Advanced Optical Communications
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Lecture No. # 07
Wave Model - II

In the last lecture, we solved what is called the characteristic equation of a mode. We saw that in general, the characteristic equation is for the hybrid mode whereas, if you take a nu equal to 0; that means, if we take circularly symmetric field. Then we get the mode, which are transverse electric or transverse magnetic.

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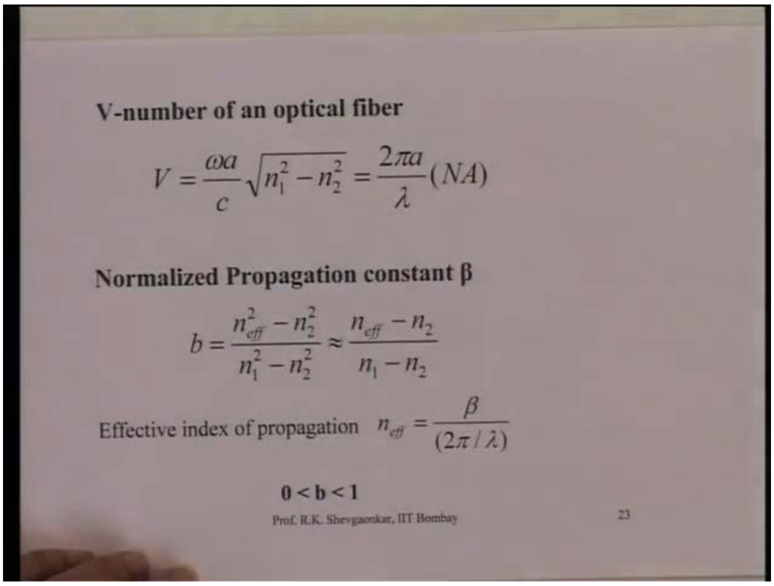

Then we define very important parameter for the optical fiber, what is call the V number of an optical fiber which was given by 2 pi a upon lambda into numerical aperture, where a is the radius of the fiber, and lambda is the wave length of the operation. So this parameter is a more comprehensive parameter to characterize the optical fiber, then the numerical aperture. And this parameter is proportional to frequency, so we said this parameter is also called the normalize frequency. Then we found that there is limit on the propagation constant that is beta 2 and beta 1 or if we define what is called the effective model index, then the model index lies between the refractive index n 2 and n 1. So we could define this quantity what is call the normalize propagation constant by this where this parameter b lies between 0 and 1.

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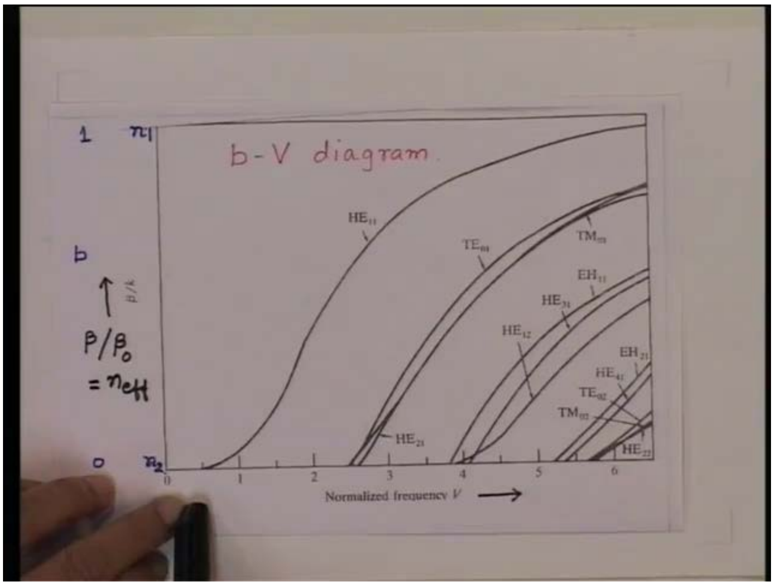

And then we got the relation between the b and V are beta and the V number. And we got this diagram what is called the b - V diagram of an optical fiber, and we found that the V number which is a combination of the refractive index of core, refractive index of cladding, and the size of core together essentially decide the propagational characteristic, individual parameters n 1, n 2 or a, do not play a role in deciding the propagation characteristics. And then we found that as the V number increases, the propagation constant monotonically increases from beta 2 to beta 1 or a modern index increases from n 2 to n 1, also as the V number increases then more and more trans propagating.

So, all the modes have a cut off; that means, below certain V numbers, certain modes do not propagate except this mode, which is HE 11 mode which propagates down to V equal to 0. And then we said this is the mode which must correspond to ray which travels along the axis of the optical fiber. So first single mode operation essentially the V number must lie between 0 and this number here which is 2.4. And then we mention the 2.4 is magic number is due to the roots of the Bessel function. So if consider j 0 Bessel function then the first root of j 0 Bessel function is 2.4.

So, if you want the fiber to be single mode then we must use the parameters refractive index of core and cladding and the size of the core such that the V number lies in the range 0 to 2.4. We also argued that if I look at this quantity beta or if I look at the and effective if an effective is query close to n 2. That means, there is mode energy lying inside the cladding whereas, if n 1 or n effective approaches n 1 then they energy get mode and mode confined to the core.

So, ideally we should choose a V number which will make the n effective as closed to n 1 as possible, where that gives you mode and mode confinement to the core. So if I look at this diagram here ideal it means that I should you the very large V number. So, that this curve here is very close to n 1. However if I choose a value of V which is lying somewhere here of course, for HE 11 mode we have a very good confinement of the energy, but we also have a very large number of mode which are propagating.

So, infect how do you find out the mode which are going to propagate I just take V number draw a vertical line from that V number all the mode which have a cut of frequency less than this V number those modes will propagate. So, for this line this mode will setup modes will propagate, this setup mode will propagate HE 11 will propagate.

However if I bring it here only this set will propagate and HE 11 will propagate theses modes will not propagate. So by increasing the V number s for a HE 11 mode we can make a good confinement of the energy inside the core, but at the same time other most propagating inside the fiber and these modes may not have n effective which is very close to n 2.

