Advanced Optical Communications

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Lecture No. # 01
Introduction

This is a course of fiber optic communication. Fiber optic communication is the most modern mode of communication and it all started just about 40 to 50 years back. In search of a wide band medium for communication, scientists explored the optical window and there merged what is called the fiber optic communication.

Let us look at the history of communication, if you look from the beginning from the graham bells time, the first revolution in communication took place, when the audio signals where converted into electrical form and were transmitted on electrical wires, and were converted back into the audio form. That was the major breakthrough in the field of communication, of course, that time the primary objective was to just carry voice from one point to another by means of electrical medium as the time progressed the need for communication increased; that means, more and more people wanted to communicate from one point to another and as a result larger and larger bandwidth was required.

See, if I look at the history of communication in brief, we can say that the frequency of operation has consistently increased from the audio frequencies to higher and higher.

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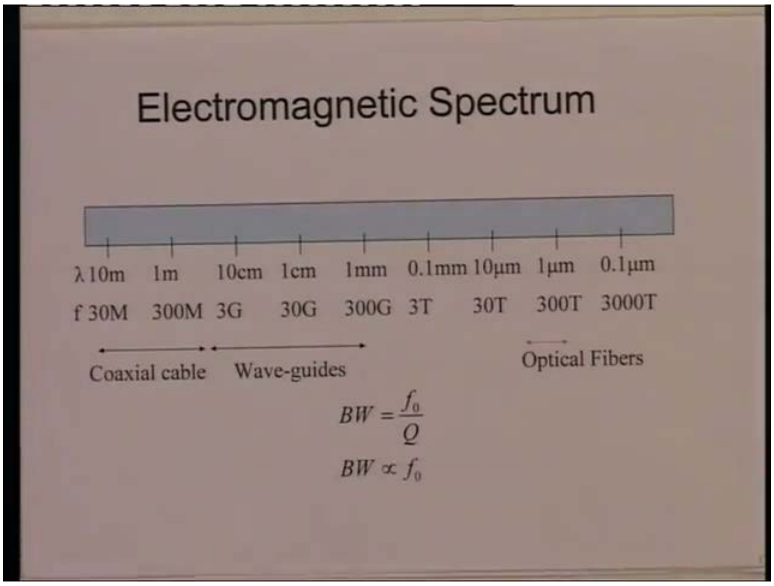

So, let us look at the electromagnetic spectrum. If I see here we have got the frequencies which are going from 10 meter. These are wavelengths 10 meter, 1 meter, 10 centimeter, 1 centimeter, 1 millimeter, 0.1 millimeter, 10 micrometer, 1 micrometer and 0.1 micrometer. Which corresponds to the frequencies for 30 megahertz, 300 megahertz, 3 gigahertz going all the way up to 300 terahertz. So initially when the communication started the communication started in low frequency bands; that means, in the range of few kilohertz then the frequency was increased to few megahertz. Then the frequency was increased to few 100 megahertz then the frequency was increased to few gigahertz and so on.

So in brief essentially over last hundred years or so, the frequency of operation for communication has consistently increased towards higher end. One can ask a very basic question. Why this happened? What was the reason to increase the frequency of communication? Before we answer this question, let us ask what are the fundamental quantities which we must assure to get a reliable communication, and what we find is there are two quantities, which are of vital importance, whenever, we want to have a high quality reliable communication. One is what is cord signal to noise ratio; that means, it is the ratio of the power of the signal to the power of noise.

Assuming that the noise is of additive nature that means, the noise is generated by some independent source. If we increase the signal power then signal to noise ratio increases.

In other words for a given input signal, if the medium has very low loss then at the receiving end the signal amplitude will be reasonably large and the signal to noise ratio will be large. So we can say that if you have a high signal to noise ratio, we must have a medium of transmission which has as low loss as possible. The another quantity which is vital for a reliable communication is the bandwidth and this can be understood in a simple form as follows.

Let us say I wanted to transmit one voice channel from one point to another. A typical voice channel would require a bandwidth of about four kilohertz even after sampling and all that we may require a bandwidth of something like 64 kilohertz. Now if you want people wanted to speak simultaneously then the bandwidth required will be double a three people wanted to speak simultaneously then the bandwidth will be three times and so on. That means, the bandwidth requirement is proportional to number of users if all of them are using the voice information.

So do I have wanted larger and larger voice information? We must have a larger and larger bandwidth. So then we can summarize that to have a reliable communication where large number of people can send information from one point to another, we must have a medium which has as low loss as possible and as large bandwidth as possible. Now if I will look at the electromagnetic spectrum here there is something very interesting about the electrical systems and typically what you find is that, if I design an electrical circuit the quality factor of an electrical circuit is practically independent of frequency.

This law is not a written law, but invariably you will see that for a typical electrical circuit the quality factor would lie in the range of let us say hundred to few hundred. If you have to design a electrical circuit which has a quality factor which is very low something like one or two it will be extremely difficult to design this kind of circuits similarly. If you want to design an electrical circuit which has a quality factor of let us say few million even that is going to be extremely difficult.

