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PERFORMANCE ANALYSIS OF SUBCARRIER MULTIPLEXED SYSTEMS USING DIRECT MODULATION OF SEMICONDUCTOR LASERS

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Abstract

Optical Sub-Carrier Multiplexing (SCM) is an efficient technique in which multiple message signals, modulated onto RF or microwave sub-carriers, are multiplexed in the radio frequency domain and transmitted over a single optical wavelength using a laser source. This paper reviews various methods of direct modulation of semiconductor lasers, aiming to highlight their respective advantages and limitations. Techniques enabling amplitude, pulse, and frequency modulation of the optical carrier are discussed in detail. However, the total number of usable sub-carrier channels is fundamentally limited by intermodulation distortion (IMD), which arises due to nonlinearities in the modulation process. For accurate and distortion-free demodulation, the IMD level must be minimized. In our study, we achieved a minimum IMD level of −18.1274 dB at a bias current of 0.5 mA. Further reduction in IMD is possible by decreasing the amplitude of the sub-carriers at the input, thereby enhancing the overall fidelity of the multiplexed optical signal.

Keywords: Sub-Carrier-Multiplexing (SCM), Modulation, Amplitude, Intermodulation Distortion (IMD), Demodulation.

Introduction

Subcarrier Multiplexing (SCM) has emerged as a promising technique in optical communication systems due to its flexibility, cost-effectiveness, and efficient bandwidth utilization. In SCM, multiple analog or digital signals are modulated onto distinct radio frequency (RF) subcarriers, which are then combined and used to modulate an optical carrier, often a single-wavelength semiconductor laser diode [1]. This approach allows for multiple channels to be transmitted simultaneously over a single optical fiber without requiring wavelength division multiplexing (WDM), thus reducing complexity and cost [2].

Among the various techniques for implementing SCM systems, **direct modulation of semiconductor lasers** offers a simple and compact solution compared to external modulation schemes. In direct modulation, the laser's driving current is varied according to the input signal, resulting in modulation of the optical output power [3]. However, the performance of such systems is strongly influenced by nonlinearities such as chirp, intermodulation distortion (IMD), and laser relaxation oscillations, which can degrade signal quality and limit the number of usable subcarrier channels [4][5].

A major limitation in SCM systems using direct modulation is intermodulation distortion, which arises due to the nonlinear modulation characteristics of the laser. IMD can cause crosstalk between subcarrier channels and reduce overall system fidelity [6]. The magnitude of IMD depends on the modulation current, laser biasing conditions, and the design of the RF and optical transmission systems. Consequently, optimizing the laser modulation parameters is essential to minimize IMD and improve system performance [7].

Recent studies have shown that controlling the modulation index and bias current of the laser diode can significantly reduce IMD and enhance the dynamic range of SCM systems [8]. Furthermore, advancements in laser diode fabrication have led to devices with improved linearity, faster modulation response, and better thermal stability, making them more suitable for SCM applications [9]. Understanding these parameters is crucial for the performance analysis of SCM systems, especially in high-data-rate and long-haul optical communication scenarios.

This paper presents a detailed performance analysis of subcarrier multiplexed systems using direct modulation of semiconductor lasers. The study focuses on the influence of IMD, laser biasing, and subcarrier spacing on system performance, with the objective of identifying optimal modulation parameters for high-fidelity SCM transmission.

1. **Semiconductor laser diode**

The semiconductor laser, in various forms, Is the most widely used of all laser, so is manufactured in the largest quantities, and is of the greatest practical importance. Every compact disc (CD) player contains one LD. Much of the world's long, and medium distance communication takes place over optical fibres along a which propagates the light beam from a semiconductor laser. A semiconductor laser diode(LD) is a small in size and high efficiency.it can produce visible and infrared light.
A semiconductor laser diode is basically a p-n junction made of direct gap semiconductor which is forward biased can produce laser radiations. As in other conventional lasers, the light emitted from a laser diode is highly coherent, monochromatic and directional in properties. The polished end surfaces act as mirrors in FP laser and provide necessary feedback. The stimulated emission emission provides amplification required for lasing

Working prinicipal of a semiconductor laser diode:
A semiconductor laser diode consists of several parts:
1. Metal contact
2. P-type material
3. Active region (depletion region of a pn junction)
4. N-type material
5. Metal contact
The LD has the same structure like a diode where these occurs recombination of charge carriers in the active region. When current starts to flow spontaneous emission kicks in. Now, one actually doesn't want to have spontaneous emission but stimulated emission which means, that trapping emitted photons is required since the emission rate for stimulated emission also depends on the amount of photons already in the laser cavity, this means, that the probability for stimulated emission grows with the number of photons already present. this can be achieved by putting mirrors on the end sides of the diode and let amount of photons inside the active region increase until the rate of stimulated emission becomes higher than the rate of spontaneous emission. In order to get laser light out, one mirrors has to be either semi-transparent or have a hole in it.

Type of semiconductor laser diode

1. Double heterostructure lasers
2. Quantum well lasers
3. Quantum cascade lasers
4. Separate confinement heteroustrure lasers
5. Distributed Bragg Reflector lasers
6. Distributed feedback lasers
7. VCSELS
8. VECSELS
9. External-cavity diode lasers

Double heterostucture lasers:

In Double heterostucture lasers are a used pair of materials such as gallium arsenide (GaAs) with aluminium Gallium arsenide (AI,Ga(1-x)As). A low band gap materials is sandwiched between two high bandgap layers. Since these are junctions between different band gap materials it is called a heterostruture, hence the name "double heterostructure laser" or DH laser. DH laser advantage is that the region where free electrons and holes exist simultaneously - For the active region -is confined to the thin middle layer. This means the electron-hole pairs can contribute to amplification, not many electron-hole pair are left out in the poorly amplifying periphery. Light is reflected from the heterojunction; hence the light is confined to the region where the amplification takes place.

