Advanced Optical Communications

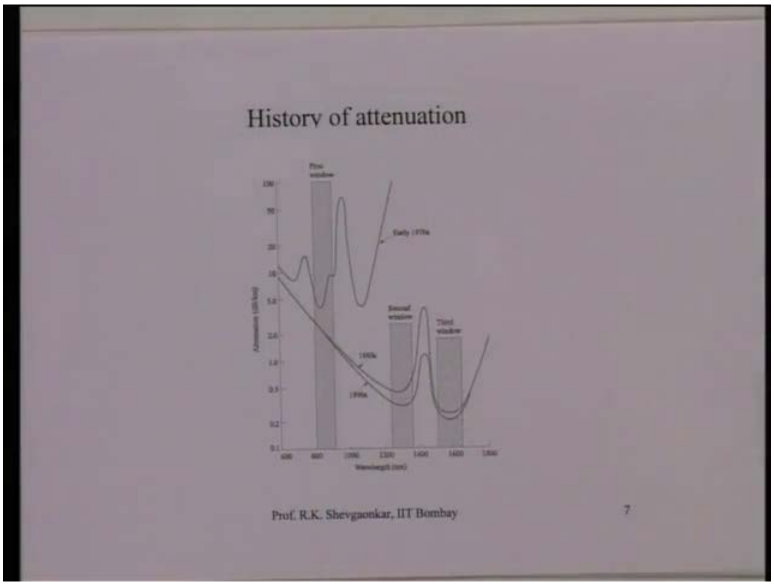
Prof. R.K. Shevagaonkar
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Lecture No. # 02
Basics of Light

In the last lecture, we discuss the basic issues about fiber optic communication. We saw the history of communication that as the time progress, the frequency of carrier increase in a continued fashion or last one century. And around middle of the century the carrier frequency is where in the range of microwave or millimeter waves. In the search of larger band width then the optical window or explore and then we look for the media which were available for transmitting light over long distances, and also we ask the questions whether optical sources where available for carrying information on this medium or long distance. Then we also saw a comparison between different transmission media like the co-axial cable or the twisted pair or satellite communication and then we found that the satellite communication and fiber optic communication are complementary in nature. So, whatever we can achieve satellite communication cannot be achieved with optical communication and vice versa.

So then we conclude that these two technologies, the optical fiber communication technology and satellite communication technology have to co-exists because they have a complementary nature. We also saw that initially when the testing on material glass was made for the attenuation it was found that after force purification the loss in glass wall about 20 d b per kilometer and we argue that time that all though this loss was not very law this loss was very comparable to alternatives which were available that time that means the coaxial cable however since then the technology has consistently worked on purifying the glass and as a result the loss in glass has come down significantly.

(Refer Slide Time: 02:48)



So let us look at the history of attenuation for glass or last 50 years so initially when the glass was tested this was some time in 1970 you had you profile of loss as a function of wave length which was something like that so there was law attenuation region somewhere around 800 nanometer or 0.8 micron wave length and when this testing was going on at the same time as we mention the laser's were invented and semiconducting material which was most studied for emission of light was gallium arsenide and gallium arsenide we will see later in this course is intrinsically capable of emitting in wave length which is around pointed microns.

So infact we saw a great combination that we had the last profile which had a minimum around 800 nanometer wavelength and also we had the source is available which were based on gallium arsenide they were capable of emitting light at 800 nanometer. So this combination of gallium arsenide base devices and low loss region of glass made the optical communication possible around 1970. This is the region now we call as the first window of optical communication.

So infact when the optical communication started most of the communication was setup in this window which is around 800 nanometer or pointed micron, as the time progress then the glass was purified further and further and then the last profile now this modified two something like this so forcing to note here is there is no window which has minimum around 800 nanometer now so the window of low loss has now is around either 1300 nanometer or around 1550 nanometer there is some region here were the attenuation very large.

So one can say that by the time to came to about 1980s the last profile was something like this that means there were two window's for operation one more around 1300 nanometer, one more around 1550 nanometer as soon as this was realize and in this time even the material technology here improved significantly so you could identify the material's which could give emission of light in any window of this this range.

So we could develop the sources which could emit light around 1300 nanometer or which could emit light around 1550 nanometer, so immediately the optical transmission was shifted format 800 nanometer to 1300 nanometer. Later on we will see that is 1300 nanometer is a very special window we are not only in this window the loss is low but, also this window can support high data rates that means this window has a very large band width.

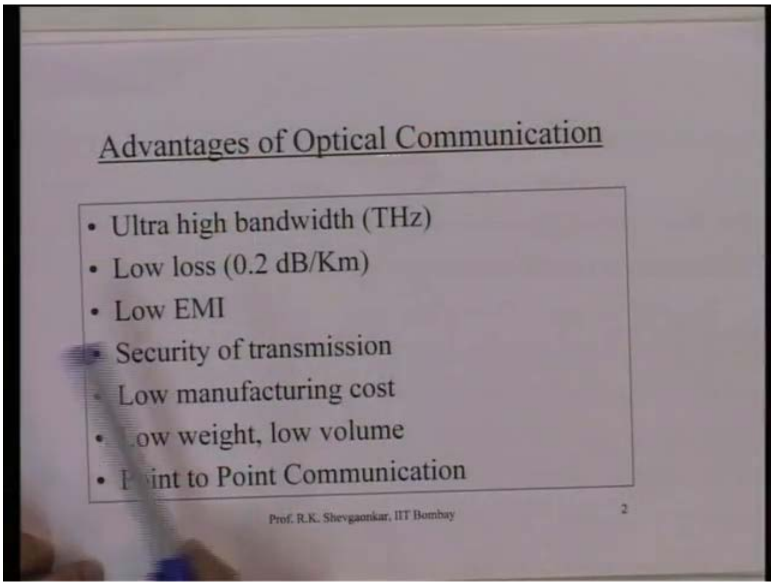
Well the 1550 nanometer window has a loss which is little smaller compared to the loss at 1300 nanometer. If I give the number here the loss will be about 0.2 d b per kilometer at 1550 nanometer that 1300 nanometer the law's is typically a broad of about 0.4 d b per kilometer and it is 100 nanometer the law's is typically the order of about 3d b per kilometer or 4 d b per kilometer.

