Physics of Linear and Non-Linear Optical Waveguides
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Module - 03
Modes
Lecture - 20
Concept of Modes

Hello student to the new class of Physics of Linear and Non-Linear Optical Waveguide. Today we will going to have lecture number 20 where we are going to understand Concept of Mode. And in the concept of mode is very important in understanding how the field will going to distribute in a given waveguide structure.

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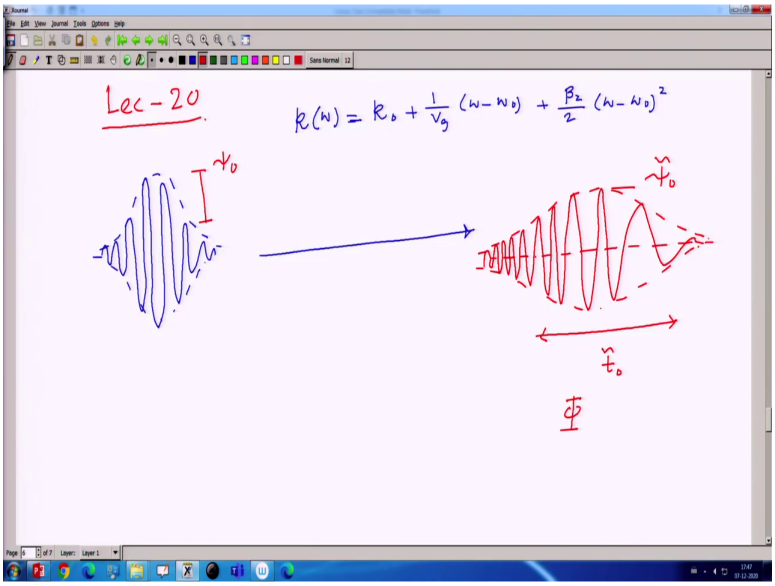

Today we have lecture 20, where we will going to learn modes, but before that let me remind once again what we have done, one concept is still we need to understand. So, in the last class, let me remind quickly if I have a dispersion with k with this form.

As a consequence of this k as a function of omega in this form I have a broadening of pulse. If this is my input pulse, it is moving through the dispersive medium defined by this k and in the output I have a pulse say something like this.

A broadened envelope not only that I may have some kind of chirping here chirping mean there is a phase associated with that. So, amplitude will going to decay this is psi 0 and now I have according to our notation psi 0 tilde with we will going to increase t 0 tilde. And also there will be a distribution because I have a phi extra phi, if you remember I have a phase and rate of change of phase is chirping, the frequency and rate of change of frequency is chirping. So, I may have some kind of chirping there will be a distribution of the frequency inside this pulse as well.

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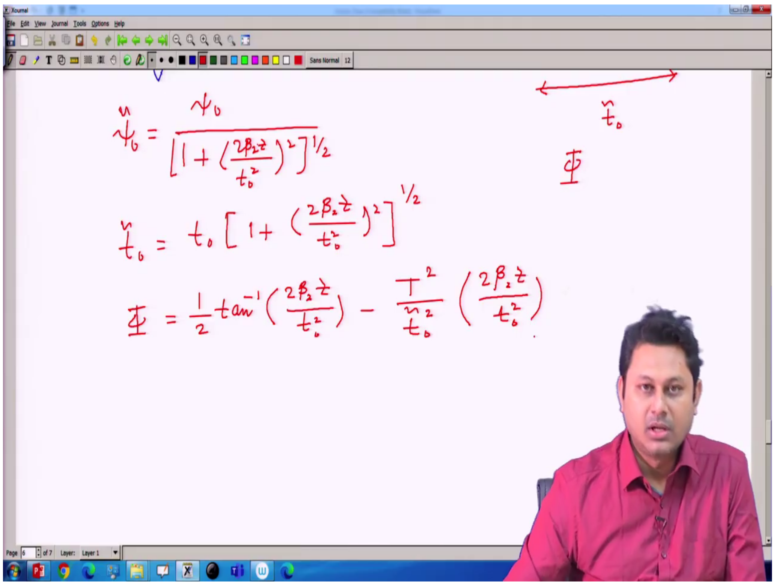

If I write down this value once again then things will be clear. So, my psi 0 tilde was psi 0 divided by 1 plus 2 beta 2 z divided by t 0 square whole square and whole to the power half my t 0 tilde is t 0 1 plus 2 beta 2 z divided by t 0 square whole square and half. And another term phi which was half of tan inverse 2 of beta 2 z divided by t 0 square minus t square divided by t 0 tilde square 2 of beta 2 z divided by t 0 square.