So, by choosing a high V number do not help us because. Firstly, it gives us large number of most propagating which gives mode dispersion and the energy which is going to be put inside the optical fiber get divided into different modes. So part of the energy still remains inside the cladding. So what that means, is that if you want to have a single mode operation on optical fiber then see the V number has to be less than 2.4. I have to operate somewhere in this range where here, but V number has to be as large possible some a single mode this range from here to here is acceptable.

But for good confinement of the energy inside the core the V number should as largest possible, that is the reason typically the single mode optical fibers operate with V number less than two point four but very close to two point four so somewhere here. So, if I take a V number let us somewhere here something like this you will see that n effect if the almost of a between n 1 and n 2. That means, there is half the energy which is lying approximately outside the core and half the energy which is lying inside the core.

So, we cannot have a single mode operation without having a substantially energy inside the cladding. So a single mode operation gives you less dispersion because only one mode is going to propagate on this, but it has a substantially energy put inside the cladding that should be understood.

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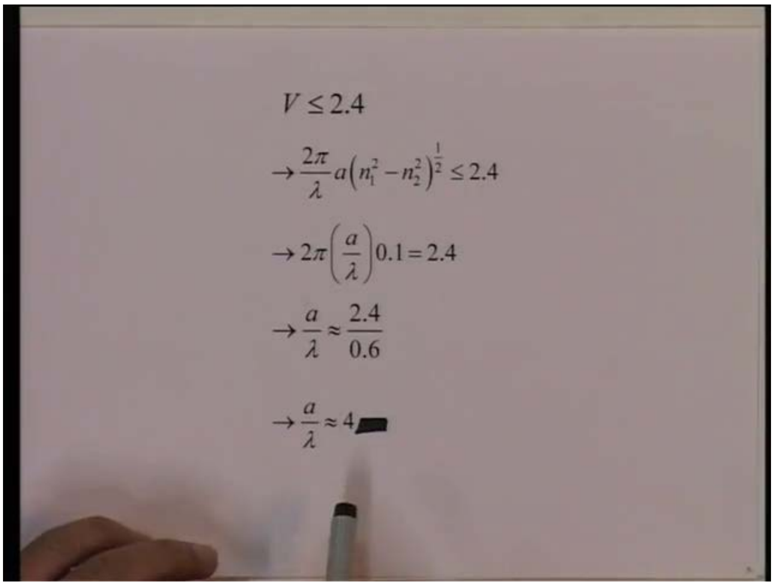

Now just to get a quantitative number from this V equal to 2.4 just take some typical numbers for single mode operation.

So we want for single mode operation. Now V should be less than 2.4. We can write down V which is two pi by lambda into a, if the numerical aperture which is n 1 square minus n 2 square square root. This quantity should less than 2.4, if I take let us say typical number for the numerical aperture it is about 0.1. Then we can get two pi into a, upon lambda 0.1 should be equal to 2.4.

So, from here we can get a by lambda approximately 2.4 divided by 0.6, this is two pi approximately 6, this is 0.6. So we get a by lambda typically of the order about four. For a numerical aperture of course, for 0.1 if you make numerical aperture smaller we can get a by lambda larger, but typically these are the value which will see in practice.

So that means, we get typically a by lambda about 4. So if I consider typically operating wave length of one micrometer we saw that there are windows eight hundred nanometer thirteen hundred nanometer are 15, 50 nanometer that means, in terms of microns it is 0.8 micron, 1.3 micron or 1.55 micron. If I take just for rough calculation the lambda equal to one micron then the radius of the fiber should be less than 4 micrometer, then and then only the fiber will single mode optical fiber.

So thus what we are seen while discussing the ray model, that if you make the core of optical fiber very thin, then there is a possibility of single mode propagation on the optical fiber and now we have got quantitative answer. That if you take typical parameters for the refractive indices for core and cladding then, if the core radius is less than about four micron or four to six micron because the wave length is going to ray between one micron and 1.55 micron then you will get single mode operation in the optical fiber.

So, that is the reason the single mode optical fibers have a very small core and as we mention earlier that is the reason there require very special type of sources for launching light inside them and this sources will be lesser type of sources. Which have a very collimated being, with this now let us look at the field distribution which were going to get for the modes.

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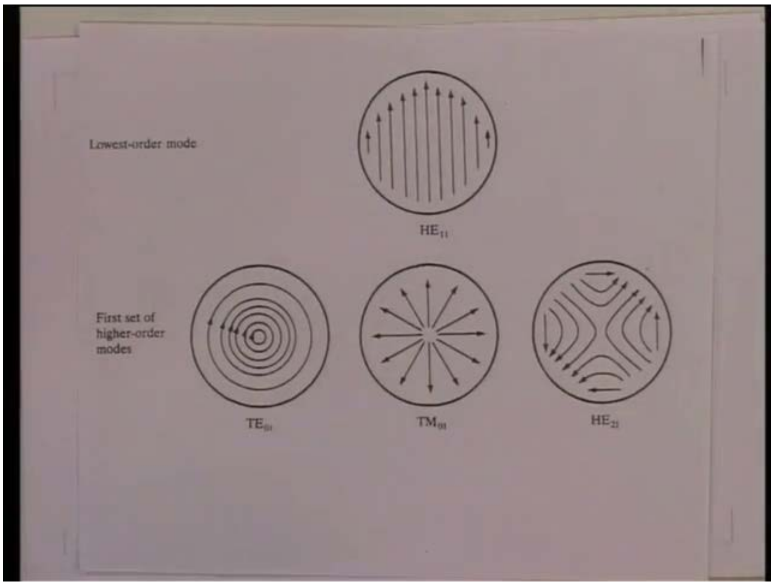

Let having said that we have got the feed expressions at least first few modes, we can have a look at and if you look at the b - v diagram, we have initial mode one is HE 11 mode then you have TE 01 mode then your TM 01 mode and then you have a HE 21 mode. All of them have more or less, same cut off frequency which is corresponding to V number 2.4.

So, if I take the now the field expression then the electric field for these modes would essentially look like that. So if I take the HE 11 mode then thus the wave feed look like That means, everywhere along the cross section the field will be oriented in the vertical direction as we move radially outwords the field decreases, but a direction of the electric field remains constant.

If we consider TE 01 mode, there as be seen that the fields are circularly symmetric thats what the fields are representing. So fields have a component which is if. .I so you have a field electric field which is going on like this a circular loops that as intensity which is at at center, if I consider TM 01 mode then the electric field will be going like this again you have circular symmetric in this and for HE 21 mode the fields would be like that.