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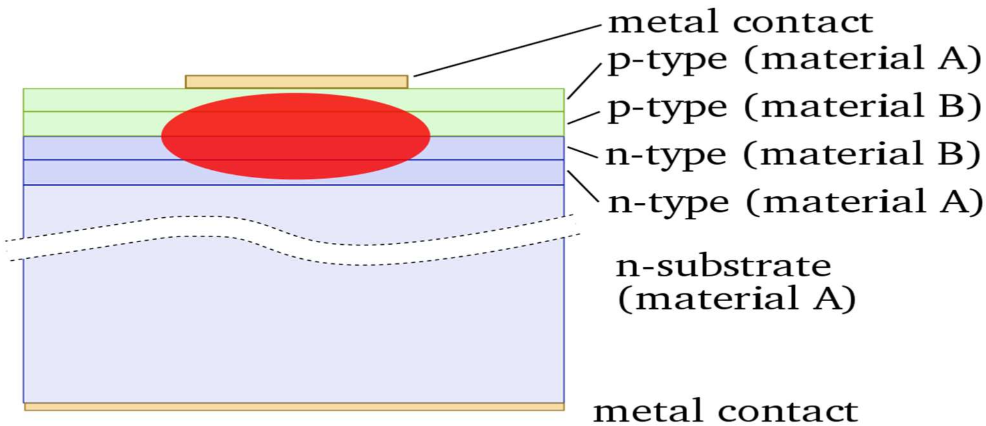

Diagram of front view of a double heterostructure Laser diode; not to scale

Quantum well lasers:

The Quantum well lasers contain quantum wells. Because the middle layer is thin enough. This means that vertical variation of the electron's wave function, and thus a component of its energy, is quantized. The density of state function of electrons in the quantum well system has an abrupt edge that concentrates electrons in energy states that contribute to laser action than the quantum well laser efficiency is greater than bulk laser.

Lasers containing more than one quantum well layer are known as multiple quantum well lasers. Multiple quantum wells improve the overlap of the gain region with the optical waveguide mode.

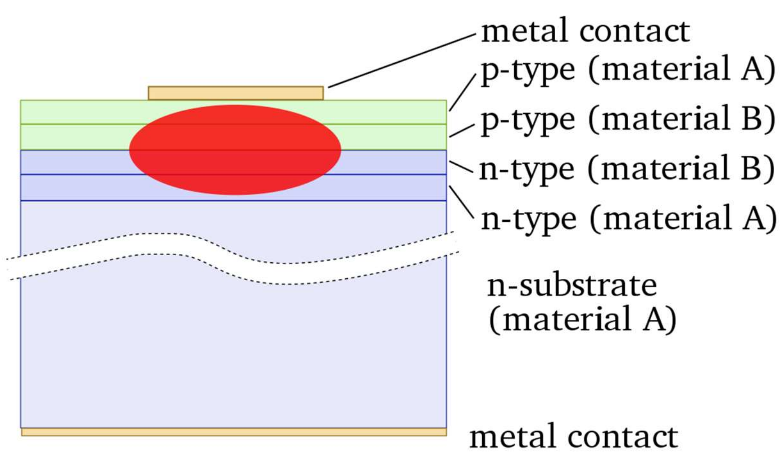

Diagram of front view of a simple quantum well laser diode. not to scale

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Quantum eascade lasers

In this laser, the difference between quantum well energy is used for the laser transition instead of the band gap. This enables laser action at relatively long wavelengths, which can be tuned simply by altering the thickness of the layer. They are heterojunction lasers. Here transition of an electron takes place from are sub-band to another sub-band in the conduction band. The potential in the conduction in stair case like. The electron shades down along the stair case like potential in the conduction band emitting a such of photon.

Separate confinement heterostructure lasers

With Simple quantum well diode problem is that the thin layer is simply too small to effectively confine the light. To compensate, additional two layers are added on, outside the first three laser These layers have a lower refractive index than the centre layers, and hence confine the light effectively by total internal reflection. Such a design is called a separate confinement heterotructure (SCH) laser diode. Almost all commercial laser diode since 1990s have been SCH quantum well diodes.

Distributed Bragg Reflector laser(DBR)

This laser is a single frequency laser diode. It is characterized by an optical cavity consisting of an electrically or optically pumped gain region between two mirrors to provide feedback. One of the mirrors is a broadband reflector and the other mirror is wavelength selective so that gain is favoured on a single longitudinal mode, resulting in lasing at a single resonant frequency. The broadband mirror is usually coated with a low reflectivity coating to allow emission. The wavelength selective mirror is a periodically structured diffraction grating with high reflectivity. The diffraction grating is within a non-pumped, or passive region of the cavity. A DBR laser is a monolithic single chip device with the grating etched into the semiconductor. DBR lasers can be edge emitting lasers or VCSELS.

Distributed Feedback Lasers

A distributed feedback laser (DFB) is type of single frequency laser diode. DFBs are the most common transmitter type in DENSE WAVELENGTH DIVISION MULTIPLEXING (DWDM) systems. To stabilize the lasing wavelength, a diffraction grating is etched close to and risk above the p-n junction of the diode. This grating acts like an optical filter, causing a single wavelength to be fed reflection from the facets is not required. Thus at least one facet of a DFB is anti-reflection coated.DFB lasers are widely used in optical communication applications where a precise and stable wavelength is required.

VCSEL

Vertical-cavity surface- emitting lasers (VCSELs) have the optical cavity
axis along the direction of current flow rather than perpendicular to the current flow as in conventional laser diodes. The active region length is very short compared with the lateral dimensions, so that the radiation emerges from the surface of the cavity rather than from its edge. The reflectors at the ends of the cavity are dielectric mirrors made from alternating high and low refractive index quarter-wave thick multilayer structure.

VCSELS emit the beam perpendicular to the active region of the laser as opposed to parallel as with an edge emitter, tens of thousands of VCSELS can be processed simultaneously on a emission three-inch gallium arsenide wafer. Furthermore, even though the VCSEL production process involves more labour -and material- sensitive, the yield can be controlled to a more predictable outcome. They normally show a lower power output level

There are several advantages to producing VCSELS when compared with the production process of edge-emitting lasers. Edge-emitters cannot be tested until the end of the production process. If the edge-emitter does not work, whether due to bad contacts or poor material growth quality, the production time and the processing materials have been wasted.

Such dielectric mirrors provide a high degree of wavelength-selective reflectance at the required free space wavelength λ if the thickness of alternating layers d_1 and d_2 with refractive indices n and n2 are such that $n_1d_1,+n_2d_2=\lambda /2$ which then leads to the constructive interference of all partially reflected waves at the interfaces.

But there is a disadvantage: because of the high mirror relativities, VCSELS have lower output power when compared to edge-emitting lasers.