These were the 3 values that we evaluated in the last class. The important thing that you need to note that when beta 2 equal to 0 then there will be no change of the pulse have at all.

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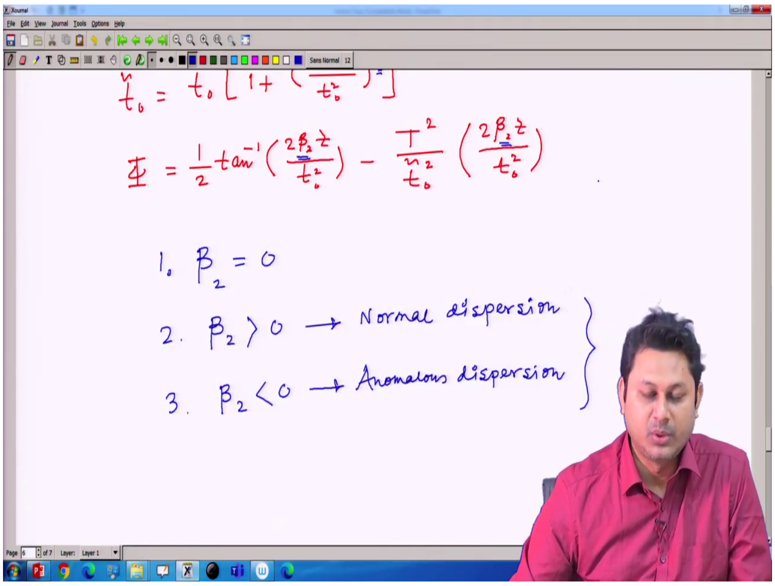

But you may remember there is a there should be 3 condition of beta 1 is beta is beta 2 is equal to 0 another is beta 2 is greater than 0. And another condition one can have is beta 2 is less than 0, this we know what we call is normal dispersion.

When beta 2 is less than 0, we know this situation is anomalous dispersion these two condition one can have. If you look very carefully to this equation here we have a square term in amplitude. So, if beta is positive and if beta is negative in both the cases it will not going to change. So, that means, amplitude will going to decay even for beta positive and negative. In this term also I have a square here.

So, t 0 tilde which basically the width of the optical pulse envelop, it will also going to increase irrespective of the sign of the beta it may be positive it may be negative depending on the situation, but in both the cases there will be a increment of pulse width. However, you can see here there is a beta 2 is sitting in such a way that it depends very much on the sign. So, that means, the distribution I just talked about that inside the pulse there should be some frequency distribution and this frequency distribution can be very much depends on the value of beta 2.

If it is anomalous dispersion then I have a negative sign and this negative sign makes this phi negative, if I have a positive sign then phi can have a different values. So, it is a combination of plus minus anyway. So, but the point is if beta 2 is positive or beta 2 is negative depending on that phi will going to modify. So, there will be a change of the frequency distribution here that you should known because this is very important in understanding something called optical solid on we will like to cover this part as well in this course.

Where these things can be compensated under non-linearity, how these things will going to be compensated under non-linearity? Then this concept you need to remember that under the dispersion there is a situation where the phase will going to modify depending on the sign of beta 2. Well after that we need to understand about the condition first condition beta 2 equal to 0 this is called the 0 dispersion this is a very very important concept in the pulse propagation problem.