So, you can see here it has an azimuth it has a index 2. If I go to this now HE 11 mode the field is oriented everywhere which is like this, let us understand how the two indices are giving you this field. So, as the name suggest this is hybrid mode and the first index gives me a field variation in the phi direction and the second index gives me the field variation in the radial direction leaves second index is one this no zero crossing in the radial direction. So, that is very clear here the second index is one the field is decreasing from the center to the h, but no zero is cross, here how do you see the first index we says you there is HE one. That means, there is one cycle variation here if I look at the field component which is like this, then consider any field component.

Let us say I consider r component E r component. So, if I come here the r is radially out words everywhere. So if I come to this direction here the r component is 0, if I come in this direction the r component is maximum if I come here the r component which should be oriented this way is 0 and when I come here the r component is oriented in this direction which is negative r direction because r should be coming these way.

So, you got one cycle variation here it goes from zero, to positive maximum to zero to negative maximum similarly, if I consider a five component the five will be in this direction azimuth. So, if I take here it is in the direction of 5 if I come here the five direction is this, but the field is oriented this five component is zero if I come here the five direction is this field is up words. That means, it is in negative five direction. So, you got a negative maximum when I come here you get the five direction these way field is these way. So five component is zero. So, what we find here is that both component r component and five component they show you one cycle variation as we move in the azimuth, under for essentially this was index is telling.

So, HE 11 mode if I consider any of the components either five component or r component will show one cycle variation in the azimuth and there is no zero crossing of the field intensity when I go in the radial direction. So, thus ways essentially the field is going to look like.

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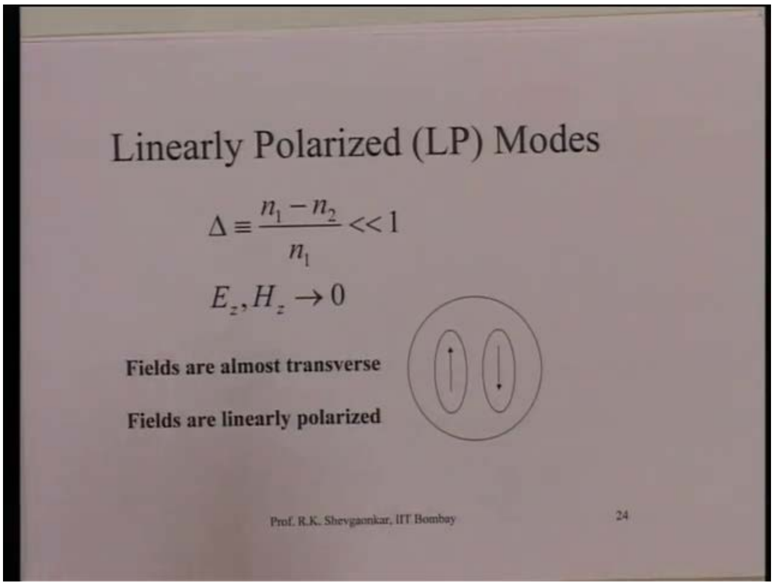

Now if I go in the practice most of the practical fibers as we have seen earlier the difference in the refractive index between core and cladding has to be made as small as possible, just want be discuss earlier when we are discussing the ray model. So, to get a substantial size for the core radius because if I make the difference and refractive index large the core size will become extremely small from here because, we want the V number for single mode propagation has to be less than two point four. So, one possibility as I make the difference n 1 and n 2 very small if I do that than I can get a reasonably large if I make this difference very large then a will become very small.

Now, since we do not want the a to go less than few microns for the light launching considerations we want this difference between n 1 and n 2 should be made very small. So, in practice therefore, what we have is this quantity what is call delta which is defined as n 1 minus n 2 upon n 1 that quantity is much, much less than one because n 1 is very close to n 2 and imagination situation suppose n 1 as exactly equal to n 2 ; that means, there is nothing like core or cladding now you are heaving only one medium with refractive index and if the light has propagate in this medium like a electromagnetic wave since there are no boundaries now the light will propagate like a transverse electromagnetic wave.

So, what; that means, is that when n 1 becomes equal to n 2, the longitudinal component of electric and magnetic fields vanish because the wave becomes completely transverse electromagnetic; obviously, this phenomena cannot take place suddenly when n 1 is equal to n 2 so; that means, as n 1 goes close to n 2 slowly the longitudinal component becomes weaker and weaker and the fields have stronger transverse component. So, for a practical fiber where n 1 minus n 2 divided by n 1 is much, much smaller than one the E z and H z component would be very small they will be eligibly small compare to the transverse components.

So, we say that the fields are almost transverse now in this approximation this approximation is also called the weekly guiding approximations why weekly guiding because if there was no boundary between core and cladding if n 1 was equal to n 2 then energy will be uniformly distributed over the entire space the confinement to the energy to the core is coming because it has higher refractive index compare to the cladding. When the difference between these to be become small that the substantially energy now, which is lying inside the cladding; that means, the guiding mechanism because core is becoming weaker and weaker.

So, in the regime when this condition is satisfied we say the propagation is weakly guiding and most of the optical fiber which are used have this weekly guiding approximation well justified because, for this fibers the difference and refractive indices for core and cladding is really very small.

So, for a practical fiber since the weekly guiding approximation is justified, the fields are almost transverse and also one can show that the fields become, what are called linear polarized what do you mean by that is the if I consider now a feel which is which is like this the field direction is continuously changing. So, I have field direction like this here like this here. So, if I consider point here the field will be oriented this way, if I consider the point here the field will be oriented this way, if I have here the field is going this way here this way here this way here so on.

So, if I look at the cross sectional plain the field direction is differented at different occasions, in the cross sectional plain what one can show is that if you have a weekly guiding approximation, then you have a intensity variation in the cross sectional plain, but does not the direction of the field is concerned it remains same practically everywhere in the cross sectional plain.

So, it could be five vertical it will remain vertical everywhere it will be positive or negative, but the field will not be oriented in this way. So this field then we called as the linearly polarized fields. So, two things essentially happen when we have weekly guiding approximation and that is the field become almost transverse and they become all mostly linearly polarized in terms of b - v diagram what essentially is happening is that as the n 1 becomes equal to n 2 or approaches n 2.

