Physics of Linear and Non Linear Optical Waveguides
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Module - 03
Modes (Cont.)
Lecture - 34
Optical Fiber Mode Morphology (Contd.)

Hello, student to the course of Physics of Linear and Non-linear Optical Waveguides. So, today, we have lecture number 34 and in this lecture, we will going to continue the Mode Morphology.

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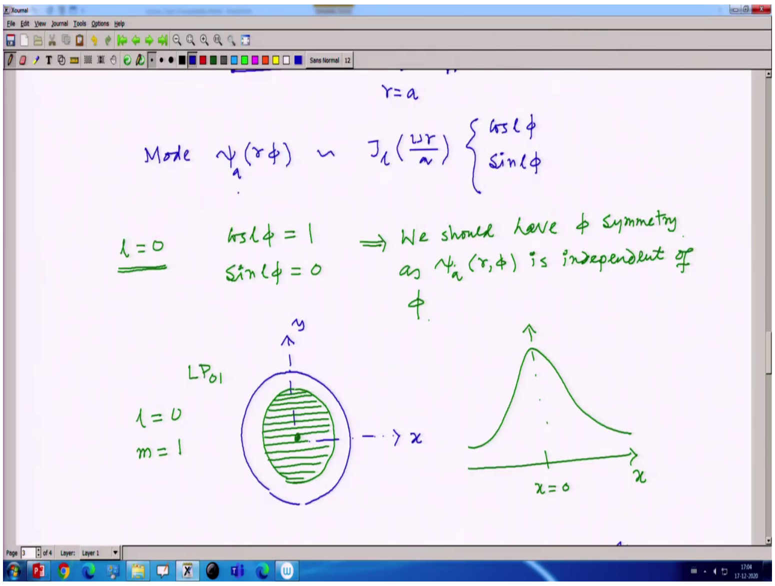

So, in the last class we try to understand the distribution of the mode if I go back to the structure here then we find that the mode is defined in this way that psi a equal to r phi, which is J l Ur and then cos l phi sin l phi. So, this is the general way to define a mode.

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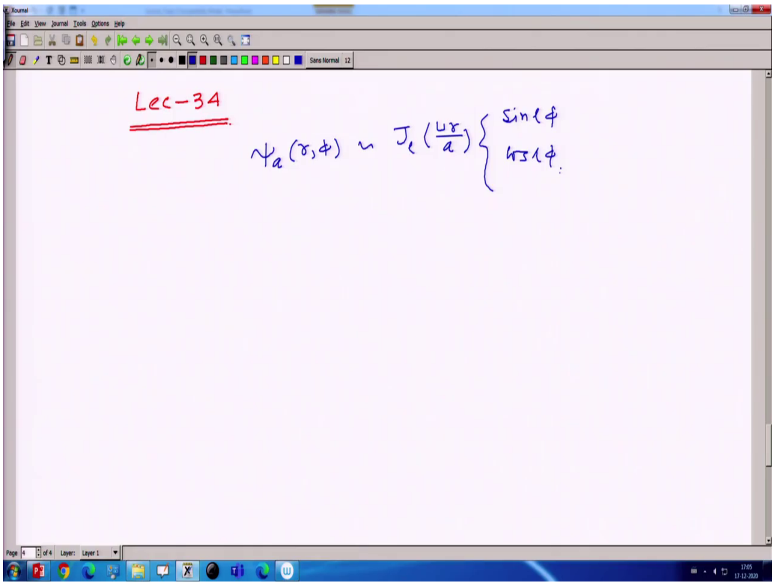

So, let me define once again that, psi of a the the spatial distribution of the mode is of the order of J l Ur by a with sin l phi cos l phi these are the solutions.