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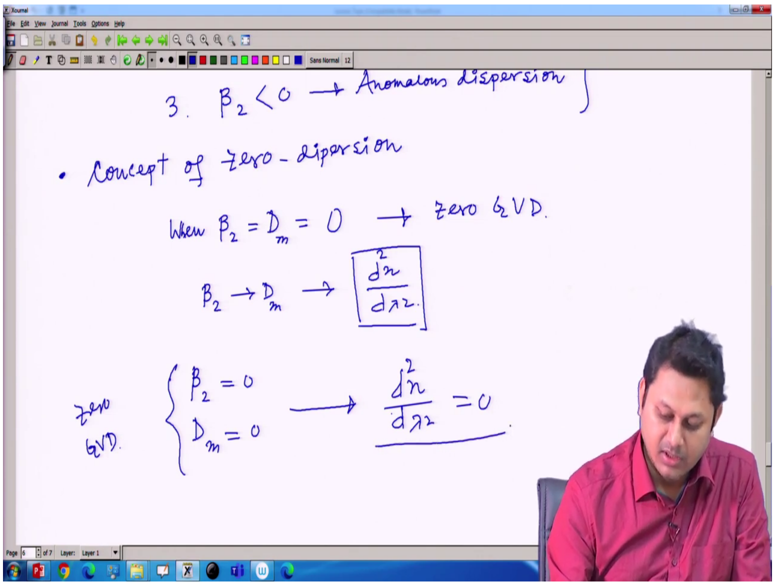

So, it is called let me write it as concept of zero dispersion nothing special. We already know that when beta 2 or material dispersion D m is 0, we can say that it is called the zero grooves velocity dispersion. If you remember that beta 2 the expression of the beta 2 and in expression of the D m in both cases we have a common term that d 2 n d lambda square that was the common term in both the cases. So, when I am saying that beta 2 equal to 0 or D m equal to 0 for zero groove velocity dispersion condition.

That essentially means that my d 2 n d lambda square this term is 0 that is the very very important condition here. Whenever I have a wavelength for which this double derivative is 0 then this is called the 0 dispersion wavelength.

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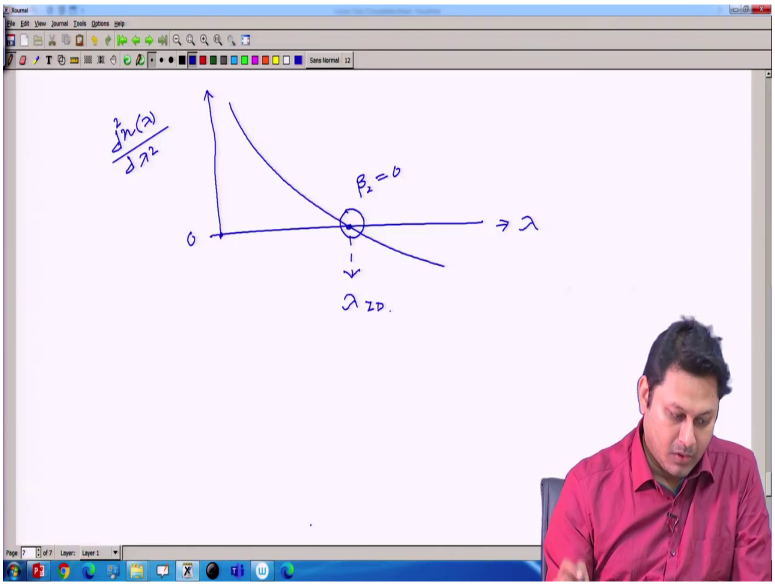

So, if I now plot my say d 2 n d lambda square d 2 n which is a function of lambda and d lambda square. So, at certain wavelength there is a possibility that it cut the 0 point, so this is 0. So, when it cut the 0 point this suppose this is my lambda when it cut the 0 point this lambda we call the 0 dispersion wavelength. That means, at that particular wavelength or at that particular lambda I have my beta 2 the consequence is beta 2 is 0 and there will be no such pulse dispersion and that particular wavelength that is interesting thing.

So, if I launch a pulse at exactly at that particular point where d 2 and d lambda square is 0. Then what happened there should not be any kind of pulse broadening. So, we need to achieve such an certain condition, so that I can reduce the pulse. So, if I make this beta 2 low enough or small enough then I can restrict these things. So, the dispersion can be restricted [vocalized- noise].

