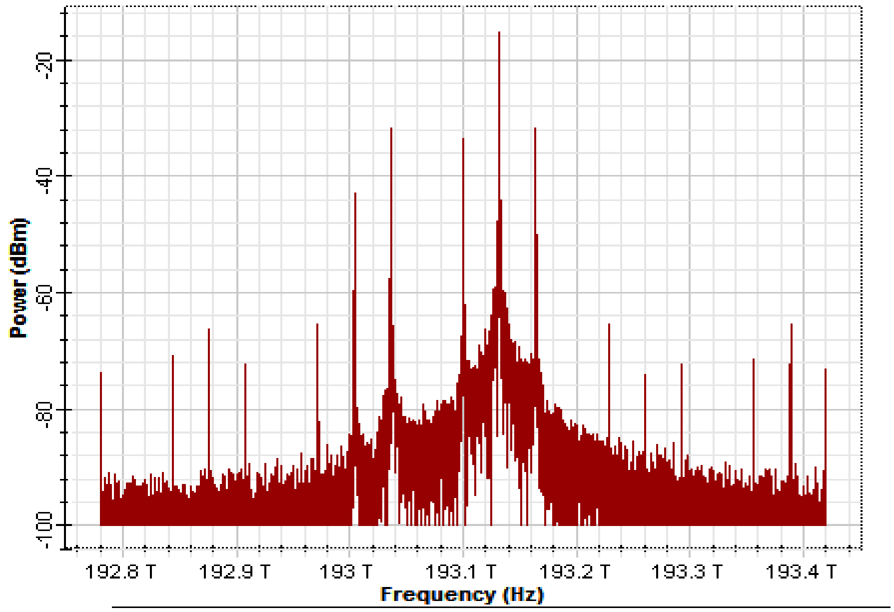
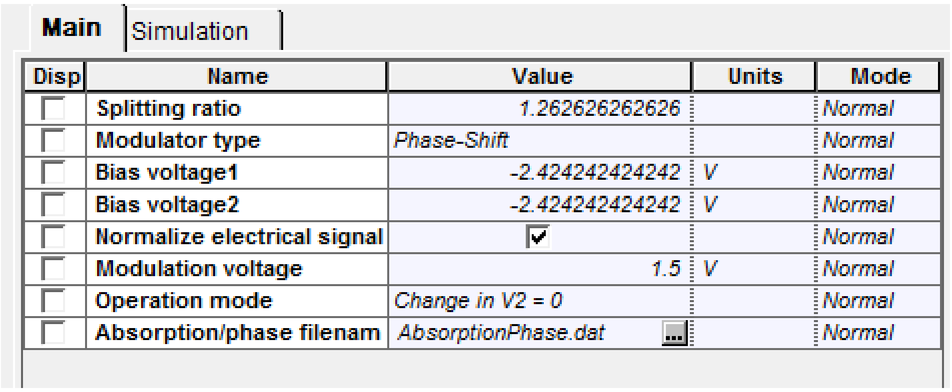


Fig3.14- SSB-SC output signal



Disp	Name	Value	Units	Mode
☐	Splitting ratio	1.262626262626		Normal
☐	Modulator type	Phase-Shift		Normal
☐	Bias voltage1	-2.424242424242	V	Normal
☐	Bias voltage2	-2.424242424242	V	Normal
☐	Normalize electrical signal	☑		Normal
☐	Modulation voltage	1.5	V	Normal
☐	Operation mode	Change in V2 = 0		Normal
☐	Absorption/phase filenam	AbsorptionPhase.dat ...		Normal

Fig.3.15 - modulator properties

3.4 proposed channelization model:

This section outlines the module set-up and there details. The whole project divided in to sub module, which are given as

1) optical frequency comb generation
2) generation of RF data signals
3) MZM modulation of RF data
4) Channelization using Fabry-perot optical filter
5) Demultiplexing at output

Block diagram of proposed channelization model:

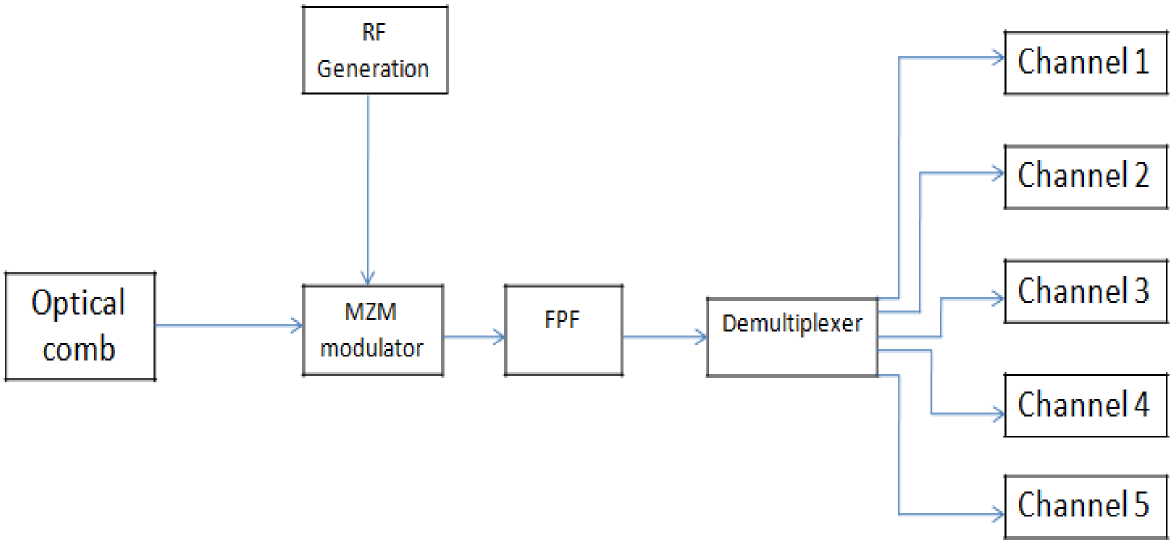


Fig.3.16 -proposed channelization technique

3.4.1 Optical frequency comb generation:

Using optical frequency comb we will generate a train of equally spaced carrier signals, which will be used to modulate our RF data, now at the output of modulator information will be carried by all the optical carrier, which will be sliced by using the fabryperot filter, and then using demultiplexer we will separate them physically. The optical comb design theory and design process is already discussed in section 3.2.

