Millimeter Wave Technology.
Professor Minal Kanti Mandal.
Department of Electronics and Electrical Communication Engineering.
Indian Institute of Technology, Kharagpur.
Lecture-15.
Guiding Structures (Contd.)

Okay so we are continuing with wave guiding structure in dielectric.

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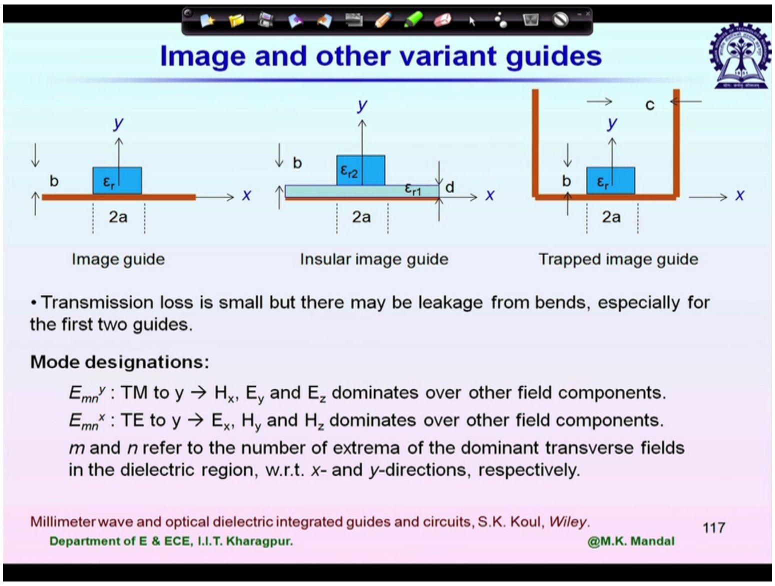

So in this case what we are expecting that transmission loss is small compare to the printed line however we have problem when we have winds. Now the more designations 2 different scenario we have just like the surface wave it can support TM like mode and TE like mode. So when we are saying TM or TE you remember we are doing we are using some simplified model in practice we have all the six components of field.

But here we are only considering the dominant field components. So the in first case sometimes it calls EMN Y MN it represents the number of extreme us along X and Y. So it is also called TM to Y. Why? You see its the perpendicular direction wave propagating in Z direction so in this case we have EY component EZ component of electric fields and the dominant component of magnetic field is HX.

So EY and EZ EY it is perpendicular to ground plane and EZ it is in direction of propagation. Do you remember the surface wave TM case similar thing in TM mode surface wave generation we also have normal component of electric field and also in the propagation of direction. So similar to that here also the dominant components are EY and EZ and in the second case which we called TE to Y transverse electric with respect to Y we have EX component so just like the TE case of surface wave and HY and HZ components.

So they dominants over other field components. So we are simply neglecting other 3 components. And M and N it refers to the number of extrema of the dominant transverse field in the dielectric region with respect to X and Y directions, respectively. So the lowest mode will call TM 11 or E11 Y for TM mode and E 11 X for the TE mode.

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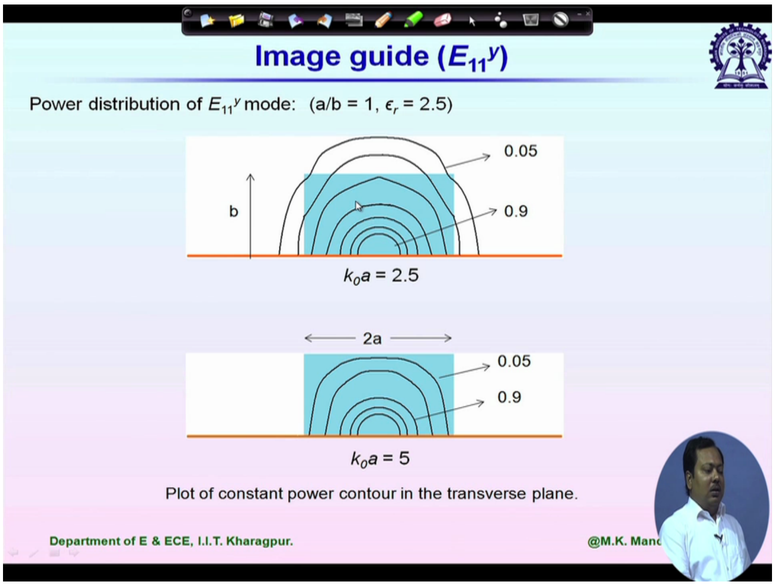

So let us see how the wave is confined inside the dielectric. We are showing the cross sectional view of 1 image guide which is sitting over this ground plane shown by this orange line and we rare concentrating 2 different scenario. For both of this 2 cases A dimension is equal to B dimension you said twice A this is the with of this dielectic cannel B is the thickness of this dielectric challenge.

Now this is the normalised umm dimension K not into A when this is equal to 2.5 so most of the energy its confined inside the dielectric. It shows the constant power control. So point 05 power control it is almost outside in air. Now if I keep on increasing the operating frequency let us say we are considering a frequency just double up the first one in the same dielectric channel.

You can say in this case almost 99 percent of my power is concentrated inside the dielectric channel. We have a less fenging field in air. And this fenging field just like the surface wave it decays exponentially inside air from the dielectric surface. So when we are going to design any dielectric channel we have to be careful about the operating frequency and we have to carefully choose its dimension with respect to guided wave length lambda g.

So that at least 99 percent of my energy is confined within the image guide or this dielectric channel otherwise we will be facing cross talk effect between 2 side by side lines.

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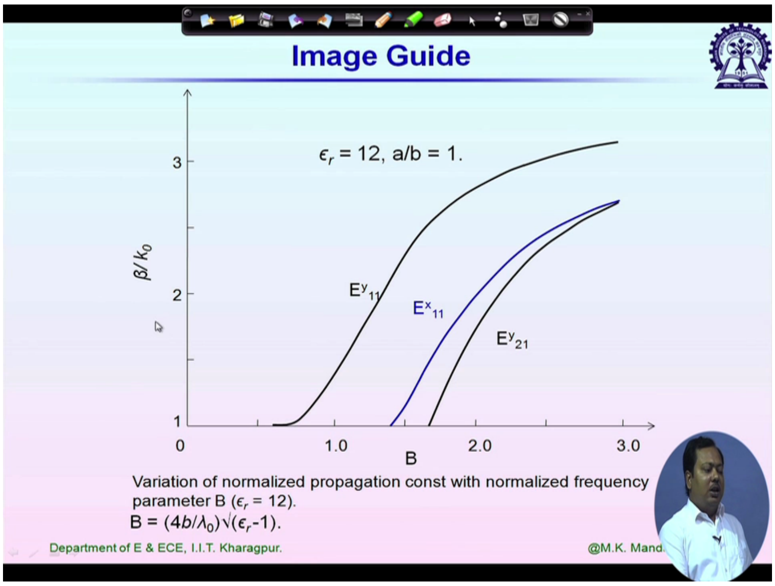

Here is plot it shows how beta by K not it varies with umm frequency so this B its a frequency parameter its define as 4 by lambda not into square root of epsilon R minus 1. So for this particular plot we are considering epsilon R equal to 12 and A by B equal to 1. So that means with in this figure width is double up the thickness and you see the first mode that appears here it is EY11.

So it shows the importance of beta by K not plot so from this we can see what is the cut off frequency of this mode the second mode that appears for this given image guide is EX 11 and you see the high radar modes for TM it is EY21 so for monomode bandwidth so for not only for millimetre wave for any RF applications we always want to excite any guiding structure in only in 1 mode.