So what we can find is typed shifting through operation wave length form 800 nanometer to 1300 nanometer we had significant improvement in the last performance and that is the reason as I mention the window operation was shifted in 1980s from 800 nanometer to 1300 nanometer. Later on even the difference of 0.2 d b per kilometer between 1300 nanometer and 1550 nanometer was becoming significant because distance's were becoming very large.

So later on the window was shifted from 1300 nanometer to 1550 nanometer and today most of the transmission takes place in the window of 1550 nanometer. So the 1300 nanometer window which was dominant in the 1980s and may be 1990s this way differ to as the second window of operation and the 1550 nanometer window is we call as the is the third window operation. See if you look at the optical communication today most of the optical communication takes place around 1550 nanometer and later on we will see some other advantages of this window because we could have now the optical amplification possible in 1550 nanometer window.

So when we have a very long distance communication you can even have periodic amplifiers installed which can amplify the signal without converting into the electronics, so these are certain advantages which essentially made this window of 1550 nanometer very interesting and applicable window and that is the reason most of the modern communication takes place in this window or 1550 nanometer. With this now let us see some in general what are the now advantages of optical communication.

(Refer Slide Time: 08:41)



So the two advantages which are highlighted are the ultra-high bandwidth, so the dimension if I look at the last profile here and if I look at the bandwidth which is to be the order of about 1560 nanometer here possible the time 1560 nanometer here you have a bandwidth of typically hundred's of gigahertz which is available in this window which is available in this window.

So just if I define the bandwidth on the basis of low loss performance then we have got a huge window around 1300 nanometer, we have got a huge bandwidth around 1550 nanometer. So this is one of the major advantage of optical communication this is has ultrahigh bandwidth of the order of about terahertz. Also as we saw that if I go to the wave length which is of the order of 1300 nanometer or 1550 nanometer then the loss is as low at 0.2 d b per kilometer.

So as we mention in the beginning for good high quality communication you require two things you require high signal to noise ratio or low loss in the system and last bandwidth and optical communication gives essentially both it gives you very large bandwidth it also has very low loss infact if you compare this loss of 0.2 d b per kilometer with all other alternative's you will see there is no medium today which can compete with suggest one loss the medium light co-axial cable or any others structure we has a loss which is much higher and of course, it is bandwidth also is very limited.

So then we have a very strong case or now optical communication because it support's a very very high bandwidth with a very very low loss. Well with this then we can go to the further advantages of optical communication and next is the low EMI, so you have very low electromagnetic interference when you transmit the signal in optical form.

One can ask very basic question at the stage the light is also a electromagnetic wave so what is special about this when we increase the frequency from kilohertz to megahertz to gigahertz as the frequency increase there was more and more electromagnetic interference so what is certainly change when we increase the frequency the still further from microwave frequency is to the optical frequency which is about three orders of magnitude higher. So one can ask if I have a coupling between different components what scale the coupling takes place between the electromagnetic fields or what distances we have the electromagnetic interference.

So typically we that a electromagnetic interference is strong if you have a distance which are comparable to wave lengths. So when we operate at microwave frequenciesthe wave lengths are typically the order of few tens of centimeters so it typically electronic circuits there is a coupling between different components because a separation between the components is comparable to the wave length. When you go to the frequency like optical frequencies where the wave length now has become typically of the order of one micro meter you will see electromagnetic interference if you bring the components within a distance of one micron.

So if you have distance are which are much larger compared to one micron then there is no coupling between these components and thats for pressingly you're talking about that this one gives you a very high a EMI performance because the distance at with we talk are much larger compared to the wave length of operation at optical frequencies. The next advantage which we have is security of transmission that is one the signal is put in a medium like optical fiber the signal cannot be tapped from outside this or not true if I had a medium let us twisted pair you the twisted pair is there the most of the electromagnetic fields are outside two just without physically touching this cables begin always put some coupling device which can couple the fields of the twisted pair and this fields can now give you the information which is flowing on the twisted pair since no light leads from the optical fiber at least an ideal condition then there is no possibility of tapping a data or information which is flowing a inside the optical fiber so it gives you very high security of transmission.

Later on we will see well that this statement has to be taken with little caution because this is very ideal situation as soon as you go to the practical systems where the fiber is deformed and so on there is always a leakage of information which can be tapped.

The next advantage of optical communication is low manufacturing cost, so here if you look at the cost the cost is primarily in the technology in the material processing the basic material which is glass is practically free it is silicon and silicon is very abundant in nature so if you ask where the cost is the material cost is practically zero, the cost is in technology for purifying this glass and then making this glass in the form of optical fiber.

So in contrary to other media like co-axial cable where the materially use a like copper which is very expensive material the most of the cost goes into material where as in optical fiber the most of the cost is only in technology and the material cost is practically zero.