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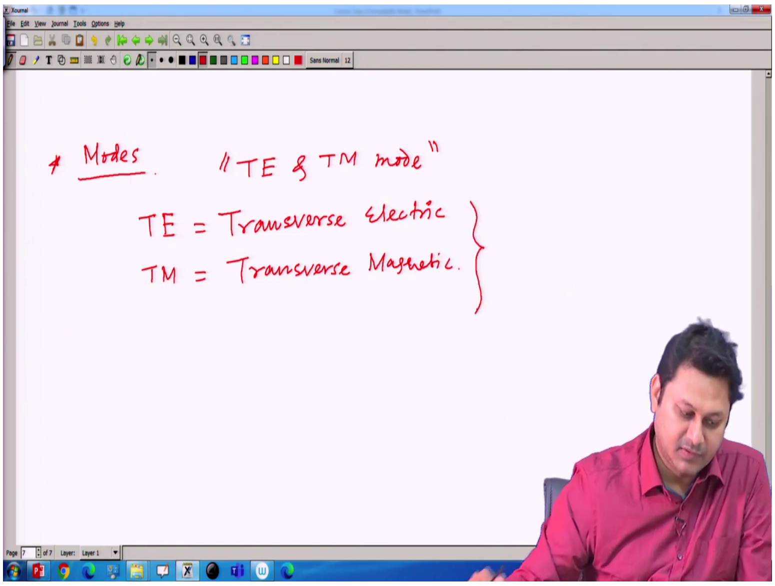

So, that is the thing we [vocalized- noise] at this point we need to know. Next we will going to start today's main topic that I mentioned, that the concept of modes which is very very important. So, let me start with modes. So, before so let me write two term terminology TE and TM modes. I will explain this in detail TE and TM modes. In optical wave guide we will find that when I launch an optical electromagnetic field, then because of the geometry of this optical wave guide certain distribution is there in the field.

So, this certain distribution is in general called the modes of this waveguides. So, we learn this in detail for different geometries for planar waveguide, how the mode will look like and for the cylindrical geometry which we find in optical fiber how the mode will look like. And also we should have something called mode equations.

So, how the mode equation can be evaluated from the from the fundamental principle like Maxwell's equation that we also going to learn in this course. At this moment we should only mention that if a geometry is given, which we called the waveguide geometry and if I excite an electromagnetic field inside this geometry.

Then this geometry guide a certain amount certain field distribution, the certain field distribution is in general called the mode we term two kind of modes we term here TE and TM mode. So, let us understand what is the meaning of this TE and TM mode. So, TE is coming the term T is for term transverse E stands for electric, TM stands for transverse magnetic.

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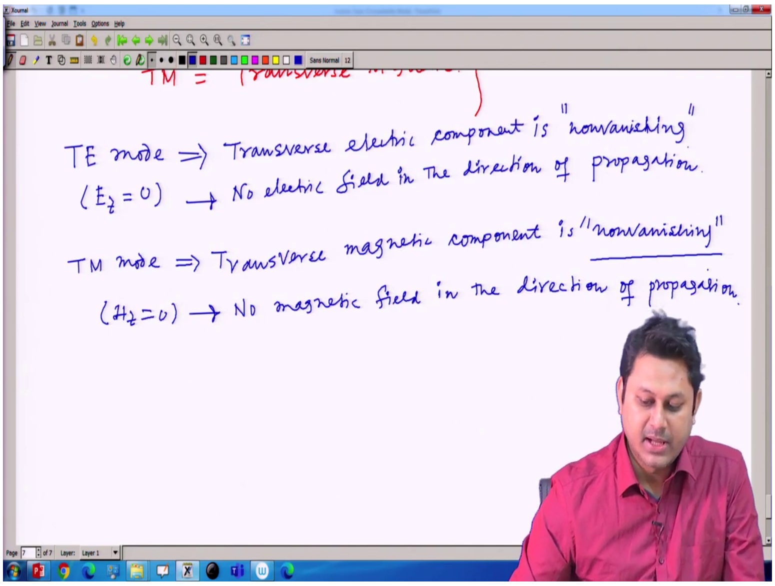

So, transverse electric and transverse magnetic. So, what is the meaning of transverse electric mode and transverse magnetic mode? So, TE mode ok, let me change my ink color. So, transverse electric mode its means that the transverse electric component is non-vanishing is non-vanishing.

That means if the transverse component is non vanishing and at the same point, if z is a propagation distance the propagation direction then this will be 0. So, no electric field in the direction of propagation no electric field in the direction of propagation.

