RADIO OVER FIBER TRANSMISSION BY SUB CARRIER MULTIPLEXING

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ABSTRACT

The performance analysis was carried out for a sub carrier multiplexed optical fiber transmission system with RF sub carrier modulated to transmit video signal for a local video distribution network. The effect of intensity noise due to the electro-optic intensity modulator will be considered in the analysis in presence of fiber chromatic dispersion. The amount of distortion due to inter-modulation crosstalk was determined analytically. The performance results were evaluated by Mat lab in terms of signal to noise ratio, signal to crosstalk ratio and the bit error rate. The optimum system parameters were determined for a specific BER.

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Introduction:

Optical communication is any form of telecommunication that uses light as the transmission medium.

An optical communication system consists of a transmitter, which encodes a message into an optical signal, a channel, which carries the signal to its destination, and a receiver, which reproduces the message from the received optical signal.

Other types of optical waveguides are used within communications gear, and have even formed the channel of very short distance (e.g. chip-to-chip, intra-chip) links in laboratory trials. The transmitters in optical fiber links are generally light-emitting diodes (LEDs) or laser diodes. Infrared light, rather than visible light is used more commonly, because optical fibers transmit infrared wavelengths with less attenuation and dispersion. The signal encoding is typically simple intensity modulation, although historically optical phase and frequency modulation have been demonstrated in the lab. The need for periodic signal regeneration was largely superseded by the introduction of the erbium-doped fiber amplifier, which extended link distances at significantly lower cost.

1.1) Fiber-optic communication

Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. First developed in the 1970s, fiber-optic communication systems have revolutionized the telecommunications industry and have played a major role in the advent of the Information Age, because of its advantages over electrical transmission; optical fibers have largely replaced copper wire communications in core networks in the developed world.

The process of communicating using fiber-optics involves the following basic steps:

Creating the optical signal involving the use of a transmitter:

1. Relaying the signal along the fiber
2. Ensuring that the signal does not become too distorted or weak.
3. Receiving the optical signal.
4. Converting it into an electrical signal.

1.2) History

The need for reliable long-distance communication systems has existed since antiquity. Over time, the sophistication of these systems has gradually improved, from smoke signals to telegraphs and finally to the first coaxial cable, put into service in 1940. As these communication systems improved, certain fundamental limitations presented themselves.

After a period of intensive research from 1975 to 1980, the first commercial fiber-optic communication system was developed, which operated at a wavelength around 0.8 μm and used GaAs semiconductor lasers.

1. This first generation system operated at a bit rate of 45 Mbit/s with repeater spacing of up to 10 km.

2.The second generation of fiber-optic communication was developed for commercial use in the early 1980s, operated at 1.3 μm, and used InGaAsP semiconductor lasers. Although these systems were initially limited by dispersion, in 1981 the single-mode fiber was revealed to greatly improve system performance. By 1987, these systems were operating at bit rates of up to 1.7 GB/s with repeater spacing up to 50 km.

3. Third-generation fiber-optic systems operated at 1.55 μm and had loss of about 0.2 dB/km. They achieved this despite earlier difficulties with pulse-spreading at that wavelength using conventional In GaAsP semiconductor lasers.

4. The fourth generation of fiber-optic communication systems used optical amplification to reduce the need for repeaters and wavelength-division multiplexing to increase fiber capacity. These two improvements caused a revolution that resulted in the doubling of

system capacity every 6 months starting in 1992 until a bit rate of 10 Tb/s was reached by 2001. Recently, bit-rates of up to 14 Tbit/s have been reached over a single 160 km line using optical amplifiers.

5. The focus of development for the fifth generation of fiber-optic communications is on extending the wavelength range over which a WDM system can operate. The conventional wavelength window, known as the C band, covers the wavelength range 1.53-1.57 µm, and the new dry fiber has a low-loss window promising an extension of that range to 1.30-1.65 µm. Other developments include the concept of "optical solutions," pulses that preserve their shape by counteracting the effects of dispersion with the nonlinear effects of the fiber by using pulses of a specific shape.

In the late 1990s through 2000, the fiber optic communication industry became associated with the dot-com bubble.

1.3) Technology

Modern fiber-optic communication systems generally include an optical transmitter to convert an electrical signal into an optical signal to send into the optical fiber, a cable containing bundles of multiple optical fibers that is routed through underground conduits and buildings, multiple kinds of amplifiers, and an optical receiver to recover the signal as an electrical signal. The information transmitted is typically digital information generated by computers, telephone systems, and cable television companies.

1.4) **Optical Transmission Link**

In the first part of this section, a general optical transmission link, shown in Fig: 1.1 is briefly described for which we assume that a digital pulse signal is transmitted over optical fiber unless otherwise specified. The optical link consists of an optical fiber, transmitter, receiver and amplifier.

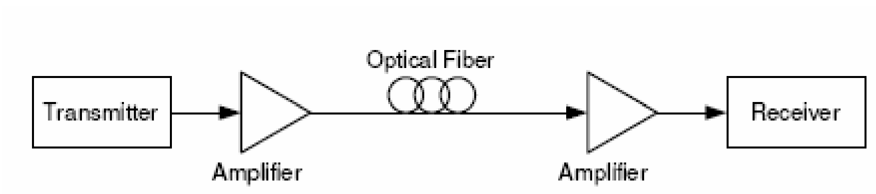

Figure 1.1: The optical transmission link

1.5) **Optical Modulation**

To transmit data across an optical fiber, the information must first be encoded, or modulated, onto the laser signal. Analog techniques include amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). Digital techniques include amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK). Of all these techniques, binary ASK currently is the preferred method of digital modulation because of its simplicity.

1.6) Optical Receivers

Photo detectors

In receivers employing direct detection, a photo detector converts the incoming photonic stream into a stream of electrons. The electron stream is then amplified and passed through a threshold device.

Whether a bit a logical zero or one is depends on whether the stream is above or below a certain threshold for bit duration. In other words, the decision is made based on whether or not light is present during the bit duration. The basic detection devices for direct–detection optical networks are the PN photodiode (a p-n junction) and the PIN photodiode (an intrinsic material is placed between p- and n- type material).

In its simplest form, the photodiode is basically a reverse-biased p-n junction. Through the photoelectric effect, light incident on the junction will create electron-hole pairs in both the “n” and the “p” regions of the photodiode. The electrons released in the “p” region will cross over to the “n” region, and the holes created in the “n” region will cross over to the “p” region, thereby resulting in a current flow.

1.7) Optical Amplifiers

Although an optical signal can propagate a long distance before it needs amplification, both long-haul and local light wave networks can benefit from optical amplifiers. All-optical amplification may differ from optoelectronic amplification in that it may act only to boost the power of a signal, not to restore the shape or timing of the signal. This type of amplification is known as 1R (regeneration), and provides total data transparency (the amplification process is independent of the signal’s modulation format). 1R amplification is emerging as the choice for the transparent all-optical networks of tomorrow. Today’s digital networks [e.g., Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH)],however, use the optical fiber only as a transmission medium, the optical signals are amplified by first converting the information stream into an electronic data signal and then retransmitting the signal optically. Optical amplification uses the principle of stimulated emission, similar to the approach used in a laser. The two basic types of optical amplifiers are semiconductor laser amplifiers and rare-earth-doped fiber amplifiers.

1.8) <u>Fiber</u>

Different Types of Fiber

Three basic types of fiber optic cable are used in communication systems:

1. Step-index multimode
2. Step-index single mode
3. Graded-index

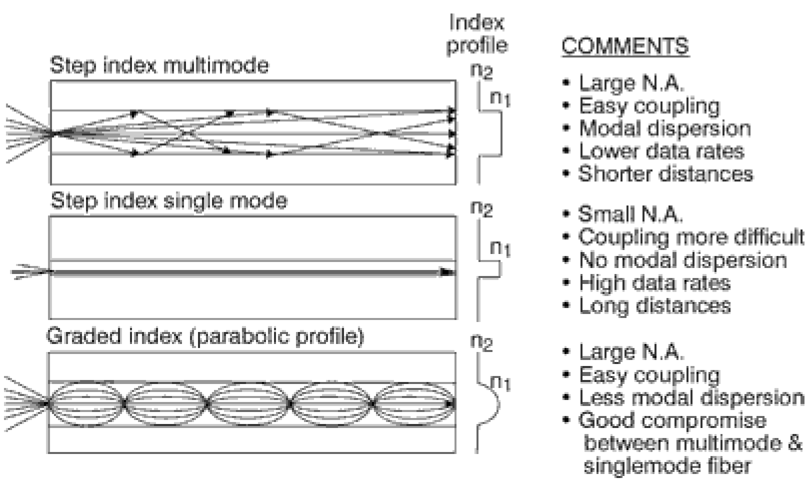

Figure1.2: Different types of fiber

Step-index multimode fiber has an index of refraction profile that steps from low to high to low as measured from cladding to core to cladding.

Single-mode step-index fiber allows for only one path, or mode, for light to travel within the fiber.

Graded-index fiber is a compromise between the large core diameter and N.A. of multimode fiber and the higher bandwidth of single-mode fiber.

An optical fiber consists of a core, cladding, and a buffer (a protective outer coating), in which the cladding guides the light along the core by using the method of total internal reflection. The core and the cladding (which has a lower-refractive-index) are usually made of high-quality silica glass, although they can both be made of plastic as well. Connecting two optical fibers is done by fusion splicing or mechanical splicing and requires special skills and interconnection technology due to the microscopic precision required to align the fiber cores. Two main types of optical fiber used in fiber optic communications include multi-mode optical fibers and single-mode optical fibers.

Optical fiber has two low-attenuation regions. Centered at approximately 1300 nm is a range of 200 nm in which attenuation is less than 0.5 dB/km. The total bandwidth in this region is about 25 T Hz. Centered at 1550 nm is a region of similar size with attenuation as low as 0.2 dB/km. Combined, these two regions provide a theoretical upper bound of 50 THz of bandwidth. By using these large low-attenuation areas for data transmission, the signal loss for a set of one or more wavelengths can be made very small, thus reducing the number of amplifiers and repeaters actually needed. Besides its enormous bandwidth and low attenuation, fiber also offers low error rates.

1.9) Optical Transmission in Fiber

Light can travel through any transparent material, but the speed of light will be slower in the material than in a vacuum. The ratio of the speed of light in a vacuum to that in a material is known as the material's *refractive index (n)* and is given by n = c/v, where c is the speed in a vacuum and v is the speed in the material. When light travels from one material of a given refractive index to another material of a different refractive index (i.e., when refraction occurs), the angle at which the light is transmitted in the second material depends on the refractive indices of the two materials as well as the angle at which light strikes the interface between the two materials. According to Snell's law

$\eta_a \sin\theta_a = \eta_b \sin\theta_b$

From Figure 1.3 we can see that the fiber consists of a core completely surrounded by a cladding (both of which consist of glass of different refractive indices). Let us first consider a step-index fiber, in which the change of refractive index at the core-cladding boundary is a step function. If the refractive index of the cladding is less than that of the core, then the total internal reflection can occur in the core and the light can propagate through the fiber as shown in Fig 1.4.

The angle above the total internal reflection will take place is known as the critical angle.