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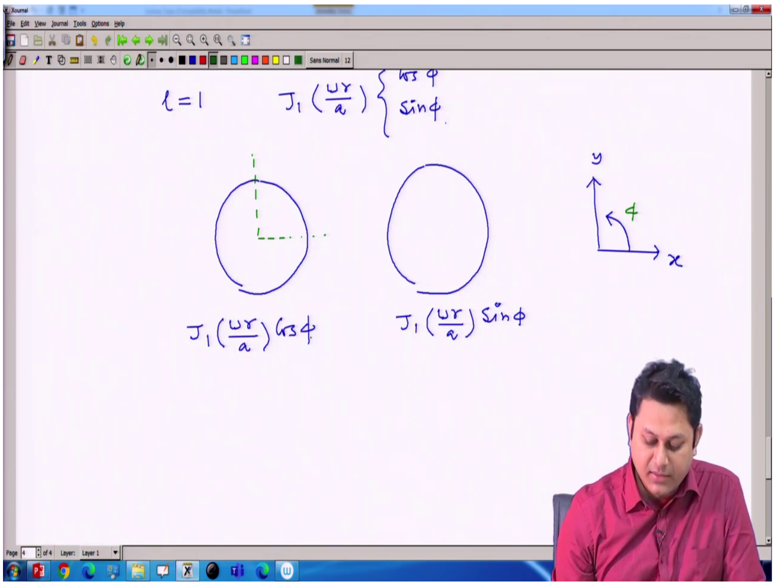

Now, for l equal to 1; last time we define l equal to 0 and try to find out what is going on there. So, I should write J 1 Ur by a then cos of phi and sin of phi because l equal to 1. So, this is this should be the structure. Now, here it is interesting to note that I we have now the contribution of the phi. So, it should not be the; there should be the, it should not be the phi symmetry at all.

So, if I now try to find out what is the structure of the mode then let me draw this in this way. So, this is this for this set of solutions and this is for this set of solutions in one case we have sin phi and another case it is cos phi. My x and y axis is this and along this direction I have phi; phi is changing in this way.

Now, if I look to this equation J 1 Ur cos phi and if I only concentrate on the phi then you can see that when the phi is 0 along this direction is phi 0 we have cos phi 1; when phi is phi by 2, we can say this cos phi value will vanish. So, entire field will going to vanish because of the fact that now the cos phi is phi by 2. So, considering that fact we can qualitatively understand the distribution. Let me first draw roughly the distribution.

By the way I am doing everything in hand and I strongly suggest to please check in the book how the mode distribution exactly look like because it is not possible for me to draw by hand the exact very exact mode distribution, but there are good books where this mode distribution is shown in a very nice way. So, you can have a look, you should look there.

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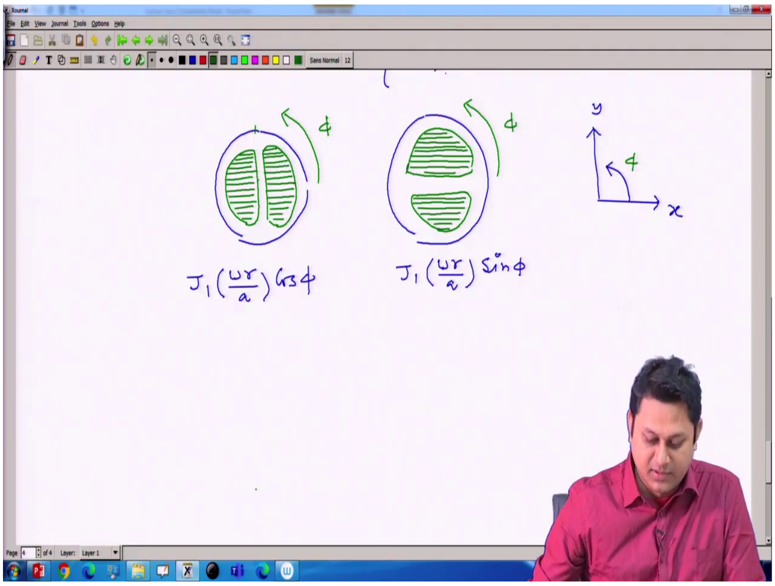

But, qualitatively if I draw the structure will be something like this I have two lobes here like this and these two lobes are distributed in this way, this is for this is the solutions related to cos phi. So, I should have two lobes and here the intensity will be maximum and here the intensity gradually in the intensity will go down. And, here in this over this line there will be no intensity at all because of the cos phi.