VECSELS

Vertical external-cavity surface -emitting lasers, or VECSELS, are similar to VCSELS. In VCSELS, the mirrors are typically grown epitaxially as part of the diode structure, or grown separately and bonded directly to the semiconductor containing the active region. VECSELS are distinguished by a construction in which one of the two mirrors is external to the diode structure As a result, the cavity include a free-space region. A typical distance from the diode to external mirror would be 1cm..

VECSEL is the small thickness of the semicondoctor gain region in the direction of propagation, less than 100 nm. The significance of the short propagation distance is that it causes the effect of "antiguiding" nonlinearities in the diode laser gain region to be minimized. The result is a large cross section single mode optical beam which is not attainable from in plane("edge-emitting") diode lasers.

Applications for electrically pumped VECSELS include projection displays, served by frequency doubling of near-IR VECSEL emitters to produce blue and green light.

External-cavity diode lasers

These laser are tunable lasers which use mainly double heterostructures diode of the AI,Ga(1-x) As type. The frist external-cavity diode lasers used intracavity etalons and simple tuning gratings. Other designs include gratings in grazing configuration and multiple-prism grating configrations.

Application / Uses of semiconductor Lasers

1. The semiconductors laser can be pulsed at varying rate and pulse widths per sec. Therefore this laser is a natural transmitter of digital data.
2. Semiconductor laser is well suited for interface with fiber optic cable used in communication.

Advantages of Semiconductor Lasers

1. Smaller size and appearance make them good choice for many applications.
2. From cost point of view the semiconductor lasers are economical.
3. Semiconductor lasers construction is very simple.
4. No need of mirrors is in semiconductors lasers.
5. Semiconductors lasers have high efficiency.
6. The low power consumption is also its great advantage.

Disadvantages of Semiconductor Lasers

1. Semiconductors laser is greatly dependent on temperature. The temperature affects greatly the output of the laser and its wavelength.
2. Semiconductor laser is greatly depend on temperature. The temperature affects greatly the output of the laser.
3. The laseing medium of semiconductor laser is too short and rectangular so the output beam profile has an unusual shape.
4. Beam divergence is much greater from 125 to 400 million radians as compared to all other lasers.
5. The cooling system required in some cases may be considered its disadvantage

Fabry perot semiconductor laser:

The Fabry perot semiconductor lasers are the most common type of diode lasers. A cavity lassing width two highly refrecting mirrors on either side in which the light can bounce in the in the back and forth. A standing wave is formed inside the Fabry perot cavity.The cavity contained 1mn wavelength and 0.001 micron wavelength light, as long as the mirror are in proper distance, apart to from a standing wave. It is made with a pair of mirror and a whole no of wavelengths in a cavity round trip. The geometrical sizes of the laser chip are 1000 渭 m 脳 500 渭 m 200 渭 m (length, width, and height). The Fabry perot semiconductor laser operates longitudinally in single or in multimode. But it is depending on the cavity length.

A Fabry Perot LD consists of two plane mirror formed by polished end faces. Plane optical resontators are special becouse their resonotors mode extended up to the edges of the mirror and diffraction within a round trip is rather weak.

Sub-carrier multiplexing(SCM):

In subcarrier multiplexed systems several electrical subcarrier are combined and used to modulate the laser diode. Because a semiconductor is a nonlinear device the various subcarriers are mixed within the laser cavity to form intermodulation products. Second and third-order distortion products are generated by every combination of two and three inputs frequencies. respectively. The interference resulting from source nonlinerity then depends strongly on the number of channels and distribution of channel frequencies
Let f_i, f_2, and f_3 be the subcarrier frequencies of the transmission channels. The third order intermodulation distortion products (IMPs) at frequencies $f_i+f_j-f_k$ and $2f_i-f_j$, will certainly lie within the transmission band leading to interchannel interference. For N channels system IMPs $_rIM_{21}^N$ and $_rIM_{111}^N$ of type $2f_i-f_j$ and $f_i+f_j-f_k$,respectively,coincident with channel r are given by

$$_rIM_{21}^N=1/2[N-2-1/2\{1-(-1)^N(-1)\}]$$

$$_rIM_{111}^N=r/2(N-r+1)+1/4[(N-3)^2-5]-1/8[1-(-1)^N](-1)^{N+r}$$

For large N,,IM_{111}^N approaches the asymptotic value of $3N^2/8$ for the central carrier.
For SCM systems occupying a bandwidth of more than one octave, the second- order nonlinear distortion will also have to be considered in which most important terms are of type are of type $f_i+ f_j$.

SCM is a scheme where multiple sub-carriers are multiplexed in the radio frequency (RF) domain and transmitted over a single wavelength. The most significant advantage of SCM in optical communications is its ability to place different optical carriers together closely. Other advantage of SCM is that microwave devices are more mature than optical devices; the stability of a microwave oscillator and the frequency selectivity of a microwave filter are much better than their optical counterparts. SCM low noise of RF oscillators makes coherent detection in the RF domain easier than optical coherent detection, its can be applied easily. A popular application of SCM technology in fiber optic systems is analog CATV (cable television) distribution, because of the low cost and simple implementation. SCM has also been proposed to transmite multichannel digital optical signal direct detection for local area optical network.


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Rate Equations of a semiconductor laser

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The coupled nonlinear rate equations describing the complex electric field and the carrier density in a simple model of the semiconductor laser.

The laser diode rate equations model the the electrical and optical performance of the laser diode. This system of ordinary differential equation relates the number or density of photon s and charge carries in the device to the injection current and device and material parameters such as carrier lifetime,photon lifetime, and optical gain..

In the multimode for mutation, the rate equation model a laser with multiple optical mode. This formulation require one Equation for the carrier density in each of the optical cavity mode

N=Electron Density.

S=Photon Density

1=Applied Current.

e=Elementary charge.

V=is the Volume of active region.

T_e=Spontaneous lifetime of electron.

I=l_o+Real part of $I_p e^{i\omega t}$

I=DC line current.

1_p=Peak current of frequency $\omega_m/2\pi$

G=A(N-Nt)= Gain due to stimulated emission.

A=Different gain co-efficient.

T_p=Photon life time

N-Transparent carrier density which corresponds to zero gain.