3.4.2 Generation of RF data signals:

In this block we will generate RF data source, which will be similar to the data coming from the different sources like local area network, small Wi-Fi area network Etc. In our experiment we will take sinusoidal signal to generate data source. Rf data generation block diagram is shown below.

Block diagram:

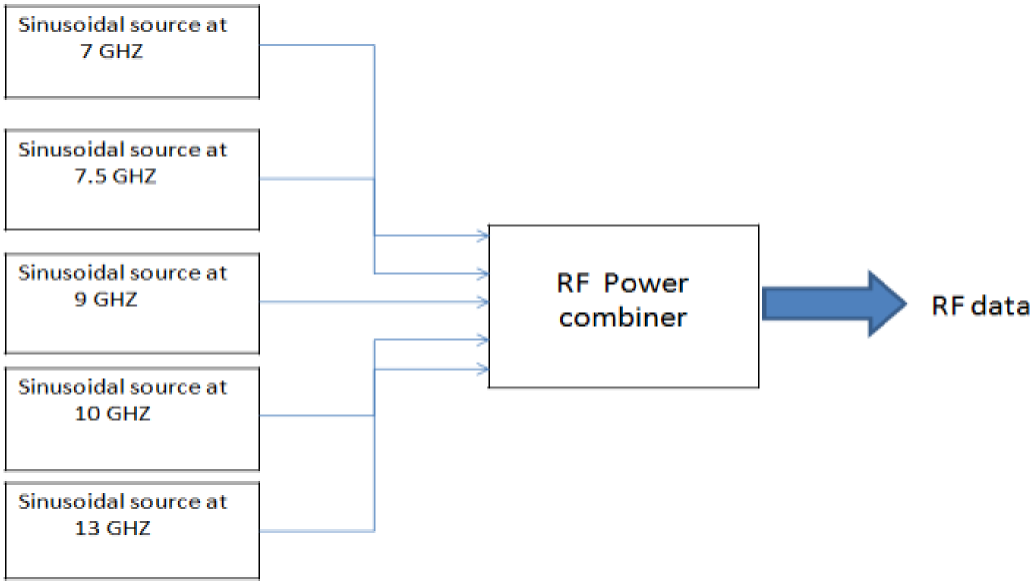


Fig.3.17 - RF data generation

3.4.3 MZM modulation of RF data:

The RF data which we have to slice is modulated by MZM, which is working in SSB-SC configuration, this block is already discussed in section 3.3.2.

3.4.4 Fabry-perot filter block:

The main objective of this block is to spectrally slice the data component.

Block diagram:

Fig.3.18 – FPF block

The modulated signal from the modulation block will contain the side bands Generated due the RF signal modulation. In our experiment we have used modulating signal containing five frequencies. So modulated output contain five side bands for each of comb line

Here FPF will spectrally slice the modulated signal. Sliced spectrum will contain the optical frequency which

3.4.5 Demultiplexer block:

The main function of an optical demultiplexer block is to receive signal from a fabry-perot filter and then separate them physically so they can be transmitted individually. Demultiplexing can be one by the arrayed waveguide grating .Block diagram in Fig. shows the demultiplexing process.

Block diagram:

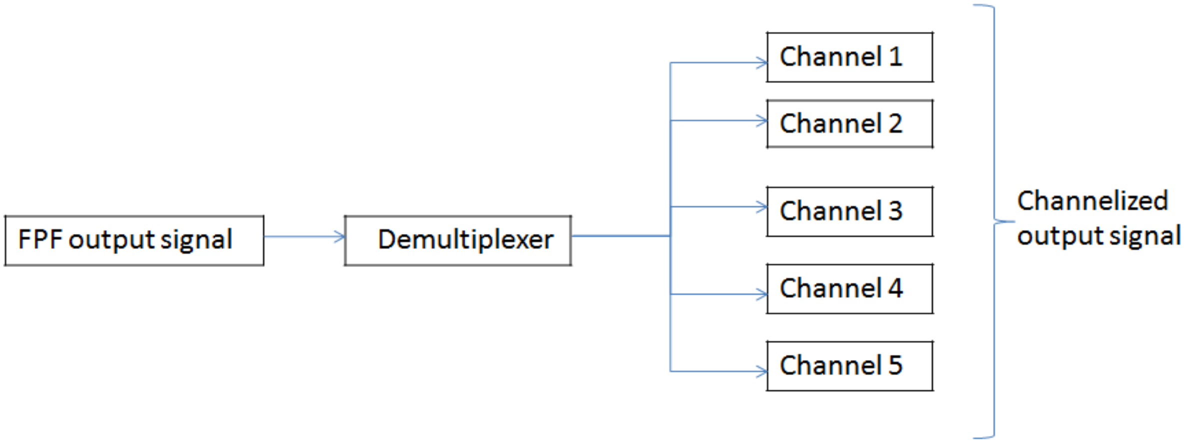


Fig.3.19 -demultiplexing process

Description: A demultiplexer works as a filter which allows the transmission of which comes under the pass band of these filter .her output of FPF Consisting of optical frequencies corresponds to the sliced data signal. Using the demultplexer we will separate them physically and coupled in individual fibers.

Chapter 4

Simulation and result discussion

4.1 simulation setup:

The proposed method to channelize the broadband RF data is simulated in Optisystem software tool, experiment setup window is shown in Fig.4.1 below.