So, without great efforts what we find is that the quality factor lies in the range of about few hundred and since the quality factor and the bandwidth are related through this relation. That is bandwidth is equal to the center of frequency of operation divided by the quality factor for a given bandwidth.

The quality factor is proportional to center frequency or for a given quality factor the bandwidth is proportional to the center frequency. Now since the quality factor is more or less independent of the operating frequency what we find is that the bandwidth required is proportional to the operating frequency.

And that is a very interesting phenomena that if I wanted to send more and more information on the channel, then I require larger and larger bandwidth and since the quality factor is more or less independent of the frequency the bandwidth is proportional to the operating frequency. In other words if I increase the operating frequency f naught then the bandwidth will scale almost in proportional to the operating frequency and precisely that is the reason they when the communication started we started in the low frequency and as the demand for the bandwidth increased we increased the frequency to higher and higher level. So, there we get larger and larger bandwidth.

Of course, this trend continue in the early part of the last century and we went up to typical frequencies of something like few centimeter and that was a reason which was what is called the microwave region. So, early when the communication started we had the frequency ranges which was in the megahertz the medium used was the coaxial cable as the frequency increased to few megahertz to few gigahertz, then the medium which was low loss or what are called the wave guides and this structure what are called the wave guides they continue typically till the wavelengths of about few millimeters.

So, if you look at the communication scenario in second world war time then most of the communication was essentially based on microwave region, as the time progressed and we came in mid fifties or sixties. The demand for bandwidth further increasing and then the extension of the wave guide technology was getting more and more difficult to accommodate larger and larger bandwidth, one could then ask the question if I could push the technology still further and I go to a region of let us say point one millimeter then I may get a increase in bandwidth again typically by factor of ten, but the difficulty was that the technology which went reasonably smooth over this frequency range was now finding difficulty of making transition beyond this frequencies.

And the reason for this was a simple and that is by the time you reached to this frequencies, where the wavelength has become the order of a millimeter the electronic component size was becoming comparable to the wavelength or in other words no electrical component could be treated truly like the lump components. So, without considering the spatial variation of the electrical quantities or the physical sizes of the electrical components one could not analyze the electrical circuits satisfactorily.

So, at the time it was worthwhile to ask question, could we now look for another technology or could we include this concepts of what are called the distributed elements and then upgrade your whole analysis procedure, but even if we had done that we would get marginally a increase in the bandwidth or something like the factor of ten. Looking at the need for the bandwidth it was very clear that just by increasing the bandwidth by factor of ten can take us forward only may be a decade not beyond that.

So, at that point people started looking at the another window which was used widely by the physicist for experimentation and that was optical window the idea was that if this law which is bandwidth is more or less proportional to center of frequency, if that law is still more or less valid by the time we go to the optical frequencies which are about three orders of magnitude compared to the millimeter wave frequencies then suddenly you will have a increase in bandwidth by factor of 1000 to 10000 and this is a very attractive composition.

So, if you could develop a new technology in the new window not a radio window, but in optical window then suddenly you would get a bandwidth which is 10000 times more than what microwave and millimeter wave circuits could provide. So, there was precise a motivation for exploring the optical communication window and the optical communication started sometime in 60. So, basically to use optical communication or the optical frequency as the medium for transporting information from one point to one to another.

One has to ask two basic questions, one is, if I use light as a carrier then do we have a medium to transport light with low loss from one point to another, and second relevant question was that do we have sources of light which could carry information on them from one point to another. Both the question if you look very superficially are very trigger questions if somebody ask do we have a medium for carrying light from one point to another we know yes, if we see around the medium around us air the light propagates through that and we feel light propagate very efficiently we receive light from sun. So, light has travelled a distance of millions and millions of kilometers and it reaches to the earth.

So that means, if I just look around us the medium like air seems to be a very good medium for transporting light. However, imagine that if you put a 100 volt bulb on a terrace of a house you can see that bulb from a distance of may be a kilometer, may be ten kilometer, but if you go further than that then practically the bulb becomes invisible. That means, the medium which we think is reasonably transparent is not really that transparent if you wanted to send the light over a distance of hundred kilometer.

So that means, we really here to explore possibility of finding a medium which can carry light over very long distances in the case of communication the distances which we are talking about are few hundred kilometers to few thousand kilometers. So, with this idea in mind that we should look for a medium which has as low loss as possible, the next alternative which was explored was glass because glass also appears to be a very transparent medium the physicist have been using glass for guiding lights focusing lights in the form of prisms and lenses. So, glass seems to be one of the very promising medium for transporting light.

However, when the glass was used in the form of prisms and lenses the distances over which the light was carrying was only a short distance it all may be few meters few tens of meters and whatever loss the glass has that loss is reasonably small, when we talk about a propagation for a distance of few tens of meters. So, the question is if I take this medium glass and if the light propagates in this medium glass for 1000 kilometer would it still be treated like a low loss medium would it still give me the properties which will be satisfactory for communication.