Then we can written

$$\frac{dN}{dt}=\frac{1}{ev}-\frac{N}{Tn}-\sum_{\mu=1}^{\mu=N} G\mu S\mu \qquad \text{(I)}$$

$$\frac{dS}{dt}=\Gamma_\mu(G_\mu-\frac{1}{TP})P_\mu+B_\mu(N/T_t) \qquad (2)$$

For signal mode

$$\frac{dN}{dt}=(\frac{1}{ev})-(\frac{N}{Te})-GS \qquad (3)$$

$$\frac{ds}{dt}=(G-\frac{1}{Tp})S \qquad (4)$$

Let

N=No+n(t) (a)

S=So+s(t) (b)

I=I+I(t) (c)

G=A(N-N_t) (d)

Then equation (3) we can written

$$\frac{d(N0+n(t))}{dt}=(\frac{Io+I(t)}{ev})-(\frac{No+n(t)}{Te})-\{A(N-N_t)(S_0+S(t))$$

$$>> \frac{dN0}{dt}+\frac{dn(t)}{dt}=\frac{I0}{ev}+\frac{I(t)}{ev}-\frac{N0}{Te}-\frac{n(t)}{Te}-\{A(N_{0+}n(t)-N_t)(S_0+S(t))$$

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>> $\frac{dN0}{dt}+\frac{dn(t)}{dt}=\frac{I0}{ev}+\frac{I(t)}{ev}-\frac{N0}{Te}-\frac{n(t)}{Te}-\{A(N_0S_0+S_0n(t)-N_tS_0+S(t)N_0+n(t)S(t)-N_tS(t))\}$

For steady state

$\frac{dN0}{dt}=0$,
And n(t) is very small,
And equal time part

$\frac{dn(t)}{dt}=\frac{I(t)}{ev}-\frac{n(t)}{Te}-\{A(S_0n(t)+S(t)N_0+n(t)S(t)-N_tS(t))\}$

Similarly

$\frac{d(S0+s(t))}{dt}=(A(N-N_t)-\frac{1}{Tp})(S_0+S(t))$

$=(A(N_0+n(t)-N_t)-\frac{1}{Tp})(S_0+S(t))$

$=A\{N_0S_0+N_0S(t)+n(t)S_0+n(t)S(t)-N_tS(t)-(S_0+S(t)(\frac{1}{Tp})\}$

For steady state
$\frac{dS}{dt}=0$,
S(t) is very small and equal time part
Then we can written

$$\frac{ds(t)}{dt}=An(t)S_0+AN_0S(t)+An(t)S_0+An(t)S(t)-AN_tS(t)-S(t)\frac{1}{Tp} \qquad (6)$$

Equation (6) derivative with respect to the t,

$$\frac{d2s(t)}{dt2}=AS_0\frac{dn(t)}{dt}+AN_0\frac{ds(t)}{dt}+AS(t)\frac{dn(t)}{dt}+An(t)\frac{ds(t)}{dt}-AN_t\frac{ds(t)}{dt}-\frac{ds(t)}{dt}\frac{1}{Tp}$$

$$=(AN_0+An(t)-AN_t-\frac{1}{Tp})\frac{ds(t)}{dt}+(AS_0+As(t))\frac{dn(t)}{dt} \qquad (7)$$

Put the value $\frac{dn(t)}{dt}$ in equation(7)

$$\frac{d2s(t)}{dt2}=(AN_0+An(t)-AN_t-\frac{1}{Tp})\frac{ds(t)}{dt}+(AS_0+AS(t))\{\frac{I(t)}{ev}-\frac{n(t)}{Te}-A(S_0n(t)+S(t)N_0+n(t)S(t)-N_tS(t))\} \qquad (8)$$

Now equation (7) solve
Let as consider
$S(t)=S_{p1}\,Sin(\omega_1t)+S_{p2}\sin(\omega_2t)+S_D\sin[(\omega_2-\omega_1)t+\varphi]+S_S\,Sin[(\omega_2-\omega_1)t+\Psi]$
$n(t)=n_{p1}Sin(\omega_1t)+n_{p2}\sin(\omega_2t)+n_D\sin[(\omega_2-\omega_1)t+\varphi]+n_S\,Sin[(\omega_2+\omega_1)t+\Psi]$
$I=I_0+I(t)\quad [I_0=0]$
$=I_{p1}\,Sin(\omega_1t)+I_{p2}Sin(\omega 2t)$
Where

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S_{p1} =The Amplitude of photon density in frequency ω_1.
S_{p2} =The Amplitude of photon density in frequency ω_2 .
S_D = The different Amplitude of photon density in frequencies ω_1,ω_2 .
S_S = The sum Amplitude of photon density in frequencies ω_1,ω_2 .
n_{p1} = The Amplitude of electron density in frequency ω_1.
N_{p2} = The Amplitude of electron density in frequency ω_2.
n_D = The different Amplitude of electron density in frequencies ω_1,ω_2 .
n_S = The sum Amplitude of electron density in frequencies ω_1,ω_2 .
I_{p1}= the current Amplitude of frequency ω_1.
I_{p2}= the current Amplitude of frequency ω_2.
Φ,Ψ = Constant Angle.

$$\frac{dn(t)}{dt} = n_{p1}\omega_1\cos(\omega_1 t) + n_{p2}\,\omega_2\cos(\omega_2 t) + n_D(\omega_2-\omega_1)\cos[(\omega_2-\omega_1)t+\varphi] + n_S(\omega_2+\omega_1)\cos[(\omega_2+\omega_1)t+\Psi] \quad (9)$$

$$\frac{ds(t)}{dt} = S_{p1}\omega_1\cos(\omega_1 t) + S_{p2}\,\omega_2\cos(\omega_2 t) + S_D(\omega_2-\omega_1)\cos[(\omega_2-\omega_1)t+\varphi] + S_S(\omega_2+\omega_1)\cos[(\omega_2+\omega_1)t+\Psi] \quad (10)$$

$$\frac{d2s(t)}{dt2} = -S_{p1}\omega_1^2\mathrm{Sin}(\omega_1 t) - S_{p2}\,\omega_2^2\mathrm{Sin}(\omega_2 t) - S_D(\omega_2-\omega_1)^2\mathrm{Sin}[(\omega_2-\omega_1)t+\varphi] - S_S(\omega_2+\omega_1)^2\mathrm{Sin}[(\omega_2+\omega_1)t+\Psi] \quad (11)$$

$$\frac{d2s(t)}{dt2} = (AN_0-\frac{1}{Tp})\frac{ds(t)}{dt} + An(t)\frac{ds(t)}{dt} + AS\frac{I}{ev} - (\frac{1}{Te} + AS_0)ASn(t) - AS(N_0+N_t)S(t) - ASS(t)n(t) \quad (12)$$