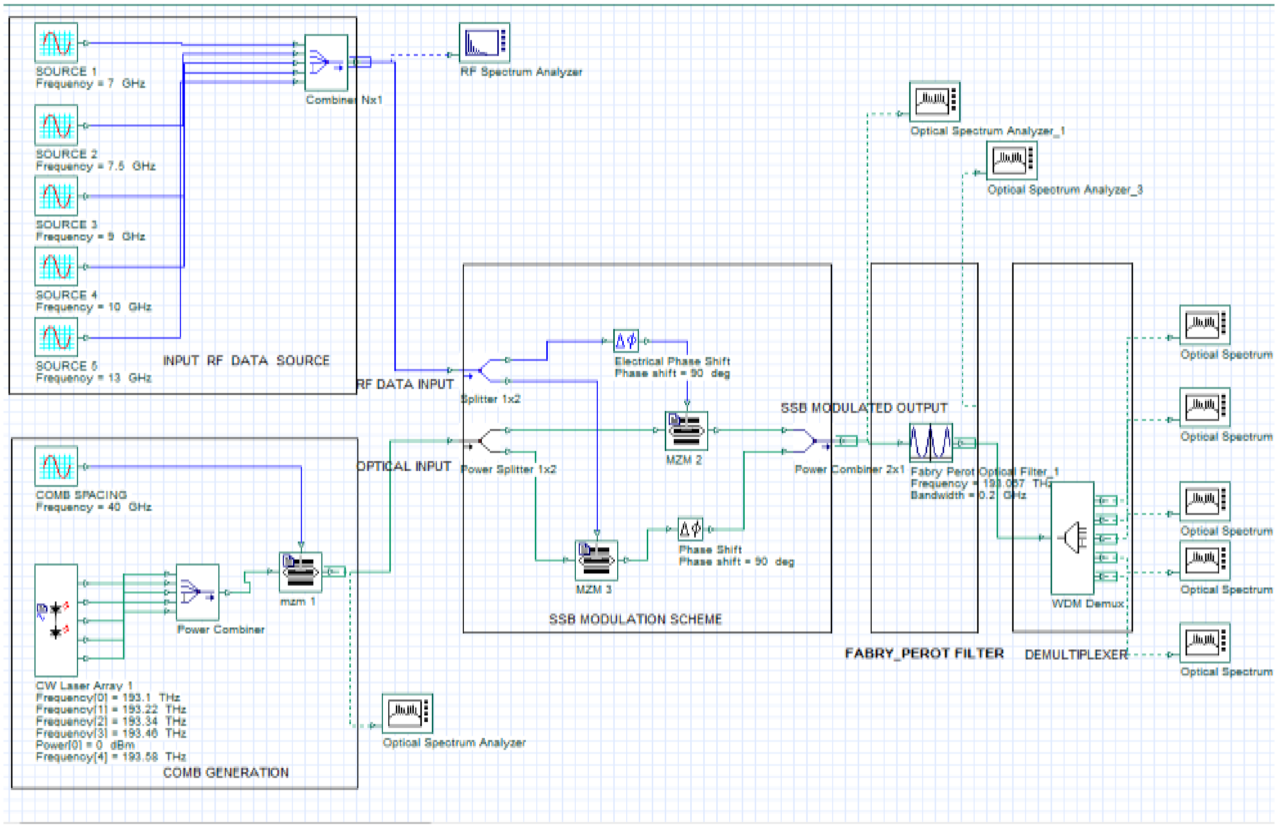


Fig.4.1-optisystem model to channelize broad band RF data

4.2 Result Observation:

In this section we will discuss result of each design block, experiment is sub divided in to five blocks as:

1) Frequency comb generation block
2) RF data source block
3) Modulation block
4) FPF block
5) Demultiplexer block

4.2.1 Observation of frequency comb output:

The comb generation block will generate optical carrier comb signal with 15optical spectral line. Here we generated 15 line comb as our requirement is to channelize data in to the 5 spectral parts. As the number of line will increased number of optical channel can be increased and accuracy will also improved. We already have shown a comb generation of 36 lines. Number of comb line can be increased depending on our application.

Here comb generated have spacing of 40GHz between two consecutive spectral lines.

Experimentally observed result for the output of comb generator is shown below.

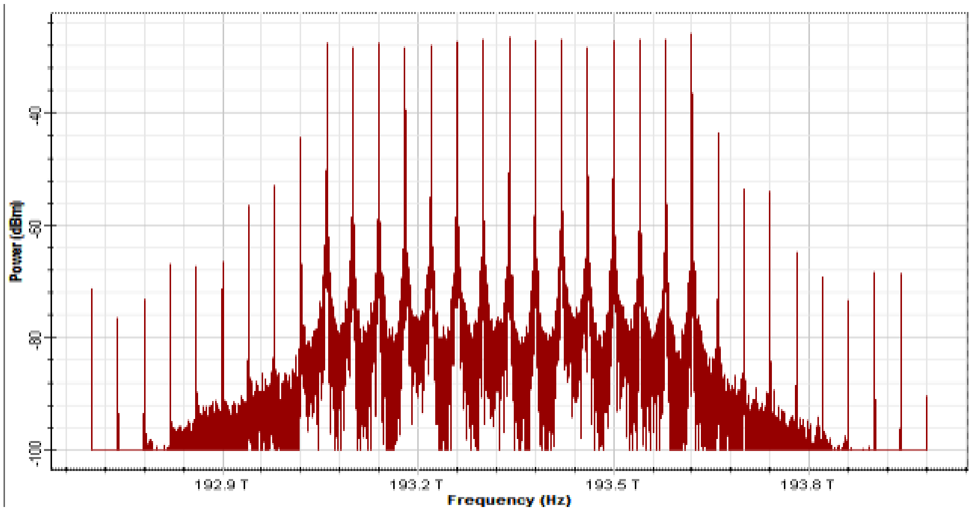


Fig. 4.2- output of comb generator represents the 15 line comb,

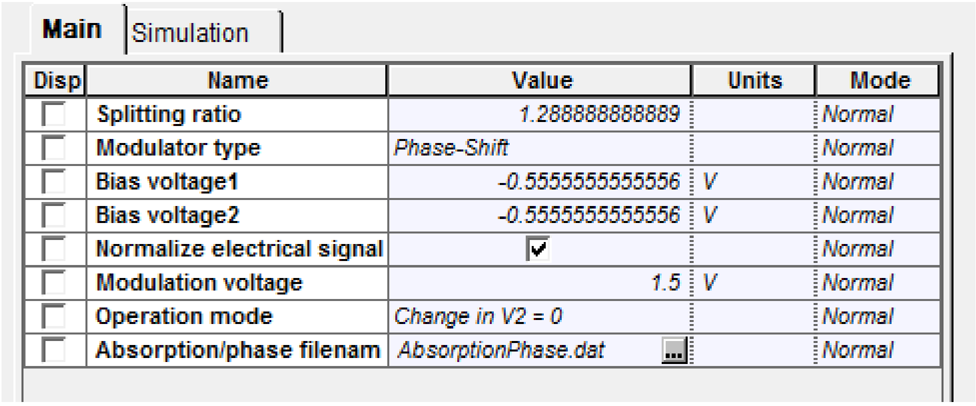
In the table given below we listed the comb line and the corresponding frequency and wavelength at the output of the comb generator

S.NO.	Comb Frequency (GHz)	Comb wavelength	Laser used	Comb line number
1.	193.060	1552.846047861	First	1
2.	193.100	1552.52438115	First	2
3.	193.140	1552.202847675	First	3
4.	193.180	1551.881447355	Second	4
5.	193.220	1551.560180106	Second	5
6.	193.260	1551.239045845	Second	6
7.	193.300	1550.91804449	Third	7
8.	193.340	1550.597175959	Third	8
9.	193.380	1550.27644017	Third	9
10.	193.420	1549.955837039	Fourth	10
11.	193.460	1549.635366484	Fourth	11
12.	193.500	1549.315028424	Fourth	12
13.	193.540	1548.994822776	Fifth	13
14.	193.580	1548.674749458	Fifth	14
15.	193.620	1548.354808388	Fifth	15

Table 4.1

To generate frequency comb we need to maintain equal power level between carrier and first sidebands. So to maintain equal power level the specified modulation index and biasing voltage can be observed at the component parameter setting window.