So, if z is a direction of propagation. So, we should not have E z component if I have a mode with this structure that E z is not there, then we can say that this mode is TE mode. In the similar way I can have something called TM mode.

So, TM mode means transverse magnetic component is non-vanishing. So, it is non-vanishing and the transverse magnetic field is non-vanishing. So; that means, here also we have the Hz component is equal to 0. So, no that means, no magnetic field in the direction of propagation ; no magnetic field in the direction of propagation. Well, now we understand roughly what is the meaning of TE and TM modes. Modes I already mentioned that it is a distribution and the field distribution inside a given magnetic in given wave guide. So, we will going to understand in detail.

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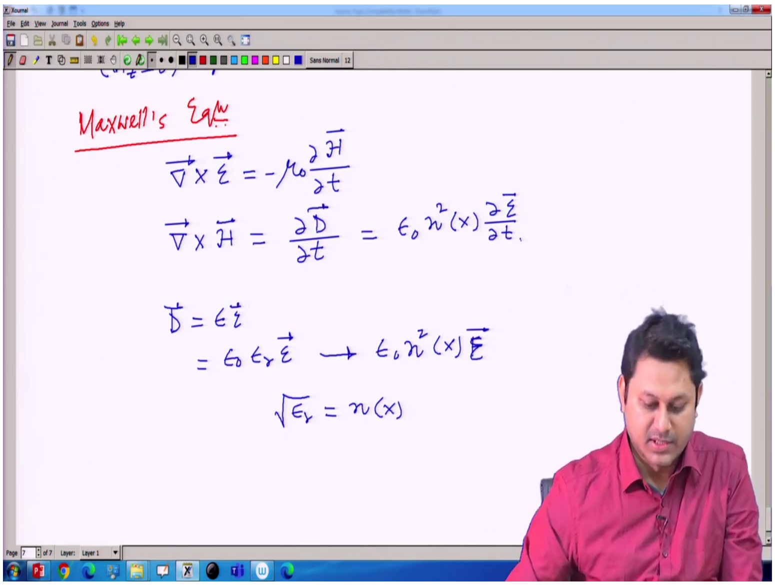

So, let us start with Maxwell's equation. So, Maxwell's equation tells me that the first equation I will going to use these two equation, curl of curly E is equal to minus of mu 0 then del curly H del t this is a one equation. And curl of curly H this one is the Faradays first one is a Faradays law I just write in terms of curly E and curly H. What is the meaning of curly E and curly H? We will going to learn we will going to see it is d of d delta of D d t.

Now, D is epsilon then E, which is epsilon 0 epsilon r E. So, from here I can write it is epsilon 0 n square x E, why it is n square x? I will explain. Where my root over of epsilon r is refractive index considering refractive is a function of x only in one direction. So, why it is that? We will going to explain. So, this equation I can write it as simply epsilon 0 then n square x dt. So, these two equation I start with and then try to understand more. So, as I mentioned that the value n is a function of x.

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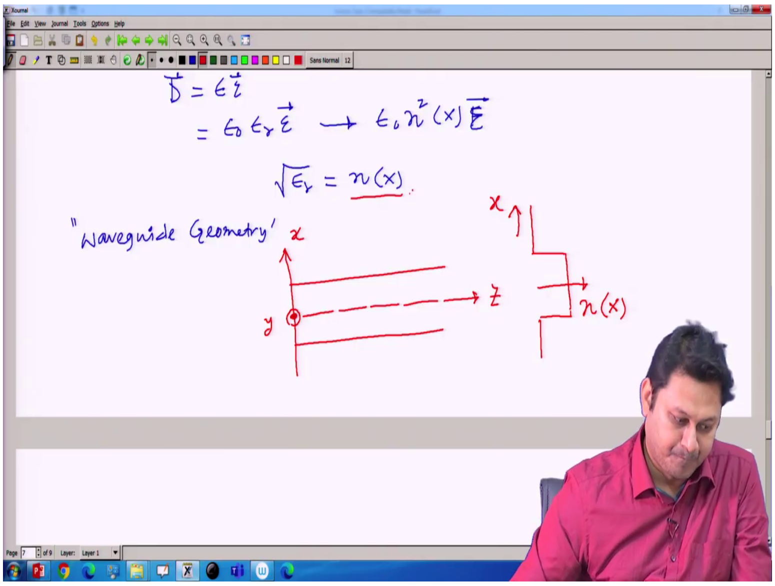

So, the waveguide geometry I need to define for which this condition is valid. So, my waveguide geometry is something like this. So, I have a block like this, this is a known waveguide geometry rather along this axis I say this is my x y axis is perpendicular to the plane and along this direction I have my z the propagation direction. So, the refractive index profile is like a step index profile. So, along this direction I have x. So, it is changing along x direction.