In the similar way, we can have the solutions for sin phi and again we have two lobes, but this lobes will now going to distributed in this way. Again, if I consider the variation of the phi it will help us to understand that how the two lobes are distributed in this way. In this line over this axis x which is for which phi is equal to 0 sin phi is 0, so, we should not have any kind of field layer the field is 0 here.

And, if I go gradually so, in this direction basically my phi is changing in this direction my phi is changing. So, if I consider this you will qualitatively understand how this field we will going to distribute for l equal to 1. Also, if I now try to understand that what should be the distribution of the electric field here how the electric field will going to distribute, then it is interesting. So, let me draw that here one by one.

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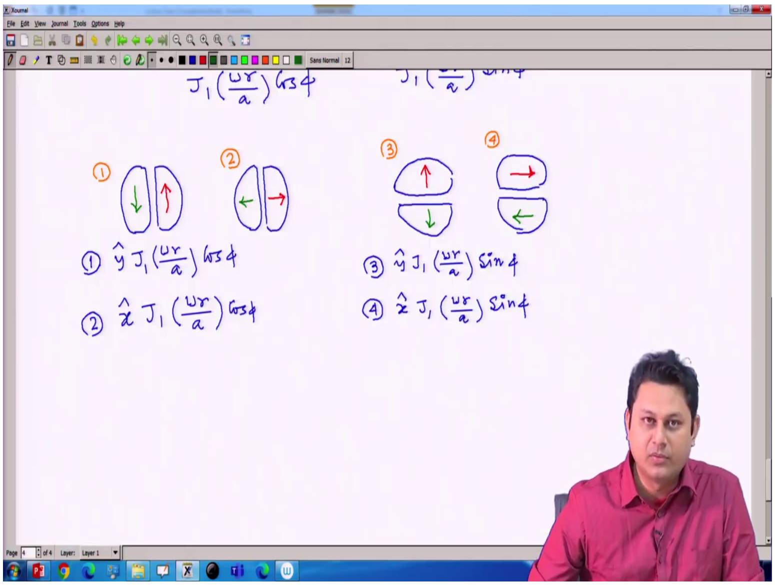

So, I have two lobes here this is one this is another one for another polarization I will show you and I have two lobes like this for sin like that. So, here if I look carefully, then the distribution of the electric the vibration of the electric field should be like that for this case and what is the case here is y J 1 U r a cos phi, this is for 1.

And, you can see that this case and this case both are cos phi and along this direction it is positive y and along this direction it is negative y. So, the why it is negative y because cos phi will be minus 1 here and that is why it goes in this direction. So, gradually it should be distributed the electric field will be distributed in this way.

Now, in the similar way if I want to find out the x of that x component of this one the x variation; so, the field say if I write it is 2, so, this is say let me write it as this is 1, this is 2, this is 3 and this is 4. So, for 2; I have x J 1 Ur a and now I have not sin phi, but cos phi because this structure is for cos phi only cos phi. So, in this direction it should be the positive and in this direction it should be the negative. So, this is the field electric field distribution inside the lobes.

Here also for 3, say this is y J 1 Ur by a sin of phi and 4; number 4 modes is it should be x unit vector J 1. So, for y when we have phi by 2, then it should vibrate in this direction and this slope it should vibrate like that. In the similar way for 4 we have this direction and this direction for the vibrations. Well, these are the direction of the electric field along which inside the lobe along which it will going to vibrate.