Here Fig. given below shows the parameter setting to generate same power level,



Disp	Name	Value	Units	Mode
☐	Splitting ratio	1.288888888889		Normal
☐	Modulator type	Phase-Shift		Normal
☐	Bias voltage1	-0.5555555555556	V	Normal
☐	Bias voltage2	-0.5555555555556	V	Normal
☐	Normalize electrical signal	☑		Normal
☐	Modulation voltage	1.5	V	Normal
☐	Operation mode	Change in V2 = 0		Normal
☐	Absorption/phase filenam	AbsorptionPhase.dat		Normal

Fig.4.3 – MZM properties setting

4.2.2 Observation of RF data output:

In practical case we will take broad band RF data, but in our experiment we demonstrate the channelization process by taking five data source. These RF signal are generated using the sinusoidal source. RF data generated from this block have five frequency components as 7 GHz, 7.5 GHz, 9 GHz, 10 GHz and 13GHz.

Output of RF data generator block can be visualize by the RF spectrum analyzer which is shown below

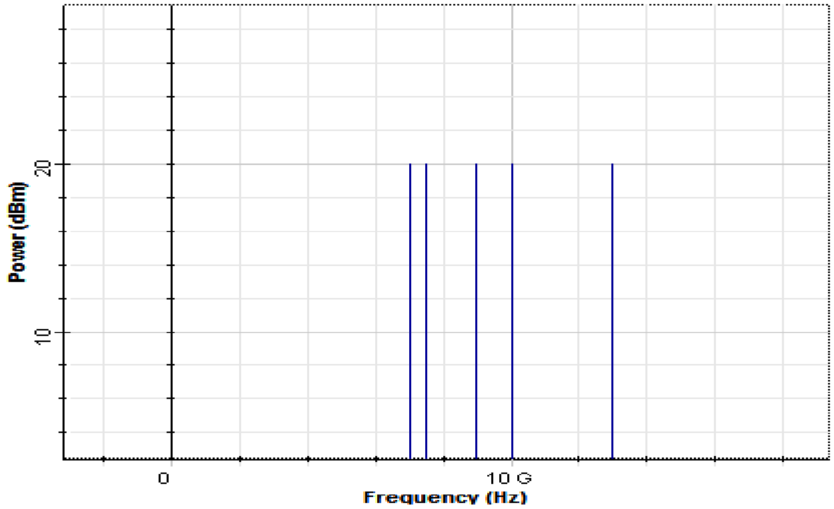
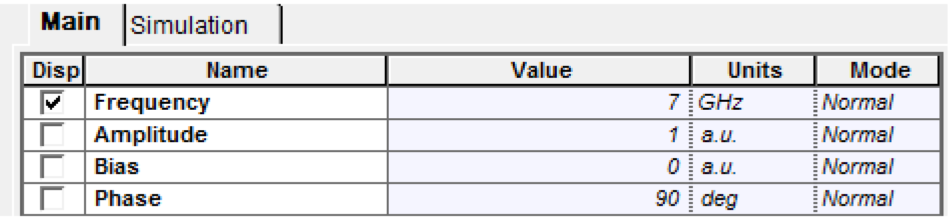


Fig.4.4 - Output of rf spectrum analyzer showing RF data components.

The sinusoidal source properties is controlled by the parameter setting window which is shown in Fig. below



Disp	Name	Value	Units	Mode
☑	Frequency	7	GHz	Normal
☐	Amplitude	1	a.u.	Normal
☐	Bias	0	a.u.	Normal
☐	Phase	90	deg	Normal

Fig.4.5 –source parameter properties.

4.2.3 Modulator output:

Modulation of RF data will take place in this block. RF data is modulated using mach-zehnder modulator; Here each comb line will work as carrier. Modulator is biased in SSB configuration Mach-zehnder modulator will generate optical output signal which contains spectral lines for carrier along with side bands lines corresponds to the five data signal for each of carrier.

Fig. shows the observed output of mach-zehnder modulator

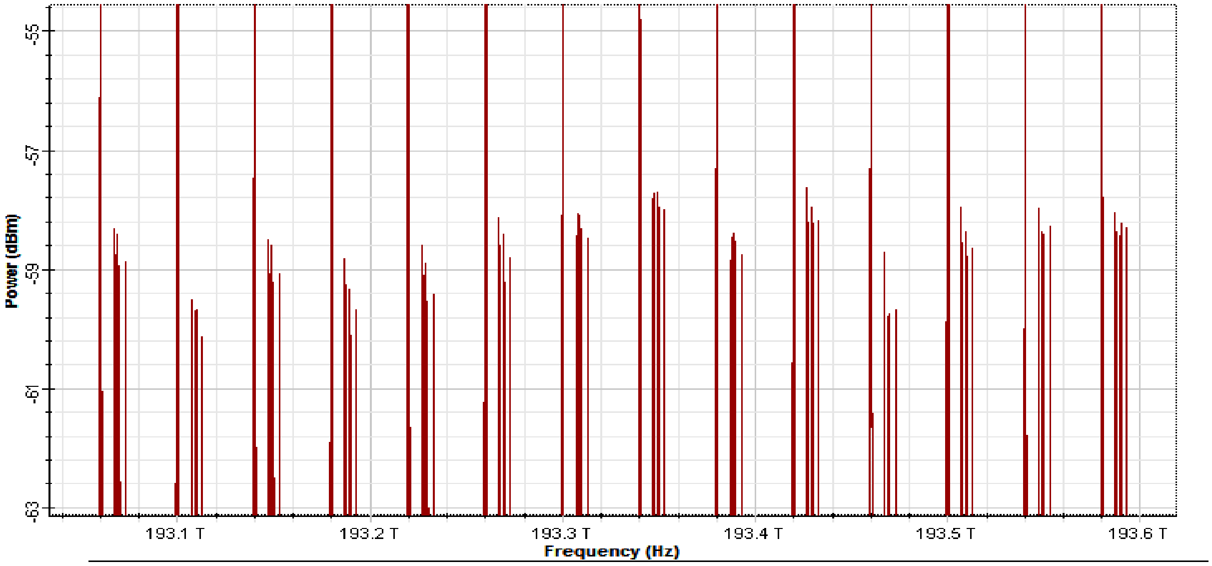
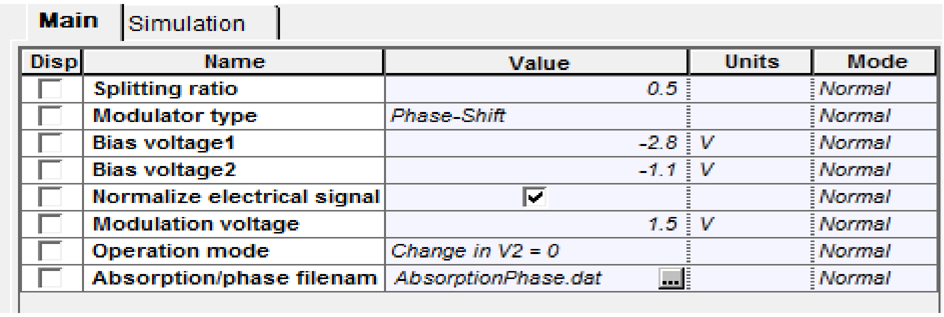