Equation(9),(10),(11) value put Equation(12), We can written as

$-S_{p1}\omega_1^2\sin(\omega_1 t) - S_{p2}\,\omega_2^2\sin(\omega_2 t) - S_D(\omega_2-\omega_1)^2\,[\sin(\omega_2-\omega_1)t\cos\varphi - \cos(\omega_2-\omega_1)t\sin\varphi] - S_S(\omega_2+\omega_1)^2[\sin[(\omega_2+\omega_1)t\cos\Psi - \cos[(\omega_2+\omega_1)t\,\sin\Psi] = (AN_0 - \frac{1}{Tp})S_{p1}\omega_1\cos(\omega_1 t) + S_{p2}\,\omega_2\cos(\omega_2 t) + S_D(\omega_2-\omega_1)\cos[(\omega_2-\omega_1)t+\varphi] + S_S(\omega_2+\omega_1)\cos[(\omega_2+\omega_1)t+\Psi] + AS\frac{1}{ev}\{I_{p1}\,\mathrm{Sin}(\omega_1 t) + I_{p2}\mathrm{Sin}(\omega 2t)\} + A[n_{p1}\mathrm{Sin}(\omega_1 t) + n_{p2}\sin(\omega_2 t) + n_D\sin[(\omega_2+\omega_1)t+\varphi] + n_S\,\mathrm{Sin}[(\omega_2-\omega_1)t+\Psi][S_{p1}\omega_1\cos(\omega_1 t) + S_{p2}\,\omega_2\cos(\omega_2 t) + S_D(\omega_2-\omega_1)\cos[(\omega_2-\omega_1)t+\varphi] + S_S(\omega_2+\omega_1)\cos[(\omega_2+\omega_1)t+\Psi]\,] - (\frac{1}{Te} + AS_0)ASn_{p1}\mathrm{Sin}(\omega_1 t) + n_{p2}\sin(\omega_2 t) + n_D\sin[(\omega_2-\omega_1)t+\varphi] + n_S\,\mathrm{Sin}[(\omega_2+\omega_1)t+\Psi] - AS(N_0+N_t)[S_{p1}\,\mathrm{Sin}(\omega_1 t) + S_{p2}\sin(\omega_2 t) + S_D\sin[(\omega_2-\omega_1)t+\varphi] + S_S\,\mathrm{Sin}[(\omega_2-\omega_1)t+\Psi]] - AS[\{S_{p1}\,\mathrm{Sin}(\omega_1 t) + S_{p2}\sin(\omega_2 t) + S_D\sin[(\omega_2-\omega_1)t+\varphi] + S_S\,\mathrm{Sin}[(\omega_2-\omega_1)t+\Psi]\}\{n_{p1}\mathrm{Sin}(\omega_1 t) + n_{p2}\sin(\omega_2 t) + n_D\sin[(\omega_2-\omega_1)t+\varphi] + n_S\,\mathrm{Sin}[(\omega_2+\omega_1)t+\Psi]\}]$

$=(AN_0-\frac{1}{Tp})[S_{p1}\omega_1\cos(\omega_1 t) + S_{p2}\,\omega_2\cos(\omega_2 t) + S_D(\omega_2-\omega_1)\cos(\omega_2-\omega_1)t\cos\varphi - S_D(\omega_2-\omega_1)\sin(\omega_2-\omega_1)t\sin\varphi + S_S(\omega_2+\omega_1)\cos(\omega_2+\omega_1)t\cos\Psi - S_S(\omega_2+\omega_1)\sin(\omega_2+\omega_1)t\sin\Psi + AS\frac{1}{ev}\{I_{p1}\,\mathrm{Sin}(\omega_1 t) + I_{p2}\mathrm{Sin}(\omega 2t)\} - (AS_0 + \frac{1}{Te})AS[n_{p1}\mathrm{Sin}(\omega_1 t) + n_{p2}\mathrm{Sin}(\omega_1 t) + n_D\sin(\omega_2-\omega_1)t\cos\varphi + n_D\cos(\omega_2-\omega_1)t\sin\varphi + n_s\sin(\omega_2+\omega_1)t\cos\Psi + n_s\cos(\omega_2+\omega_1)t\sin\Psi] - AS(N_0+N_t)[S_{p1}\,\mathrm{Sin}(\omega_1 t) + S_{p2}\sin(\omega_2 t) + S_D\sin(\omega_2-\omega_1)t\cos\varphi + S_D\cos(\omega_2-\omega_1)t\sin\varphi + S_S\,\mathrm{Sin}(\omega_2-\omega_1)\cos\Psi + S_S\cos(\omega_2-\omega_1)t\sin\Psi] - AS[S_{p1}\,\mathrm{Sin}(\omega_1 t) + S_{p2}\sin(\omega_2 t) + S_D\sin(\omega_2-\omega_1)t\cos\varphi + S_D\cos(\omega_2-\omega_1)t\sin\varphi + S_S\,\mathrm{Sin}(\omega_2-\omega_1)t\cos\Psi + S_S\cos(\omega_2-\omega_1)t\sin\Psi]$
$[n_{p1}\sin(\omega_1 t) + n_{p2}\,\sin(\omega_2 t) + n_D\sin(\omega_2-\omega_1)t\cos\varphi + n_D\cos(\omega_2-\omega_1)t\sin\varphi + n_S\,\mathrm{Sin}[(\omega_2+\omega_1)t\cos\Psi + n_S\cos[(\omega_2+\omega_1)t\sin\Psi] + A[n_{p1}\sin(\omega_1 t) + n_{p2}\sin(\omega_2 t) + n_D\sin(\omega_2-\omega_1)t\cos\varphi + n_D\cos(\omega_2-\omega_1)t\sin\varphi + n_S\,\mathrm{Sin}(\omega_2+\omega_1)t\cos\Psi + n_S\cos(\omega_2+\omega_1)t\sin\Psi][S_{p1}\,\mathrm{Sin}(\omega_1 t) + S_{p2}\sin(\omega_2 t) + S_D\sin(\omega_2-\omega_1)t\cos\varphi + S_D\cos(\omega_2-\omega_1)t\sin\varphi + S_S\,\mathrm{Sin}(\omega_2-\omega_1)t\cos\Psi + S_S\cos(\omega_2-\omega_1)t\sin\Psi]$