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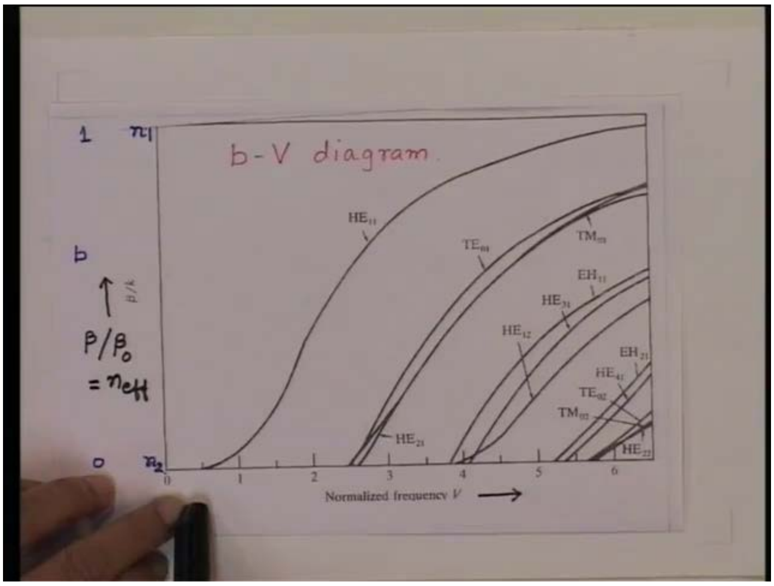

Then the mode which you see separately here in this group they almost become degenerate; that means, this characteristic b - v diagram for this setup mode they almost merge into each other.

Similarly, this mode will merge into each other this way merges into each other. So, will never see individual modes like TE 01, TM 01 and HE 1 you will always a combination of these three modes, it should be there and these combination would generate field distribution which would be linearly polarize these mode which is isolated mode will be linearly polarize that was already a linearly polarized mode as you can see the field distribution you have a polarization which is linear everywhere, but if I consider the second set which is combination here even after this three mode become degenerate; that means, they have same phase constant you will see the distribution which will be linearly polarized.

So, in any practical fiber we do not have the general hybrid or TE or TM modes visible because combination of this mode, which are degenerate always generate the field distributions which are linearly polarize that is the reason normally the mode which propagate inside the optical fibers are designated by linearly polarize modes or LP modes.

So, you will see in the literature if you are treating the optical fiber as a simple wave guide the structure then you, would have the mode which will be hybrid modes or TE, TM modes, but most of the practical situations we will talk about the modes which are the linearly polarized modes. So, in general then we can say that we can have now the combination of different modes which can generate well linearly polarized modes.

So, if I take a HE 11 mode, the HE 11 mode will become the linearly polarize 01 mode now, here the indices essentially are telling us the first index tells me the azimuthal variation and now note here this is not telling you the variation of E r and if I component it is telling give the variation of linearly polarized fields.

So, if I say that [my lin] polarize fields was vertical, vertically polarize then for vertically polarize field what is the variation in the azimuth direction that is given by the first index. So, for HE mode the first index was one, but was a linear polarize nature is concerned a does not have any variation in the five direction because once direction is taken care of everywhere the intensity is going to be same for a given value of r. So, as a change the value of five, the value of the electric field amplitude does not change.

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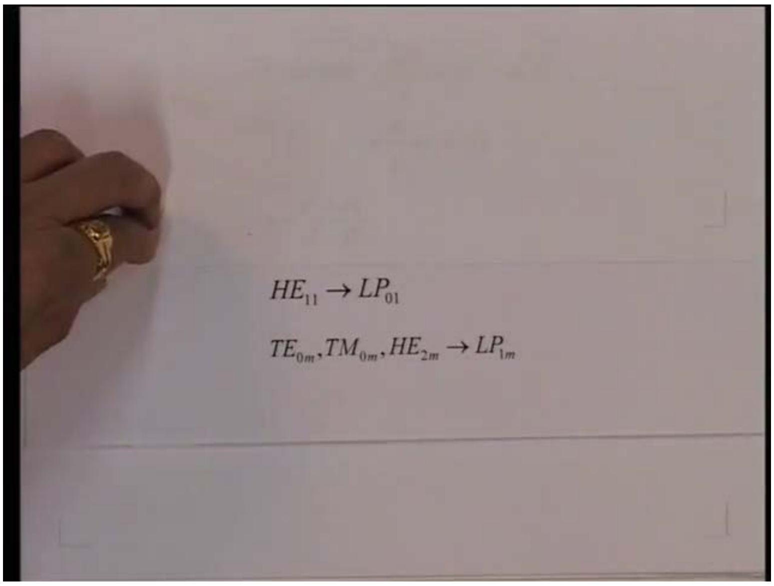

So, the HE 11 mode then essentially becomes the LP 01 mode. So, first index tells me that it is in the azimuth direction there is no variation in the field amplitude second index one tells me that there are no zero crossing in the radial direction. So, the field distribution this would be the linearly polarize will be LP 01, then the mode which are lying in the cluster like T E 0 m TM 0 m and HE 2m, mode they will become degenerate and they will give the linearly polarize mode which is LP 1m mode. So, here we will see one cycle variation in the azimuth direction and m will be the m minus one will be the number of zero crossing the radial direction. So, if I consider the first set of these modes. So, m equal to one that will give me a mode which is LP 11 mode.

So, if I consider in the b - v diagram and if I take the next set of modes this one they will degenerate and they will give a field distribution which will be called as the LP 11 mode. So, in the weekly guiding approximation you have the first mode which travels which is LP 01, the next mode which will travel which will be combination of this three which we LP 11 and so on. Now we are just talk about this two mode because these are two mode which are useful for long distances communication LP 01 mode which is same as HE 11 mode of course, is the mode which propagates on a single mode optical fiber.

But later on we will see that the next mode which is LP 11 mode is useful in what is called dispersion compensation. So, later on when we discuss how do compensate dispersion on optical fiber that time we will refer back to this mode again which is the LP 11 mode now a just see qualitatively how LP 11 mode will be created.