Fig.4.6 – output of mach-zehnder modulator

As Fig. shows the spectral lines with high power, shows the frequency corresponds to the carrier signal ,while spectral line with low power value are side bands generated corresponds to the input data signal.

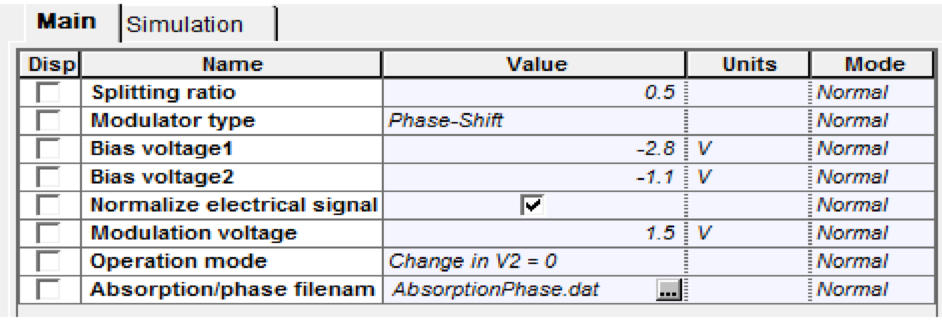
From Fig. we can say that, data signal is now transported to the each of carrier signal,

For generate single side band modulation the bias voltage and other parameter can be shown as



Disp	Name	Value	Units	Mode
☐	Splitting ratio	0.5		Normal
☐	Modulator type	Phase-Shift		Normal
☐	Bias voltage1	-2.8	V	Normal
☐	Bias voltage2	-1.1	V	Normal
☐	Normalize electrical signal	☑		Normal
☐	Modulation voltage	1.5	V	Normal
☐	Operation mode	Change in V2 = 0		Normal
☐	Absorption/phase filenam	AbsorptionPhase.dat		Normal

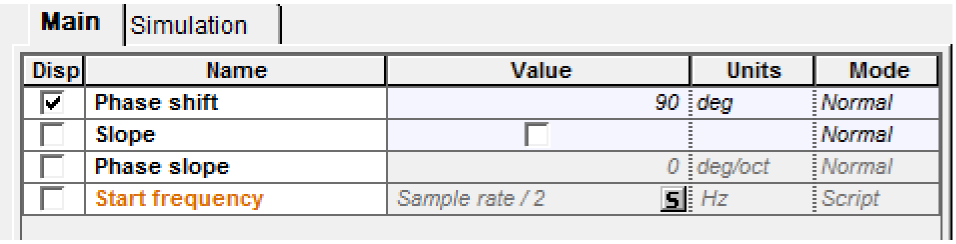
Fig.4.7 – properties of MZM 2



Disp	Name	Value	Units	Mode
☐	Splitting ratio	0.5		Normal
☐	Modulator type	Phase-Shift		Normal
☐	Bias voltage1	-2.8	V	Normal
☐	Bias voltage2	-1.1	V	Normal
☐	Normalize electrical signal	☑		Normal
☐	Modulation voltage	1.5	V	Normal
☐	Operation mode	Change in V2 = 0		Normal
☐	Absorption/phase filenam	AbsorptionPhase.dat		Normal

Fig.4.8 - properties of MZM 3

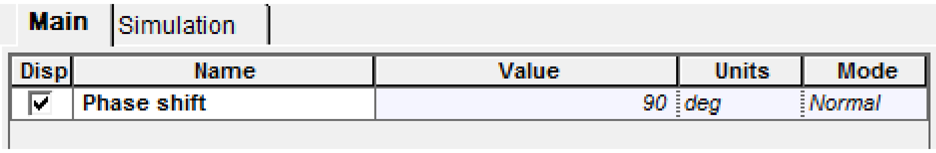
With the help of MZM 2 and MZM 3 are biasing and electrical and optical phase shift we will generate the single side band modulation, the properties of electrical and optical phase shifter can be given by



Disp	Name	Value	Units	Mode
☑	Phase shift	90	deg	Normal
☐	Slope	☐		Normal
☐	Phase slope	0	deg/oct	Normal
☐	Start frequency	Sample rate / 2	Hz	Script

Fig.4.9- electrical phase shift properties

To generate SSB signal we given the phase shift of 90 degree in case of both electrical and optical.



Disp	Name	Value	Units	Mode
☑	Phase shift	90	deg	Normal

Fig 4.10.- optical phase shift properties

4.2.4 FPF output:

Now our aim is to spectrally slice the data signal and then we have to separate it physically. As spectral data line is contain by each of carrier component so it is easy to slice data by using fabry-perot filter

A fabryperot filter have periodic transmission window , so by setting the free spectral range so that it will transmit side band corresponds to the rf data from each of carrier component. In our experiment as we have frequency spacing og 40GHz betwwen comb line , so to extract the frequency corresponds to rf data we have to select free spectral range at 40.5 GHz of Fabry-perotfiltor. Output of fabry –perotfiltor is given in Fig.