Also you should see this statement in a different way if you compare the cost of optical fiber with a coaxial cable per kilometer may be the cost will be very comparable but, if you ask what is the cost per voice channel flowing on a optical fiber and the cost per voice channel flowing on co-axial cable, see the optical fiber can carry the voice channel which could be thousand times more than a co-axial cable the cost per voice channel will be one thousand of the cost of the co-axial cable.

So even if the cost per kilometer of this two are comparable the cost per voice channel would be much smaller further optical fiber so thus we have a significant advantage there then of course, as we see here later in this course that optical fiber is a very thin glass rod so it is very low weight and it is not very voluminous so in those situations where the volume or weight is the constraint like space borne devices.

So the optical fibers could be much more advantageous then any of the metallic cables, only disadvantage if at all you want to point out for optical communication is that it is point to point communication as we saw satellite communication is a broad casting medium you can transmit the information from one point to multi point where as in case of optical communication since it is wired communication the point information can go only from one point to another point. However at least in urban area's where you have now a good network of optical fiber practically every house in the city can be reached by optical fiber.

So though the technology intrinsically is point to point technology you can use it like a broad casting thing because a fiber is practically easing to every home at least inside the cities so then we see here the optical communication has many more advantages compared to any other mode of communication not only large band width and low loss but, it gives you many other features also which are very attract. The fourth profile is reason why optical communication technology grew so rapidly in last thirty to forty years.

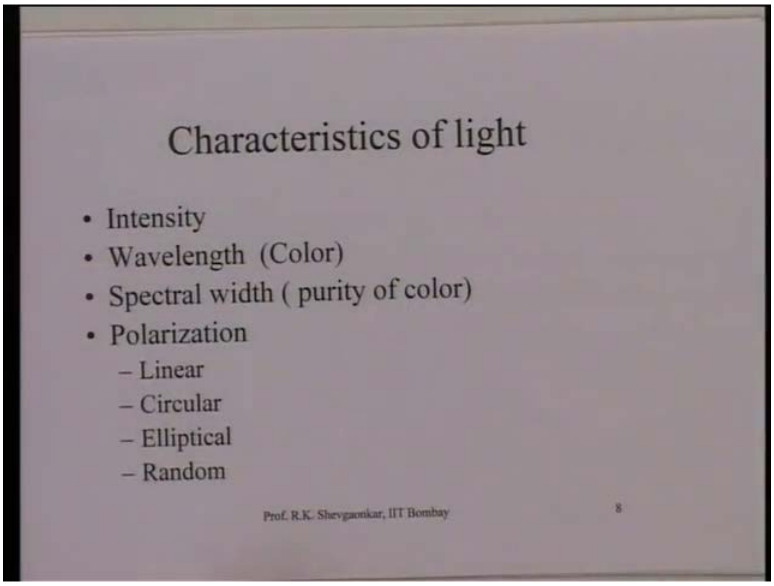
Infact every ten years there has begin a completely revolutionary change in the optical communication technology so the technology which was in 1970s was obsolete by 1980s. Technology which was in 1980s became obsolete in 1990s and the same is true one from 1990s to the beginning of this century.

So optical communication has grown very rapidly and of course, the credit goes to the material science technology which gave high quality materials what make the fibers and optical sources also it has been because of the improvement in the communication technology so today if you look at the networks the networksare using the optical fiber as the backbone large number of wavelengths are transmitted what are called wavelength division multiplexing systems and though overall capacity of this optical communication system has been very large with this then now let us get into the first topic of the optical communication and that is the optical fibers however before you get into the optical fibers let us first revise some of the basic concepts of light. We know the light is an electromagnetic radiation we also know that in high school we have studied light as rays so we could establish laws likes Snell's law, laws of reflection treating light as rays and then also know that the light could be treated life photons.

So infact you have to deal with light depending upon the context any of this three models so what we do in this course first we establish some of the basic things about the light in terms of ray model, so first we treat light as a ray then when we find that this model the ray model of light is inadequate for explaining some phenomena then we depart to well higher level of model which is the wave model were the light is electromagnetic wave and in those situation where you find though model cannot explain the phenomena like interaction of light with matter then we go to the model which is the quantum model where light will be treated like photon.

So in this course essentially this started with ray model then will go to the wave model and then finally, we will go to the quantum model of light. Let us now ask that if a light source is given to us what way light source can be characterized and specially from the communication point of view what are its implications ?

(Refer Slide Time: 20:37)



So firstly all of us know that a light source can be characterized by what is called the intensity of light while intensity of light is the power per unit solid angle, so for a given power if the light is confined to very narrow beem where solid angle is very small then the source will appear brighter so this will be one of the parameters which essentially tells me how focus the light is so for given power if the light goes into a very wide angel like a normal bulb then it will not appear as bright as it the laser would appear even the power of the laser is very small but, they power comes in a very narrow cone so laser light appears much brighter compare to the light which we get form a simple tube light.

So that is one of the characteristic parameter of light the second parameter which is of light is the wave length or in the common terminology there is the color of the light however easiest in earlier that the low loss window for optical communication is 1300 nanometer or 1550 nanometer the visible range of light is somewhere here which is from 400 nanometer to seven hundred nanometer so that means the glass which used to be so transparent to the human eye, it is not really fully transparent at the optical visible wave lengths infact it is much more transparent in the wave length which are lying in the infa red region which are in 1300 nanometer or 1500 nanometer so see the operation is not now confined to the visible range of light the color does not have any sense but, still we can use the same notion of color to characterized the light.