$\sin\theta_c = \eta_{clad} / \eta_{core}$

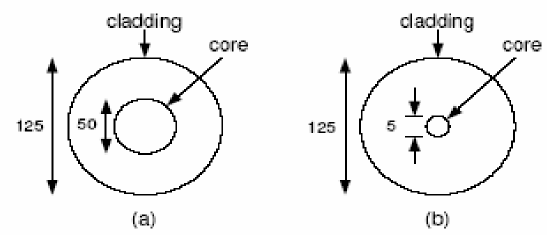

Figure 1.3: Multimode (a) single mode (b) optical fibers

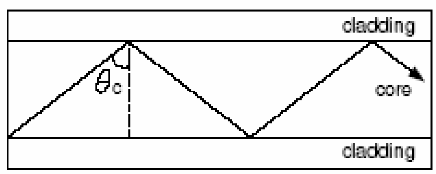

Figure 1.4: Light traveling via total internal reflection with an optical fiber

1.10) <u>Multimode and Single mode</u>

A mode in an optical fiber corresponds to one of the possible multiple ways in which a wave may propagate through the fiber. It can also be

For the light to enter a fiber, the incoming light should be at an angle such that the refraction at the air-core boundary results in the transmitted light's being at an angle for which total internal reflection can take place at the core-cladding boundary. The maximum value of θ_{air} is

$$\eta_{air} \sin\theta_{air} = \eta_{core} \sin(90^\circ - \theta_c)$$

We can rewrite it as $\eta_{air} \sin\theta_{air} = \sqrt{(\eta_{core}^2 - \eta_{clad}^2)}$

viewed as a standing wave in the transverse plane of the fiber. More formally, a mode corresponds to a solution of the wave equation that is derived from Maxwell's equations and subject to boundary conditions imposed by the optical fiber waveguide.

For some of these angles, light will not propagate due to destructive interference between the incident light and the reacted light at the core-cladding interface within the fiber. For other angles of incidence, the incident wave and the reacted wave at the core-cladding interface constructively interfere in order to maintain the propagation of the wave. If more than one mode propagates through a fiber, then the fiber is called multimode. In general, a larger core diameter or high operating frequency allows a greater number of modes to propagate.

The advantage of multimode fiber is that, its core diameter is relatively large; as a result, injection of light into the fiber with low coupling loss can be accomplished by using inexpensive, large-area light sources, such as light-emitting diodes (LED's). The disadvantage of multimode fiber is that it introduces the phenomenon of intermodal dispersion. In multimode fiber, each mode propagates at a different velocity due to different angles of incidence at the core-cladding boundary.

This effect causes different rays of light from the same source to arrive at the other end of the fiber at different times, resulting in a pulse that is spread out in the time domain. Intermodal dispersion increases with the distance of propagation, so that it limits the bit rate of the transmitted signal and the distance that the signal can travel.

Thus, in RoF networks multimode fiber is not utilized as much as possible, instead, single-mode fiber is widely used.

Single-mode fiber allows only one mode and usually has a core size of about 10 μm, while multimode fiber typically has a core size of 50–100 μm. It eliminates intermodal dispersion and hence can support transmission over much longer distances.

1.11) Wavelength-division multiplexing

Wavelength-division multiplexing (WDM) is the practice of dividing the wavelength capacity of an optical fiber into multiple channels in order to send more than one signal over the same fiber. This requires a wavelength division multiplexer in the transmitting equipment and a wavelength division demultiplexer (essentially a spectrometer) in the receiving equipment. Arrayed waveguide gratings are commonly used for multiplexing and demultiplexing in WDM. Using WDM technology now commercially available, the bandwidth of a fiber can be divided into as many as 80 channels to support a combined bit rate into the range of terabits per second.

1.12) Bandwidth-distance product

Because the effect of dispersion increases with the length of the fiber, a fiber transmission system is often characterized by its bandwidth-distance product, often expressed in units of MHz×km. This value is a product of bandwidth and distance because there is a trade off between the bandwidth of the signal and the distance it can be carried. For example, a common multimode fiber with bandwidth-distance product of 500 MHz×km could carry a 500 MHz signal for 1 km or a 1000 MHz signal for 0.5 km.

Through a combination of advances in dispersion management, wavelength-division multiplexing, and optical amplifiers, modern-day optical fibers can carry information at around 14 Terabits per second over 160 kilometers of fiber. Engineers are always looking at current limitations in order to improve fiber-optic communication, and several of these restrictions are currently being researched:

1.13) Dispersion

Dispersion is the widening of pulse duration as it travels through a fiber. As a pulse widens, it can broaden enough to interfere with neighboring pulses (bits) on the fiber, leading to intersymbol interference. Dispersion thus limits the bit spacing and the maximum transmission rate on a fiber-optic channel. As described earlier, one form of the dispersion is an intermodal dispersion. This is caused when multiple modes of the same signal propagate at different velocities along the fiber. Intermodal dispersion does not occur in a single-mode fiber.

Another form of dispersion is material or chromatic dispersion. In a dispersive medium, the index of refraction is a function of the wavelength. Thus, if the transmitted signal consists of more than one wavelength, certain wavelengths will propagate faster than other wavelengths. Since no laser scan create a signal consisting of an exact single wavelength, chromatic dispersion will occur in most systems.

A third type of dispersion is waveguide dispersion. Waveguide dispersion is caused as the propagation of different wavelengths depends on waveguide characteristics such as the indices and shape of the fiber core and cladding. At 1300 nm, chromatic dispersion in a conventional single-mode fiber is nearly zero. Luckily, this is also a low-attenuation window (although loss is higher than 1550 nm). Through advanced techniques such as dispersion shifting, fibers with zero dispersion at a wavelength between 1300–1700 nm can be manufactured.

The overall effect of dispersion on the performance of a fiber optic system is known as *intersymbol interference* shown in Figure 1.5 Intersymbol interference occurs when the pulse spreading caused by dispersion causes the output pulses of a system to overlap, rendering them undetectable.

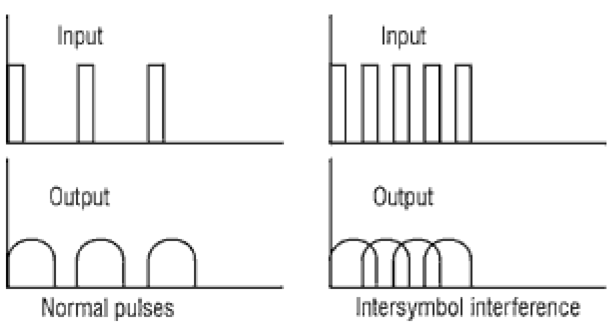

Fig 1.5: Intersymbol Interference

1.14) Attenuation

Fiber attenuation, which necessitates the use of amplification systems, is caused by a combination of material absorption, Rayleigh scattering, Mie scattering, and connection losses. Although material absorption for pure silica is only around 0.03 dB/km (modern fiber has attenuation around 0.3 dB/km), impurities in the original optical fibers caused attenuation of about 1000 dB/km. Other forms of attenuation are caused by physical stresses to the fiber, microscopic fluctuations in density, and imperfect splicing techniques.

Band	Description	Wavelength Range
O band	original	1260 to 1360 nm
E band	extended	1360 to 1460 nm
S band	short wavelengths	1460 to 1530 nm
C band	conventional ("erbium window")	1530 to 1565 nm
L band	long wavelengths	1565 to 1625 nm
U band	ultralong wavelengths	1625 to 1675 nm

Comparison with electrical transmission

An underground fiber optic splice enclosure opened for splicing.

The choice between optical fiber and electrical (or copper) transmission for a particular system is made based on a number of trades-offs. Optical fiber is generally chosen for systems requiring higher bandwidth or spanning longer distances than electrical cabling can accommodate. The main benefits of fiber are its exceptionally low loss, allowing long distances between amplifiers or repeaters; and its inherently high data-carrying capacity, such that thousands of electrical links would be required to replace a single high bandwidth fiber cable. Another benefit of fibers is that even when run alongside each other for long distances, fiber cables experience effectively no crosstalk, in contrast to some types of electrical transmission lines. Fiber can be installed in areas with high electromagnetic interference (EMI),(along the sides of utility lines, power-carrying lines, and railroad tracks). All-dielectric cables are also ideal for areas of high lightning-strike incidence.

In certain situations fiber may be used even for short distance or low bandwidth applications, due to other important features:

- Immunity to electromagnetic interference, including nuclear electromagnetic pulses (although fiber can be damaged by alpha and beta radiation).
- High electrical resistance, making it safe to use near high-voltage equipment or between areas with different earth potentials.
- Lighter weight—important, for example, in aircraft.
- No sparks—important in flammable or explosive gas environments.
- Not electromagnetically radiating, and difficult to tap without disrupting the signal—important in high-security environments.
- Much smaller cable size—important where pathway is limited, such as networking an existing building, where smaller channels can be drilled and space can be saved in existing cable ducts and trays.

Optical fiber cables can be installed in buildings with the same equipment that is used to install copper and coaxial cables, with some modifications due to the small size and limited pull tension and bend radius of optical cables. Optical cables can typically be installed in duct systems in spans of 6000 meters or more depending on the duct's condition, layout of the duct system, and installation technique. Longer cables can be coiled at an intermediate point and pulled farther into the duct system as necessary.

1.15) Multiplexing techniques

Multiplexing is the process where multiple channels are combined for transmission over a common transmission path.

There are two predominant ways to multiplex:

i) Frequency Division Multiplexing

ii) Time Division Multiplexing

Frequency Division Multiplexing (FDM)

In FDM, multiple channels are combined onto a single aggregate signal for transmission. The channels are separated in the aggregate by their FREQUENCY.

There are always some unused frequency spaces between channels, known as "guard bands". These guard bands reduce the effects of "bleed over" between adjacent channels, a condition more commonly referred to as "crosstalk". FDM was the first multiplexing scheme to enjoy wide scale network deployment, and such systems are still in use today. However, Time Division Multiplexing is the preferred approach today, due to its ability to support native data I/O (Input/Output) channels.

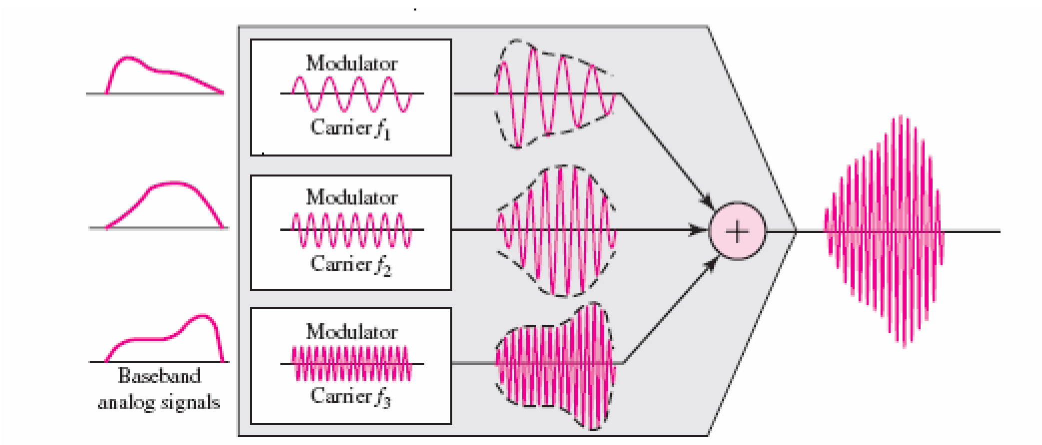

Figure1.6: Frequency Division Multiplexing (FDM)

1.16) FDM Data Channel Applications

Data channel FDM multiplexing is usually accomplished by "modem stacking". In this case, a data channel's modem is set to a specific operating frequency. Different modems with different frequencies could be combined over a single voice line. As the number of these "bridged" modems on a specific line changes, the individual modem outputs need adjustment ("tweaking") so that the proper composite level is maintained. This VF level is known as the "Composite Data Transmission Level" and is almost universally -13 dBm0.

1.17) FDM Voice Channel Applications

Amplitude Modulation (AM), using Single Sideband-Suppressed Carrier (SSB-SC) techniques, is used for voice channel multiplexing. Basically, a 4 KHz signal is multiplexed ("heterodyned") using AM techniques. Filtering removes the upper sideband and the carrier signal. Other channels are multiplexed as well, but use different carrier frequencies.

Advances in radio technology, particularly the developments of the Reflex Klystron and integrated modulators, resulted in huge FDM networks. One of the most predominate FDM schemes was known as "L-Carrier", suitable for transmission over coaxial cable and wideband radio systems.