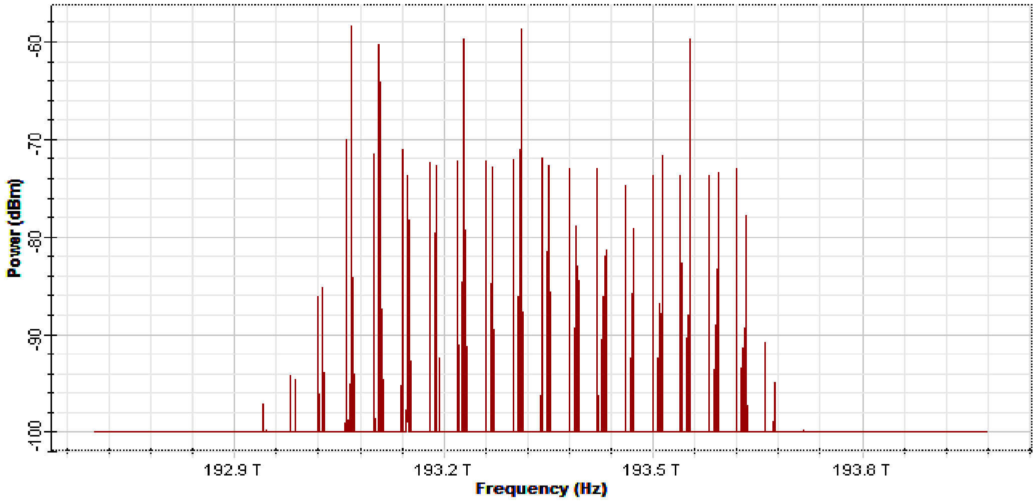


Fig.4.11-output of fabry -perot filter .

Taking 40.5 GHz as free spectral range the rf component ,comb line and corresponding frequency is listed in table below,

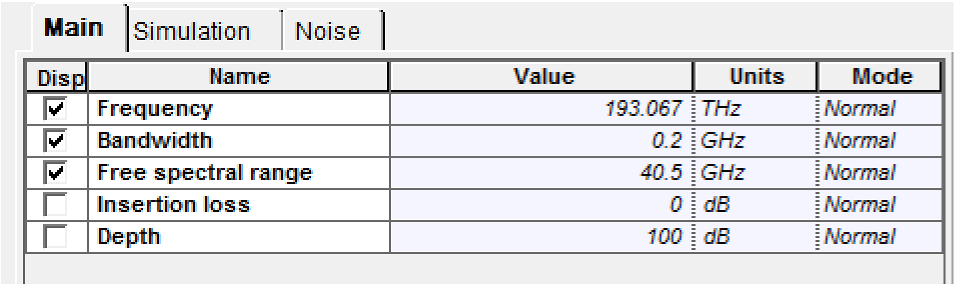
Table

S.NO.	Comb Frequency (GHz)	RF component (GHz)	Laser used	Comb line number
1.	193.067	7	First	1
2.	193.1075	7.5	First	2
3.	193.229	9	second	5
4.	193.310	10	third	7
5.	193.553	13	fifth	13

Table4.2

Here table shows the sliced output spectrum, from table and the output observed at Fig. we find the frequency component containing data.

Fig. shows the FPF parameter setting windows



Disp	Name	Value	Units	Mode
☑	Frequency	193.067	THz	Normal
☑	Bandwidth	0.2	GHz	Normal
☑	Free spectral range	40.5	GHz	Normal
☐	Insertion loss	0	dB	Normal
☐	Depth	100	dB	Normal

Fig.4.12 - properties of FPF

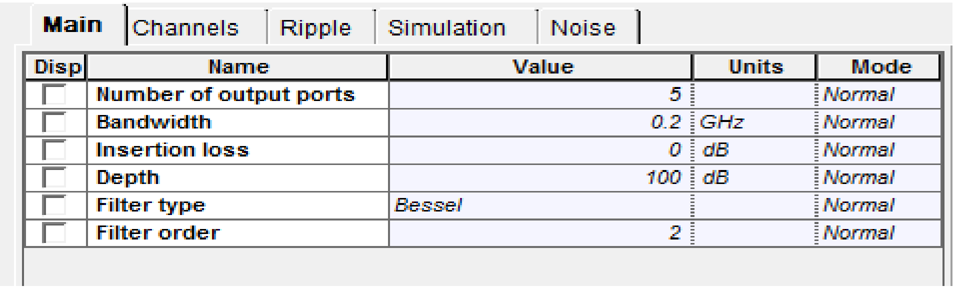
Here we have selected starting centre frequency as 193.067 GHz , which will provide transmission window for 7 GHz component , as we have selected free spectral range as

40.5GHz in second transmission window it will transmit 7.5GHz component . Similarly 5,7and 13 window will transmit the signal corresponds to 9GHz, 10 GHz, and 13 GHz. Which are shown in above Fig. 4.12.

4.2.5 Demultiplexer output:

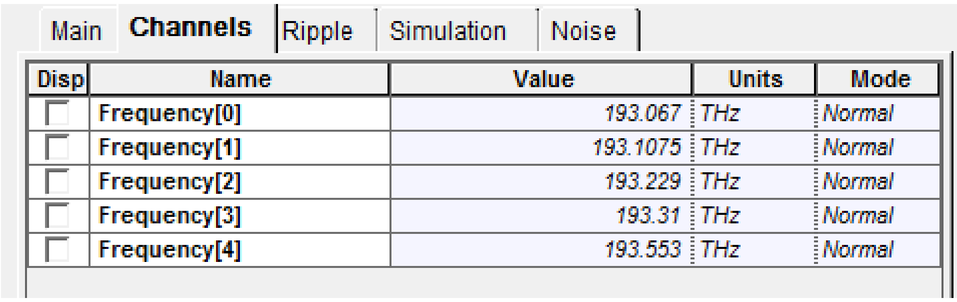
To separate physically, we will use a 1×5 demultiplexer .channelized output will be given to the optical fibre to transmit the signal and at the receiver end using the photo detector we can recover the original data signal. Which is now easy to process on electronic hardware . Whose outputs are given below in Fig. no .

Given Fig.4.13 shows the properties of demux.