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$=\frac{1}{2}An_{p1}S_{p1}\omega_1 Sin(2\omega_1 t)+\frac{1}{2}An_{p1}S_{p2}\omega_2 Sin(\omega_2+\omega_1)t+\frac{1}{2}An_{p1}S_{p2}\omega_2 Sin(\omega_2-\omega_1)t+\frac{1}{2}An_{p1}S_D(\omega_2-\omega_1)cos(2\omega_2-\omega_1)tsin\varphi+\frac{1}{2}An_{p1}S_D(\omega_2-\omega_1)cos(\omega_2)tsin\varphi+\frac{1}{2}Anp1Ss(\omega2+\omega1)sin(\omega2+2\omega1)tcos\Psi+\frac{1}{2}Anp1Ss(\omega2+\omega1)sin(\omega2)tcos\Psi-\frac{1}{2}An_{p1}S_s(\omega_2+\omega_1)cos(-\omega_2)tsin\Psi+\frac{1}{2}An_{p1}S_s(\omega_2+\omega_1)cos(2\omega_2+\omega_1)tsin\Psi+\frac{1}{2}An_{p2}S_{p1}\omega_1 sin(\omega_2+\omega_1)t+\frac{1}{2}An_{p2}S_{p1}\omega_1 sin(\omega_2-\omega_1)t+\frac{1}{2}An_{p2}S_{p2}\omega 2sin(2\omega_2)t+\frac{1}{2}An_{p2}S_D(\omega_2-\omega_1)\omega sin(2\omega_2-\omega_1)tcos\varphi+\frac{1}{2}An_{p2}S_D(\omega_2-\omega_1)sin(\omega_1)tcos\varphi-\frac{1}{2}An_{p2}S_D(\omega_2-\omega_1)cos(\omega_1)tsin\varphi+\frac{1}{2}An_{p2}S_D(\omega_2-\omega_1)cos(2\omega_2-\omega_1)tsin\varphi+\frac{1}{2}An_{p2}Ss(\omega_2+\omega_1)sin(2\omega_2+\omega_1)tcos\Psi-\frac{1}{2}An_{p2}Ss(\omega_2-\omega_1)sin(\omega_1)tcos\Psi-\frac{1}{2}An_{p2}Ss(\omega_2+\omega_1)cos(\omega_1)tcos\Psi+\frac{1}{2}An_{p2}Ss(\omega_2+\omega_1)cos(2\omega_2+\omega_1)tsin\Psi+\frac{1}{2}An_DS_{p1}\omega_1 sin(\omega_2)tcos\varphi-\frac{1}{2}An_DS_{p1}\omega_1 sin(2\omega_1+\omega_2)tcos\varphi+\frac{1}{2}An_DS_{p1}\omega_1 cos(2\omega_1)tsin\varphi+\frac{1}{2}An_DS_{p1}\omega_1 cos(2\omega_1+\omega_2)tsin\varphi+-\frac{1}{2}An_DS_{p2}\omega_2 sin(2\omega_1+\omega_2)tcos\varphi-\frac{1}{2}An_DS_{p2}\omega_1 sin(\omega_1)tcos\varphi+\frac{1}{2}An_DS_{p2}\omega_2 cos(2\omega_2-\omega1)tsin\varphi+AnDSp2\omega2cos(\omega1)tsin\varphi+AnsSp1\omega1sin(2\omega2+\omega1)tcos\Psi++AnsSp1\omega1sin(\omega1)tcos\Psi+\frac{1}{2}AnsS_{p1}\omega 1cos(\omega_2+2\omega_1)tsin\Psi+\frac{1}{2}AnsS_{p1}\omega 1cos(\omega_2)tsin\Psi+\frac{1}{2}AnsS_{p1}\omega_2 sin(2\omega_2+\omega_1)tcos\Psi+\frac{1}{2}AnsS_{p2}\omega_2 sin(\omega_1)tcos\Psi+\frac{1}{2}AnsS_{p1}\omega_2 cos(2\omega_2+\omega_1)tsin\Psi+\frac{1}{2}AnsS_{p2}\omega_2 cos(\omega_1)tsin\Psi-\frac{1}{2}A(AS_0+\frac{1}{Te})[n_{p1}S_{p1}cos(2\omega_1)t-n_{p1}S_{p2}cos(\omega_2-\omega_1)t+n_{p1}S_{p1}cos(\omega_2+\omega_1)t-n_{p1}S_Dcos(2\omega_1-\omega_2)tcos\varphi+n_{p1}S_Dcos(\omega_2)tcos\varphi-n_{p1}S_Dsin(\omega_2)tsin\varphi-n_{p1}S_Dsin(2\omega_1-\omega_2)tsin\varphi-n_{p1}Sscos(\omega_2)tcos\Psi+n_{p1}Sscos(2\omega_1+\omega_2)tcos\Psi-n_{p1}Sssin(2\omega_1+\omega_2)t+n_{p1}S_{p1}sin(\omega_2)t-n_{p2}Sp_1cos(\omega_2-\omega_1)t+n_{p2}Sp_1cos(\omega_1+\omega_2)t+n_{p2}S_{p2}cos(2\omega_2)t-n_{p2}S_Dcos(\omega_1)tcos\varphi-n_{p2}S_Dcos(2\omega_2+\omega_1)tcos\varphi-n_{p2}S_Dsin(2\omega_2-\omega_1)tsin\varphi-n_{p2}S_Dsin(\omega_1)tsin\varphi-n_{p2}Sscos(\omega_1)tcos\Psi+n_{p2}Sscos(\omega_1+2\omega_2)tcos\Psi-n_{p2}Sssin(\omega_1+2\omega_2)tcos\Psi+n_{p2}Ss\,sin(\omega_1)tsin\Psi-n_DS_{p1}cos(2\omega_1-\omega_2)tcos\varphi+n_DS_{p1}cos(\omega_2)tcos\varphi-n_DS_{p1}sin(\omega_2)tsin\varphi-n_DS_{p1}sin(2\omega_1-\omega_2)tsin\varphi-n_DS_{p2}cos(\omega_1)tcos\varphi+n_DS_{p2}cos(2\omega_2-\omega_1)tcos\varphi-n_DS_{p2}sin(2\omega_2-\omega_1)tsin\varphi-n_DS_{p2c}cos(\omega_1)tsin\varphi-n_DS_D-n_DS_Dsin2(\omega_2-\omega_1)tsin\varphi cos\varphi-n_DS_Dsin2(\omega_2-\omega_1)tsin\varphi cos\varphi-n_DS_Dcos2(\omega_2-\omega_1)tsin\varphi^{2-}n_DS_scos(2\omega_1)tcos\varphi cos\Psi+n_DS_scos(2\omega_2)tcos\varphi cos\Psi-n_DS_ssin(2\omega_1)tcos\varphi sin\Psi-n_DS_ssin(2\omega_2)tcos\varphi sin\Psi+n_DS_ssin(2\omega_1)tcos\varphi sin\Psi-n_DS_ssin(2\omega_2)tsin\varphi cos\Psi-n_DS_scos(2\omega_2)tsin\varphi sin\Psi-n_DS_scos(\omega_1)tsin\varphi cos\Psi-n_sS_{p1}cos(\omega_2)tcos\Psi+n_sS_{p1}cos(2\omega_1+\omega_2)tcos\Psi-n_sS_{p1}sin(2\omega_1+\omega_2)tsin\Psi+n_sS_{p1}sin(\omega_2)tsin\Psi-n_sS_{p2}cos(\omega_1)tcos\Psi+n_sS_{p2}cos(2\omega_2+\omega_1)tcos\Psi-n_sS_{p2}sin(2\omega_2+\omega_1)tsin\Psi+n_sS_{p2}sin(\omega_1)tsin\Psi-n_sS_D\{cos(2\omega_1)t-cos(2\omega_2)t\}-n_DS_ssin\varphi cos\Psi\{sin(2\omega_1)t+sin(2\omega_2)t\}-n_DS_ssin\varphi cos\Psi\{sin(2\omega_1)t-sin(2\omega_2)t\}-n_DS_ssin\varphi sin\Psi\{cos(2\omega_1)t+cos(2\omega_2)t\}-n_sS_s+n_sS_scos^2\Psi cos2(\omega_2+\omega_1)t-n_sS_scos\Psi sin\Psi sin2(\omega_2+\omega_1)t-n_sS_ssin^2\Psi cos2(2\omega_1+\omega_2)t-n_sS_scos\Psi sin\Psi sin2(\omega_2+\omega_1)t]-\frac{A}{2ev}[I_{p1}S_{p1}-I_{p1}S_{p1}cos(2\omega_1)t+I_{p1}S_Dcos(2\omega_1-\omega_2)tcos\varphi\ I_{p1}S_Dcos(\omega_2)tcos\varphi-I_{p1}S_Dsin(\omega_2)tsin\varphi-I_{p1}S_Dsin(2\omega_1+\omega_2)tsin\varphi+I_{p1}Sscos(\omega_2)tcos\Psi+I_{p1}Sscos(2\omega_1+\omega_2)tcos\Psi+I_{p1}Sssin(2\omega_1+\omega_2)tsin\Psi-I_{p1}Sscos(\omega_2)tsin\Psi+I_{p1}Sscos(\omega_2-\omega_1)t-I_{p2}S_{p1}cos(\omega_2+\omega_1)t+I_{p2}S_{p1}-I_{p2}S_{p1}cos(2\omega_2)t+I_{p2}S_Dcos(\omega_1)t\ cos\varphi-I_{p2}S_Dcos(2\omega_2-\omega_1)t\ cos\varphi+I_{p2}S_Dsin(2\omega_2-\omega_1)t\ sin\varphi+-I_{p2}S_Dsin(\omega_1)t\ sin\varphi+-I_{p2}S_scos(\omega_1)t\ cos\Psi-I_{p2}S_Scos(2\omega_2+\omega_1)t\ cos\Psi+I_{p2}S_Ssin(2\omega_2+\omega_1)t\ sin\Psi-I_{p2}S_Ssin(\omega_2)t\ sin\Psi$ (13)