So we say that the second parameter which is important for the optical communication is the color of the light or the wave length and this quantity we can say is let us say some lambda depending upon the loss performance we can choose lambda either in 1300 nanometer or 1550 nanometer so the choice of wave length has a direct varying on the laws performance of your particular communication system the second parameter which we have down is the which is related to the spectrum of of light is what is called as spectral width let me denote this quantity as proceed delta lambda.

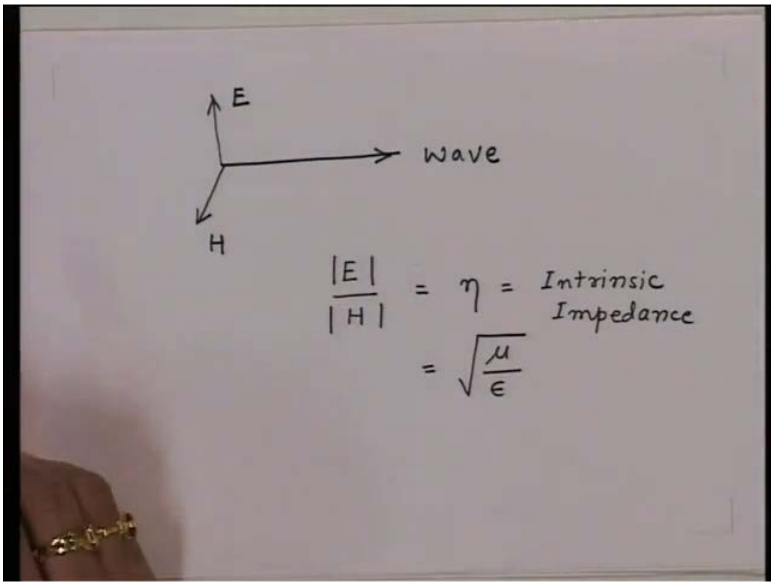
So it is the wave length range or is the ambition takes place so we can say that the spectral width is something like a purity of the color, so the wave length is representing a color in the spectral width represent purity of the color; so if I have a very wide spectral range let us say visible range goes from the blue to red then I will get a light which will look like a white light, if I reduce the bandwidth to a smaller region let us say around red then I will get a very sharp red color, if I put a wave length around yellow I will get a sharp yellow color, if I move the wave length around blue I will get a sharp blue color. So reducing the wave length essentially increase the purity of the color.

So we find now that is spectral width which in terms of the normal human vision is the purity of the color is important parameter we are later on we will see that this is directly related to the data rate which you can transfer. Smaller the value of delta lambda higher will be the bandwidth of the communication system or higher the data rate which you can transmit on the optical fiber.

So the choice of wave length has a varying on the signal to noise ratio or loss and the purity of the color of the spectral width has a direct varying on the bandwidth of your optical system. So these two parameters are extremely important parameters for the optical communication of course, these three parameter the intensity, the wave length and the spectral width of the light source treat light as a energy source. No where the wave nature of light comes into picture so you have energy source which is giving the certain path you find out or what angular zone the power is confined which is related to intensity what color the light has it gives the wave length and what is the purity of color it gives a spectral width.

However when we talk about the propagation of light inside the optical fiber the light cannot be simply treated like a energy source, it has be treated like electromagnetic wave and if you use a electromagnetic wave then at least if the medium is very large we treat the light as a transpose electromagnetic wave. What that means is that if I consider a light energy source and let us say light is a moving something in this direction,

(Refer Slide Time: 26:17)



The light is transpose electromagnetic that means it has electric and magnetic fields like that so this is the electric field for the light this is the magnetic field for the light and this is the direction of light, so wave propagates in this direction.

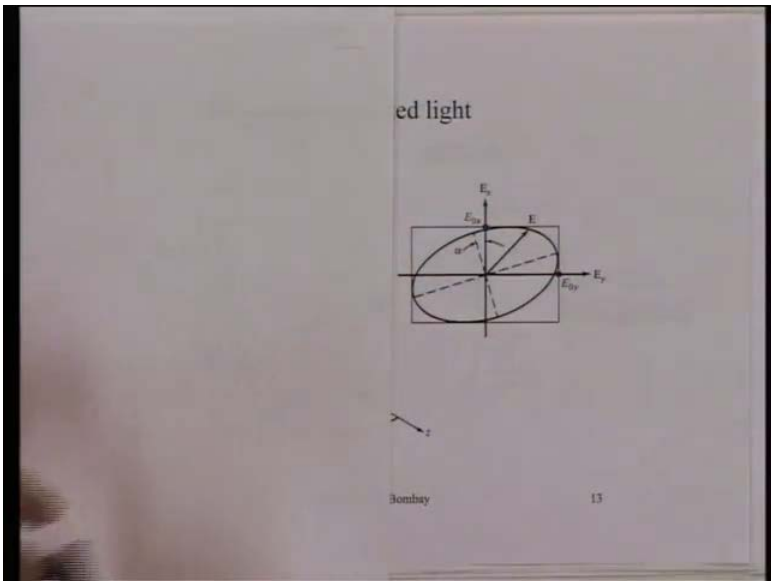
So the electric field, the magnetic field and the direction of light or the wave they are perpendicular to each other and if I put my fingers going from E to H their my thumb points in this direction which is the wave direction. So in a medium which is having a size much larger compared to the wave length of the light, the light can be treated like a transpose electromagnetic wave and then the E and H are also related through the medium parameter's so you have this quantity E by H magnitude that is equal to a quantity called 'eta' which is intrinsic impedance of the medium and which is given by the squareroot of permeability of the medium divided by the permittivity of the medium.