And in the first look to answer this question was no because then the people carried the experiment on the loss characteristics for glass they found that the glass has a very high attenuation or very high loss which is about 1000 d b per kilometer, now note here we are talking about d b scale which is logarithmic. So, 10 d b means reduction in power by factor of 10, 20 d b means reduction in power by factor of 100,30d b means reduction in power by factor of 1000. Glass has an attenuation of 1000 d b per kilometer.

Therefore, originally even the testing was done people found so; that means, if I could construct a let us say long pipe of glass or long rod of glass and you first send light through this rod the light would attenuated by 1000 d b over a distance of one kilometer or in other words for a reasonable input power for the light there will be hopelessly low output which will be reaching to the other end of this rod at a distance of one kilometer.

So in the first look it appeared that although the glass is a very transparent medium for conducting laboratory experiments using lenses and prisms this is not the medium for communication because the distance is involved for communication were very, very large compared to the laboratory distances however, immediately scientists realize that is loss 1000 d b per kilometer is not because of the intrinsic nature of glass, this is because of the impurities, which are present in the glass and the impurities were not removed from the materials for prisms and lenses because their presence was not that harmful as far as the loss is concerned in the laboratory experiments.

But one thing became clear to the scientist, that the loss which was measured in the glass was not because of the glass molecules, it was because of the impurities which were present and as soon as this was realized the people tried to purify glass to the best possible level which was available that time and what they found is in the first purification process they could reduce the loss for the glass from 1000 d b per kilometer to 20 d b per kilometer, now 20 d b per kilometer in today's scenario is still a very large loss

But if you compare this loss with the other alternative which were available that time, like wave guides or coaxial cables this loss was comparable; that means, if I take a glass rod which is purified to a good level then the light would attenuate per factor of hundred over a distance of one kilometer and similar attenuation also takes place (( )) therefore, it was very attractive now to at least explore this possibility that if this medium glass does not give superior performance compared to the coaxial cables or wave guides as far as the attenuation is concerned, at least this pdf will give me a bandwidth which is thousand times more.

So if I get a medium whose loss performance is very identical to what are the alternatives present, but it gives a bandwidth which is 1000 time more the medium is still very attractive and precisely that is the reason that the optical communication people started exploring, the glass is a medium for sending information over long distances and later on we will see that the glass was molded in to a form what are called optical fibers which now can carry information over very, very long distances.

The second question which I asked was, that do we have a sources of light which can carry information on them now again this question that I mention, if you see superficially this is a very trivial question because we see light everywhere we have light bulbs we have tube lights we get light from the sun question one can one is asking is, can I use the light bulb for carrying information on that carrier carries information, when it has some variation in its characteristic either in frequency or in time; that means, if I consider a light source whose amplitude does not changes a function of time whose frequency does not change, the function of time, then this source does not carry any information because amplitude is constant if frequency is constant.

So if I use light source then this is not carrying any information. So the question we are asking is if I have to change the properties of light; that means, if I wanted to change amplitude of this light or if I wanted to change the frequency of the light how simple or difficult it is to change the frequency or amplitude of the single light. So, what we find is if I consider a source like a light bulb and if I try to switch on and off a light bulb, I will not be able to do at a rate fast enough or in other words if the information was sent by us switching on and off, the light bulb I can send the light pulses may be at the rate of only few cycles.

That means, if I am looking for well large bandwidth or if I wanted that my signal should vary at a very high rate then the sources like light bulbs or tube lights are not suitable sources what you find is that, the rate at which an optical source can be switched on and off depends upon what is called the spectrum width of a light source if I take a light source which has a very large spectral width like white light, but white light has a very large spectrum width it goes from red to blue this source, cannot be switched on and off at a very fast rate.

In other words for switching the light on and off at a very fast rate we must have an optical source whose spectral width is as narrow as possible. So, we look for the sources which are like laser kind of sources which intrinsically had a spectral width which is very narrow and if we can get that kind of source then you could send a fast information by using this optical sources, incidentally when the optical fibers were getting explored the lasers were still not invented. It so, happened that the lasers and optical fibers were invented more or less at the same time.

So, we had a compatibility we had the sources available with us which were of type which could be switched on and off or which could be modulated at a fast rate and we could get a medium in the form of optical fibers which could carry information over very long distances. So, this combination of laser kind of sources and the optical fiber made the optical communication possible. So, this is the very brief introduction of the origin of optical communication, what were the issues which were investigated before the optical communication became a reality.

And once we say that well, now we are going to use this medium the optical fiber for transmitting light and a source light laser for carrying information there one can ask a question what basic optical communication link would consist of and optical communication link is no different than any communication link, it has the same basic modules and this modules are as follows..