Euating the Co-efficient of $Sin(\omega_2+\omega_1)t$ in equation (13) both side

$-S_s(\omega_2+\omega_1)^2 cos(\Psi)=\frac{1}{2}A(n_{p1}S_{p1}\omega_2+n_{p2}S_{p2}\omega_1)$ (14)

Euating the Co-efficient of $cos(\omega_2+\omega_1)t$ in equation (13) both side

$-S_s(\omega_2+\omega_1)^2 sin(\Psi)=\frac{1}{2ev}A\{I_{p2}S_{p1}-I_{p1}S_{p2}\}-\frac{1}{2}A(AS_0+\frac{1}{Te})\{n_{p2}S_{p1}+In_{p1}S_{p2}\}$ (15)

Euating the Co-efficient of $Sin(\omega_2+\omega_1)t$ in equation (13) both side

$-S_D(\omega_2-\omega_1)^2 cos(\varphi)=\frac{1}{2}A(n_{p1}S_{p1}\omega_2+n_{p2}S_{p2}\omega_1)$ (16)

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Euating the Co-efficient of $\cos(\omega_2 - \omega_1)t$ in equation (13) both side

$-S_D(\omega_2 - \omega_1)^2 \sin(\varphi) = \frac{1}{2}A(AS_0 + \frac{1}{Te})\{n_{p2}S_{p1} + In_{p1}S_{p2}\} - \frac{1}{2e}A\{n_{p2}S_{p1} + In_{p1}S_{p2}\}$ (17)

Squaring (14) and (15), Then add

$S^2_s(\omega_2 + \omega_1)^4 = [\frac{1}{2}A(n_{p1}S_{p1}\ \omega_2 + n_{p2}S_{p2}\omega_1)]^2 + [\frac{1}{2ev}A\{I_{p2}S_{p1} - I_{p1}S_{p2}\} - \frac{1}{2}A(AS_0 + \frac{1}{Te})\{n_{p2}S_{p1} + In_{p1}S_{p2}\}]^2$ (18)

Squaring (16) and (17), Then add

$S^2_D(\omega_2 - \omega_1)^4 = [\frac{1}{2}A(n_{p1}S_{p1}\ \omega_2 + n_{p2}S_{p2}\omega_1)]^2 + [\frac{1}{2}A(AS_0 + \frac{1}{Te})\{n_{p2}S_{p1} + In_{p1}S_{p2}\} - \frac{1}{2ev}A\{n_{p2}S_{p1} + In_{p1}S_{p2}\}]^2$ (19)

Let $I = nev_v\,\alpha$

Where e= current, v_v = velocity of electron, α= cross section area.