1.18) Time Division Multiplexing

Timeplex is probably the best in the business (IMHO) at Time Division Multiplexing, as it has 25+ years or experience. When Timeplex was started by a couple of ex-Western Union guys in 1969 it was among the first commercial TDM companies in the United States. In fact, "Timeplex" was derived from TIME division multiplexing! In Time Division Multiplexing, channels "share" the common aggregate based upon time! There are a variety of TDM schemes, discussed in the following sections:

Conventional Time Division multiplexing

Statistical Time Division multiplexing

1.19) Cell-Relay/ATM Multiplexing

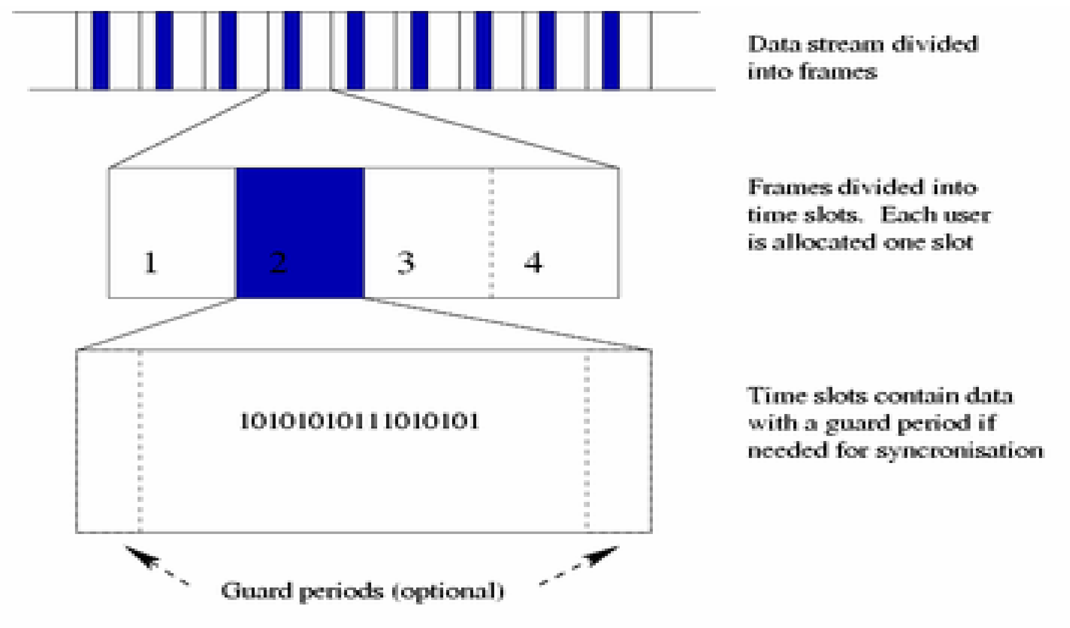

Figure1.7: Cell-Relay/ATM Multiplexing

1.20) Bit-Interleaved Multiplexing

In Bit-Interleaved TDM, a single data bit from an I/O port is output to the aggregate channel. This is followed by a data bit from another I/O port (channel), and so on, and so on, with the process repeating itself.

A "time slice" is reserved on the aggregate channel for each individual I/O port. Since these "time slices" for each I/O port are known to both the transmitter and receiver, the only requirement is for the transmitter and receiver to be in-step; that is to say, being at the right place (I/O port) at the right time. This is accomplished through the use of a synchronization channel between the two multiplexers.

The synchronization channel transports a fixed pattern that the receiver uses to acquire synchronization.

Bit-Interleaved TDM is simple and efficient and requires little or no buffering of I/O data. A single data bit from each I/O channel is sampled, then interleaved and output in a high speed data stream.

1.21) <u>Byte-Interleaved Multiplexing</u>

In Byte-Interleaved multiplexing, complete words (bytes) from the I/O channels are placed sequentially, one after another, onto the high speed aggregate channel. Again, a synchronization channel is used to synchronize the multiplexers at each end of the communications facility.

For an I/O payload that consists of synchronous channels only, the total I/O bandwidth cannot exceed that of the aggregate (minus the synchronization channel bandwidth). But for asynchronous I/O channels, the aggregate bandwidth CAN BE EXCEEDED if the aggregate byte size is LESS than the total asynchronous I/O character size (Start + Data + Stop bits).

1.22) <u>Statistical Time Division Multiplexing (STDM)</u>

Statistical TDMs are such that they only utilize aggregate bandwidth when there is actual data to be transported from I/O ports. Data STDMs can be divided into two categories: Conventional STDM, Frame Relay/X.25 Networking

1.23) <u>DEMULTIPLEXING</u>

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Separating two or more signals that have been combined into one signal.

Demultiplexing is the extraction of the original channels on the receiver side. A device that performs the demultiplexing process is called a demultiplexer (DEMUX). The demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals. The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines.

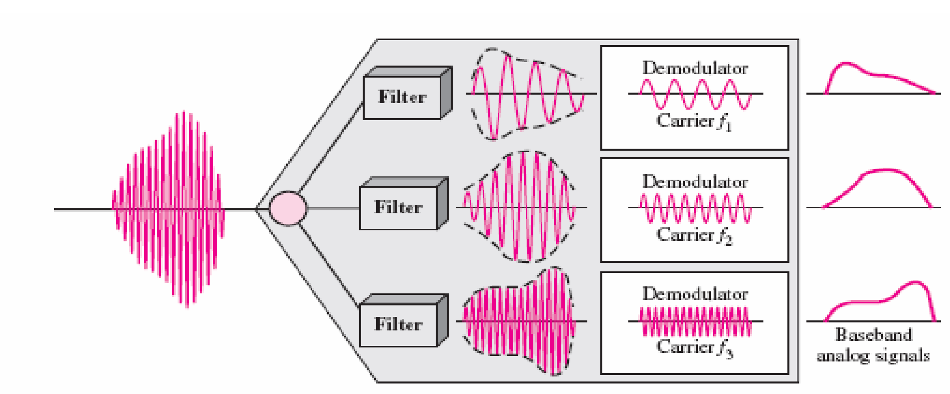

Figure1.8: Demultiplexing

1.24) Merging of the Wireless and Fiber optic Worlds

Current trends in cellular networks in mobile are to reduce cell size to accommodate more users. It demands a large number of base stations to cover a service area. Base stations are cost effective. This requirement has led to the development of system architecture where functions such as signal routing and processing, handover and frequency allocation are carried out at a central control station , rather than at the Base Station.

Centralized configuration like this one allows sensitive equipment to be located in safer environment and enables the cost of expensive components to be shared among several Base Stations. To link a Central Station with Base Stations in such a radio network is via an optical fiber network, since fiber has low loss, is immune to EMI and has broad bandwidth. To minimize costs the process to follow is transmission of radio signals over fiber, with simple optical-to-electrical conversion, followed by radiation at remote antennas, which are connected to a Central Station. The resources provided by the Central Station among many antenna technique of modulating the radio frequency subcarrier onto an optical carrier for distribution over a fiber network it is known as “radio over fiber” (RoF) technology.

Optical fiber microcellular systems, in which microcells in a wide area are connected by optical fiber and radio signals are over an optical fiber link among base stations and control stations, has attracted much attention. This is because of

i) The low loss and enormous bandwidth of optical fiber

ii) The increasing demand for capacity or coverage

iii) The benefits it offers in terms of low-cost base station deployment in microcellular systems.

To be specific, the RoF network typically comprises a central Central Station, where all switching, routing, medium access control (MAC) and frequency management functions are performed, and an optical fiber network, which interconnects a large number of Base Stations for wireless signal distribution. The Base Station has no processing function and its main function is to convert optical signal to wireless one and vice versa. Radio over fiber's applications range are mobile cellular networks, wireless local area network (WLAN) at mm-wave bands broadband wireless access networks to road vehicle communication (RVC) networks for intelligent transportation system (ITS). System cost for deploying infrastructure can be dramatically reduced compared to other wire line alternatives due to simple Base station structure. Some of its characteristics are described below

• The system control functions, such as frequency allocation, modulation and demodulation scheme, are located within the Control Station, simplifying the design of the Base Stations. The primary functions of the BSs are optical to Radio Frequency conversion, Radio Frequency amplification, and Radio Frequency to optical conversion.

• Centralized network architecture allows a dynamic radio resource configuration and capacity allocation.
• Due to simple Base Station structure, its reliability is a lot high and system maintenance becomes simple.
• Optical fiber in Radio Over Fiber is transparent to modulation, radio frequency, bit rate so multiple services on a single fiber can be supported at same time
• Large distances between the Central Station and Base Station are possible.

Most of the complexity is in the base stations. To reduce number of base station alternative is to move the complex portions of the network to a central processing location where the number of expensive signal processing elements can be reduced by greater sharing among users.

By using highly linear optical fiber links to distribute Radio Frequency signals from a central location to radio access points (RAPs) Radio Over Fiber allows the RAPs to be extremely simple since they only need to contain optoelectronic conversion devices and amplifiers. All communication functions such as coding, modulation and up conversion can be performed at a central location.

A simple Radio Access Point means easier and more flexible installation and low cost of equipment and maintenance. Centralization results in equipment sharing, dynamic source allocation and more effective management. This technology makes life easier and cheaper for operators.

Radio over Fiber is able to shift complexity away from the antenna because optical fiber is an excellent low-loss (0.2 dB/km optical loss at 1550 nm) and high bandwidth (50 THz) transmission medium.

In this process transmission takes place at the radio carrier frequency rather than the more conventional digital base band systems. The optical links in Radio over Fiber are therefore analog in nature, and they reproduce the carrier waveform. The radio carrier can be modulated with a digital modulation scheme such as GMSK (in GSM) or QPSK (in UMTS).

Radio Over Fiber links has reduced number of base station or remote antenna unit. Reducing the remote base station complexity is attractive because equipment, construction, and maintenance costs may be reduced.

Base station and remote antenna unit density can be increased economically which leads to lower power mobiles and higher bandwidth transmission. Increased wireless and optical network incorporation is therefore seen as a reasonable means of decreasing costs in voice and data networks, while increasing network capacity. This solution increases the frequency reuse enables broadband access by providing a micro cell scenario for cellular radio networks. The micro/picot cell scenario is possible through the use of radio access point (RAP).

Instead of usual base station these inexpensive low power Radio Access Points provide wireless access. It is important to keep the Radio Access Points complexity and cost at a minimum in order to allow for large scales deployment. By doing so, a large cell can easily be split into smaller cells by dispersing Radio Access Points throughout. The robust Radio Access Points are connected to the central base station via the RoF links.

1.25) <u>Radio Over Fiber System</u>

In a micro cellular system, each microcell radio port would consist of a simple and compact optoelectronic repeater connected by an Radio Frequency fiber optic link to centralized radio and control equipment, possibly located at a preexisting macrocell site.
The much lower power level eliminates the need for the expensive frequency multiplexes or high-power amplifiers currently employed at base stations. The limited coverage due to low antenna height greatly reduces the co-channel interference from other cells. RoF systems are now being used extensively for enhanced cellular coverage inside buildings such as offices, shopping malls and airport terminals.

A microcellular network can be implemented by using fiber-fed distributed antenna networks as shown in Figure 1.9. The received Radio Frequency signals at each remote antenna are transmitted over an analog optical fiber link to a central base station where all the de-multiplexing and signal processing are done. Each remote antenna site simply consists of a linear analog optical transmitter, an amplifier and the antenna.