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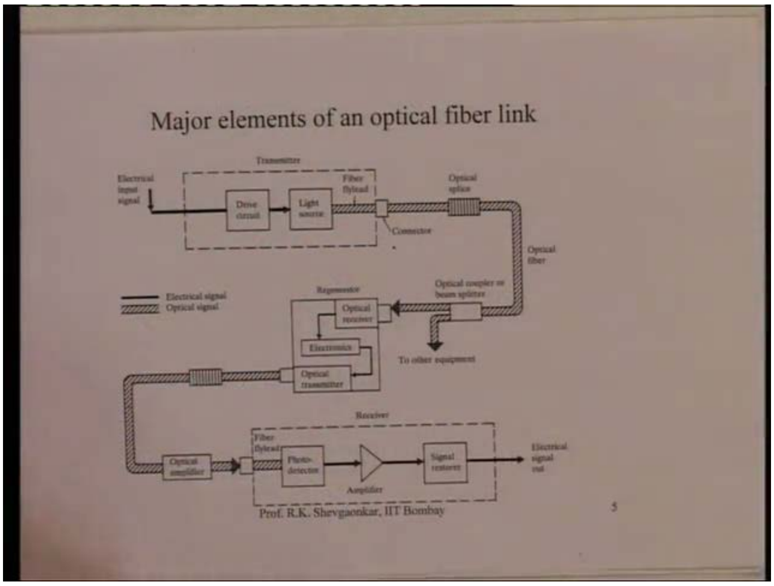

So, while you look at now the signal flow we have now the electrical signal input which could be either a conversion of the audio signal or which could be data or which could be video.

This signal has to be given to a module here which we call as transmitter, this transmitter converts the electrical signal in to the optical signal. So, optical signal goes on this medium what is called optical fiber then, like a typical communication if the signal deteriorates we put a module in between what is called the regenerator. The regenerator signal again is send on a optical fiber till you reach to the destination where the signal is converted back by using the receiver optical receiver and the signal is received in the form of electrical signals.

So, if you look at a typical optical fiber link it would consist of three components one is the transmitter, the medium which is optical fiber and a receiver which is an optical detector, now a typical transmitter would require a device what is called a driver which drives an optical source which feels something like a laser kind of source. So, electrical signal is given to a driver, the driver drives an optical source which is a laser which gives you output which is in the form of light and this light has a signature of the signal which we want to transport which is the electrical signal.

When the signal propagates on this medium, which is the optical fiber due to certain propagation characteristics of optical fiber, the signal has some deterioration somewhere the signal reaches the other side it does not reach exactly in the same form as it started from here. So, we must understand what are the propagation characteristics of optical fiber. So, that I get a faithful reproduction of the signal what was transmitted from the optical transmitter, once you get the signal reached to the receiver then the signal is detected or what is called a photo detector is amplified because the signal by the time it reaches to the receiver has already attenuated to a significantly low level.

So, you have to amplify, you have to clean the signal because in this processes of propagation the signal is corrupted with noise distortions and so on. So, you regenerate your signal and then your electrical signal is decoyed. So, if you ask them what are you going to discuss in this course primarily we are going to discuss these three modules. So, to start with and later on the systems which are going to be configured around three modules. So, in this course we start first with the propagation of the light inside the optical fiber we investigate the characteristics of optical fibers, then we go to what are called the optical sources in which we discuss the issues of generating light and its modulation.

And in this we would be discussing two sources one is the light emitting diode or LEDs and second one is the laser diode or injection laser diode, after that we will go to the next device what is the photo detector which is of this side then we talk about signal to noise ratios associated with the optical receiver and then we will go to the communication aspects of the optical fiber link, having understood this basics of optical communication then we will go to the advanced topics of some basic idea or optical networking and some issues related to the non-linear phenomena which takes place inside the optical fibers.

For enhancing the capacity of optical link we use now a modern technology what is called the wavelength division multiplexing. So, we will discuss some issues related to the wavelength division multiplexing. So, in this course essentially starting from the very basics of optical communication we will discuss the most advanced issues towards the end of the course. So to understand this one of the prerequisites. Firstly, to understand the propagation of light inside the fiber we must know the fundamentals of light we must know what is light, what are the characteristics of light how the light propagates in a medium.

So, you require essentially some basic knowledge of electromagnetic waves. So, as the course starts we expect that you are thorough with the basic propagation of electromagnetic waves inside a medium then we go towards the second topic which is the optical sources where you will be using some basics of physics and then you will be using the light emitting diodes, which are p n junctions. So, we expect that you have the basic knowledge of semiconductor physics.

later when we go to the communication aspects of optical link, then we expect that you have the fundamental knowledge of basic communication systems; that means, you know what are different modulations what is signal to noise ratio what is bitarate and so on.