So, refractive index whatever the refractive index I have is only a function of x along z direction or along y direction there is no change. That is why I i wrote here that n is a function of x only.

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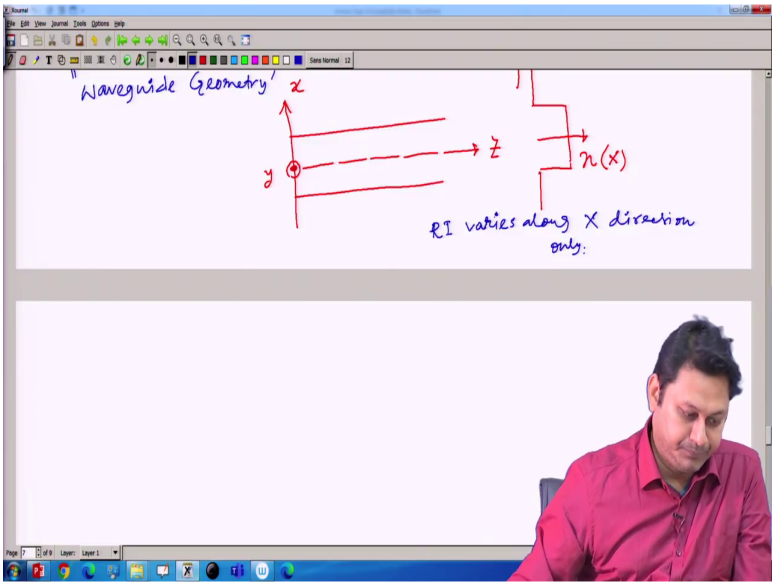

So, refractive index RI varies along x direction only well.

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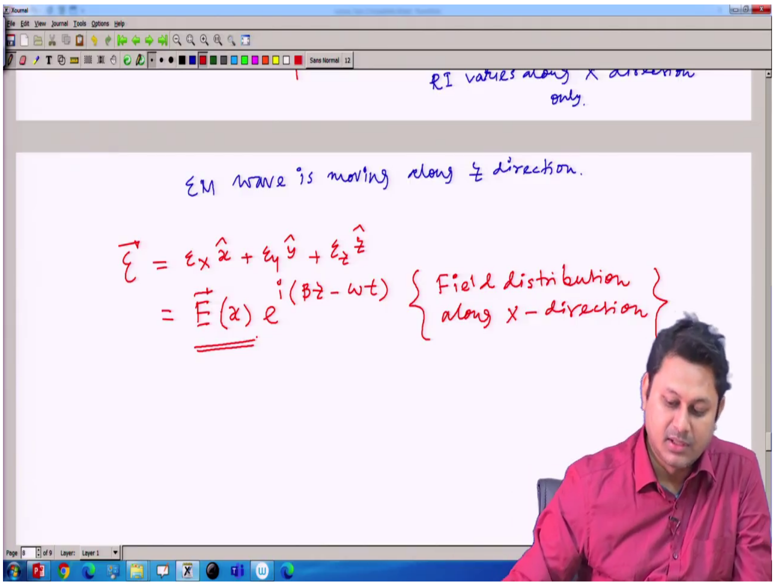

An EM wave EM wave is moving along z direction. So, now, I will write my electric field the curly E as this way, Ex x unit vector plus Ey y unit vector plus Ez z unit vector.

And I can also write these as E vector which is a function of x e to the power of I beta z minus omega t. So, I write an electric field in this form. So, field distribution, so this is field distribution along X direction. So, this is a field distribution along X direction. So, this is a special geometry for which I considered my electric field is varying along X direction and I will going to show that in which condition it is correct, under which condition I can write that.