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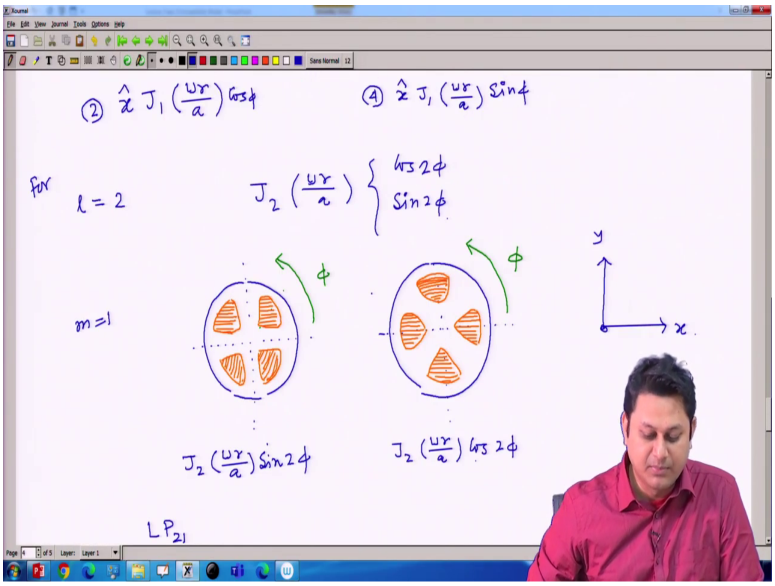

Now, will go for the higher order more higher order modes which looks rather interesting say l equal to 2 and for l equal to 2, the solution will be of the form like this. Now, we have cos 2 phi and sin 2 phi. Now, if I draw the field distribution let me divide into four parts and by the time I believe you have a rough idea that how the fields will look like how the mode distribution will look like.

So, along this direction I have y and along this direction I have x. So, for J 2 Ur by a cos of 2 phi, this is the mode. So, let me write it properly, cos 2 phi and this is for J 2 Ur a sin 2 phi. So, now, again I am going to change the phi along this direction. So, this is the variation of phi, this is the variation of phi and the mode will be distributed in this way.

We have a patch here in this regime, we have a patch here in this regime, we have a patch in here in this regime and we have a patch here in this regime. Sorry, this is I make a mistake here this will be ok let me erase this part then it will be this will be for sin 2 phi because this will be for sin 2 phi.

Why? Because when the sin is phi 0 I should not have any kind of distribution here. When the sin is phi again I should not have any kind of distribution here, mind it, the argument is now 2 phi. So, when the phi is phi, then in the argument phi by 2 in the argument I am having phi here. So, that is why this portion will be not there anymore.

But, this angle around this 45 degree angle I have a distribution which is maximum why because when this phi is phi by 4, then we have sin 2 into phi by 4; that means, sin phi by 2 and in sin phi by 2 I have a maxima here. So, that you need to take a account here because now argument is multiplied by 2 phi and accordingly, you should distribute your modes.

So, the mode will be distributed like this. So, here we have a patch, here we have a patch symmetrically you just rotate your phi and find out the values and really you can go to get the modes. The distribution here is something like this. In a similar way for cos let me change it because for cos 2 phi I am having the mode structure ok.

Let me erase this the mode structure I am having like this. So, one patch will be here, one patch will be here, the patch will be here and another patch will be here. So, in all cases this is l 2, this is l 1, this is l 0, the first one l 0 and m equal to 1. So, in all the cases I am drawing for m equal to 1. So, here also m equal to the first mode I am drawing.

So, you can see that here this mode and this mode both the cases this mode is defined one can define this as LP say 21 for LP 21 this is the distribution. And, one distribution I have this and another for another case I have the distribution like this, but interestingly in both the cases the value of the beta propagation constants are same. Because this is a, a point solutions and in this point solution I have a single value of b and from the single value of b, I can have a single value of beta propagation constant.