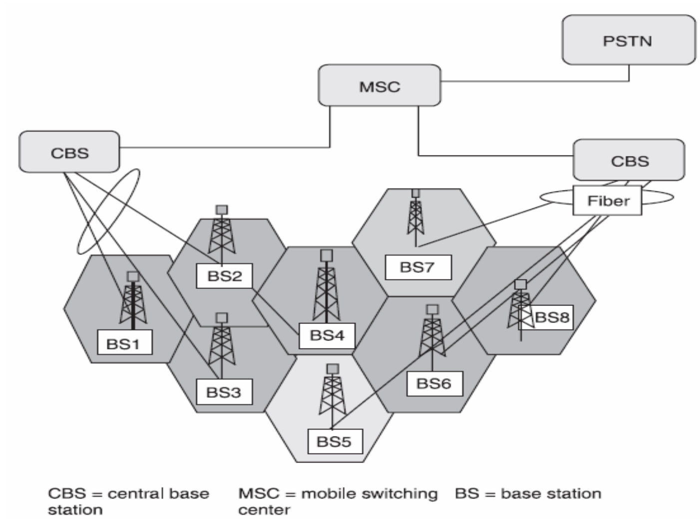

Fig1.9: Optically fed remote antenna network for microcellular RoF systems

1.26) <u>Advantages of Using RoF In Mobile Communication Networks</u>

The radio network is a distributed antenna system and its channel allocation is used to increase the spectrum efficiency. The distributed antenna system provides an infrastructure that brings the radio interface very close to the users. Some of its benefits are as follows:

1) Low Radio Frequency power remote antenna points
2) Line-of sight operation and multipath effects are minimized
3) Enabling of mobile broadband radio access close to the user in an economically acceptable way

4) Reduced environment impact (small RAPs)

5) Good coverage

6) Capacity enhancement by means of improved trucking efficiency

7) Dynamic radio resource configuration and capacity allocation

8) Alleviation of the cell planning problem

9) Reduction in the number of handovers

10) Centralized upgrading or adaptation

11) Higher reliability and lower maintenance costs

12) Support for future broadband multimedia applications

13) Better coverage and increased capacity

14) High-quality signals

15) Low fiber attenuation (up to 0.2dB/km)

16) Reduced engineering and system design costs

17) Multiple services on a single fiber

18) Lightweight fiber cables

19) No electromagnetic interference

20) Reliability

The use of low Radio Frequency power Radio Access Points has following advantages:

1) Low interference

2) Increased spectrum efficiency

3) Easier frequency and network planning

4) Increased battery lifetime of mobile terminals

5) Relaxed human health issues

1.27) Benefits And Applications of Radio over Fiber Systems

Low Attenuation Loss

Electrical distribution of high frequency microwave signals either in free space or through transmission lines is problematic and costly. In free space, losses due to absorption and reflection increase with frequency. In transmission lines, impedance rises with frequency as well. Therefore, distributing high frequency radio signals electrically over long distances requires expensive regenerating equipment. Hence it is feasible to use optical fibers which has low loss. Commercially available standard Single Mode Fiber (SMFs) made from glass (silica) have attenuation losses below 0.2 dB/km and 0.5 dB/km in the 1.5 μm and the 1.3 μm windows respectively.

Another type of fiber called Polymer Optical Fiber (POFs) exhibits higher attenuation ranging from 10 – 40 dB/km in the 500 – 1300 nm regions. These losses are much lower than those encountered in free space propagation and copper wire transmission of high frequency microwaves.

Hence by transmitting microwaves in the optical form, transmission distances are increased several folds and the required transmission powers reduced greatly.

Large bandwidth

Large amount of bandwidth can be offered in Optical fiber. There are three main transmission windows, which offer low attenuation. They are 1310 nm and 1550 nm wavelengths. If a lot of bandwidth is to be gained than out of the optical fiber than low dispersion (or dispersion shifted) fiber is required, the Erbium Doped Fiber Amplifier (EDFA) for the 1550 nm window, and the use of advanced multiplex techniques which are Optical Time Division Multiplexing (OTDM) in combination with Dense Wavelength Division Multiplex (DWDM) techniques.

Optical fibers offer enormous bandwidth and has other benefits apart from the high capacity for transmitting microwave signals. High speed signal processing is achieved from high optical bandwidth, that may be more difficult or impossible to do in electronic systems. Hence some of the important microwave functions such as filtering, mixing, up- and down-conversion, can be implemented in this optical domain.

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Reduced Power Consumption

Due to having simple Radio Stations, reduced power consumption is achieved. Most of the complex equipment is kept at the central Station. In some applications, the antenna sites are operated in inactive mode. For instance, some 5 GHz Fiber-Radio systems having picocells (small radio cells) can have the Base Stations to operate in inactive mode. Reduced power consumption at the Radio

Dynamic Resource Allocation

Radio over Fiber does offer operational benefits in terms of operational flexibility. The Intensity Modulation and Direct Detection (IMDD) technique can be made to operate as a linear system.
This is achieved by using low dispersion fiber (SMF) in combination with pre modulated Radio over Fiber sub carriers (SCM). The same Radio over fiber network can be used to distribute multi-operator and multi-service traffic which results in huge economic savings.

For GSM Traffic in Radio Over Fiber based distribution system more capacity can be allocated to an area like shopping malls during peak times and then re-allocated to other areas during off-peak times, like to the populated residential areas in the evenings. This can be achieved by allocating optical wavelengths as the need arises.

Satellite Communications

One of the first uses of Radio over Fiber technology was Satellite communications.
One of the applications involves the remoting of antennas to suitable locations at satellite earth stations. In this case, small optical fiber links of less than 1km and operating at frequencies between 1 GHz and 15 GHz are used. By so doing, high frequency equipment can be centralized.
The second application involves the remoting of earth stations themselves. With the use of Radio over Fiber technology the antennae can be positioned many kilometers away for the purpose of improved satellite visibility or reduction in interference from other terrestrial systems.

Wireless Lans

As portable devices and computers have become more and more powerful as well as widespread, the demand for mobile broadband access to LANs will be increasing. This will lead to higher carrier frequencies to meet the demand for capacity. Higher carrier frequencies in turn lead to microcells and picocells, and all the difficulties associated with coverage discussed above arise. A cost effective way around this problem is to deploy RoF technology.

Vehicle Communication and Control

Vehicle Communication and control is another potential application of Radio over Fiber technology. Frequencies between 63-64 GHz and 76-77 GHz have already been allocated for this service within Europe. The objective is to provide continuous mobile communication coverage on major roads for the purpose of Intelligent Transport Systems (ITS) such as Road-to-Vehicle Communication (RVC) and Inter-Vehicle Communication (IVC). ITS systems aim to provide traffic information, improve transportation efficiency, reduce burden on drivers, and contribute to the improvement of the environment. In order to achieve the required coverage of the road network, numerous base stations are required. These can be made simple and of low cost by feeding them through RoF systems, thereby making the complete system cost effective and manageable

1.28) Subcarrier Multiplexing

Optical Subcarrier multiplexing (SCM) is a scheme where lots of signals are multiplexed in the radio frequency(RF) domain and transmitted by a single wavelength. SCM has an advantage that microwave devices are more matured than optical devices.

A popular application of SCM technology in fiber optic systems is analog cable television (CATV) distribution system. Because of the simple and low-cost implementation, SCM has also been proposed to transmit multichannel digital optical signals using direct detection for local area optical networks.

The basic configuration of SCM optical system is shown below in **Figure 1.10**

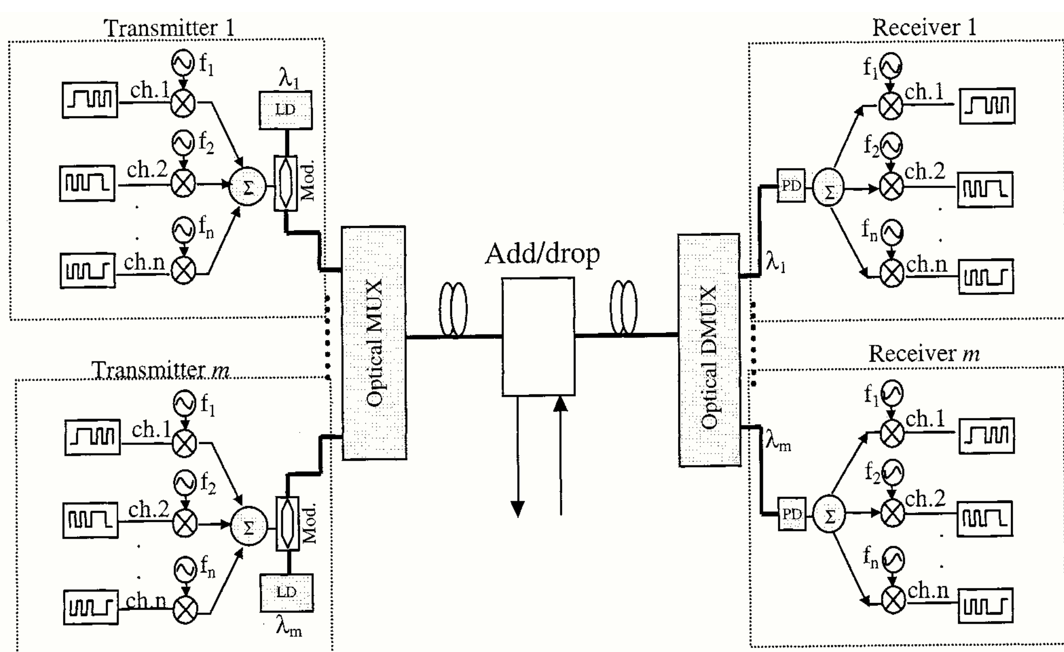


Figure 1.10: The basic configuration of SCM optical system

In this example n independent high speed digital signals are mixed by N different microwave carrier frequencies $f_{i.}$ These are combined and optically modulated onto an optical carrier. m wavelengths are then multiplexed together in an optical WDM configuration. At the receiver an optical demultiplexer separates the wavelengths for individual optical detectors. To separate digital signal channels Radio Frequency coherent detection is used.

SCM is less sensitive to fiber dispersion because the dispersion penalty is determined by the width of the baseband of each individual signal channel. Compared to conventional
WDM systems, on the other hand, it has better optical spectral efficiency because much narrower channel spacing is allowed.

Conventional SCM generally occupies a wide modulation bandwidth because of its double-sideband spectrum structure and, therefore, is susceptible to chromatic dispersion. In order to reduce dispersion penalty and increase optical bandwidth efficiency, optical SSB modulation is essential for long-haul SCM–WDM optical systems. Fortunately, optical SSB is relatively easy to accomplish in SCM systems. This is because there are no low-frequency components, and the Hilbert transformation is, thus, much simpler than OSSB in conventional TDM systems.

Chapter-2

Analysis & system model

2.0) SYSTEM MODEL

The system model considered for analysis is shown in Figure 2.1

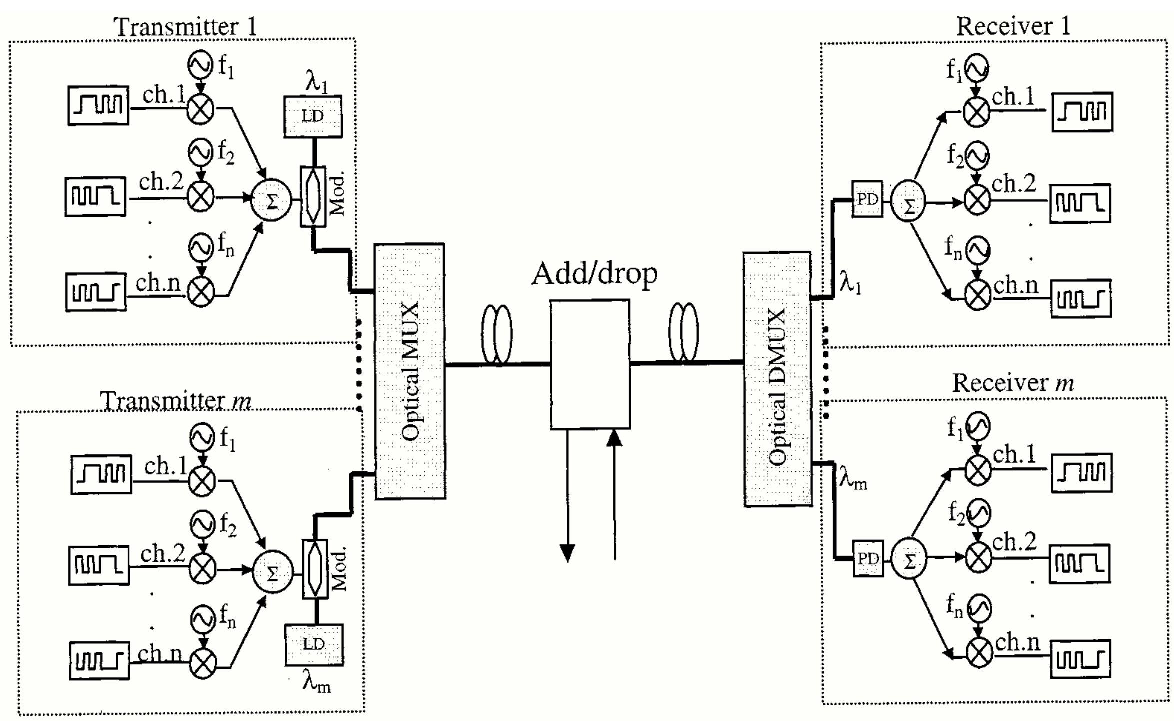


Figure 2.1: Subcarrier multiplexing System Architecture

In this example n independent high speed digital signals are mixed by N different microwave carrier frequencies f_i. These are combined and optically modulated onto an optical carrier. m wavelengths are then multiplexed together in an optical WDM configuration. At the receiver an optical demultiplexer separates the wavelengths for individual optical detectors. To separate digital signal channels Radio Frequency coherent detection is used.