So infact the electric and magnetic fields are related through the medium parameters, they are perpendicular each other and are perpendicular to direction of the wave propagation. So H is completely dependent on then electric field so if I treat the light as transpose electromagnetic wave then I at least should observe the behavior of E as a function of time.

Once I know the behavior of E H, I can always find out because H is always perpendicular to E and E by H ratio is given by the medium parameters. These behavior of light as a function of time that means the way the electric field behaves as a function of time that is what is called the polarization of light and this is one of the very important parameters of any electromagnetic field.

So if I now treat the light as transpose electromagnetic wave then the electric field vector it like an arrow the tip of this vector can will drop as a function of time differentiate and that shape is what is called the state of polarization. So infact that polarization is a parameter which captures the vector nature of light. All this quantity the intensity the wave length and the spectral width they treat light as a scalar quantity because it treats only light as in that is source whereas, this is the quantity polarization we says that the light is made of electric and magnetic fields and that is why there is some vector nature associated with that, so in general if I ask what kind of shapes are drawn by the light then you can get in general it shape which will be elliptical shape.

(Refer Slide Time: 29:44)

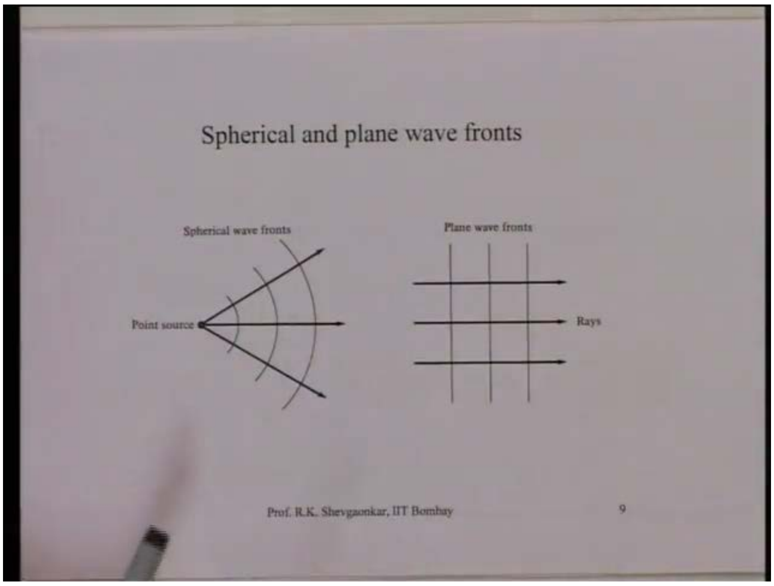


So if I look at the tip of the electric field vector as the function of time the electric field vector will draw a shape which will something like that and then because of this behavior is the polarization and since the shape is a elliptical we say that this light is elliptically polarized. So in general one can say that a light is elliptically polarized in some special cases the ellipse can degenerate either into a straight line or into a circle. So if the ellipse is compressed it becomes line and then I call this polarization a linear polarization if the ellipse is stressed so then the major axis and miner axis become equal then this becomes a circle and then I call that polarization as circular polarization.

Sothe general state of polarization which is elliptical can degenerate into either a linear polarization or into a circular polarization so in general then we can say a transpose electromagnetic light has three state’s of polarization : linear polarization, circular polarization and elliptical polarization. Also if the light does not have a systematic behavior like this which would happen if I have a light source has a very large bandwidth then the electric field vector is a functional time orients randomly its amplitude varies randomly and then we call the state of polarization as a random polarization. So typically the lights which are so called incoherent light they do not have a definite way state of polarization and we can call that as randomly polarization light.

So this is the parameter which is important parameter for wave propagation because this parameter essentially describes the vector nature of light, with this now let us come to the simplest possible description of light what is called the rays. So there are two possibility's.

(Rerfer Slide Time: 32:02)



One is let us say I have a light source here and this light source essentially throw's the energy out in the optical form the energy propagates radially away from this source for what essentially we have is a wave of which is travelling of wave from this in the form of the spherical shells.

So essentially these line's which were drawing here what we call rays are only the fictitious lines, what actually is travelling is this what is called the face front or the cost and face surfaces. So if I look at this constant face fronts here they are the one which are moving radially out words and if I draw the lines perpendicular to this face front at every point then they give me a representation of light in the form of rays.

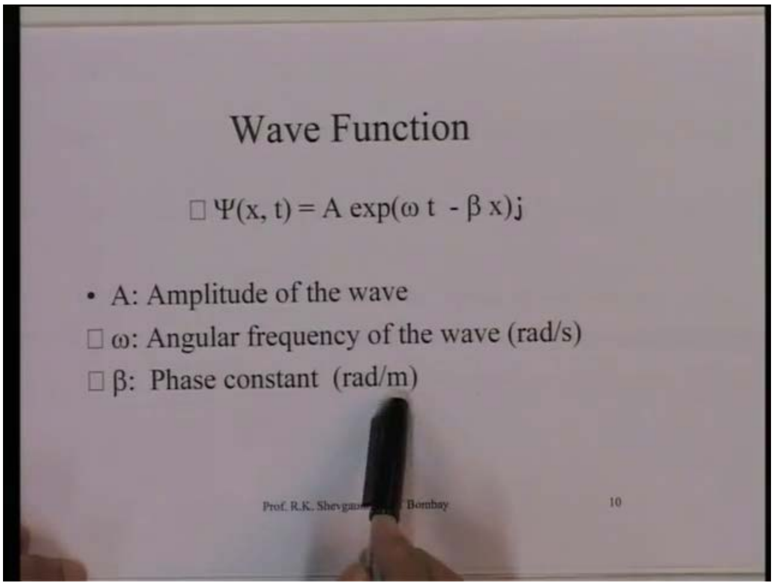
So infact there is nothing like ray what we have here is a face front which is moving and if I get a collection of this face fronts and draw this lines which are perpendicular to them then they give us what I call the light rays. So if you are having a source located at finite distance then the wave essentially would be what is called a spherical wave because the face fronts are like sphere's.