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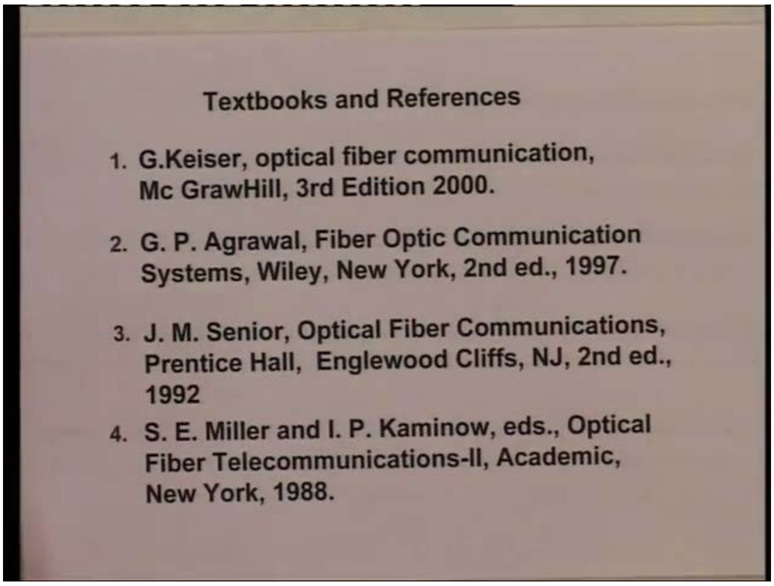

The text which we are going to follow for this course are as follows say is a large list of courses textbooks and references which you are going to use for this courses first one is by Gerd keiser these optical fiber communication is a Mc.Grawhill book which is available in low price edition.

The second book which has a good system oriented approach for optical communication is by Govind. P. Agrawal published by Wiley second edition 1997, then there are further books which could be called as a text books one is by J. M. Senior optical fiber communication published by prentice hall and then the books which are two books by miller and Kaminow which is on optical fiber telecommunications, published by academic press. So, we have the volume two and also volume three which covers various aspects of optical communication.

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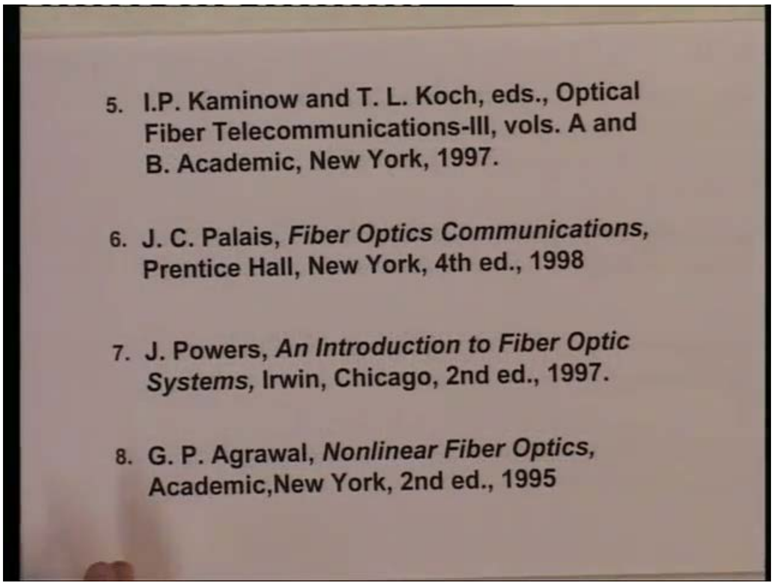

There are another introductory book on fiber optic communication by Palais, then there is another book which again of introductory nature by J. Powers. So, the books starting from one to seven, Keiser Agrawal Senior Miller and Kaminow part two and part three palais and powers they essentially cover the introductory portion of optical fibers, then we go to the advanced topics where you will use the book by Govind Agarwal on non-linear fiber optics for laser technology we will be using the book by Ghatak and Thyagarajan.

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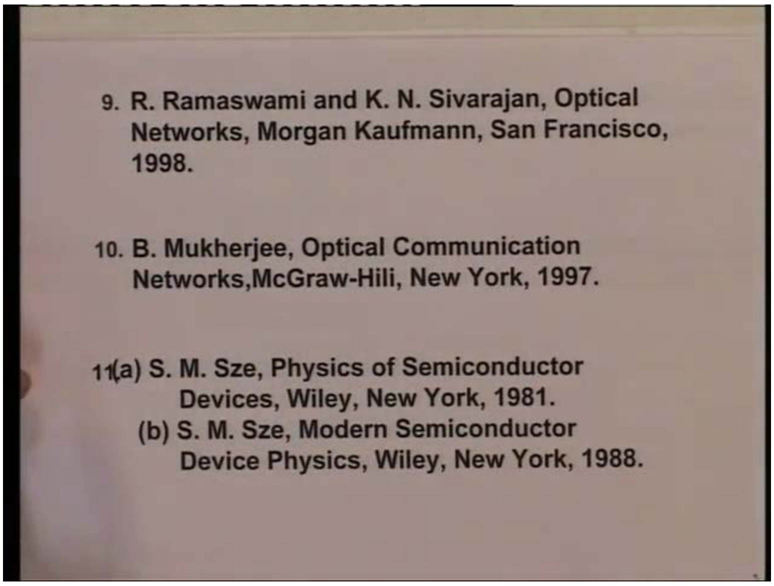

For networking side we will be using some material from Ramaswami and Sivarajan optical networks published by Morgan Kaufmann. There is another book on optical communication networks by Biswajit mukherjee published by Mc.Grawhill the book by Sze will be essentially used for the semiconductor physics needed for investigating the characteristics of the semiconductor lasers and LEDs.