Disp	Name	Value	Units	Mode
☐	**Number of output ports**	5		*Normal*
☐	**Bandwidth**	*0.2*	*GHz*	*Normal*
☐	**Insertion loss**	*0*	*dB*	*Normal*
☐	**Depth**	*100*	*dB*	*Normal*
☐	**Filter type**	*Bessel*		*Normal*
☐	**Filter order**	*2*		*Normal*

Fig.4.13 properties of demux

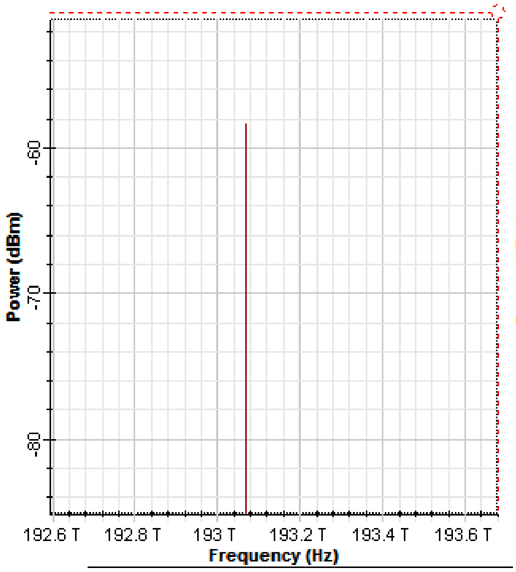


Disp	Name	Value	Units	Mode
☐	**Frequency[0]**	*193.067*	*THz*	*Normal*
☐	**Frequency[1]**	*193.1075*	*THz*	*Normal*
☐	**Frequency[2]**	*193.229*	*THz*	*Normal*
☐	**Frequency[3]**	*193.31*	*THz*	*Normal*
☐	**Frequency[4]**	*193.553*	*THz*	*Normal*

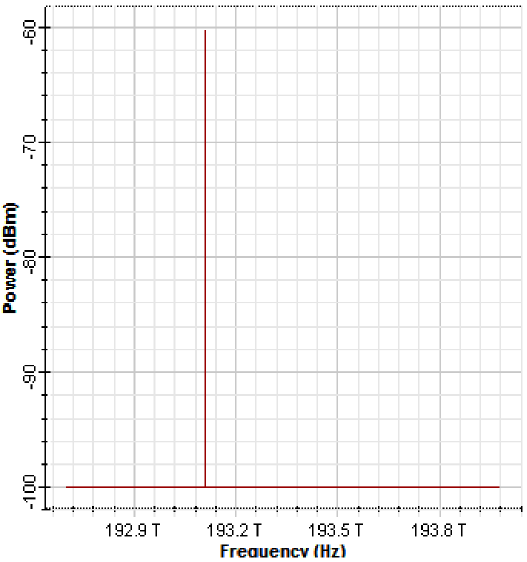
Fig.4.14 -properties of demux

Here we have taken the bandwidth 200MHz for each channel transmission and the transmission filter is selected as Bessel type. In second Fig. we selected the centre frequency for the demux which are corresponds to the rf data source.

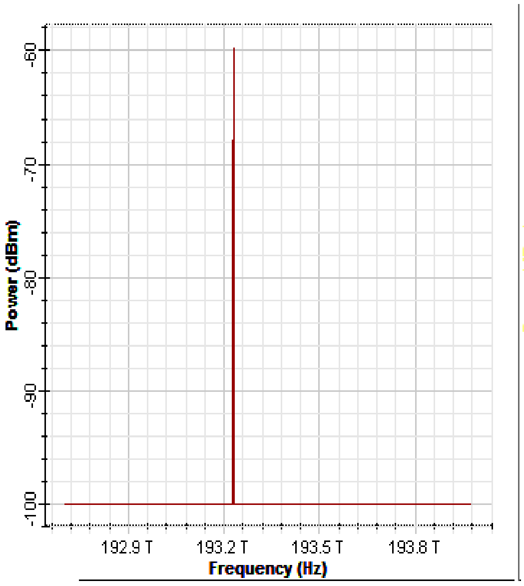
Output of demux is shown in Fig. below



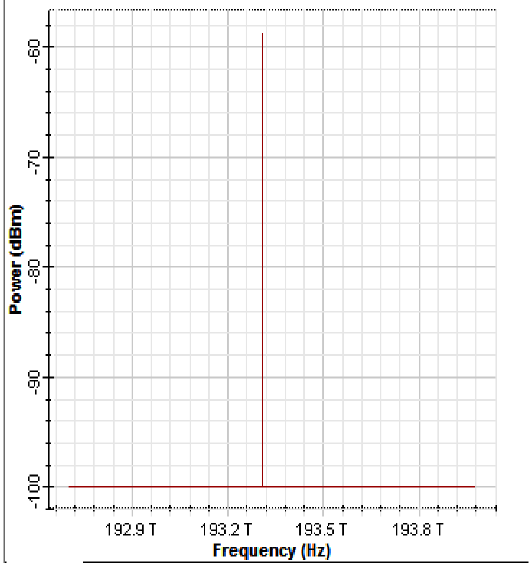
(a)



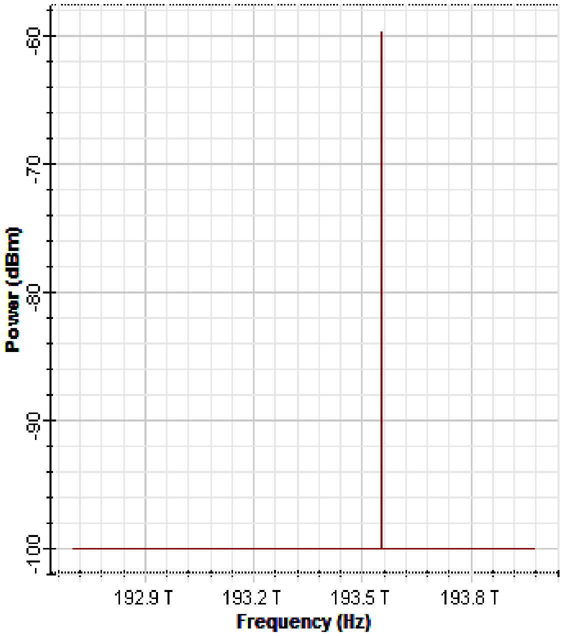
(b)



(c)



(d)



(e)

Fig.4.15 - (a), to (e) shows the output of signal corresponds to the five different modulated signals. Which are now successfully physically separated and can be transmitted through the individual fibers.

Here demultiplexed output can be easily process by the electronic hardware systems.