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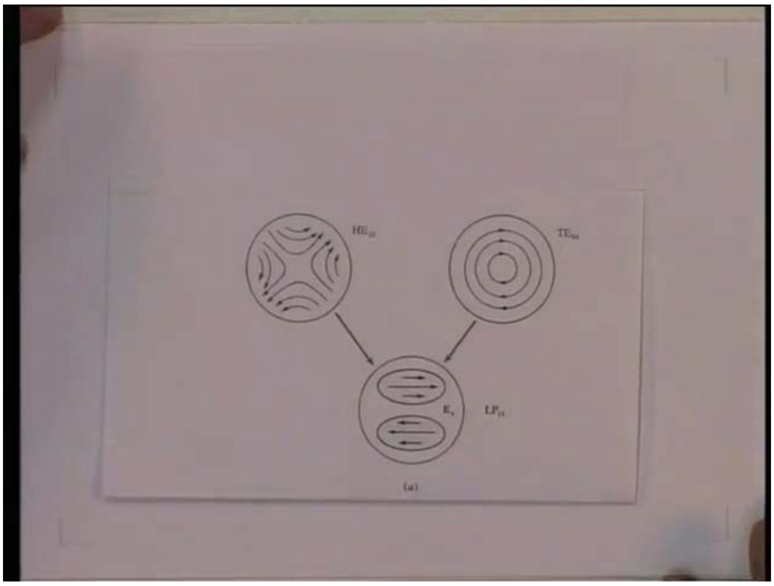

So, let us say I have a HE 21 mode we have a t 01 mode and since this combination here this diagram we have a combination of TE 01, TM 01 and HE 21, TE 01 and HE 21 can give you a pattern TM 01 and HE 21 and we give you another pattern. So, we can see here if I consider the HE 21 mode and if I consider TE 01 mode and if had this two.

We will see here, the field direction is vertically up words here the field direction is vertically down words the cancel each other ,when I come here that is location the field direction is this way here also field direction is this way. So, the field will add and when I come to this location this is going up words this is down words. So, field will cancel and again here the field will add because, this will direction of the field here this will direction of the field here.

So, the combination of this two fields essentially would generate a net electric field which will be a horizontal everywhere, but the intensity variation will follow a one cycle variation. So, this LP mode because the field is linearly polarize everywhere and in this case horizontal and it has one cycle variation in the azimuth. So, its first index is one it also as cross one zero in this; so, its first solution that is why it is the LP 11.

So, LP 11 mode typically will have 2 intensity blocks like this and the electric field will be polarize with the opposite rest instead of T E 0 if I take a TM 01 mode and again HE 21 mode (( )) orientation by forty five degrees you get a combination of these two again which will give me distribution something like this because here when I come this location the field get added this location the field directions are again getting added opposite direction and we come here the fields are an opposite direction this is up words this is down words. So, it cancels and same thing there is a cancellation it is location also. So, again you see in the azimuth direction you have one cycle variation. So, it is LP 11 mode.

So, LP 11 mode there are two possibilities one is I have this two intensity blocks and electric fields are going like that or we have the two intensity blocks and the electric fields are like that. So, there are two possibilities for the LP 11 mode or it further four possibilities for LP 11 mode, for each of this seeing I can orient this one ninety degrees.

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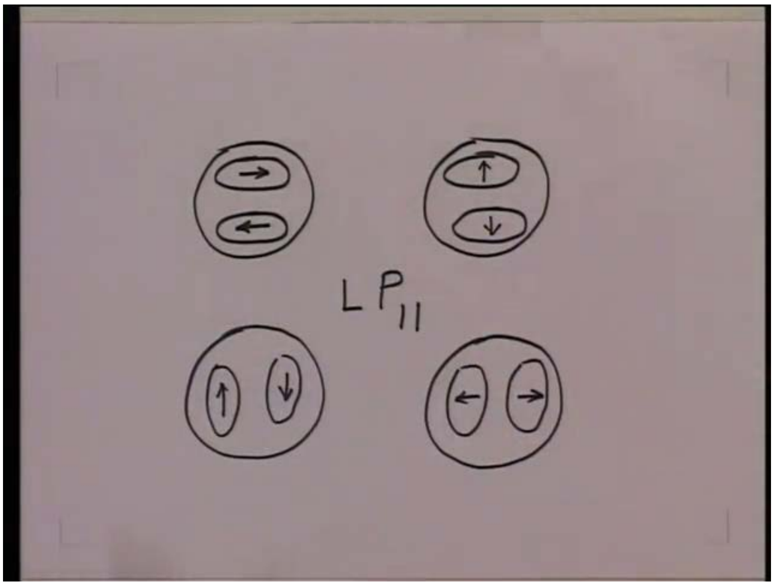

So, I can have four possibilities for LP 11 mode one is I can have the intensity blocks, which are like that and the field could be this way and this way or it could be this way and this way other possibilities the ninety degree rotation of the coordinate axis which would be like this like this. So, when we say we have a LP 11 mode infect there are four modes which are having a exactly same phase characteristics and their intensity and polarization would be given by this.

So in fact, whenever we launch light with arbitrary polarization inside weekly guiding fiber and if the exaction mode is LP 11 infect we have a combination of this four modes which will be propagating simultaneously inside the optical fiber.

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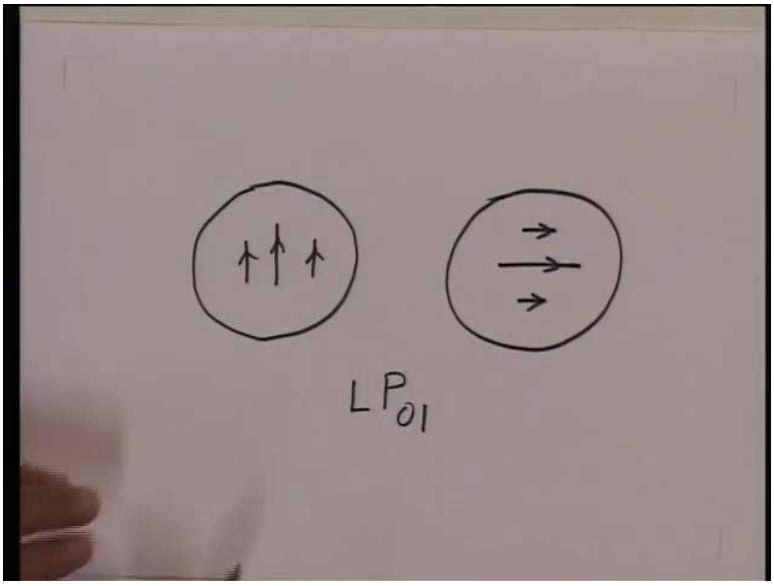

Same thing than one can ask for what is the situation for LP 01 mode and LP 01 mode as we saw is circularly symmetric. So, the rotation of the fiber (( )) play roll, but it certainly depends upon what is the orientation of the electric field. So, one possibility this other possibilities could be horizontally polarize something like that.