Another system model considered for analysis is shown in Figure 2.2

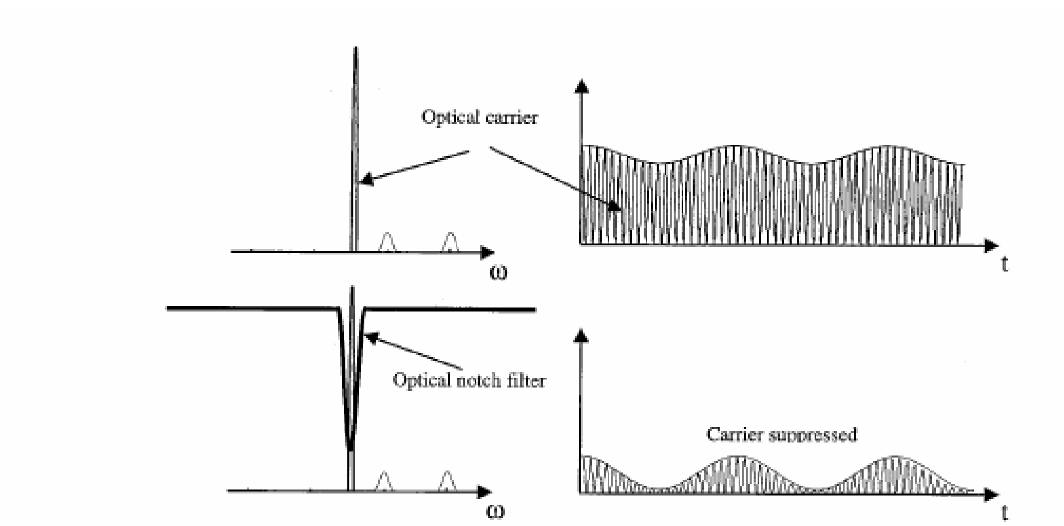


Figure 2.2: Optical Carrier Suppression

Fig 2.2 illustrates the optical carrier suppression. The carrier cannot be completely suppressed because the energy in the carrier must be equal to or higher than that of the signal. Otherwise, signal clipping will occur, which may introduce significant waveform distortion.

Another system model considered for analysis is shown in Figure 2.3.

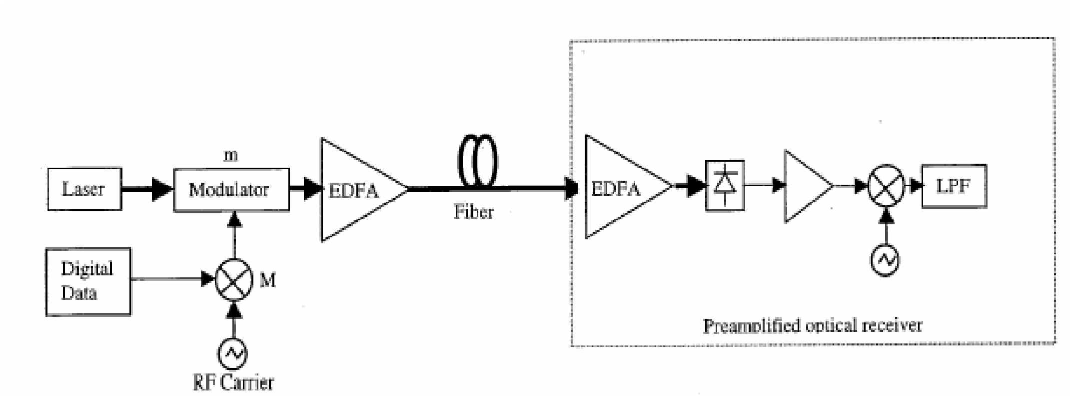


Figure 2.3: SCM system with amplified optical receiver

Here in the block diagram the sensitivity was analyzed of a digital SCM system with an optically preamplified receiver.

2.1) ANALYSIS

2.1.0) Carrier Suppression

Intermodulation distortion is an important issue in an SCM system. This mainly comes from nonlinear modulation characteristics of opto electronics modulator. For an OSSB modulation using a dual-electrode MZ modulator, if the modulator is single-frequency modulated by the cosΏt, the output optical field is

$E_0 = E_i/2\ \{\cos[\omega_c t + (\pi/2) + \beta\pi \cos Ώt] + \cos[\omega_c t + \beta\pi \cos(Ώt + (\pi/2))]\}$

Where Ei (t) is the input optical field, $\omega_c = 2\pi f_c$ is the light wave carrier frequency

Ώ is the RF frequency of the modulation

βπ= normalized amplitude of the RF drive signal

If Bπ is too high than this introduces cross talk between channels. Hence βπ «1 must be maintained. A small modulation index means inefficient modulation and poor receiver sensitivity because the strong carrier component does not carry information.

In order to increase the modulation efficiency while maintaining reasonably good linearity, optical carrier suppression may be applied using an optical notch filter.

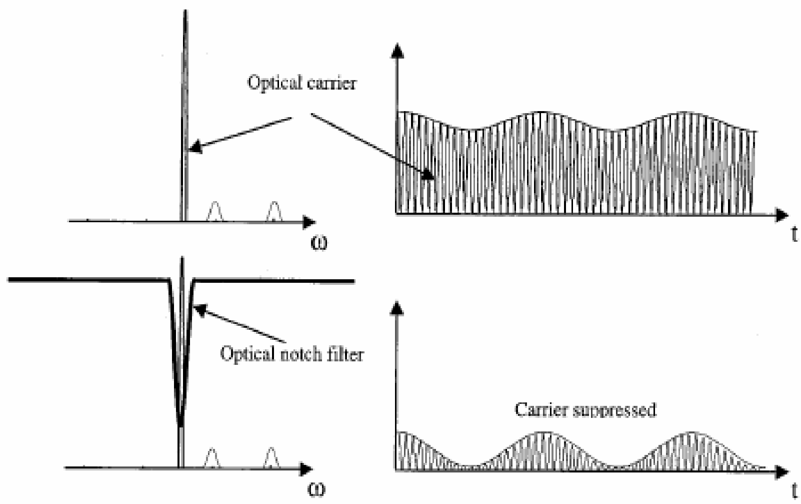


Figure 2.2: Optical Carrier Suppression

The carrier cannot be completely suppressed because the energy in the carrier must be equal to or higher than that of the signal. Otherwise, signal clipping will occur, which may introduce significant waveform distortion.

2.1.1) Receiver sensitivity

The sensitivity of a digital SCM system is analyzed with an optically preamplified receiver. A simplified block diagram of this system is shown in

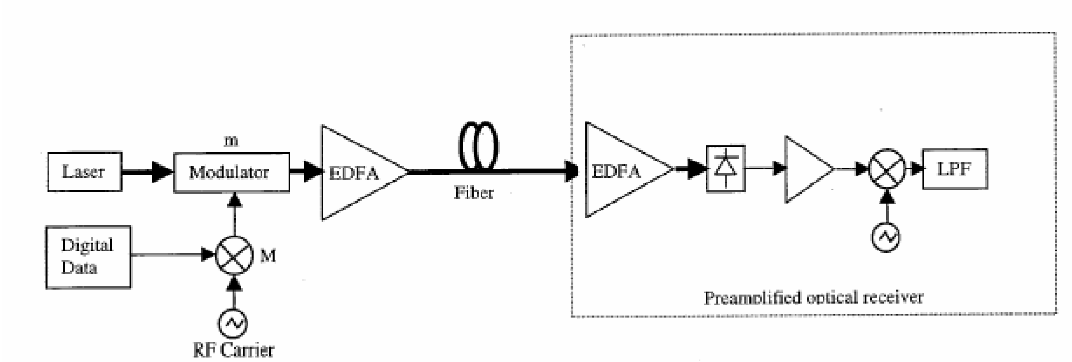


Figure 2.3: SCM system with amplified optical receiver

In a SCM optical system there are N subcarrier channels. The output electrical field from modulator is

$E_{0=}$ $(E_i/2)\{\cos[\omega_c t - \Sigma^N_{k=1} u_k(t)\, \beta_k\, \pi \sin \Omega_k t] - \sin[\omega_c t + \Sigma^N_{k=1} u_k(t)\, \beta_k\, \pi \cos \Omega_k t]\}$------(1)

Where

$u_k(t)$ = is the normalized digital signal at the kth subcarrier channel

ω_c= is the carrier frequency

Ω_k = is the RF is the subcarrier frequency of the *k*th channel

To keep high order harmonics small and to operate the modulator in linear region, the modulation has to be weak. The assumption for smaal signal modulation

$|\Sigma^N_{k=1} \beta_k \pi| \ll 1$

Equation (1) is linearized as

$E_{0=}$ $(E_i/2)\{\sin(\omega_c t - \pi/4) - (1/\sqrt{2})\, \Sigma^N_{k=1} u_k(t)\, \beta_k\, \pi \cos(\omega_{c+}\Omega_k)t\}$-------------(2)

If carrier suppression is considered equation (2) can be modified as

$E_{0=}$ $(E_i/2)\{\sin(\omega_c t-\pi/4)\sqrt{\zeta}-(1/\sqrt{2})\,\Sigma^{N}_{k=1}u_k(t)\,\beta_k\,\pi\,\cos(\omega_{c+}\acute{\Omega}_k)t\}$----------(3)

Where $0\leq\zeta\leq1$ is the power suppression ratio of the carrier

At the receiver the optical carrier beats with the subcarriers at the photo diodes, converting the optical subcarrier into the RF domain.