Let us see if I push this source very far away, I see from a very long distance practically the face front for very long distance will almost look like a plane and then face front will look almost like a plane here. That means if I look at source from very far away distance practically the face fronts have become planes and they are parallel to each other than the lines which are perpendicular to this which we call rays are this parallel are lines.

So this wave then we can call as the plane waves, so whenever we have a source at a finite distance the light which is emitted by that is of spherical nature where as if the source was very far away then we can say practically that the light has become like a plane wave under in this cases essentially if you draw a ray like this the ray essentially means that there are face front which are perpendicular to that which are travelling and this line is just a representation of those face fronts.

So later on when we talk about propagation of light inside optical fiber first we will try to explain certain phenomena with the help of simply ray's and then we slowly put the face front behind them and then ask a question where are understanding was correct or not and we will a refine our observation. The second basics of light is the define consider the light as electromagnetic wave then as any wave of phenomena can be defined by function which is like this.

(Refer Slide Time: 35:16)

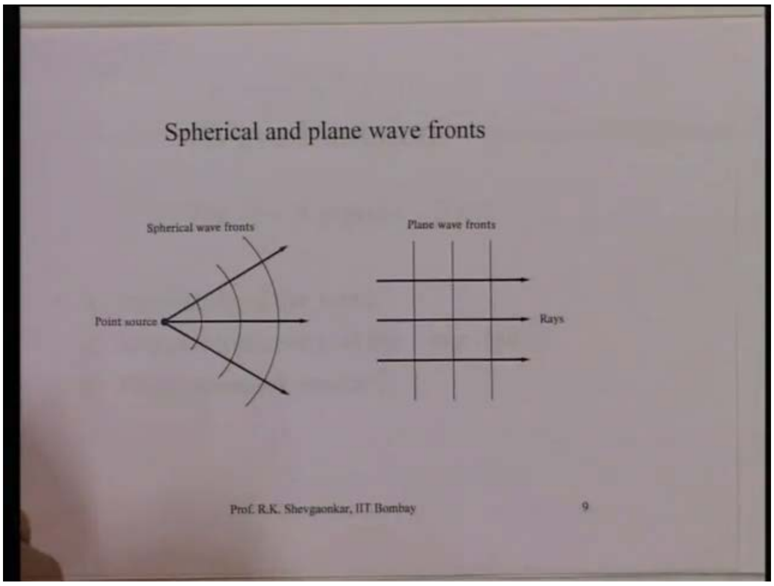


So way of function psi which is combination of space and time has an amplitude A and as a face function which is omega t minus beta x, they should be j here this is the face function.

So now the face of this quantities psi x of t is a combination of omega t which is the time and the space which is beta x. So if I say that I freeze time that means if I make a x equal to constant minus beta x is a constant quantity then this quantity psi x comma t, it has an amplitude a and it varies E to the power j omega t so it has variation as function of time and omega is the angular frequency. If I freeze time that means if I instantaneously look at this function in space this quantity is constant now, again I will variation with E to the power minus j beta x in space.

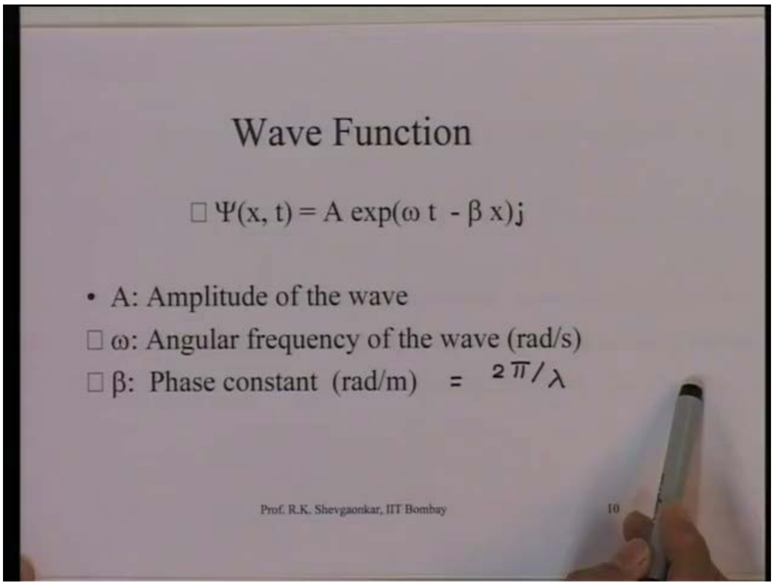
So we have this functions wave function which is a combination of time and space, the function varies in time but the given location is space, it variesin space at a given set of time and the two together essentially constitute what is called the way of phenomena. So seen this quantity here beta x represent’s face in space we call this quantity beta as the face constant omega as we all know is what is called the angular frequency of the wave. Its unit is radiance per second and here we have this quantity beta which we call as face constant and since beta into x gives you face the beta is the face divide by distance so it has a unit which is radian per meter.