For example for rectangular wave guide we want to use only TE 10 mode so if we have multiple mode in excited inside the guide so the we have we face 2 problem 1 problem power is loss to high radar modes. We cannot utilize those power so for example let us say we are designing one SMA to rectangular wave guide transition or coaxial cable to rectangular wave guide transition so in that case we can design it with respect to only 1 mode.

Let us say TE10 mode now if somehow TE 20 mode is excited inside your rectangular wave guide structure that power will not be corrected by the coaxial cable. So its a wastage for my circuit at millimetre wave frequencies already there are many sources of losses and loss increases with frequency.

So we cannot tolerate any other loss this is the first reason and second reason that different umm modes have different velocities so that means we will be facing dispersive effect so pulse it region, pulse dispersion.

So that is why with single mode operation or we call it monomer bandwidth that is very important so for X standard WR 90 rectangular wave guide we know the cut off frequency approximately 6.3 gigahertz and we use it over 8 to 12 gigahertz and it is the monomer bandwidth of that WR 90 waveguide.

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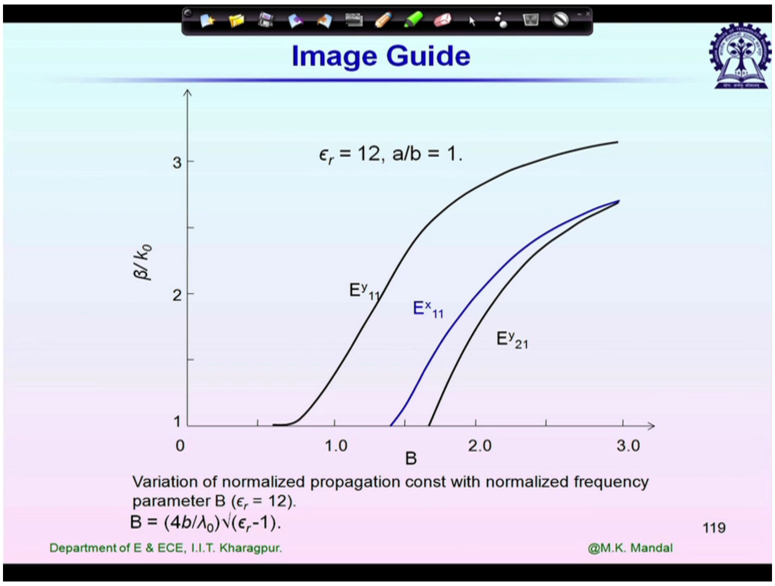

Now for the image guide if I look at this values. So obviously if I plot alpha it will be infinite almost at the cut off frequency so we have to take away from it and the monomer bandwidth if you compare the value with rectangular wave guide it is much smaller. So this is another problem with image guide. And not only that this line near to cut off frequency and at higher frequency it becomes dispersive. Always beta by K not is more than 1 so it supporting only slow wav.

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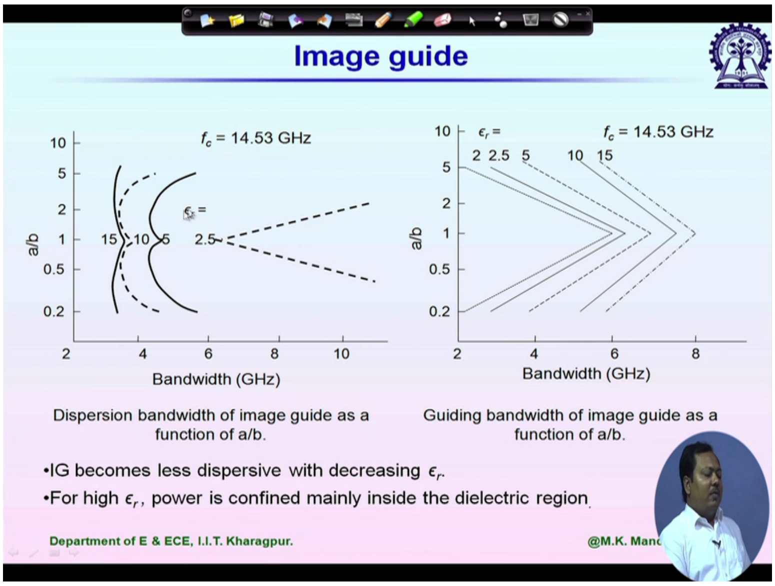

We face 2 problems for image guide 1 is lower monomode bandwidth and another one is dispersive effect so how then the looking at this 2 point how we can choose the dimension. We have some design graph for that so here it showing A by B versus bandwidth plot considering dispersion effect.

We are considering that dispersion effect is minimum within let us say plus minus 10 percent so in that case this is plotted for a given image guide with FC equal to 14.53 gigahertz so we see that if I change epsilon R values then the dispersion bandwidth it changes. Smaller epsilon R it has higher dispersion bandwidth and not only that it is highest for A equal to B.

Then the first design rule for image guide you take A is equal to B or width should be twice of that thickness and from this if we one to minimize dispersion we have to choose a lower epsilon R now look at the right hand side we are considering here guiding bandwidth or monomode bandwidth so that no higher radar mode is present here. Here we have opposite variation at A equal to B it is having highest value but with increasing epsilon R.

Now the bandwidth is increasing so from this design chart, design graphs we have to choose an optimum value depending on our requirements we are giving preference to disperse less dispersion or maximum guiding bandwidth.

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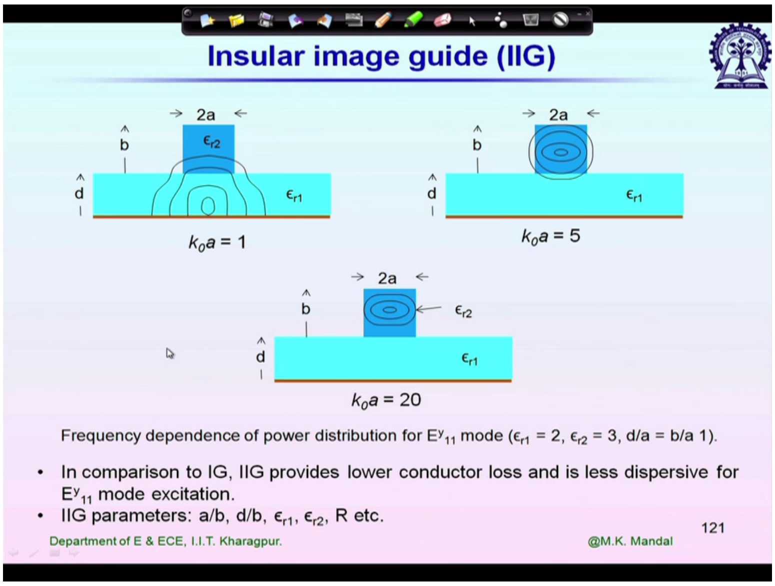

Next is insular image guide. So what is the need of the insular image guide? Insular image guide actually it can decrease the conductor loss further compare to image guide. If I go back to image guide.