So, eventually these two are some sort of degenerate modes we are talking about. Its structure is different, but the energy that it should carry is same. Well, after that we need to understand something which is important that the there is a distribution over the mode. For example, the fundamental mode; we have a structure like this fiber structure, fiber core and over the fiber core we have a distribution of the mode.

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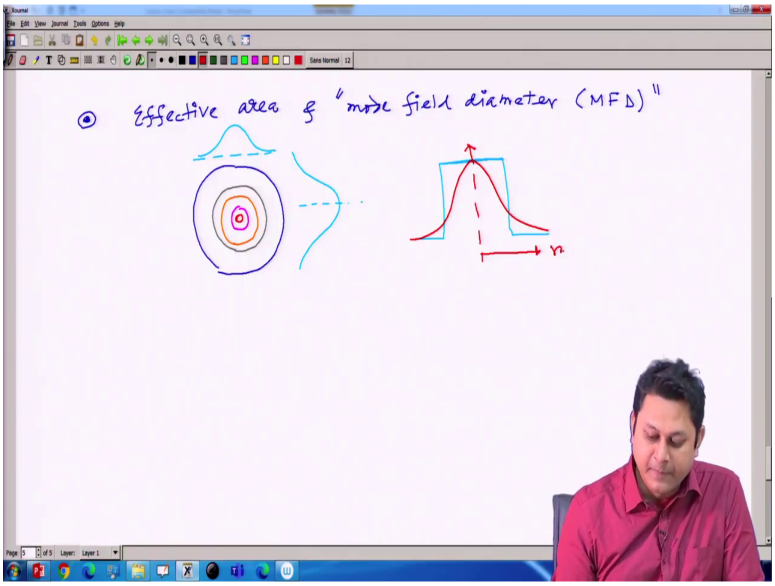

So, now based on that that the mode is distributed over the fiber, we need to find out what is the effective area that a mode is having for that when it is distributed. So, next is effective area and important concept called mode field diameter; mode field diameter or MFD in short. In many cases we need to understand what is the field diameter.

So, if I draw once again this is the core part of the fiber and over the core part the mode is distributed. So, this is the mode we have and it is distributed. So, I have a higher intensity here, then gradually the intensity is going down. So, these I can represent it by these lines. So, if I draw the distribution the of what should I say the distribution of the field, then the distribution of the field inside the fiber is something like this. In x-axis, in y-axis these are the distributions I am talking about ok.

So, effective area means what is the. So, you can see this distribution is not it is a varying distribution this distribution is not a flat distribution. If the distribution is this then we can understand ok this is a flat kind of distribution. But, the distribution of the mode is something like this. So, it is varying over r it is distributed like this. So, there is a variation over r or over x y, over r.

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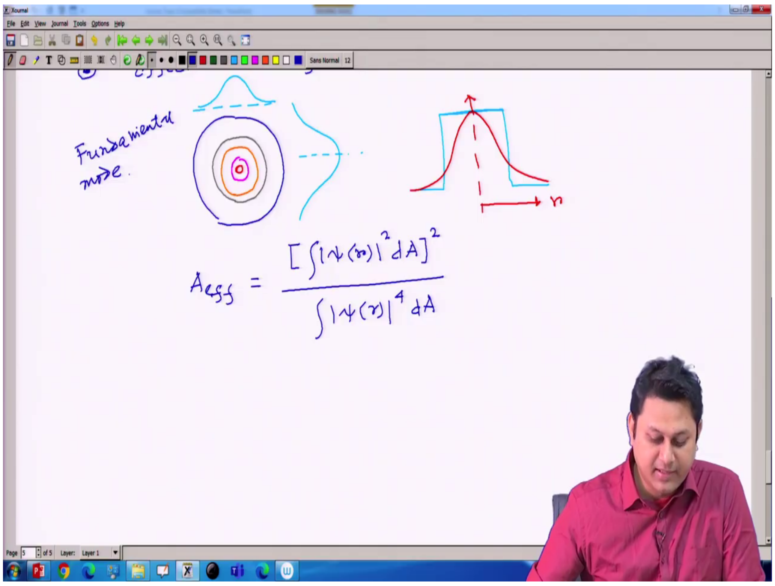

So, we can define a effective area of this mode and this effective area by definition it should be this. So, I have psi r which is my distribution I make a mode of square of that and then I am going to integrate over this area, whatever the area I am talking about I will going to integrate it and then divide it. Then I going to divide this with mode of psi r to the power 4 and I am going to integrate over area.