4.3 Performance Analysis:

In given experiment the main component are optical frequency comb and the SS-SC modulation of RF data. In proposed structure we made improvement, firstly on frequency comb design and then modulation technique used. In this section we have made an comparatively analysis on comb design and modulation technique. Section 4.3.1 will describe comb design analysis while section 4.3.2 will present a discussion on modulation technique used.

4.3.1 Comb design:

We have analyzed two designees for optical comb in first design we use cascade modulators

But we are able to generate only 10 to 12 comb line, while using second design i.e. recirculating frequency shift (RFS) we can generate up to 50 com line but there we can take frequency spacing to 10GHz which is again creates limitation on RF data.

In our experiment we have demonstrated 36 line comb, comb line can be further increased. Also the frequency spacing between comb line achieved up to 40GHz.so we can take more broad band data to slice.

4.3.2 MZM modulator configuration:

In previous modulation technique MZM is configured to DSB-SC signal generation .which takes twice bandwidth as compare to the proposed SSB-SC technique. So using SSB-SC technique we can channelize data of higher bandwidth (twice).

These two parameter makes proposed design more efficient as compare to the previous designs.

Chapter 5

Conclusion and Scope for Future Work

In this project we proposed a photonic based channelization scheme using optical frequency comb. The use of OFC provides both a low-noise channelization and a simplified spectral alignment to the following passive filters. With a 40-GHz-spacing OFC, we demonstrated our scheme experimentally, as well as the instantaneous multiple frequencies measurement. We used SSB modulation technique to increase Microwave frequency range to be processed. Other applications include the integrated RF channelized fiber delivery, simultaneous multiple frequency measurement of wideband signals and channelized coherent detection.

As in future the demand for broadband services is going to increase indefinitely, so we require a precise, fast and easy method for processing our microwave signal. As conventional electronics circuitry fails for these high frequencies we have no other option than channelization. So it has a wide scope in near future.

References

1. XiaojunXie, Yitang Dai, Yu Ji, Kun Xu, Yan Li, Jian Wu, and Jintong Lin, "Broadband Photonic Radio-Frequency Channelization Based on a 39-GHz Optical Frequency Comb" IEEE Photonics Technology Letters, vol.24, No. 8, April 15, 2012.

2. J. Capmany and D. Novak, "Microwave photonics combines twoworlds," *Nature Photon.*, vol. 1, no. 6, pp. 319–330, 2007.

3. F. A. Volkening, "Photonic channelized RF receiver employing densewavelength division multiplexing," U.S. Patent 724 583 3B1, 2007.

4.] W. T. Rhodes, "Acousto-optic signal processing: Convolution and correlation,"*Proc. IEEE*, vol. 69, no. 1, pp. 65–79, Jan. 1981.

5. D. B. Hunter, L. G. Edvell, and M. A. Englund, "Wideband microwave photonic channelised receiver," in *Proc. Microw. Photon.*, Oct. 2005, pp.249–252.

6. W. Wang, *et al.*, "Characterization of a coherent optical RF channelizer based on a diffraction grating," *IEEE Trans. Microw. Theory Tech.*,vol. 49, no. 10, pp. 1996–2001, Oct. 2001.

7. X. Zou, W. Pan, B. Luo, and L. Yan, "Photonic approach for multiplefrequency-component measurement using spectrally sliced incoherentsource," *Opt. Lett.*, vol. 35, no. 3, pp. 438–440, 2010.

8. R. Jales Lima Ferrerira and Daniel M. Pataca "Optical Comb Generation Techniques"

9. S. Chandrasekhar and Xiang Liu, "Terabit Superchannels for High Spectral Efficiency Transmission", *ECOC 2010*, Tu.3.C.5, Sep. 2010.

10. D. M. Pataca, F. D. Simões and M. L. Rocha, "Optical Frequency Comb Generator for Coherent WDM System in Tb/s Applications", *IMOC 2011*, October 2011.
11. F. D. Simões, D. M. Pataca and M. L. Rocha, "Design of a Comb Generator for High Capacity Coherent-WDM Systems", *IEEE-LATINCOM 2011*, October 2011.

12. A. D. Ellis, and F. C. G. Gunning. "Spectral density enhancement using coherent WDM." IEEE Photonics Technology Letters, vol. 17, pp. 504-506, 2005.

13. T. Kawanishi, T. Sakamoto, S. Shinada, and M. Izutsu. "Optical frequency comb generator using optical fiber loops with single-sideband modulation." IEICE Electronics Express, vol. 1, pp. 217-221, 2004.

14. R. Maher, P. M. Anandarajah, S. K. Ibrahim, L. P. Barry, A. D. Ellis, P. Perry, R. Phelan, B. Kelly, and J. O'Gorman. "Low cost comb source in a coherent wavelength division multiplexed system.", in Proceedings of ECOC 2010, P3.07, Torino, Italy, 2010.

15. R. Maher, "Low cos comb source in a coherent wavelength division multiplexed system", Proceedings of ECOC 2010, Torino, Italy.
16.

17. Introduction to fiber optics – A. Ghatak and K. Thyagrajan.

18. Optical fiber Communication- J.M Senior.

19. http://copradar.com/chapts/chapt7/ch7d1.html

20. https://www.engineering.leeds.ac.uk/imp/

21. http://b2bphotonics.com/

22. Microwave Photonics IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 50, NO. 3, MARCH 2002

23. http://www.mwp2013.org/.

24. R. Montgomery, and R. De Salvo, "A Novel Technique for Double Sideband Suppressed Carrier Modulation of Optical Fields," *IEEE Photonics Technol. Lett*., **7**, pp. 434-436, 1995.

25. A.Loayssa, J.M. Salvide, D. Benito and M.J. Garde, "Novel Optical Single-Sideband Suppressed-Carrier Modulator Using Bidirectionally-Driven Electro-optic Modulator", *Technical Digest: Microwave Photonics 2000 conference*, Alwyn Seeds, pp.117-120, IEE, Oxford, 2000.

26. Hernandez,G.(1986). *Fabry–Pérot Interferometers*. Cambridge: Cambridge University Press. ISBN 0-521-32238-3.

27. T. Kawanishi, T. Sakamoto, S. Shinada, and M. Izutsu. "Optical frequency comb generator using optical fiber loops with single-sideband modulation." IEICE Electronics Express, vol. 1, pp. 217-221, 2004.

28. D. M. Pataca, F. D. Simões and M. L. Rocha, "Optical Frequency Comb Generator for Coherent WDM System in Tb/s Applications", *IMOC 2011*, October 2011.

29. http://en.wikipedia.org/wiki/Frequency_comb