And $S_{p1} = S_{p2} = S_p$, $I_{p1} = I_{p2} = I_p$, $AS_0 + \frac{1}{Te} = k_1$

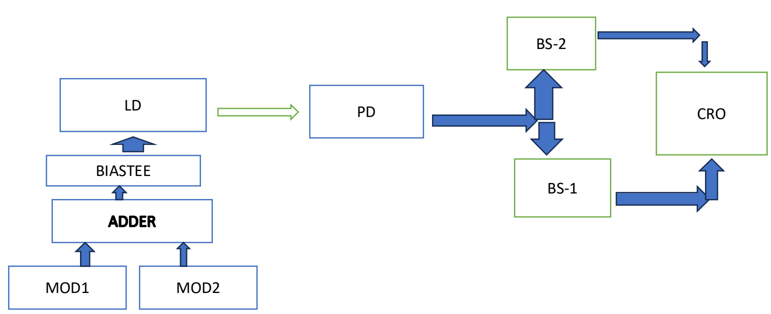
Equation(18) we can write,

$S_s = \frac{AIp\ Sp}{2evv\ \alpha(W2 + W1)}[(\omega_2 + \omega_1)^2 + 4k^2_1]^{1/2}$ (20)

Equation(18) we can write,

$S_D/S_p = \frac{AI}{e(W2 + W1)2}[(\omega_2 + \omega_1)^2 n^2 e^2 / I^2_0 + (n\,ek_1/I_0 - 1/v)^2]^{1/2}$ (21)

BLOCK DIAGRAM:



Block diagram of two optical sub- carrier multiplexs commnication system

Operation of the Circuit:

Two channels of sub carrier 1 are entering in two adder circuit. Here the two channel become ac and depart from sub carrier 1 and re-enter in two basis. Here dc voltage is already putted in two biased. To brasis the LD and signal is coming from LD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into PD. Now PD has two signal to divide the two signal we have use bs-1 and bs-2 filter, then we have to connect it in cro , thenwe can see to different signal.

Difference Frequency generation as IMD:

Calculation

$A=6x10^{-21}\ m^2$ | Carrier velocity(v_c)=$10^5\ m\ s^{-1}$

$V=1.2x10^{-16}\ m^3$ | $T_e=(0.6-1)x10^{-9}$ sec

$AxVc=6x10^{-16}\ m^3\ s^{-1}$ | $I_p=(1-5)$mA

$n= 8.3x10^{20}\ m^{-3}$ | $I_0=(60-100)$ mA

$S_p=(20-30)x10^{18}\ m^3$ | $S_p=(200-300)x10^{18}\ m^3$

Set-1

Frequecy(ω_1)= 1 GH_z Frequecy(ω_2)= 2 GH_z

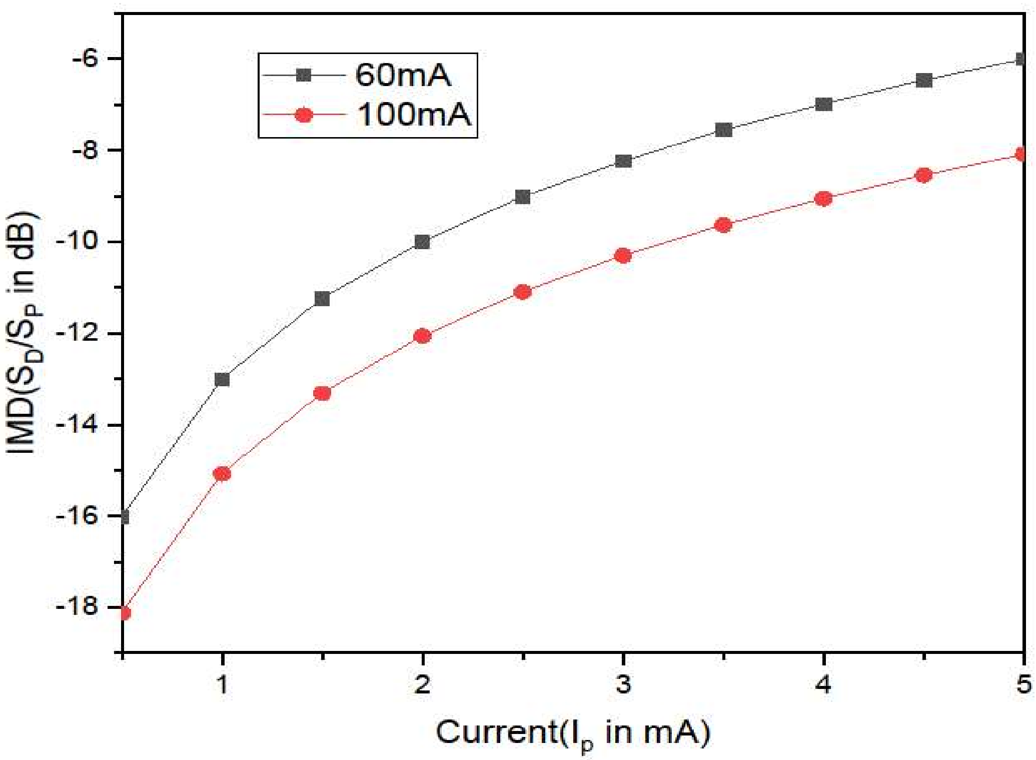
Table-1

I_0=60 mA

Ip(mA)	S_D/S_p in dB
0.5	-16.0205
1.0	-13.0100
1.5	-11.2400
2.0	-10.000
2.5	-9.0170
3.0	-8.2390
3.5	-7.5548
4.0	-6.9897
4.5	6.4628
5.0	-6.0050

Table-2 I_0=100 mA

Ip(mA)	S_D/S_p in dB
0.5	-18.1274
1.0	-15.0754
1.5	-13.3145
2.0	-12.0652
2.5	-11.0960
3.0	-10.3042
3.5	-9.6347
4.0	-9.0548
4.5	-8.5433
5.0	-8.0857



Conclusion:

The arthur has carried out a details analysis of the optical subcarrier multiplexing communication system in general n no of sub carrier can be multiuse in this communication system but due to large inter modulation distortion the maximum no of sub carrier that can be multiples is limited. We have consider two sub carrier multiples in the system and carried out analysis. We have obtain a Minimum IMD level of -18.1274dB for 0.5mA however IMD can furdiffer the reduce lowing theamplitude level of sub-carrier in input.

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