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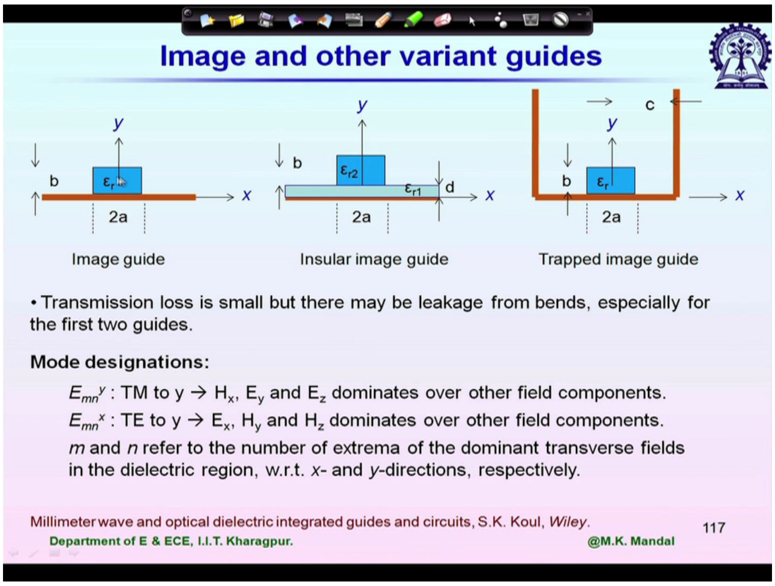

You see this is the basic image guide structure now we have perpendicular electric field component and parallel electric field components. So EY it is maximum on the ground plane so it is associated it will induce current and associated with high conductor loss.

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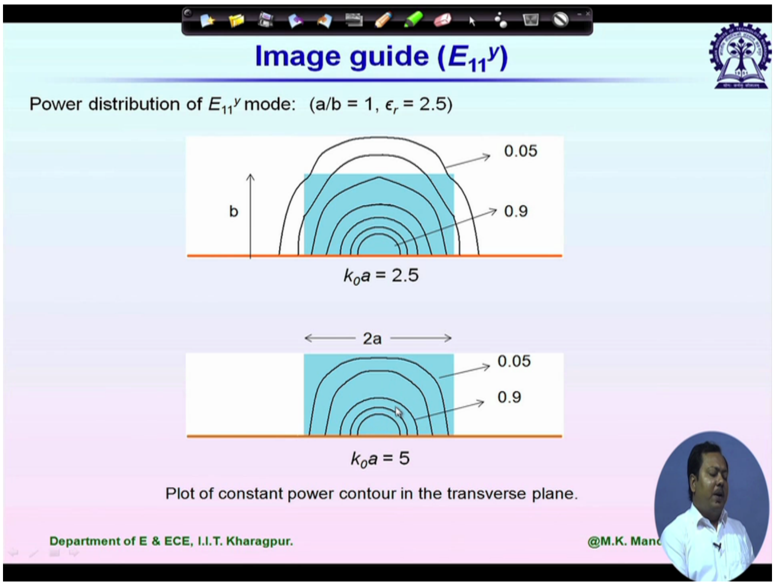

Here also if I look at the constant power control maximum power is confined near to conductor which will give me high conductor loss we are designing image guide for lower loss compare to printed line then again we have we are facing with high loss so how we can avoid it?

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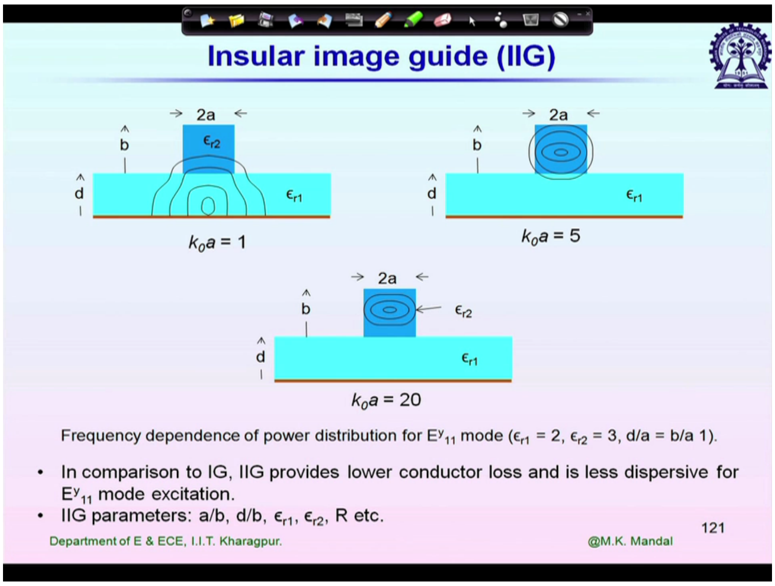

Now we have some very good dielectric material for which loss tangent value is very small. So if we can avoid conductor loss to some extend we can actually decrease the overall loss. So how we can do it intentionally? We are introducing one more layer of substrate of dielectric constant epsilon R1 in between the dielectric channel and the ground plane epsilon R1 it should be much smaller compare to epsilon R2.

So now we are again plotting the constant power (())(12:38) so if I increase the frequency you see to K not A equal to 5 here since epsilon R2 is much higher compare to epsilon R1 so most of my electromagnetic energy it will be confined to this top layer inside the channel and that is how the maximum umm point we can shift it from the conductor right. So we will be facing only the dielectric loss and we can minimize conductor loss.

So that how insular image guide provide lower loss compare to image guide so we have one additional parameter here. The thickness of the second dielectric and the dielectric constant of the second dielectric so one observation we have that epsilon R1 for this bottom dielectric it should be as small as possible so that most of my electromagnetic wave is confined to this top dielectric channel.

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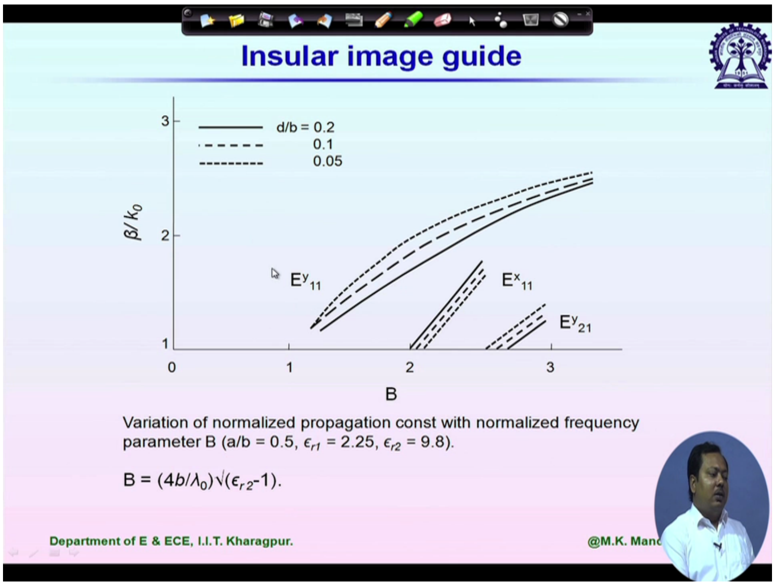

Here is the beta by K not plot versus normalised frequency parameter B we are for this example we are considering A by B equal to point 5 you look at the dimension how we define twice A is the width and B is the thickness of the dielectric channel. So that means thickness is equal to width and epsilon R for the lower material its 2.25 for the channel its 9.8 in that case again the first mode that appears is TM mode TM2 Y, EY11.

And second mode is EX11 but if I look at the characteristics of the plot you see these are the different values of D by B its more straight. We can say its less dispersive compare to the image guide and we are increasing umm if I decrease D by B from point 2 to point 05. What will happen? You see the cut off frequency it decreases and monomode bandwidth it increases but at the same time we see the line it becomes the dispersive so the actual solution it will be an optimum 1 in between this extreme values and the suggested value of D by B is point 015 to point 15.