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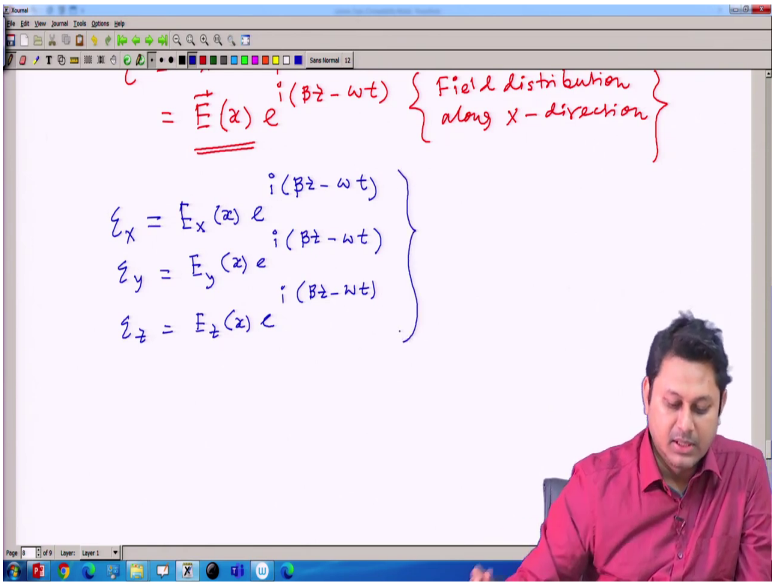

So, my let me write it component wise. So, how the component will look like E x component will be E x component will be E of x as a function of x e to the power of I because it is a scalar quantity. So, it will be like omega t.

In the similar way E of y is E of y x e to the power of i beta z minus omega t. In the similar way E z curly E z is E of z that is also a function of x e to the power i beta z minus omega t. So, this is the way one can define the E x, E y, E z component.

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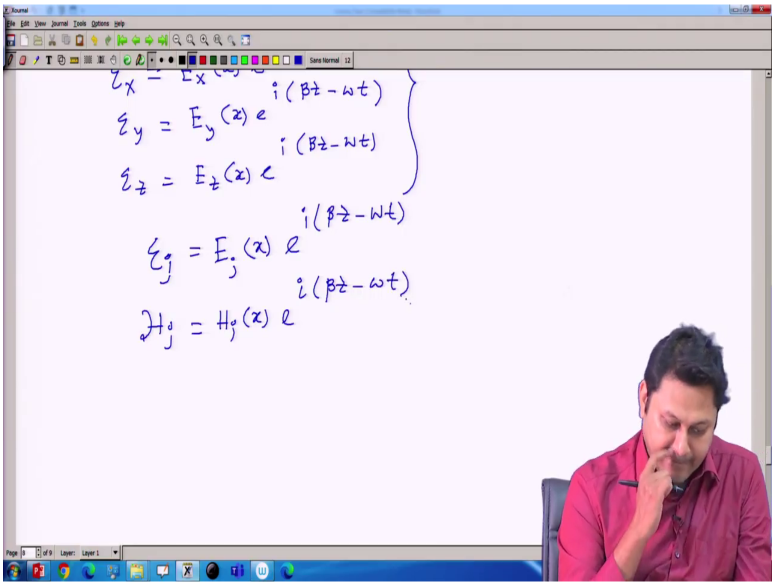

So, in general if I write the ith component is the ith component rather jth component because there is already one i sitting as exponential e to the power i. So, e to [vocalized- noise] e to the power i beta z minus omega t and H j component H j is H of j x e to the power of i beta z minus omega t.