(Refer Slide Time: 37:39)



which are having the same face that with the difference between them is two pi by definition any two point from the wave which are having same face is called the wave width that means if I consider two point separated by distance

(Refer Slide Time: 37:57)



Now if I look at the face fronts here, if I consider the two face fronts which is two pi then that distance we call as the wave length so that means beta into distance lambda which is a wave length, that should be equal to two pi.

So essentially the phase constant beta which we have here is pi definition is two pi divided by lambda. So in any propagation of light if you know lambda then we can find out what is the face constant beta and if you know the face constant beta we can find out the corresponding wave length lambda.

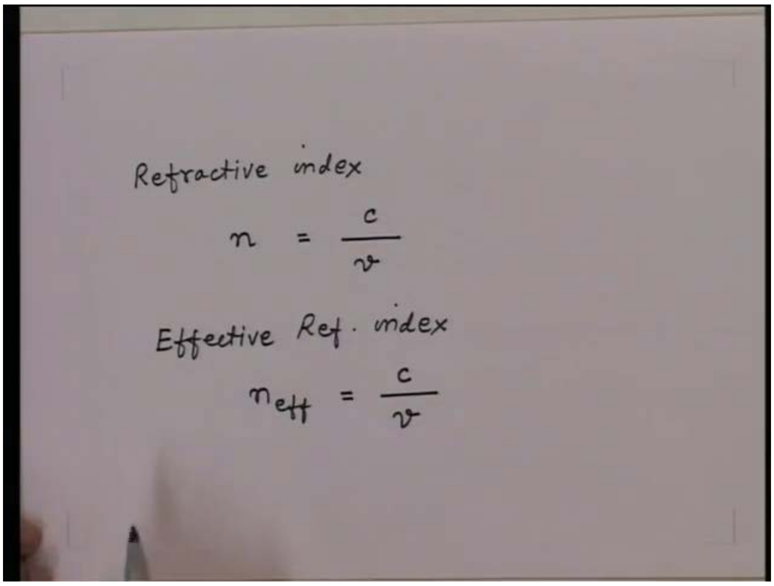
What I wonder at this point thus once I know the frequency of the light then I can find out the value of lambda and from this relation I can find out the value of beta so what is so special about it but, what one should note at this point is that the lambda is not always the velocity of light divided by frequency because velocity of light is a medium dependent property if you go from vacuum to another material the velocity of light changes, if you go in the within the same materiel but, if you make them medium bound the velocity of light changes that means this quantity velocity of light is medium dependent is structure dependent.

So once you know the frequency of light you can either find out is constant face constant beta once know the value of beta then you can find out from this relation model value of lambda and then this lambda multiplied by the frequency that gives you essentially velocity of light so will use this concept more often as we progress later in this course.

Now if you consider the light as a electromagnetic wave transfer electromagnetic wave then we have important parameter define what is call the reflect index of the medium.

Now different index of the medium is the define as the velocity of light in vacuum divided by the velocity of light in that medium.

(Refer Slide Time: 40:18)



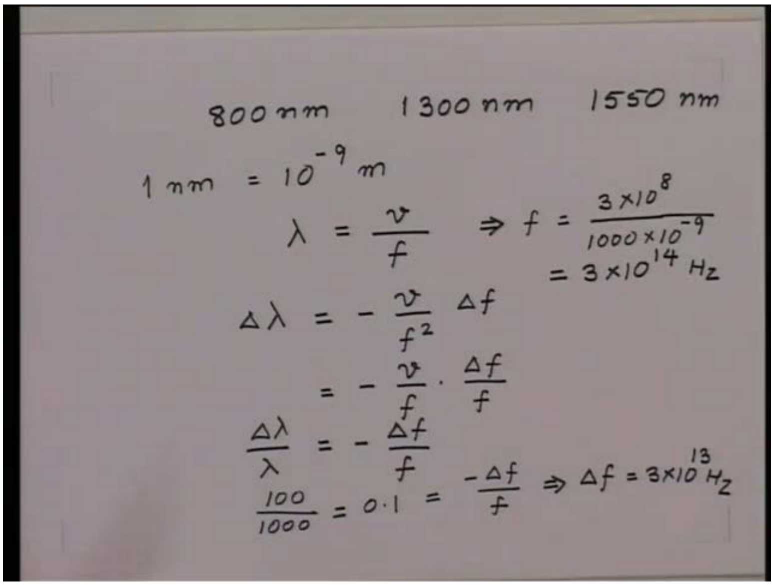
So we have this important quantity here what is called the refractive index and let us denote that by n that is equal to the velocity of light in vacum c divided by the velocity of light in that medium v. Since for most of the directive media which will be discussing here the refractive index is greater than one the velocity of light always reduces when the light goes from vacuum to the medium. So light infect travels fastest in the vacum any any other medium is slows down. If you take a material like glass the refractive index of glass is the approximately one point five, if you take refractive index water we got 1.33.

So this parameter is essentially telling you by what factor the speed of light reduces when it enter that medium. Later on we will see there is something called the effective refractive index, so we have a quantity which is effective refractive index and effective which is again defined as c divided by the velocity half the light but now this velocity of light need not be only the medium which could be a one bound nature this velocity know is a structure which could be like a optical fiber structure or bound structure and we will see that the velocity since it is structure dependent as the size of your medium changes this quantity velocity will change so keeping them medium same just by changing the size of the medium, you will have a change in the velocity of light and as a result y this ratio will change so we will say effect will effective index of that guiding structure would change.