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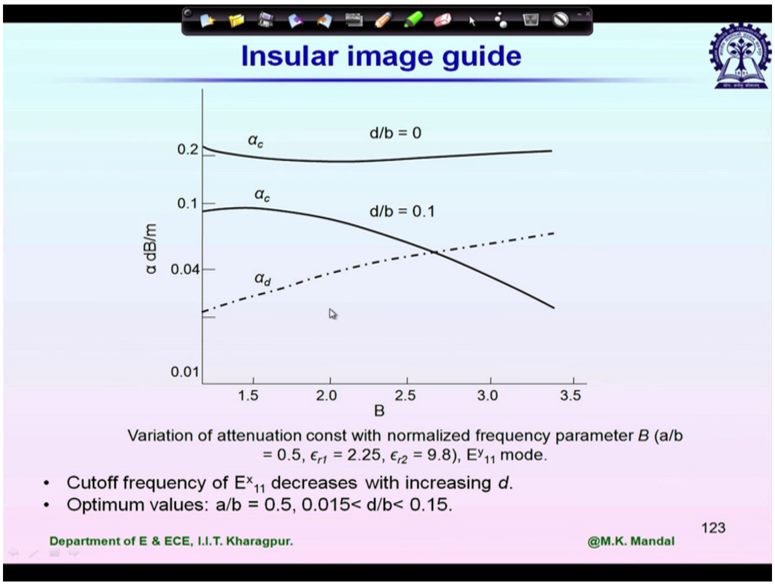

So let us see the loss plot because loss is very important at millimetre wave frequency. We are plotting alpha D and alpha C separately in DB per meter and we are considering again A by B equal to point 5epsilon R 1 2.25and epsilon R2 9.8 so alpha D it increases with frequency and alpha C it decreases with frequency. Why? Let us go back to the power conclude plot.

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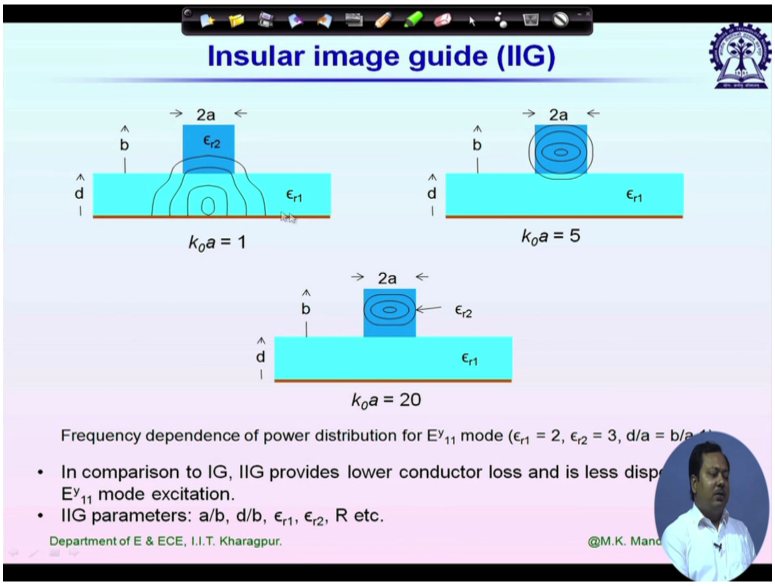

So at low frequency you see some of the power is near to conductor we are expecting higher conductor loss but as I increase frequency almost all of this electromagnetic wave propagation is through dielectric channel. This top one so conductor loss will decrease but dielectric loss will increase so if we can choose a dielectric layer with minimum tan delta value in that way we can decrease the overall loss.

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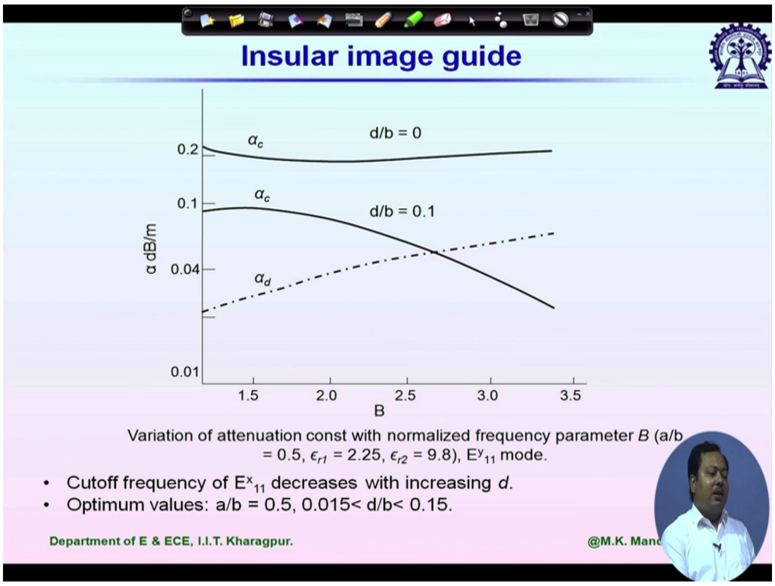

So this top layer represents the D by B equal to 0 that is nothing but the image guide where we don’t have any epsilon R1. So you can compare the alpha C for this 2 cases in the first case when we have image guide D by B equal to 0. Alpha C more or less it remains constant with frequency but in the second case it decreases significantly so that how we can decrease overall loss for insular image guide.

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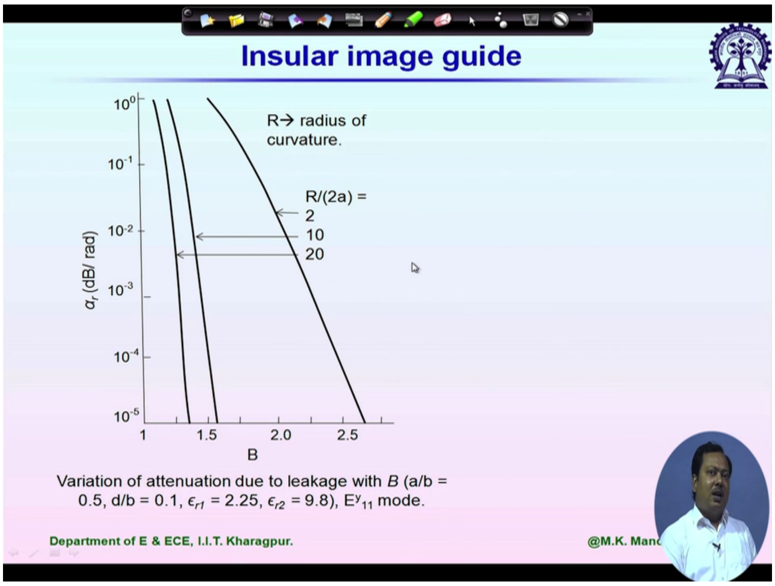

But this type of wave guide has one more problem. Whenever we have bend it is associated with high radar modes and we have leakage from this modes. So that is why we have one more design graphs it suggest how to keep your leakage loss minimum. So its leakage due to radiation mainly alpha R Db per radian angle we are plotting.

So we have some radius of curvature. Its given by capital R and we are considering it for different R by twice A value you remember. A is the width of the channel now for R by 2A equal to 2 this is the graph and if R by 2A equal to 20 when R is small so this is the graph so from this then you have some idea how to minimize the leakage loss from insular image guide.