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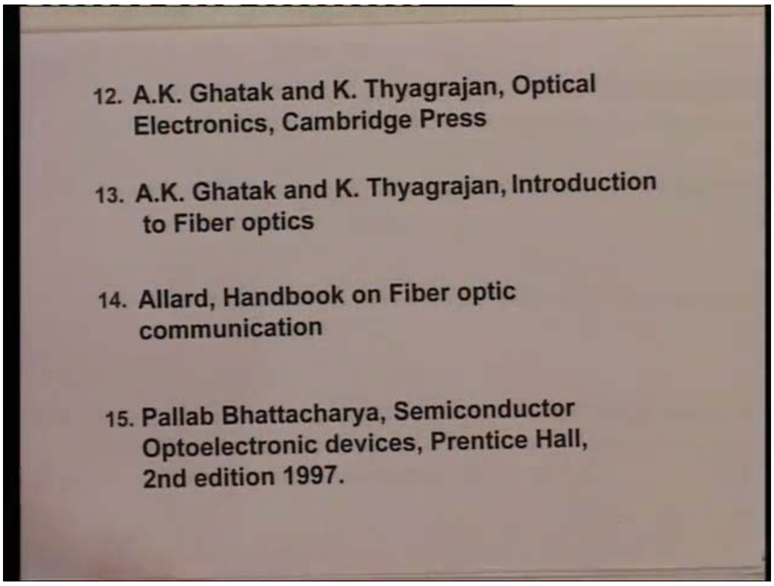

The basics of physics related to the lasers will be taken from book by Ghatak and Thygarajan, there are two books one is on introduction to fiber optics and other one is on optical electronics. So, up to number thirteen essentially we will use the material for the basic portion on optical fiber lasers and photo detectors.

This book by Allard it is an hand book on fiber optic communication this can be used more like a reference book because it gives you lot of formula and ready to use material for practicing engineers, then the books here which is by Pallab Bhattacharya this is published by prentice hall semiconductor optical electronic devices this is an very good book for the semiconductor devices for optical electronics like the injection laser diodes, LEDs and photo detectors. So, currently we just have the set of this fifteen books which will be referring at various times and later on when we will go to more advanced topics various time to time I may introduce more books to you.

So, this is basically the structure of the scores that we will be topping primarily about three topics optical fibers, optical sources, optical detectors, communication systems, optical network related issues and then the modern technology like non-linear fiber optics and the w d m technology before we close the introduction discussion on the optical fibers let us say some kind of a comparative statement between the optical fiber communication and other technologies which are available.

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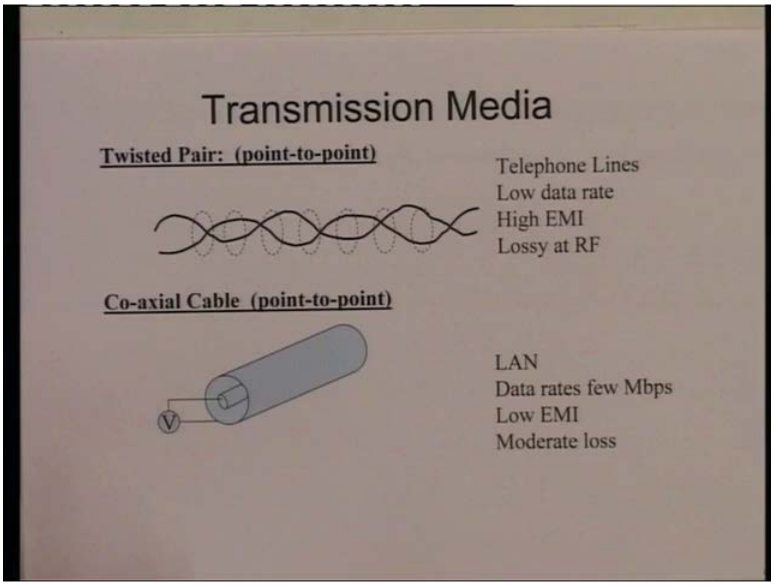

So, if I consider a transmission medium invariably you see a medium which is what is called the twisted pair, the two conductor system which can carry signal from one point to another. So, this medium essentially used for point to point communication so, two wires are twisted and this kind of wire you will see in your telephone lines.

So, a cable reaches to your home for carrying telephone signals they are in the form of twisted pair, now these medium twisted pair can support a very low data rate and since telephone lines essentially use the data rates typically of the order of about tens of kilobits per second this medium is quite suited for that since the structure is completely open structure, the structure has a relatively high electromagnetic interference and also it has a very high loss as the frequency increases.

So, a twisted pair is a good medium for carrying the signals which are at the low frequencies as a frequency increases, the structure which is more useful it is what is called the coaxial cable again the structure is used for point to point communication, you have a cylindrical shell here and there is this rod which is inside this signal is connected between the center conductor and the outer shell and the energy is confined between the region of the outer shell and the inner rod. So, this structure does not have expose electromagnetic fields and because of that the structure has low electromagnetic interference.