The generated photocurrent at the receiver is

$I_0=\eta\zeta G\acute{R}E_i^2/2=P_{in}G\acute{R}$

Pin= is the average power of the optical signal reaching reaching the pre amplified optical receiver

$m_k=\sqrt{2}\,\beta_k\,\pi$ is the normalized modulation index

In order to calculate the receiver sensitivity, amplified spontaneous emission (ASE) noise generated by the EDFA preamplifier must be considered. The ASE noise spectral density is

$\rho_{ASE}=2n_{sp}hv(G-1)=Fhv(G-1)$ --(4)

where

n_{sp}= the spontaneous emission factor

F= noise figure of EDFA

h= Planck's constant

v= optical frequency

G=optical gain of EDFA

The double sideband electrical power spectral density of signal ASE beat noise is

$<i^2_{sig\text{-}sp}>=(1/2)\, Ŕ^2 2\, \rho_{ASE}\, Pin\, G$--*(5)*

The total alternating current (ac) signal of the kth RF channel entering the RF demodulator is

$U_1=\{Pin\, G\, Ŕ\, m_k\, u_k(t) \cos(Ώ_k t)\}/\sqrt{\zeta} + \{n_c(t)\cos(Ώ_k t)+n_s(t)\sin(Ώ_k t)$-----(6)

Where $n_c(t)$ and $n_s(t)$ are quadrature components

Total noise power is $(1/2)\, n_c^2 + (1/2)\, n_s^2=2B_e<i^2_{sig\text{-}sp}>$

$=2Ŕ^2\, \rho_{ASE}\, PinGBe$

Where B_e = spectral width of the signal baseband

At the RF demodulator, $U_1(t)$ coherently mixes with a local oscillator $2\cos(Ώ_k t)$

And the output of the demodulator is

$U_2= (Pin\, GŔ\, m_k\, u_k(t))/\sqrt{\zeta} + (n_c(t))$

Assuming G »1, SNR is

$SNR= \{(Pin\, G\, Ŕ\, m_k\, u_k(t)) / \sqrt{\zeta}\}/\{\sqrt{(2Ŕ^2\, \rho_{ASE}\, Pin\, G\, B_e)}\}$

$= \{(Pin\, GŔ\, m_k\, u_k(t))/\sqrt{\zeta}\}/\{\sqrt{(2Ŕ^2\, P_{in} Fhv(G-1)GB_e)}\}$

$=\sqrt{((Pin\, m_k^2 u_k^2(t))/(2FhBe\zeta))}$

3.0) RESULTS AND DISCUSSION

Figure 1

SNR or Signal to Noise ratio is plotted as a function of input power (Pin) in dbm in Figure: 1

SNR= $\sqrt{(Pin\ m_k^2 u_k^2(t))/(2FhBe\zeta)}$

Values taken for Figure 1:

m_k= 1

$u_k(t)$= 1

F=1

ζ =1

Where

Pin= is the average power of the optical signal reaching reaching the pre amplified optical receiver

m_k= normalized modulation index

$u_k(t)$= normalized digital signal at the kth subcarrier channel

h= Planks constant

F= noise figure of EDFA

Be= spectral width of the signal baseband

ζ = power suppression ratio of carrier

SNR or Signal to Noise ratio is plotted as a function of input power (Pin) in dbm in Figure: 1

Here the value of Rb(bit rate) is 10GHz. The Pin is taken from range -60 dbm to -40 dbm. The SNR is calculated from the equation

SNR= $\sqrt{((Pin\ m_k^2 u_k^2(t))/(2FhBe\zeta))}$

The resulting graph of SNR VS Pin is plotted above. It is seen that the SNR increases with increase in Pin.

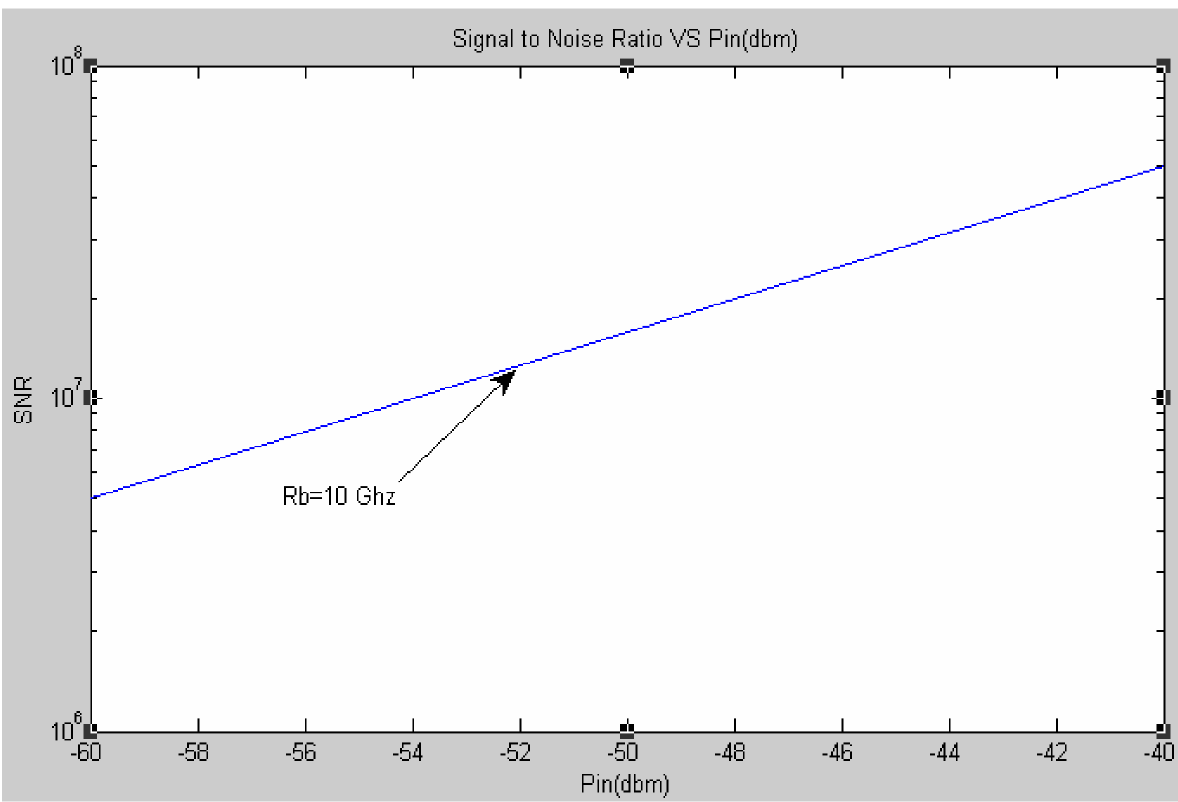


Figure 1: Signal to Noise ratio (SNR) VS Input power (Pin)

Figure 2:

This is a plot of SNR (signal to noise ratio) VS Pin for different bit rates. Here different values of Rb (bit rate) were taken and have been shown in the graph. Than the corresponding values of SNR is plotted against Pin for the corresponding different values of Rb. The Pin is taken from range -60 dbm to -40 dbm.

T

he SNR is calculated from the equation

SNR= $\sqrt{((Pin\ m_k^2 u_k^2(t))/(2FhBe\zeta))}$

The resulting graph of SNR VS Pin is plotted above. It is seen that the SNR increases with increase in Pin. As SNR increases noise decreases, power increases and the bandwidth increases. For the lowest bit rate we got highest SNR. Hence more bandwidth is achieved with increasing SNR.

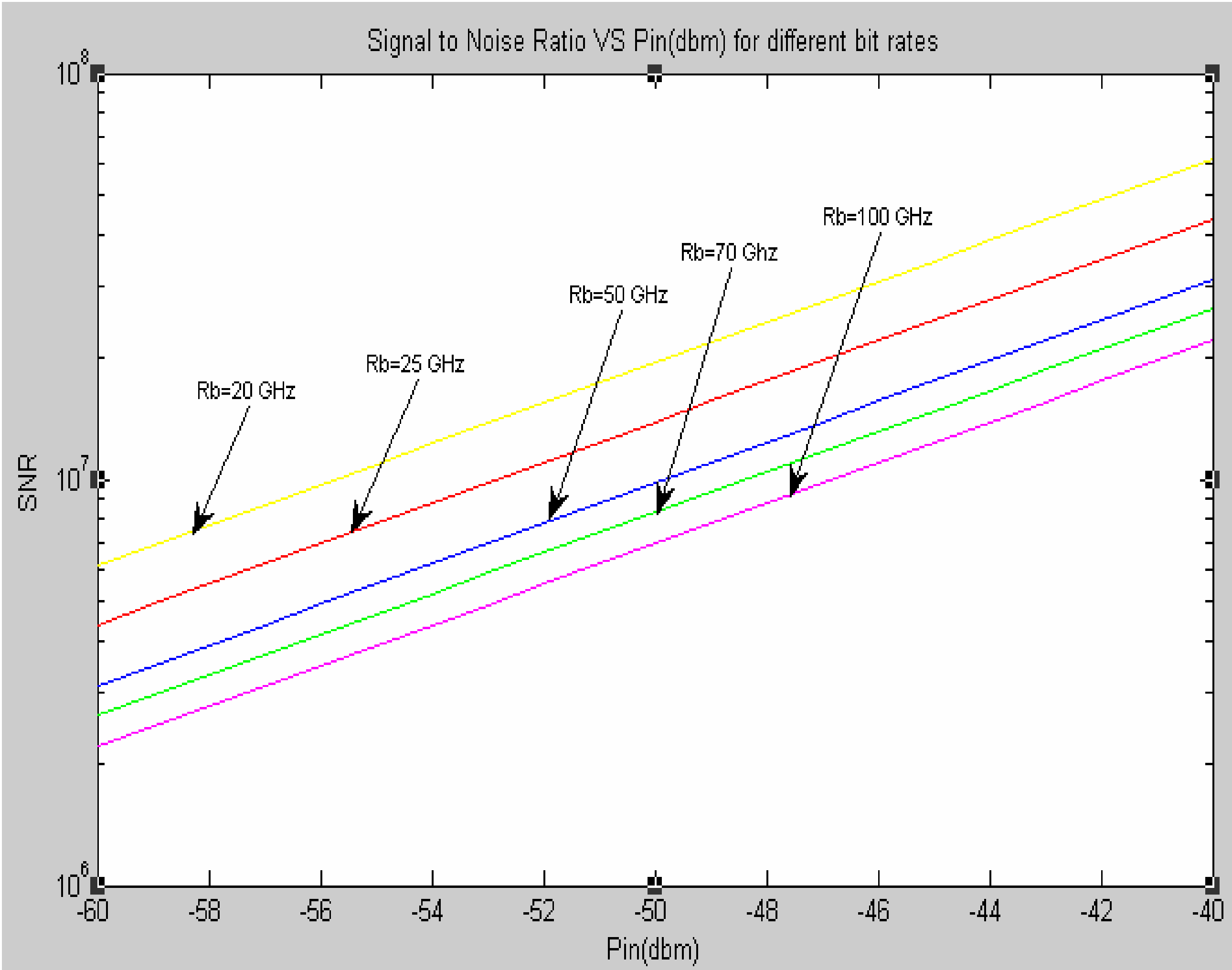


Figure 2: Signal to Noise Ratio VS Pin(dbm) for different bit rates

Figure 3:

Figure below shows Bit Error Rate (BER) plotted against Pin(dbm). Here Rb is 10 GHz as shown in the graph below. The Pin is taken from range -60 dbm to -40 dbm.

Equation for BER is

BER=0.5* erfcx(SNR/2√2)

Where

erfcx= scaled complementary error function

SNR= $\sqrt{(P_{in}\, m_k^2 u_k^2(t))/(2FhBe\zeta)}$

It is seen that BER is decreasing for increasing values of Pin (dbm). As BER increases noise decreases. Due to reduction of noise the quality of signal enhances and hence low BER is feasible.