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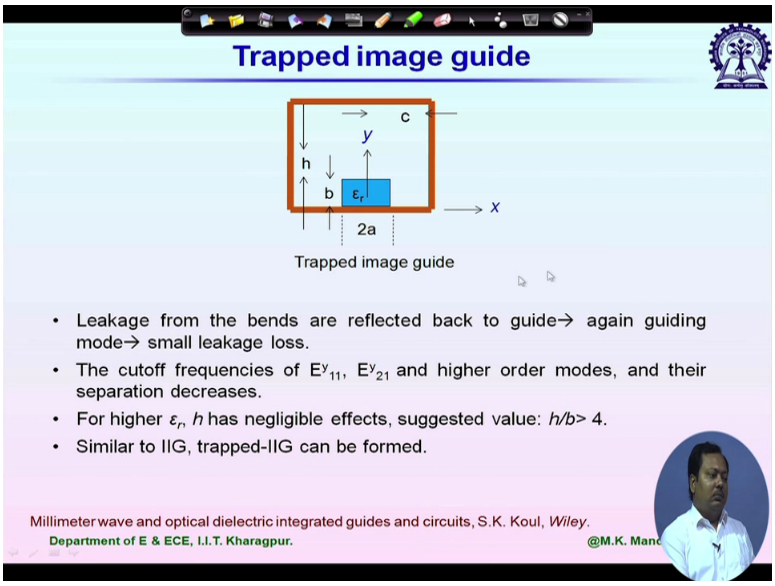

Next one is trapped image guide. So what is the difference with the previous one we are using a metal packaging somewhat looking like a rectangular wave guide inside we placing the image guide. so this is called the trapped image guide. So the packaging wall separation from these wave guiding structure it should be sufficiently high so that it does not disturb the image guide mode.

What is the advantage of that we can avoid cross (())(18:47) between 2 side by side lines. And another advantage is that we can avoid that radiation loss. So how if there is any vent let us say there is some high radar mode excitation and from that we have radiation but since now it is an enclosed structure so all of these radiation will be reflected back from this boundary wall and it will again excite the original mode inside the guiding structure.

So that is how we can minimize leakage loss as well as cross (())(19:25). So not only for image guide similar trapped guide we can also design for insular image guide.

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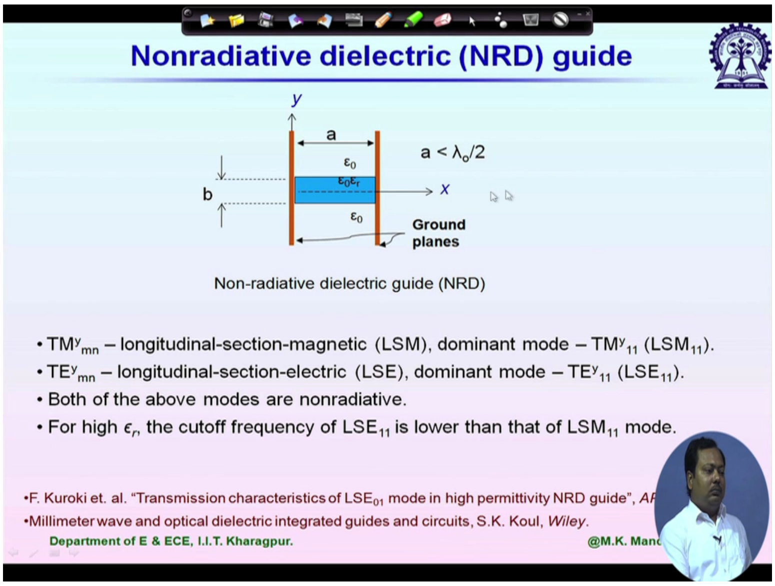

Next one non radiative dielectric guide or (())(19:43) guide. it is another popular form of guiding structure at millimetre wave frequency. So here we will see that mostly energy propagation it is through the dielectric layer. So that is how we can minimize conductor loss here if you look at the structure it we are using a dielectric slab in between two metal plates you look at this structure.

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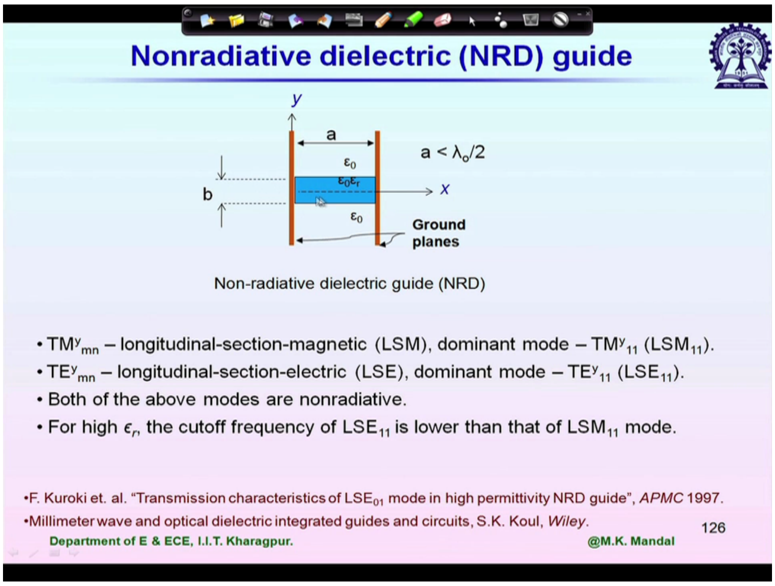

So we have one dielectric slab of thickness B and it is placed in between 2 metallic ground planes wave propagation its in Z direction and metallic ground planes its in YZ direction just like surface wave we have again TM mode and TE mode. So again we are having air dielectric boundary we have hybrid modes.

But we will be using simplified model considering only the dominant field components and we have 3 dominant field components just like the image guide and (())(20:53) guide. so we can define in similar way the mode names but we have 1 more popular name so better let us use those popular names instead of TMY or TE 2Y.

Those popular names are LSM11 for the fundamental mode and LSE 11 the full form is longitudinal section magnetic so that means in the propagation direction mainly we will be having magnetic field component and in the second case longitudinal section electric so in the propagation direction mainly we will be having the electric field components. And we will see for high epsilon R the cut off frequency of LSE 11 which is actually TEY is lower than that of LSM 11 mode.

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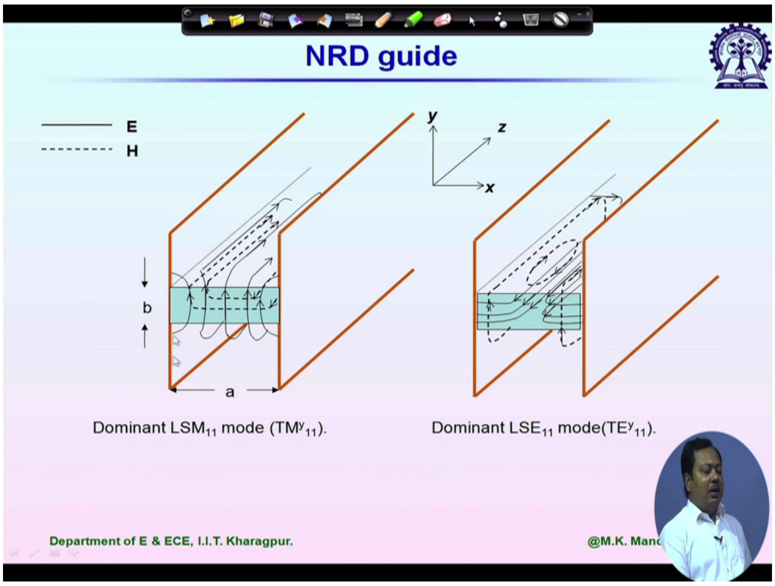

Let us look at the field configuration its showing the 3 dimensional field plot so we have a dielectric slab in between 2 metal planes. So magnetic fields mainly this is in ZX plane right in the direction of propagation we have magnetic field component as well as in perpendicular direction and if you look at the electric field component here all the 3 electric field components are shown.