So later on we will see that this concept of effective refractive index will be use more frequently in defining the propagation of light inside the optical fiber. As we mention earlier normally when we talk about light we do not talk about frequencies but, we describe light in terms of wave length just for historical reason with earlier the light was characterized pi's wave length in terms of angstrom.

So here also we maintain that tradition and that is the reason as you saw that we define the windows of operation not in terms of frequency well we define this window in terms of wavelength.

(Refer Slide Time: 43:21)



So we had this three wave lengths which were 800 nanometer, then we had a window which is 1300 nanometer and then we had window which is 1550 nanometer. Nanometer is 10 to the power minus 9 meter's so essentially 1 nanometer is equal to 10 to the power 9 meters and wave length is nothing but, the velocity of light divided by the frequency of the light.

Now to define the spectral width of the source, we require the parameter what is called delta lambda and delta lambda you can write as minus v upon f square to delta f. So we can write here this is minus v upon f delta f upon f and this quantity we upon f is nothing but, lambda so we can write here delta lambda upon lambda is equal to minus delta f upon f.

So let us say if I consider just for sake of argument, if I consider wave length of 1000 nanometer and if I take a spectral width is saw in our earlier discussion a typical window size will be of the order of its 100 nanometer so if I consider this is 100 nanometer your whiled a 1000 nanometer you will get this quantity typically of the order of 0.1 which will be minus delta f upon f. Also from here if I calculate what is the frequency typically corresponding to 1000 nanometer of wavelength you will get frequency f f which is equal to 3 into 10 to the power eight meters let us say we are working in vacum divide by the wave length which is 1000 nanometer so which is 1000 to 10 to the power minus 9.

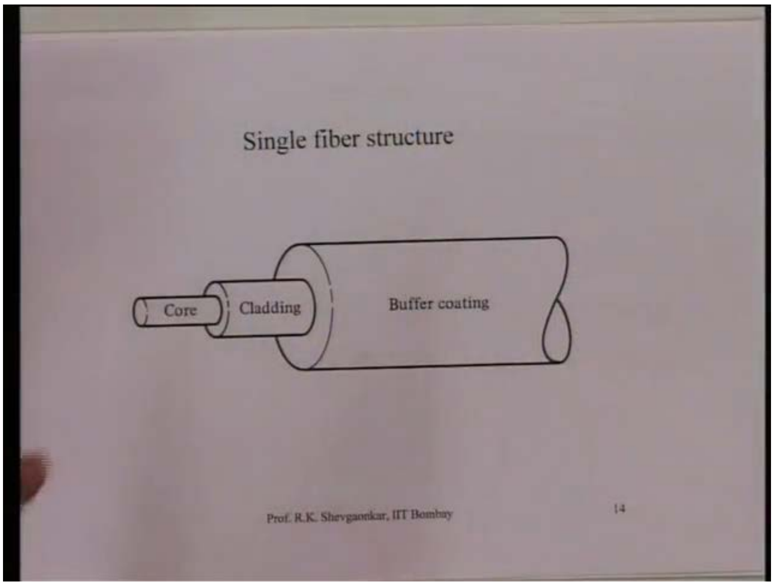
So this gives you frequency which is this will be 9817 so this will get about 3 into 10 to the power 14 hertz. So 1000 nanometer wave length would correspond to a center frequency of 3 into 10 to the power 14 hertz typically and if I substitute that here I will get now a quantity delta f, delta f which is point one of this so which will be equal to 3 into 10 to the power 13 hertz.

So since when we talk about communication we normally talk the bandwidth of system in terms of hertz, if you look at the number corresponding to the optical window we have a bandwidth as large as about 3 into 10 to the power 13 hertz available in each window.

So this is the very small excercise which gives you a feel of what kind of large bandwidth we are talking about. When we talk about radio systems the large bandwidth means few hundred megahertz may be gigahertz may be few gigahertz but, when we talk about large bandwidth in optical communication system the large bandwidth means few terahertz. 1 terahertz is 1 into 10 to the power 12.

So we are talking here bandwidth also then like 30 terahertz. So optical is system is really extremely wide band system compare to the conventional communication systems. With this basic now preliminary understanding of light now we can go to the basic structure which can guide light over very long distances and this structure is what is called an optical fiber. So optical fiber basically is a solid glass rod through which the light propagates and this forward glass rod is surrounded by a shell again made of glass what is call cladding. So basic structure which can guide light is a combination of core and cladding as shown here

(Refer Slide Time: 48:49)



So we have solid glass rod here which is score and you have a cell which is surrounding it which is called cladding. The size of this total thing core and cladding together is of the order of about 125 microns.

So is a extremely thin rod we are talking about to protect this mechanically then there are another layers which are present what I call the buffering layers and then some jacketing layers and so on which do not have any role to play as far as light propagation is concerned they adjust for the mechanical support but, the basics structure which is needed for guiding light effectively is the combination of core and cladding and the light essential propagates inside the structure by phenomena what is called the total internal reflection.

So if the light is sent inside the core and if the refractive index of core is larger compared to the reflective index of cladding then we get a phenomena what is called total internal reflection and then by multiple total internal reflection essentially the light propagates inside this core over very long distances. So to start with now what we can do is we can take the simplest model of light that is ray model and we can say that if the lay ray is launched inside the core and if this conditions are made such that the light can be total internally reflected at the boundary of core and cladding at the interface between core and cladding then through multiple total internal reflection the light can be guided. Therefore precisely we will investigate when we meet next that you will take the structure the core and cladding structure first discuss very briefly about the basic laws of reflection and refraction. We also discuss about what is total internal reflection and then we discuss the issues related to the propagation of light inside this core by multiple total internal reflection.