This cable is used for connections like local area networks, the data rate also could be relatively higher on this. So, the structure can support the data rates of few megabits per second and the loss for the structure is moderately low so, typically whenever we talk about a local area network you will see that generally it will be cabled by using what is called the coaxial cables.

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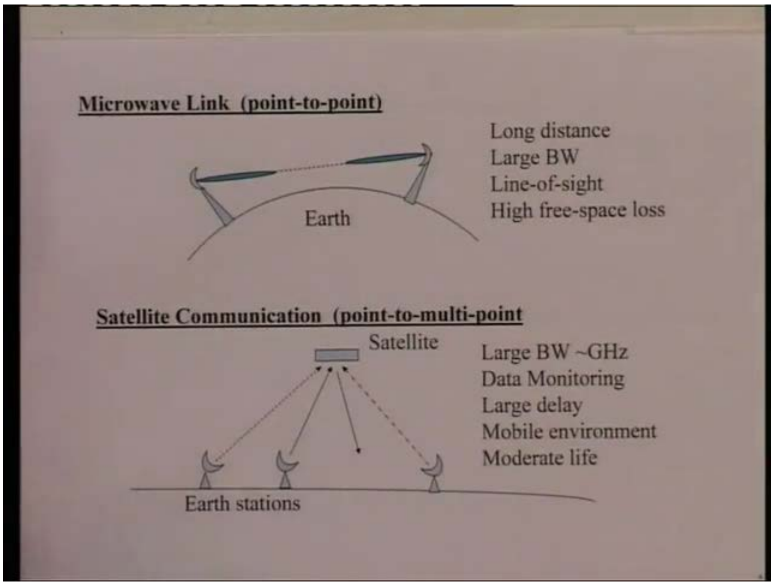

Then if I go under higher frequency side we have a possibility or what is called a microwave link again we have a communication which is point to point communication but, this is a wireless communication. The previous two structure which we saw they were wired communication the twisted pair or coaxial cable had to be laid then and only the communication could be established, in this case the signal is transmitted by using a highly directional microwave antenna it is received on the other side by another antenna and without laying actual cables the signal can be transmitted over long distances this world is very attractive where laying the cable is rather difficult. So, in those situation where laying of cable get difficult the microwave link is a very attractive proposition.

So, this mode can be used for long distance communication since now the frequency is in the microwave range this has a bandwidth which is much larger compared to the coaxial cable. So, typically it can support bandwidth of few 100 megahertz only problem is this communication is more or less like a line of site communication because for a directional antenna the signal goes almost in a straight line from this antenna to this antenna and there is a very high loss because of the free space propagation there although the signal is going from this point to this point it goes in the form of electromagnetic waves and it always has a loss which is one over r square loss.

So, by larger and larger distance the signal attenuates very rapidly, another limitation it has is because of the curvature of the earth, though transmitting and receiving antennas had to be mounted on very high towers. So, that you can get a line of sight, but for reliable communication this is one of the options which has a reasonably large bandwidth, the next option which has a large bandwidth and again which can operate in a wireless mode is a satellite communication, now satellite communication in contrast to other previous media which we talked about this is the point to multipoint communication.

What that means, is the satellite communication can be used for point to point communication, but this can also be used for broadcasting applications. So, whenever we have a situation from one point to multipoint transmission like a television transmission or any information which you want to disseminate over a large region without really laying cables satellite communication is one of the best options. So, here you have stations on the earth what are called the earth stations you have a satellite the signals are transmitted from the earth station through the satellite.

The satellite reflects those signal back in different frequency and signals are received on the earth by different receiving antennas and the communication is established. Satellite communication is the frequency used here are typically microwave frequencies it has the large bandwidth could be of the order of about gigahertz, since the signal after scattered by the satellite is received by the transmitting station itself it has a data monitoring capability which is not there in the other systems because when you transmit a signal here the signal is received at this point but, what is the quality of the signal received here there is no way to find out at the transmitter location.

However, the satellite communication when the signal goes up and is scattered back it illuminates the entire region on the surface of the earth. So, you receive your own signal and then you can monitor the quality of the data which is received on the earth, one of the problems with satellite communication is very large delay that if we have the satellite which is a geostationary satellite then the satellite is located at a very high altitude and then there is a substantial delay because of that travel of the signal from the earth station to the satellite and back to the earth.

This mode however, has an advantage that it gives you mobile environment in all other cases once you have either the cables laid or the microwave towers installed there is no mobility there. So, this mode have an advantage that it gives you a mobile environment and it has a lifetime which is moderate the other systems have a lifetime which are much larger compared to the satellite lifetime a typical satellite life would be of the order of about seven years or something like that.

So, if you now look at the media which are available to us and if I am looking for a medium which is a broadband medium, then probably there are two technologies which may complete with each other. One is a satellite technology which can give you a bandwidth of the order of about a gigahertz or so and another technology would be the fiber optic technology which may give a very large bandwidth. So, if I compare these two technologies which could be of competing nature if I that media of transmissions are essentially complimentary to each other.