But in the propagation direction EZ is minimum we can simply neglect EZ. So then the dominant electric field component will be UY and EX component and they are perpendicular to propagation direction so that is why we call it longitudinal section magnetic in the direction of propagation we have negligible EZ so mainly its magnetic in the second case we have another scenario it is called longitudinal section electric.

So we have dominant electric field component as EZ and EX and for magnetic field it is parallel to YZ plane and again in the direction of propagation HZ component is negligibly small. So that is why its called longitudinal section electric or LSE mode. Now just looking at this field plot can you say which one is lossy.

So if I compared left hand side and right hand side plot inside dielectric you see the electric field components EX having higher values which is perpendicular to this conductor and for this left side this electric field component having highest value it is actually in between this 2 plates which is parallel so right side we are expecting higher conductor loss.

Since its it max umm electric field maximise near the conductor plane that is why LSE mode it will give you higher loss compared to LSM mode and not only that this two modes are orthogonal to each other that means if I excite this structure in LSE configuration LSM mode will not be easily excited or vice versa.

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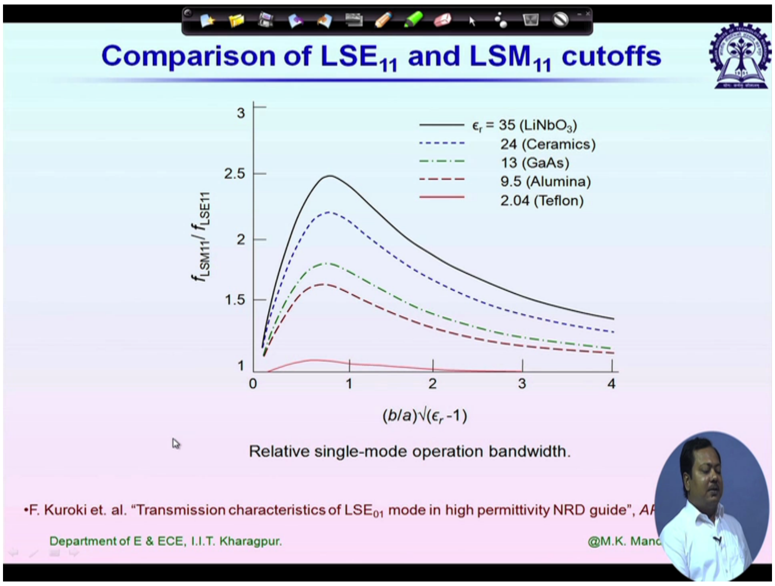

Next is the mode separation we are plotting the cut off frequency versus B by A. So LSM 11 by LSE 11 versus B by A into root epsilon R minus 1 so LSM 11 is having higher value than LSE 11 so that means the cut off frequency of longitudinal section electric is smaller compare to LSM and we are plotting it for different values of epsilon R. If we increase epsilon R we see the mode separation or separation between this 2 cut off frequency increases.

So its a function of epsilon R not only that it is also a function of B by A. We have some optimum B by A for which this mode separation is highest so if we want to excite this structure only (())(25:58) in that we have to choose the dimension B A and epsilon R accordingly so but in practice people prefer LSM mode why? It has lower loss compare to LSE mode.

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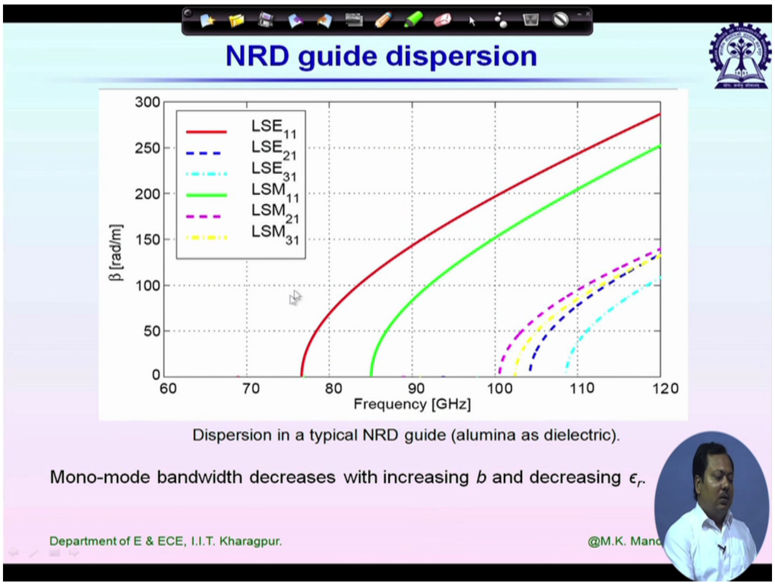

This is the plot of beta versus frequency. So for a given structure we are plotting beta for LSE mode as expected its having the lowest cut off frequency beta equal to 0 approximately at 76 gigahertz for this typical example. Next mode that appears here this is LSM 11. Look at here the mode designation next another mode the pink one LSM 21 so if I use this channel for LSE mode.

Then the effective bandwidth I can utilize from 76 gigahertz to approximately 85 gigahertz its very this narrow band. But usually prefer people prefer LSM mode due to lower loss and if I utilize it for LSM mode excitation it is from 85 to almost 100 gigahertz so for monomode bandwidth for LSM will be higher and for LSM we are not expecting any LSE mode generation. Why? I said that they are orthogonal to each other. Okay let me explain the orthogonality little more in details.

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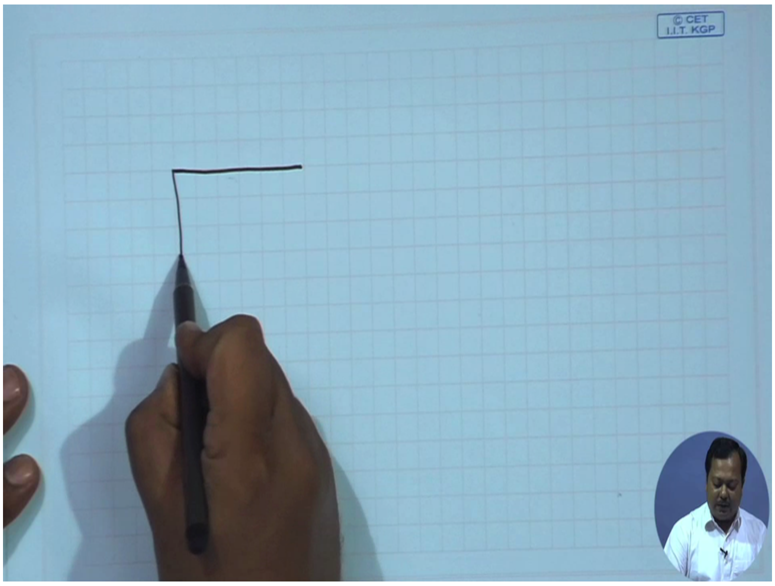