So, for LP 11 mode we have a degeneracy by the vector of four whereas, for LP 01 mode we have a degeneracy of vector of two because essentially we have two orthogonal polarization which are going to propagate in the form of LP 01 distribution like that, if we consider the degeneracy for all the modes which are going to propagate for a large number one can some of the total number of mode, which are going to be present in each of this groups and then one gets a result, which gives us the total number of mode which are going to propagate inside the optical fiber and that is approximately given by this square by two.

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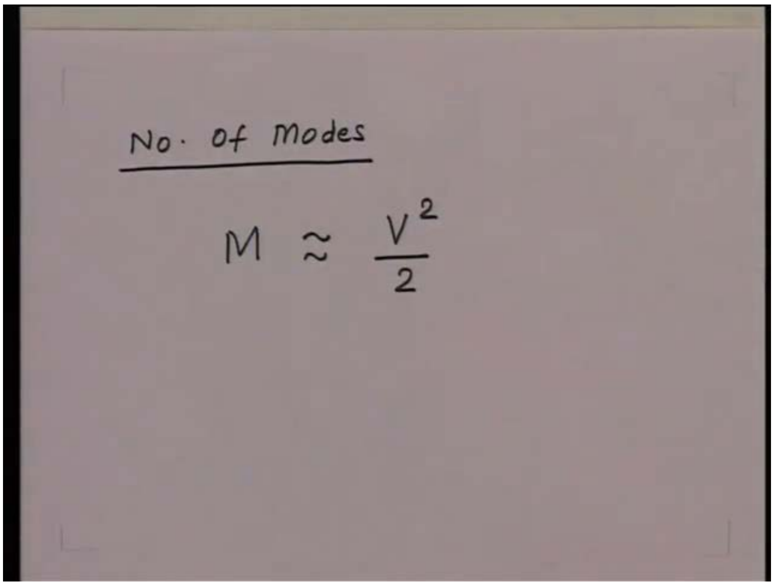

So, the total number of modes m is approximately equal to V square by two this is number of modes. So, if I consider a multimode optical fiber and the V number is much, much greater than one then approximately the number of modes which will propagate considering all this degeneracies, which we talked about will be approximately given by V square by two. So, if I consider a optical fiber with V number let us some 10 this will be ten square which will be hundred divide by two. So, you will get about 50 modes propagating on the optical fiber of course, this relation is not valid when the V number become a very small.

So, if I take V number of two or 2.5 then this relation will not be valid. So, this relation is valid when the V number is much, much greater than one. So, in a multimode fiber the V number is large and because of the large number of most propagate and since each mode has this own effective index you have a very large dispersion and they if had seen from the multiple ray propagation inside the optical fiber.

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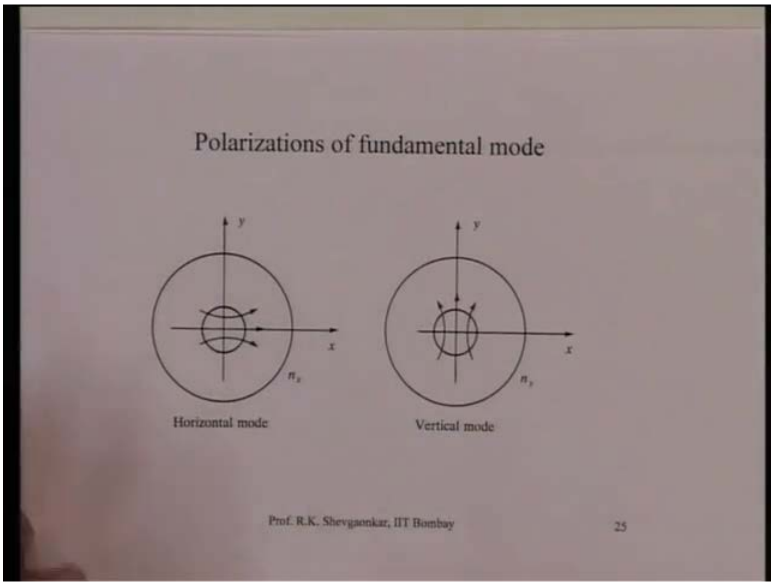

So, with this then one can come back and say that for the LP 01 mode, which is same as the HE 11 mode for a single mode optical fiber, you may have a filed distribution which would look like this. So, you may have LP 01 mode, which we vertically polarize or you may have a LP 01 mode which could be horizontally polarize.

And later on we will see the implication of this. This since we are having two orthogonal polarization here if the fiber was not perfectly circular then the two modes will not propagate with the same phase constant and it will have some effect on the performance of the data rate per at the moment which would simply note that, when we say LP 01 mode we essentially are referring to two modes, which are having orthogonal polarization which is horizontal or vertical or any two orientation which are perpendicular to each other.