Values taken for Figure 3:

m_k= 1

$u_k(t)$= 1

F=1

ζ =1

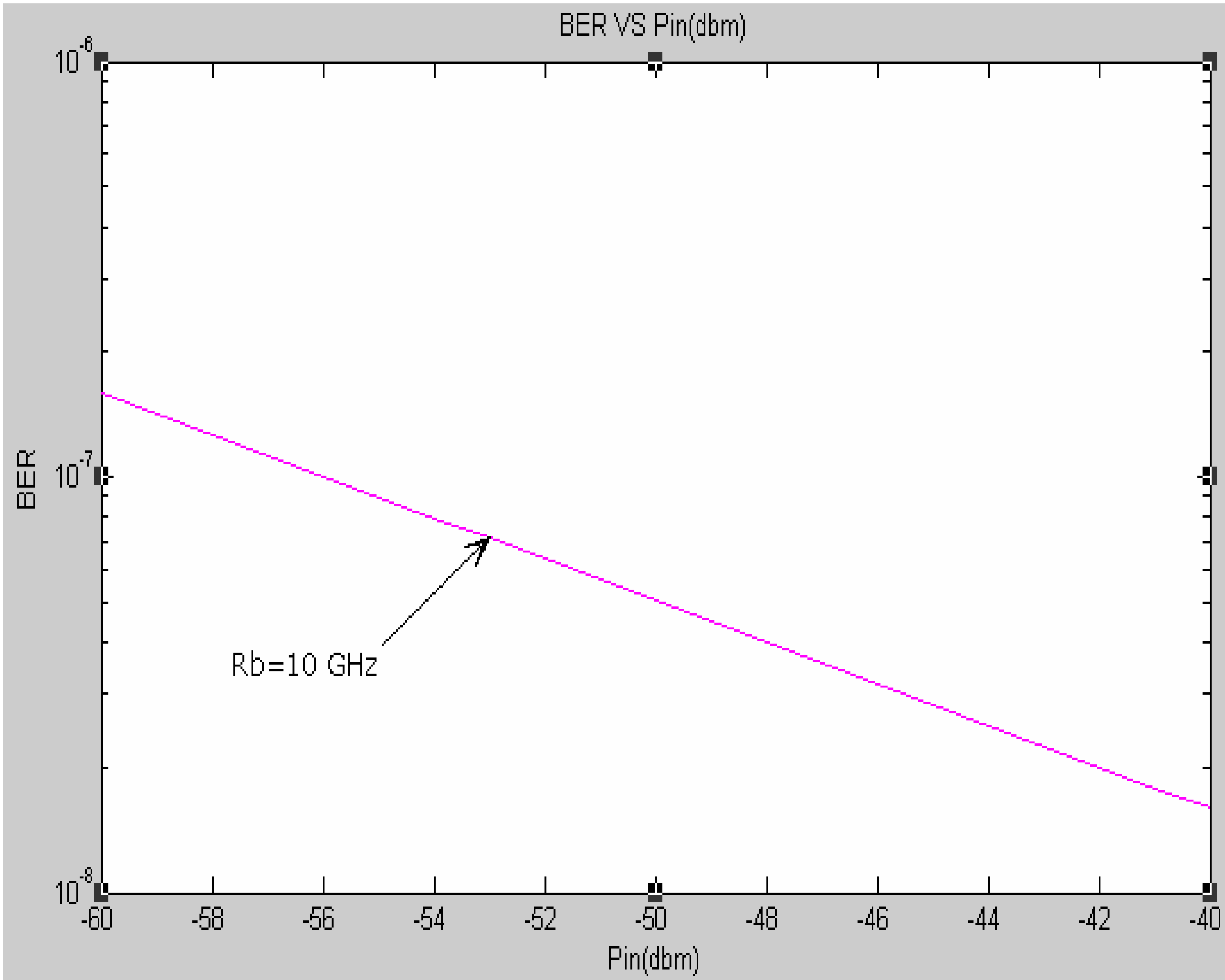


Figure 3: Bit Error Rate (BER) VS Pin(dbm)

Figure 4:

Bit error rate (BER) against Input Power (Pin) in dbm

It is measured as

BER=0.5* erfcx (SNR/2√2)

SNR= $\sqrt{((Pin\ m_k^2 u_k^2(t))/(2FhBe\zeta))}$

Different values of Rb (bit rate) were taken as stated below .As the value of Rb decreases, BER decreases for increasing Pin.

As the bit rate decreases, the BER decreases and noise decreases for increasing Pin. So we see that for low bit rates, BER decreases and hence low bit rates is feasible.

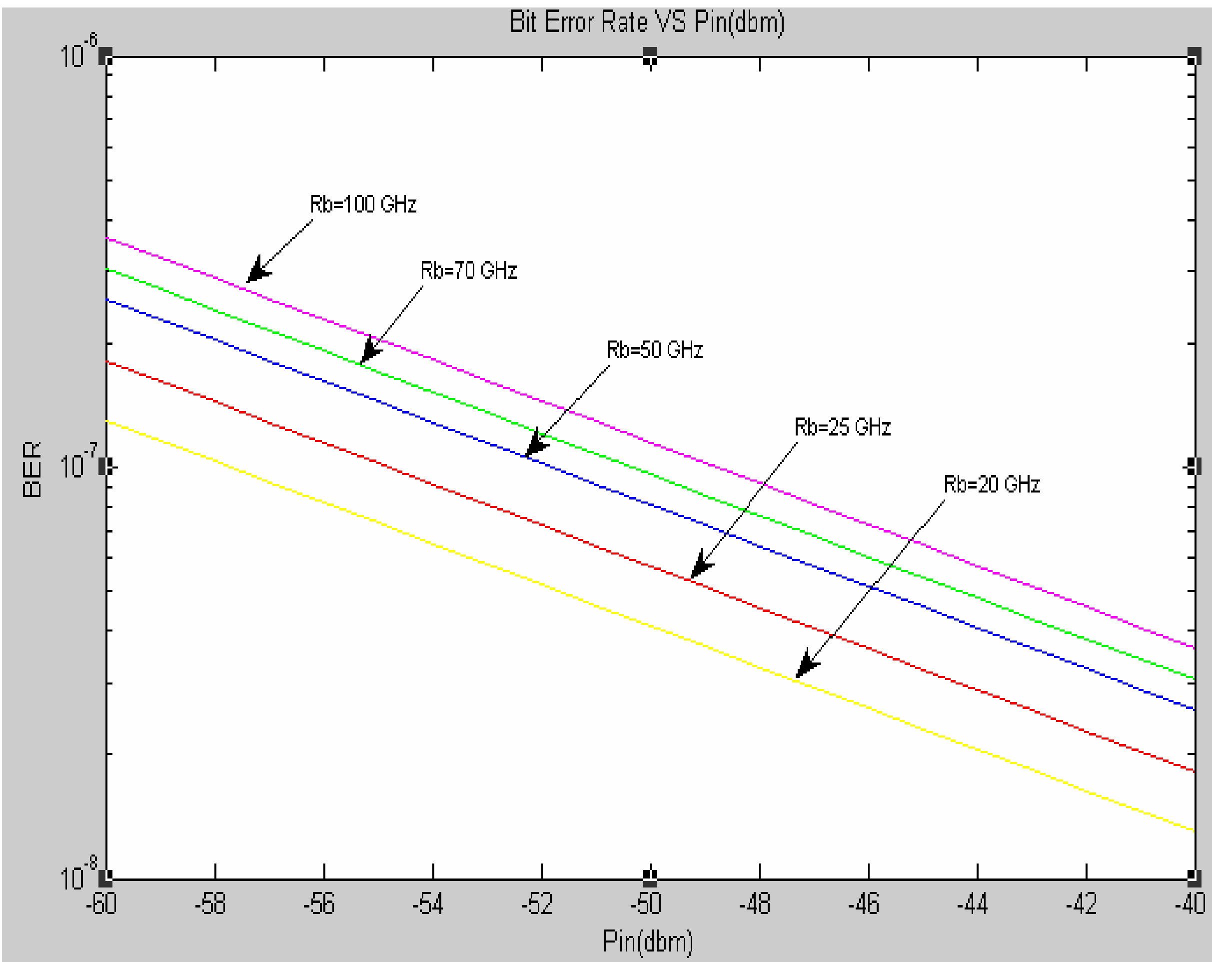


Figure 4: Bit error rate (BER) against Input Power (Pin) in dbm

Figure 5

Bit Error is plotted (BER) against Number of Sub carriers (N).

It is seen that as number of sub carrier increases, BER increases.

As BER increases intermodulation term increases.

The receiver Q is

$Q= \{x\ (\sqrt{Pin})\ m_k)/(2\sqrt{2FhBe\zeta})\}$

$m_k \leq \sqrt{\zeta}/N$

$BER= 0.5\ erfcx(Q/\sqrt{2})$

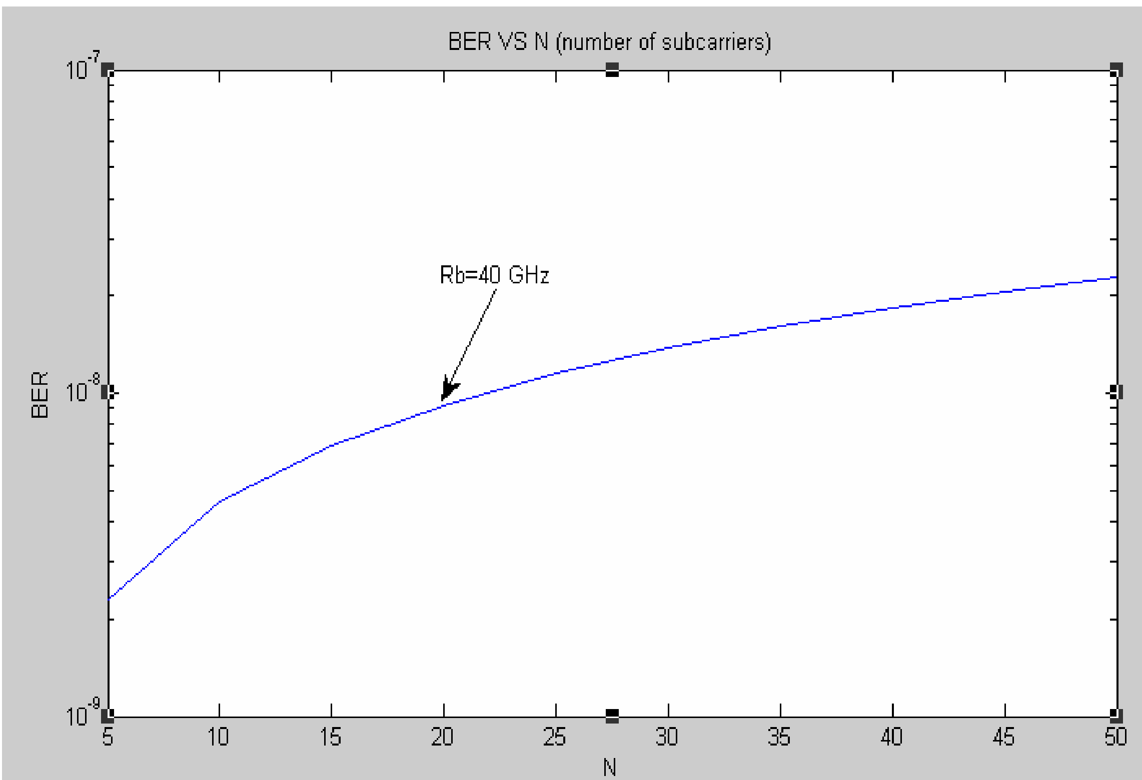


Figure5: Bit Error is plotted (BER) against Number of Sub carriers (N)

Figure 6

For different values of Rb the graph of BER VS N is plotted. The values of Rb are shown in graph. As Rb decreases, BER decreases. As number of sub carrier increases, BER increases, and bit rate increases. So we want to decrease BER and hence lower number subcarrier is feasible. If number of sub carrier has to be increased than bit rate should be kept low.