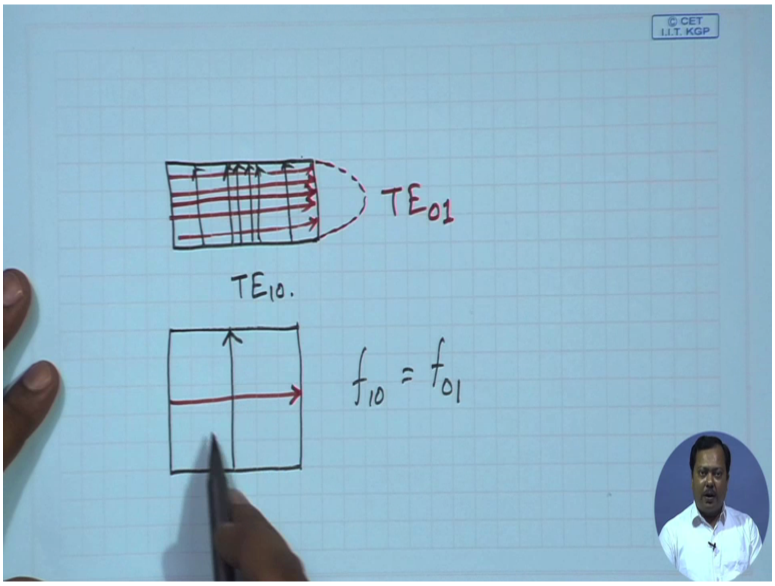

Again we will be considering rectangular wave guide the very basic structure. We have a rectangular wave guide and it supporting TE 10 electric field configuration. If I plot the electric field we are having maximum on the central plane and then it decreases left hand side and right hand side. Now if I keep on increasing the operating frequency it is highly possible that this side also we can excite one more mode let us designate it by TE01 mode.

In that case we will be having maximum on the central plane here. And then on the side walls it will be zero. This 2 mode TE10 and TE01 they will be called orthogonal to each other. And if we don't use any bend or any other structure there won't be any mode coupling. That means this rectangular wave guide or better let us take a square wave guide so that the cut off frequency for both TE10 and TE01 mode is same then we have TE10 in this direction.

And TE01 in this direction and the square wave guide it can support this 2 wave propagation at the same time without any interference between this2. They are called orthogonal to each other. So by using this orthogonal property simply we can double the bandwidth. Similar thing is possible for NRD guide also.

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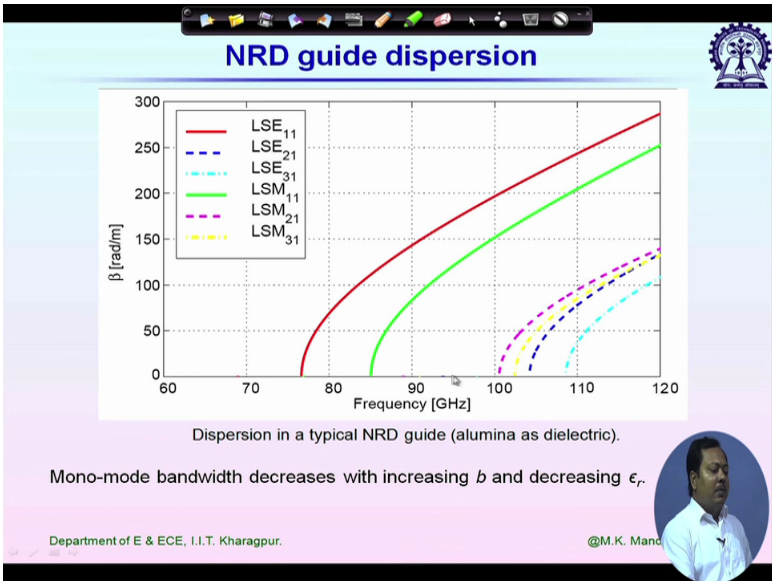

If I excide it in LSM mode field configuration in that case it will not excite longitudinal section electric mode but remember only if this structure is straight the guiding structure is straight. If I use any bend it can generate high radar modes and from that high radar modes LSE mode can be excited. So we have to use some mode suppresser so there are some components which can suppress that unwanted LSE mode if excited form that bend.

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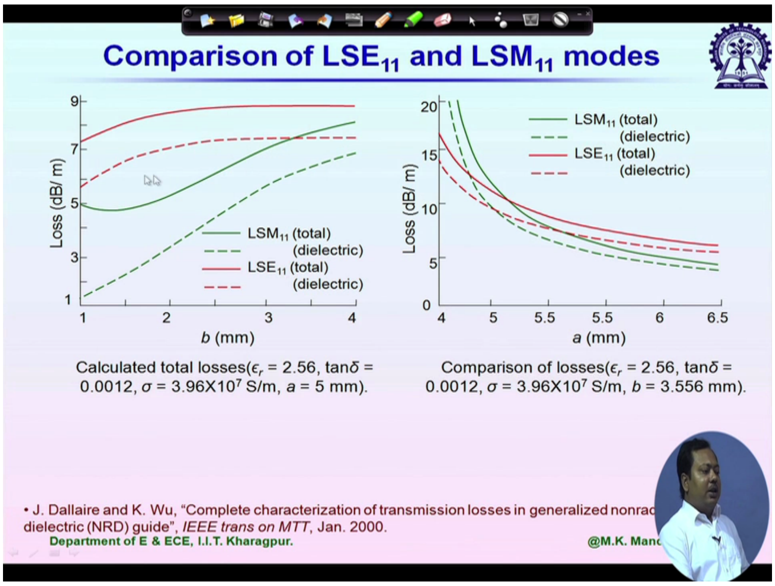

Let us compare the losses. For the left hand side we are using a dielectric slab umm of epsilon R 2.56 and a plate separation is 5 millimetre. We are plotting total loss and dielectric loss for both longitudinal section magnetic mode and longitudinal section electric mode as we expect you see for LSM mode total loss is lower than that of LSE mode.

Because of that conductor loss conductor losses lower for longitudinal section magnetic now right hand side plot loss in DB per meter versus A plate separation so if we increase plate separation loss decreases for both longitudinal section magnetic and longitudinal section electric.

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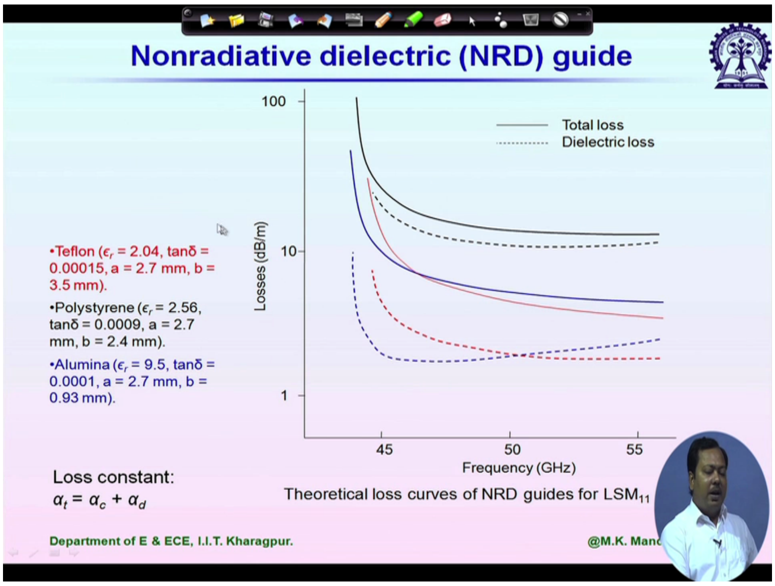

Here are some more plots in this case what we are doing? We are plotting loss in DB per meter versus frequency for 3 different types of substrate parameters. We are using 3 different dielectric constant for that Teflon dielectric constant 2.04 and tan delta point triple not 15. We are considering plate separation 2.7 millimetres and the thickness of dielectric 3.5 millimetre in the second example polystyrene epsilon R 2.56 A and B values are 2.7.