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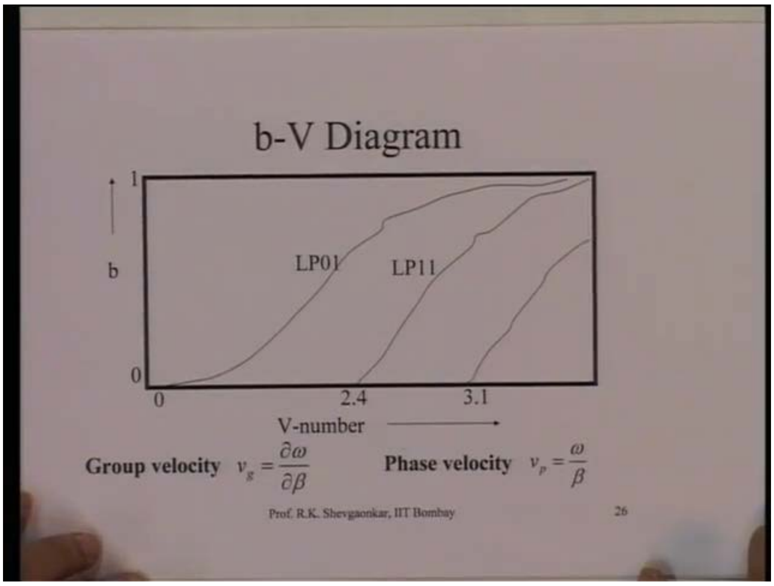

So, if I know look at the b - v diagram for the LP modes, as we seen the LP HE 11 mode as become LP 01 mode. So, this is more or less same what we saw earlier the cluster of three modes has now become LP 11 mode and then so on.

So, now for weekly guiding approximation this is the diagram which is the diagram because, it give you relationship between the propagation constant beta and the frequency omega and once you get this quantities here essentially, then we can find out the quantity which is d omega by d beta which gives you the group velocity and the phase velocity which is omega by beta.

So, if your operating in the frequency range or the fiber parameter range where the fiber is single mode optical fiber, then the location on this graph here gives you the quantity which is related to the phase velocity, I can value measure the value of V I can measure the value of beta and except them proportionality constants essentially the quantity which is V by beta, will give me the quantity proportional phase velocity whereas, this quantity here group velocity which is d omega by d beta is related to the slop of this function.

So, if I go to the curve somewhere here, essentially we will see that this quantity here slop of this will give me d beta by d omega which is one upon this quantity here. So, here the slop is very small here again the slop becomes very small and that is region where the slop is very large. So, you will see that if I calculate the group velocity the slope here is very small which is d beta by d omega. So, velocity is large here same is true when I go to this region also and even I go here thus where I get the velocity which will be where is similar to what I am get from the selection. So, the b - v diagram once we get for a particular mode then by numerically calculating the quantity omega by beta r d omega by d beta I can calculate the phase and the group velocity.

Now, once I get the phase and group velocity then I can ask, if the either g was send in the form of pulse what will be the distortion of the pulses, when we propagates on the optical fiber and so on. So, having analyze now the optical fiber in the form of this wave model and having often this characteristic what is call the b - v diagram now, next thing would be to find out the group velocity and then from there to find out what will be the distortion of the signal when it propagates on the optical fiber.

So, the next topic which essentially we have to discuss is that if the signal is launched in the form of pulse on the optical fiber. What way the signal will get distorted during propagation before we get into this question; however, first ask a question what do you mean by signal distortion and what are they conditions in general first signal not to be distorted.

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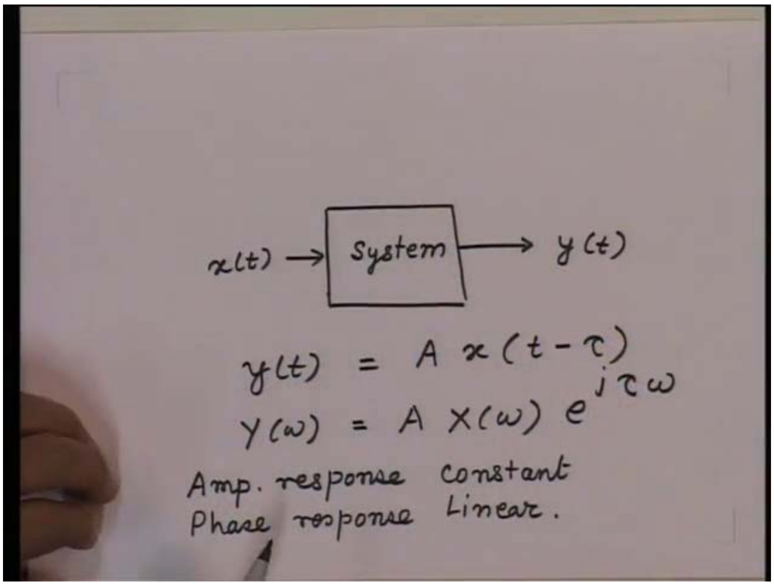

So, let us say suppose add a system and suppose if put signal x of t and this we get from the system a signal which is y of t, we say the signal is not distorted while passing through the system if y t is a replica of this signal x t; however, by saying replica, the amplitude of this signal as a whole is reduced or increased, then we do not call that as a distortion for example, when we are speaking let us say our voice is pass through an amplified given to a loud speaker the signal amplitude increase significantly, but that we do not call a distortion let us see simply increase an amplitude similarly, when we speak from this location by the time sound reaches to somebody else it has taken some finite time.

So, as sound reached there after some time in other words the sound words the late in time that the receiving point and there also be do not call as distortion. So, when the signal is reduce or increase in a amplitude as a whole, we do not call that as distortion, if the signal is delayed in time there we do not call as distortion what; that means, is that if the signal y of t is A times some x t minus tau if we get that then we say my system is the distortion less system, if this thing does not happen then we say the system produce a distortion. So, any signal under going to amplitude change as a whole and delayed in time is not called a distorted signal.

One can then ask a question to get this behavior and time what should be the frequency response of this signal. So, if I take the fourier transform of this signal you can get y of omega, that will be equal to A x of omega e to the power j tau omega, what is give the tau stand is that the frequency response which is y omega divided by x of omega that is equal to A e to the power j tau omega. So, to have as system distortionless two things have to happen, first is the amplitude response which is given by this should be independent of frequency and the phase response which is given by this is linear with frequency.

So, which should have amplitude response constant as a function of frequency and the phase response, linear with frequency if this two condition are satisfied then there will be not any distortion of the signal, when the signal passes through the system with this understanding than let us now, go to the optical fiber and ask a question wherever these two conditions are satisfied and if they are not satisfied then, only will get distortion on the optical fiber if this conditions are satisfied then will distortion less propagation on the optical fiber.

Before we get into that; however, let us first look at the fundamental difference between the optical communication and the normal radio communication when we talk about radio communication, we have a carrier and we have a modulating signal same thing we do an optical also we have a carrier which is the optical carrier we modulate this by the signal which we want transmit.