The equations used are:

$Q= \{x\ (\sqrt{Pin})\ m_k)/(2\sqrt{2FhBe\zeta})\}$

$m_k \leq \sqrt{\zeta}/N$

BER= 0.5 erfcx($Q/\sqrt{2}$)

The values used are:

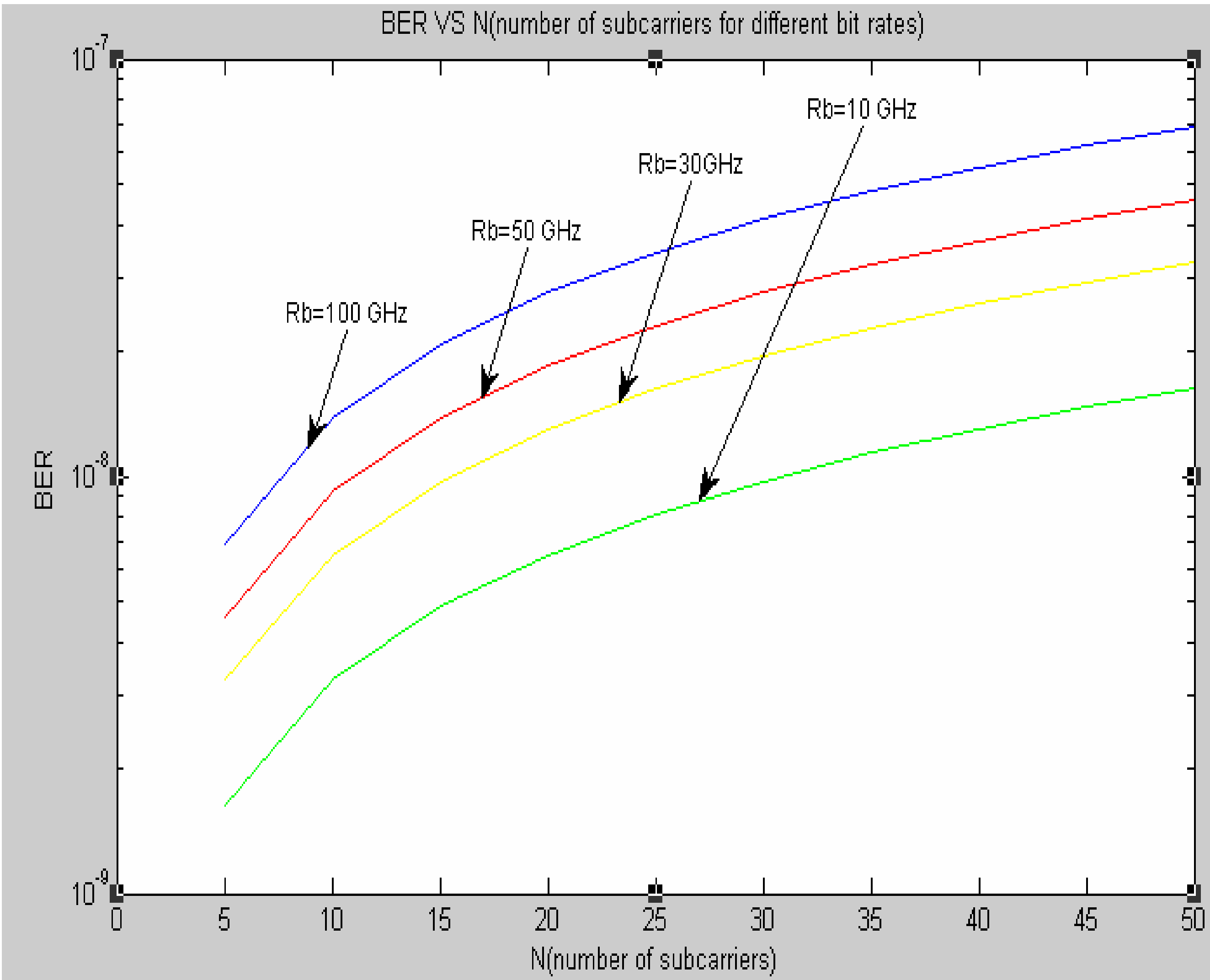
X=1

$u_k(t)= 1$

F=1

ζ =1

h=6.63*10^(-34);



<u>Figure 6:</u> Bit Error rate (BER) VS Number of subcarriers (N) for different bit rates (Rb)

Figure 7

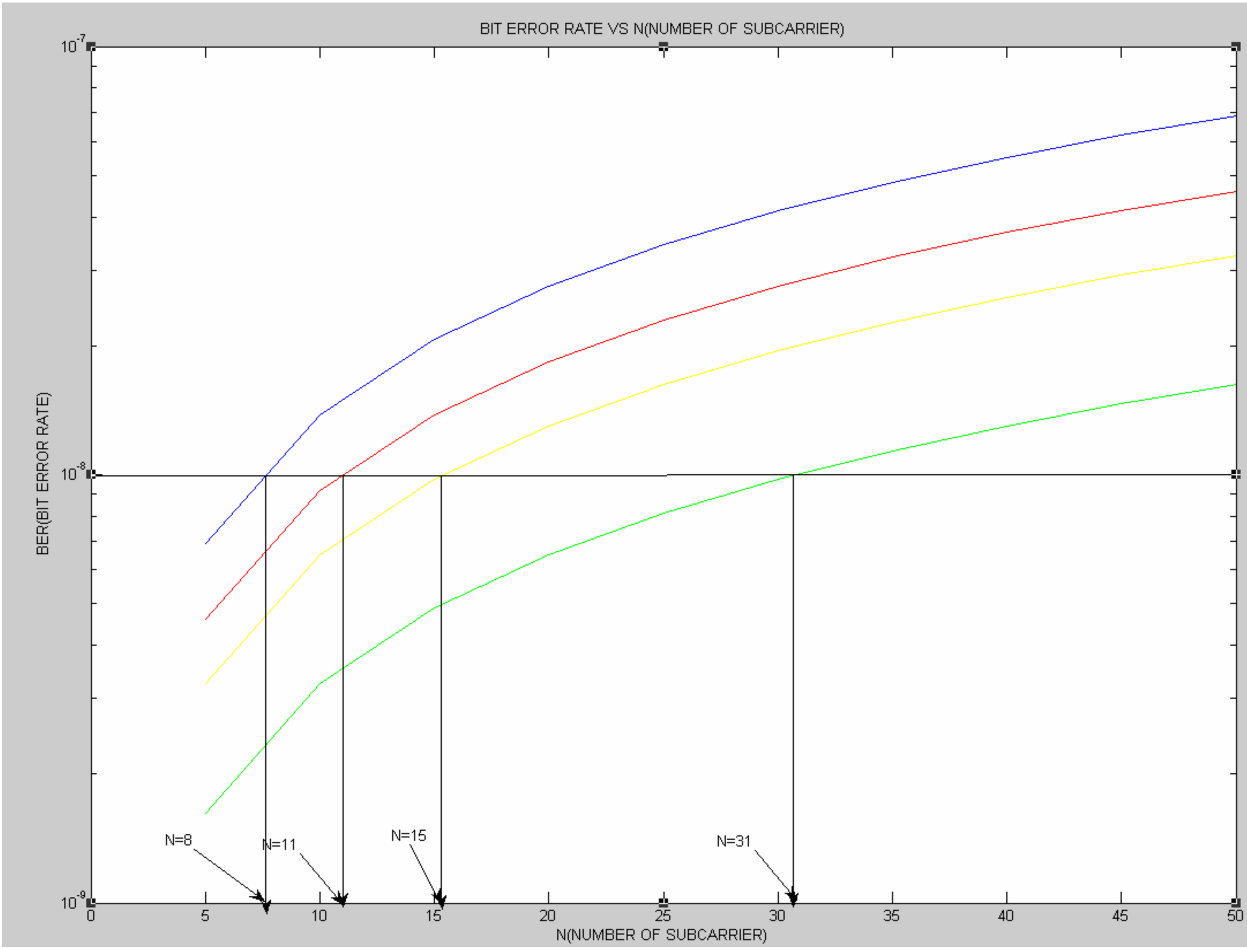


Figure 7: Bit Error rate VS number of subcarriers

A straight line was drawn through the graph of BER VS N for BER value of 10^-8.The four graphs has four particular values of bit rate (Rb) which was mentioned in the previous Figure 6. From this line, four different values of sub carrier was measured for the corresponding four values of Rb (bit rate) as shown in graph above using arrows.

Figure 8:

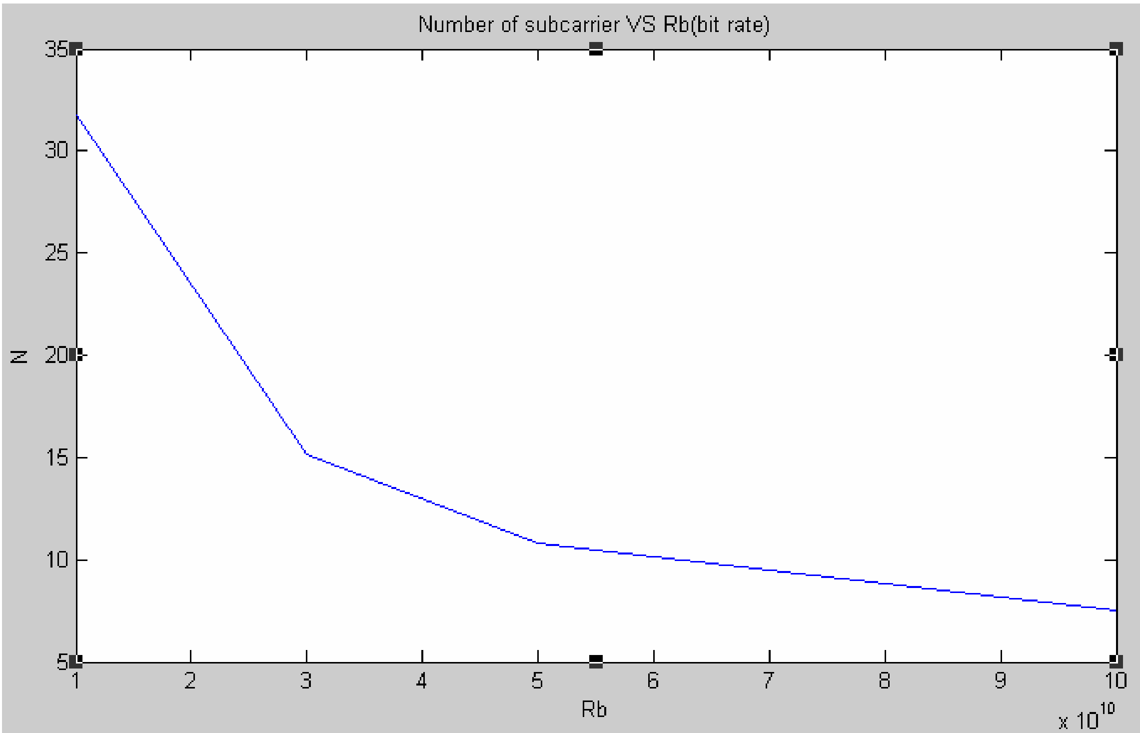


Figure8: Number of subcarrier VS Rb

Figure 8 is drawn from the graphical values of plot 7. In here four values for N were plotted against the four values of Rb (bit rate).

The four values of Rb are [100 GHz, 50 GHz, 30 GHz, 10 GHz]

The four corresponding values of N are [8, 11, 15, 31] The graph is a downward sloping graph.

So as bit rate (Rb) increases, the number of subcarrier decreases.

Chapter-4

Conclusion and Future Work

We have worked extensively on our thesis and verified our work theoretically. We have carried out the analysis for a sub carrier multiplexed optical fiber transmission system with RF subcarrier modulation to transmit video signal for a local video distribution network.

We have plotted the graphs on mat lab that has been shown in analysis section. From the plots it is seen that as the bit rate goes higher signal to noise ratio (SNR) decreases and noise increases. It is not feasible to keep the SNR low and keep the noise level high. So operating in high bit rate is not efficient. So lower bit rate should be used.

Also the bit error rate (BER) increases with higher bit rate with respect to increasing power. BER should be kept as low as possible and it is not hence feasible to keep the BER high. So lower bit rate should be used.

Finally the subcarrier rate decreases with increasing bit rate. Hence bit rate should be lower.

Hence we conclude saying that the bit rate should be kept lower due to decrease in noise, decrease in BER.
Hopefully in future the implementation of Radio Over fiber by Subcarrier Multiplexing will come to fulfill the requirements of high speed transmission.

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Subcarrier Multiplexing for High-Speed Optical Transmission

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