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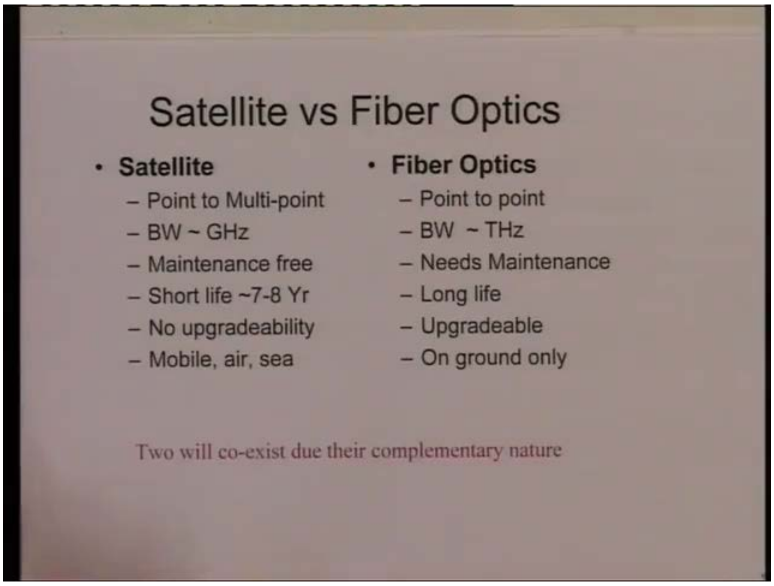

So here we have a comparison between the satellite transmissions versus the fiber optic transmission in satellite we have a point to multipoint communication whereas, in fiber optics we still have a cable medium you have to lay an optic fiber. So, signal can go only from one point to another, so we have here point to point communication, whereas, satellite has a point to multipoint communication. The bandwidth of satellite is large, but not very large. You can get a bandwidth typically if the order of gigahertz. Whereas, if you go to the fiber optic communication, you get a bandwidth which is typically of the order of terahertz; that means, about 1000 gigahertz.

Satellite once launched is relatively maintenance free you have to maintain only the equipment on the earth, whereas, if you go to the fiber optic communication, you require the maintenance of the link; you have to maintain the status of the fiber; you have to maintain the peripheral equipments which are there in communication link and so on. The satellite link has a limited lifetime typically 7 to 8 years whereas, the fiber optic link has a very long lifetime typically 20 to 25 years both the satellite is launched, there is no upgradability possible see if we design a satellite for 500 megahertz bandwidth you have to operate only with 500 megahertz bandwidth till the life of the satellite whereas, in the fiber optic communication as the technology improves you can upgrade your system. So, there is a full upgradability possibility for this technology, the satellite you can have a communication established between any location on the earth or above the earth.

So, you can get an environment which is a mobile environment you can receive signals in air you can receive signals on surface of sea and also on the ground. So, this mode of transmission gives you a complete flexibility over the domain over be the signal can be transmitted whereas, if you go to the fiber optic communication if the signal can be send only on the ground where essentially the fiber has to be laid and then only the signal can be reached from one point to another. So, what we find from this comparison is that these two technologies are not competing technologies.

These two technologies are rather complimentary technologies the thing which the satellite can do the fiber optic will not be able to do for example, the things like the mobility and all that the satellite communication gives, but the fiber optics cannot be and the bandwidth which the fiber optic communication give which is 1000 gigahertz satellite communication will never be able to give. So, there are certain advantages of satellite communication which cannot be obtained from the fiber optic medium and there are certain advantages of fiber optic communication which cannot be achieved by using the satellite.

So, essentially these two technologies are complimentary in nature and that is the reason the combination of the optical fiber and satellite that is the best combination for transmission of a very high quality information over very, very long distances. So, with this comparison of this satellite and optical communication, now we will focus our attention to the fiber optic technology and we will discuss the issues now related to the fiber optic technology. So, in the coming lectures we will start discussing first, the basics of light, what are the characteristics of light? What are the attributes of life?

Once you understand the nature of light then we will ask questions about the propagation characteristics we define the structures optical fibers then we will investigate the propagation of light in the optical fiber, whenever we discuss light just for the historical reason we do not talk in terms of frequency generally we talk in terms of wavelengths, you may recall that if I talk about red light it has a wavelength of 7000 angstrom, if I talk about blue light it has a wavelength of about 4000 angstrom.

So, in optical communication course also invariably we identify the frequency in terms of wavelength. So, typically we will see that when we discuss optical communication we do not talk the frequencies like terahertz for the optical career we will talk the corresponding wavelength which will be one micrometer or point five micrometer or point eight micrometer, we also do not talk the unit for the wavelength which is angstrom which is used typically for the physics material, we use the wavelength which is metric.

So, wavelength for light we will talk in terms of the micrometers so thousand angstrom would correspond to one micrometer so essentially in this optical communication source we will talk about the optical sources which will be characterized in terms of wavelengths and these wavelengths will be measured in terms of micrometers. So, let us close at this point. So next time when we meet, we will be discussing about the basic nature of light and then the propagation of light inside the optical fibers.