But in upper case we have a square as well. So, you need to make a square of that. So, this is essentially the fundamental mode the distribution is essentially for fundamental mode. Note that for single mode fiber this fundamental mode is only mode that one can excite inside the fiber. So, that is why it is very very important.

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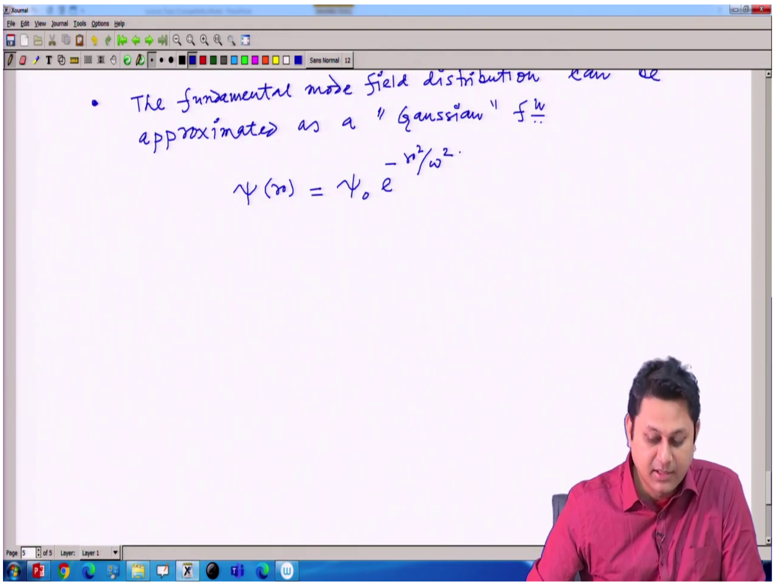

Now, if I want to execute the value of effective area, then we need to find out what is my psi r then only we can integrate. So, the fundamental mode field distribution; the fundamental mode field distribution can be approximated. Because we know this is a Bessel kind of solution.

It can be approximated as a Gaussian function of the form like this psi which is a function of r because it is a distributed it should be something like psi 0 e to the power of it is a Gaussian.

So, r square minus w small w square. So, this small w is a very important parameter because it characterize that how the Gaussian distribution is having its width.

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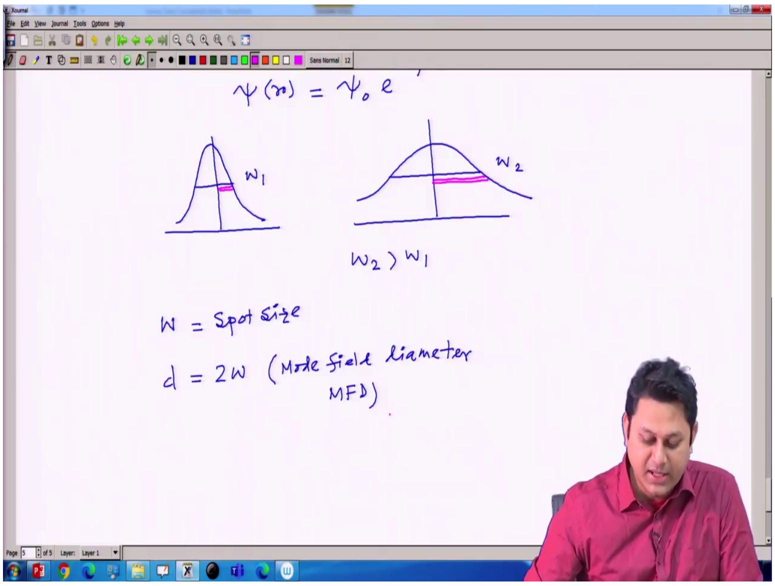