However, when we go to radio frequency if you ask what is the spectral width of the carrier and invariable is question is not even ask because the spectral width of carrier which we get radio frequency is so, small then we do not have to take there in consideration.

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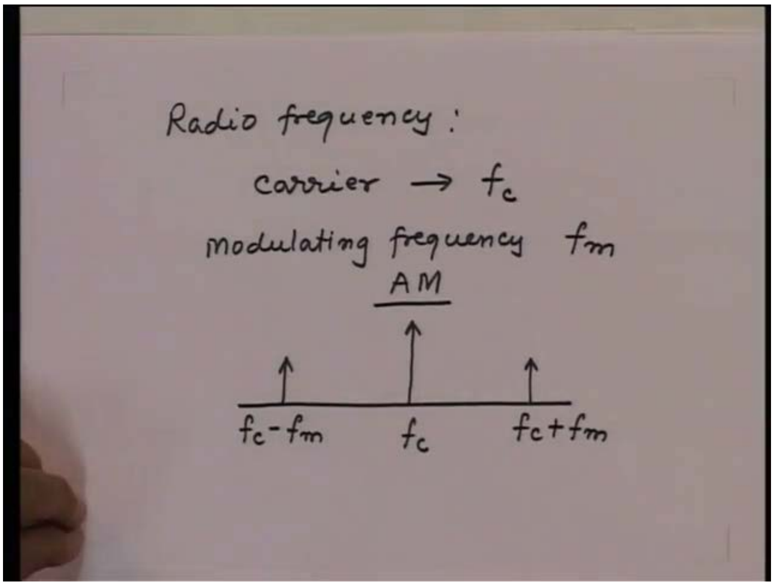

So, if the radio frequency if I consider a signal, if I have a frequency carrier frequency which is given by let us some f naught or f c and if I have a modulating signal frequency, let us say f m and let us say if I do the simple amplitude modulation of this. We get frequency is which are f c plus f m, f c minus f m and the carrier frequency f c.

So, if I look at the spectral of a signal which is a m signal, we get a carrier frequency which is f c, we get water call the side bands which is f c minus f m and we get f c plus f m. So, at radio frequency since the spectral width intrinsically is very small for carrier. You see the frequency spectral which consist of three delta functions one located at f c and the side bands located at f c plus f m and f c minus f m. So, radio frequency if I take amplitude modulated signal and put on spectrum analyzer you will really see the three sharp frequency picks in the spectral. Question one can ask is when we go to the optical frequency is the same picture valid at optical frequency is also.

So let us say, we have the so, called the carrier frequency that optical signals and then they carrier signal is modulated by frequency which is again f m, but an optical signal you have spectral width which could be of the order of few nanometers your seen earlier that if I consider a source like laser you can have a spectral width beginning of the order of one to two nanometers, if you have a source like LED then we can have spectral width typically of the order of about twenty to thirty nanometer and we have seen, if you go to typically one micron wavelengths kind of signals, approximately one nanometer spectral width is hundred gigahertz.

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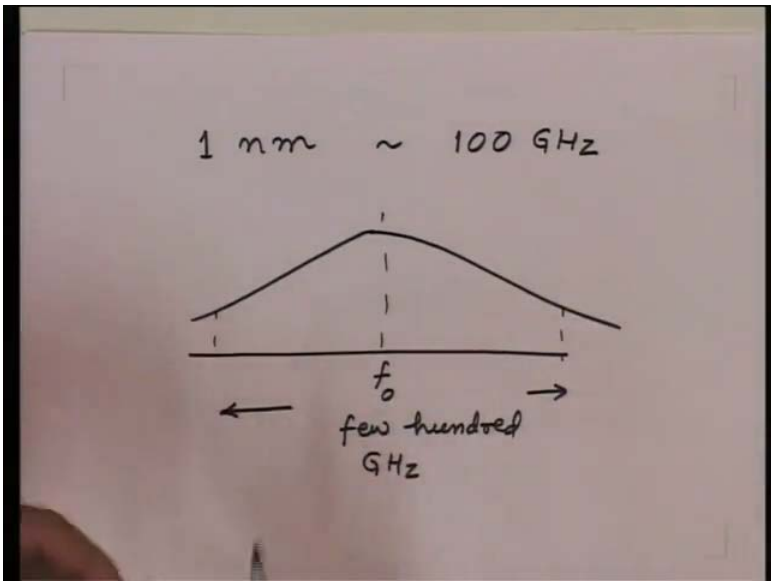

So, we have almost say rule of thumb that typically one nanometer is of the order of the hundred gigahertz. So, if I have a optical carrier whose spectral width is one nanometer then this carrier, if I look at the spectrum analyzer it will not look like a delta function at will look like a distributed spectrum with a frequency range effectively of the order of eight hundred gigahertz. So, if I look at the carrier without modulation the carrier will look something like is, this is my center frequency f 0 and typically this will be of the order of about few hundred gigahertz.

So, now there is a fundamental difference between the way the optical carriers are modulated and the radio carriers are modulated. In the radio the spectral width of carrier is negligibly small compare to this frequency which is f m whereas, when we go to optical signals the spectral width of carrier is not only comparable, but will be much larger compare to the modulating signal and obviously, when this thing happens something fundamentally changes conceptually changes.

So, the modulation processes optically is not same as what we can visualize for the radio signals. So, radio signals we have very clearly seen the carrier and we can very clearly see the side bands. So, when we go to the optical signals where the spectral width of carrier is very, very large compare to modulating in signal we have to now visualize this modulation process it will more in depth before we make any conclusions.

And presides this what will do when we meet next time we ask a question if we take a light source which is having a spectral width few hundred gigahertz and if I try to modulate this with a modulate signal, which has a frequency may be few gigahertz what way the spectrum will be represented what will be the implification of this for the signal transmission and what will be implication for the dispersion of the signals on optical fiber.

So, all though in first look from the ray model as we saw earlier, when we have a simple one ray propagating a along the axis of the fiber there was no dispersion. So, first look it might appear that if I use a single model optical fiber, there will not be distortion of the signal on the optical fiber essentially we have to understand this phenomena in depth before we might conclusion.

So, next time will be meet essentially first we investigate in this situation when the spectral width of the carrier is very large, how the modulation can be visualize and then we answer the question what would be distortion of the signal on the optical fiber.