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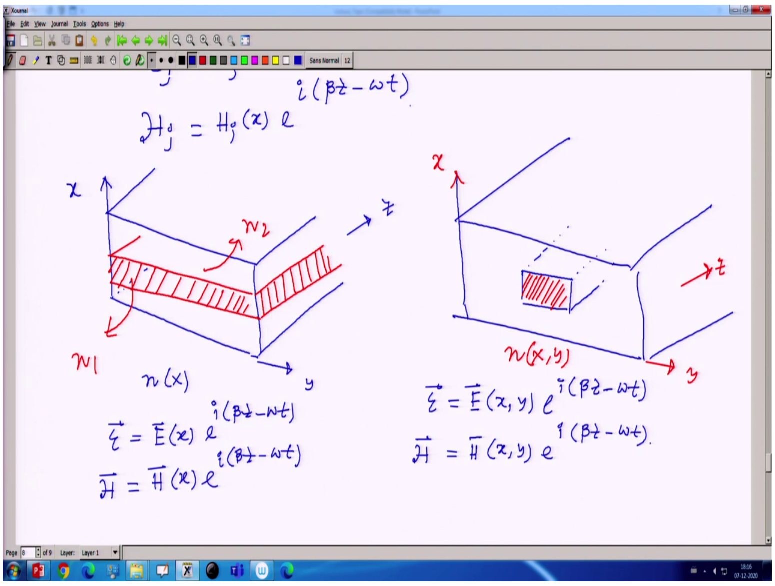

So, the geometry I was mentioning. So, let me quickly define the geometry and then I will going to conclude the class. So, if I have a geometry like this, along this axis I have x, along this axis I have y and this is my z direction and I have a. So, here the refractive index is different. So, in this regime I have refractive index say n 1 and other part it is n 2.

So, this at this regime there is a change of refractive index like this. So, here I have say refractive index n 1 and in this region I have refractive index n 2 for this kind of structure when it is extended infinitely along y direction, if that is the case.

I can write, so n is a function of x; obviously, because it is changing along x direction. So, my electric field can be written in terms of E as a function of x because the distribution in on this direction, this direction there will be no distribution and this direction the pulse is propagating. So, I can write the distribution in this way or my H will be H x e to the power of i beta z minus omega t.

On the other hand if I have a structure like this similar structure, but here I have a block that is inside the system. And the refractive index is now function of. So, along this direction I have x, along this direction I have y, along this direction I have z and this is the this is the place where the refractive index is varying. So, refractive index is no more a function of x it is a function of x and y both.

So, there is a restriction over y as well. In this case if I now write my E it should be E because the field now we are going to distribute in x and y both direction, it will be distributed in x and y. So, there will be a variation of electric field in both x and y direction. So, it should be a function of x and y.

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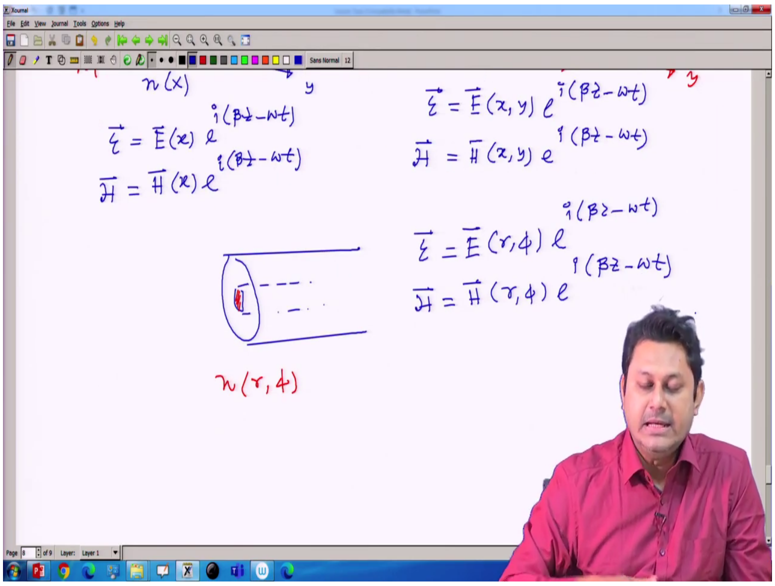

Also it is not restricted with this geometry another kind of geometry is possible which is very important, which is the optical fiber. So, in optical fiber we know that my geometry is something like this. So, the refractive index is changing here. So, my refractive index is a function of r and phi. So, here I can write my electric field in this structure as E as a function of r phi e to the power of i beta z minus omega t and my H as H r phi e to the power of i beta z minus omega t.

So, today we do not have much time to go forward. So, I will going to conclude my class here. So, in the next class we will study in detail about the mode distribution and calculate the mode for a very simple planar waveguide. And till then I will thank you for your attention and hope we will again have in the next class all this mode distribution and all these things.

Thank you.