For example, one can have this mode like this structure this is say w 1 and also one can have a Gaussian like this. Here also this is his characteristics with and I can define is w 2, but; obviously, w 2 is greater than w 1. So, these two mode distribution is different. So, how this mode will going to distribute even though I can define is a Gaussian function then this the value of this omega a is w is important.

And, this w small w is called the spot size of the mode if w is high, then we have a high spot size of the mode and if it is small then you can say the spot size of the mode is small. So, how the mode is going to spread is defined by this spot size. So, d which is 2 of w is essentially called the mode field diameter or MFD.

If I go back to our previous picture, so, essentially this w 1 and w 2 measure the width this one and from that if I multiplied is to 2 then I will going to get the total struck total distribution of the mode.

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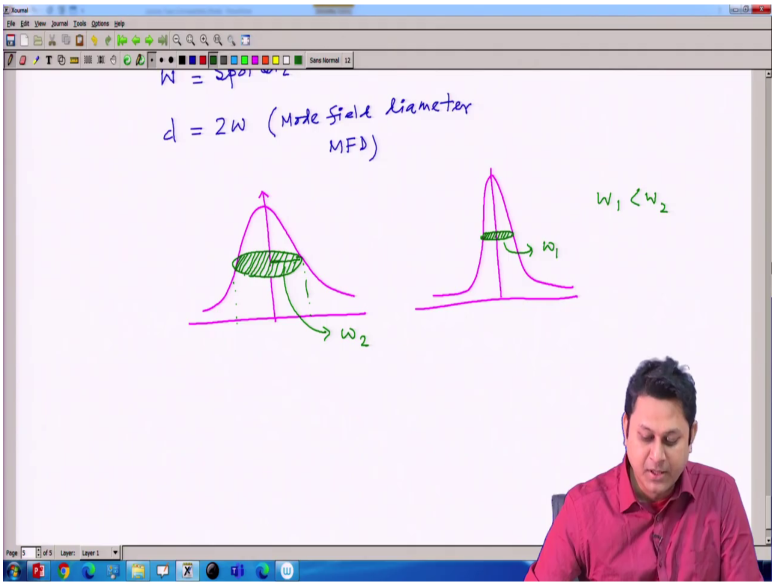

So, eventually if this is my fundamental mode distribution which is approximated as a Gaussian, then this is the mode field diameter we are talking about. So, in 3D if I ok my drawing is let me erase this part and draw it once again. So, I have a field distribution which is Gaussian and this is basically related to w and when I have a multiplication of 2 then the diameter basically gives me the distribution of the mode.

So, this is essentially the spot size we are talking about. There is a distribution you can see there is a distribution I have also the intensity here in this region out of that. But, the effective intensity I can consider with this portion which is associated with the spot size and this basically gives the idea that if the spot size is high or the spot size is small low.

For example, for a serve distribution like this we have a spot size smaller because my is small if this is one if it is 2, then w 1 is less than w 2 the same thing we I have already done shown here in this figure earlier figure here. So, well with this note I will like to conclude today's class.

So, in the next class we try to calculate the with this approximation whatever the approximation is shown here that one can write the fundamental mode as a Gaussian function like psi 0 e to the power r square divided by w square, where w is defined as a spot size.

So, if this distribution is given, then if I want to calculate the effective area then what should be the value of the effective area that we going to calculate. So, with this note I like to conclude in the next class we will meet again and try to find out the effective area of the fundamental how to calculate the effective area of a fundamental mode.

Thank you very much and see you in the next class.