And 2.4. third example alumina now epsilon R is much higher 9.5 A same value B point 93 this is to minimize loss. Now we are plotting the total loss and the dielectric loss. If I concentrate on any 1 plot ppolystyrene let us say polystyrene it has point triple not 9 so mostly the losses due to dielectric right.

We are doing for LSM conductor losses minimum so difference between this total loss and dielectric loss that is due to the conductor at cut off its going to infinity and if I move away from cut off it decreases variation is somewhat looking like rectangular wave guide. now consider alumina it has lower cut off frequency since A is same but epsilon R is higher.

So its having the lowest cut off frequency among this 3 and for this 1 you see again we are having similar plot. Now if I compare this 2 rate card and this black one so almost similar epsilon R but for this black one it is showing higher loss. Why? Because of its tan delta for this black one its point triple not 9 where as the Teflon its point triple not 15.

So mainly for LSM mode what we see? Main source of loss is dielectric loss we can avoid conductor loss to some extend we have to choose a proper dielectric material which will give you small loss tangent value.

And you can design a wave guiding structure whose loss is very close to air filled rectangular wave guide and that is how we can actually obtain at very lower loss. But the problem again we face at millimetre wave frequencies is fabrication problem and loss from any bend if you have in MMIC.

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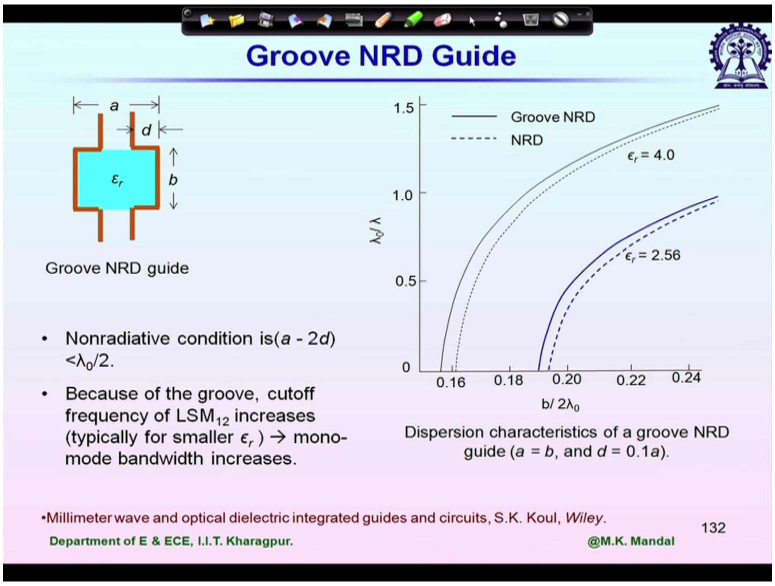

Some other guides groove NRD guide. so in this example you see the middle part we are using little thicker and umm this is actually increases the separation between 2 different modes. T

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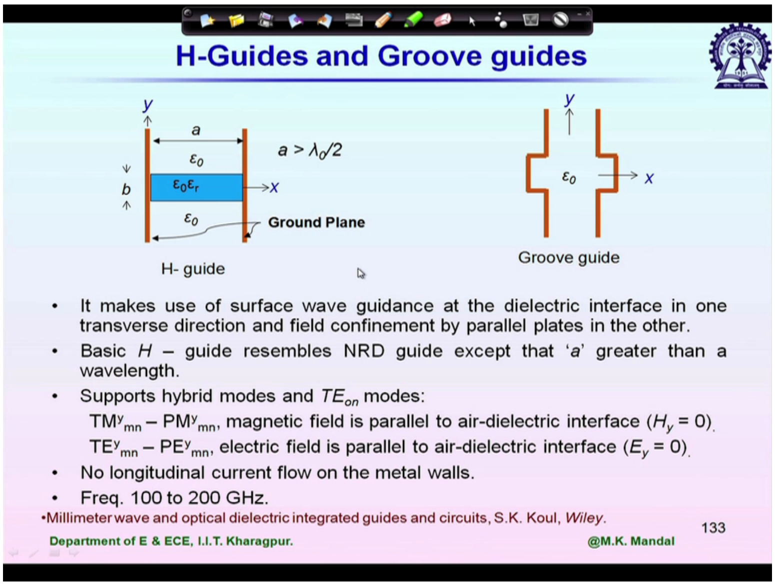

These another example H guides and groove guides. So there are different types of wave guiding structures. Those came in 1980 and some of them in 1970 umm when they came it was thought that they will replace all other wave guiding structures because they provide much lower loss but for most of this structures the problem common problem we face is excitation of high radar mode.

Whenever we are going to design any components we have to deal with bend, we have to deal with crossing or junctions. We cannot avoid them and whenever we have a junction we will be having high radar mode excitation. Here are some examples.

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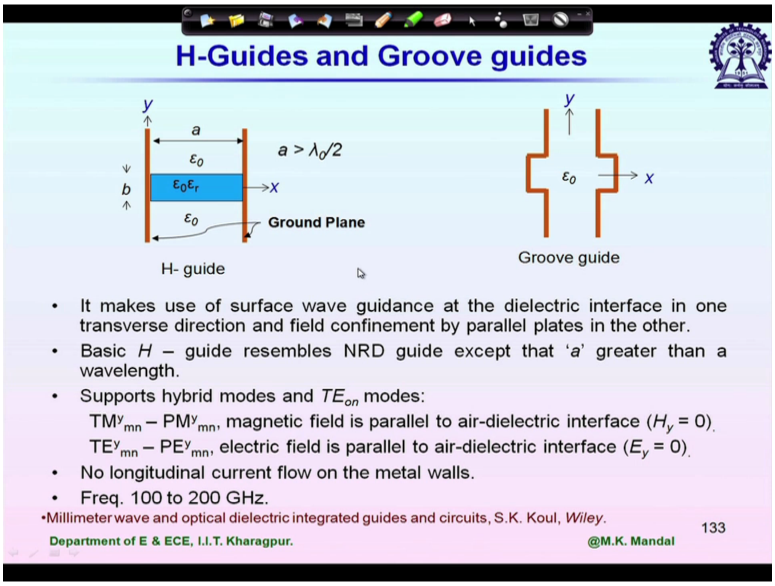
H-Guides and Groove guides
• It makes use of surface wave guidance at the dielectric interface in one transverse direction and field confinement by parallel plates in the other.
• Basic H – guide resembles NRD guide except that 'a' greater than a wavelength.
• Supports hybrid modes and TE_{on} modes:
$TM^y_{mn} - PM^y_{mn}$, magnetic field is parallel to air-dielectric interface ($H_y = 0$).
$TE^y_{mn} - PE^y_{mn}$, electric field is parallel to air-dielectric interface ($E_y = 0$).
• No longitudinal current flow on the metal walls.
• Freq. 100 to 200 GHz.
•Millimeter wave and optical dielectric integrated guides and circuits, S.K. Koul, Wiley.
Department of E & ECE, I.I.T. Kharagpur.
@M.K. Mandal
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This is H guide it looks similar to NRD but the plate separation A in air it is more than lambda not by 2. For NRD A in air it is less than lambda not by 2. So basically we are increasing the cross sectional volume that is how we are decreasing loss. This is for the H guide we have one more version of this so we are simply replacing the dielectric by air and that is why we are increasing the thickness of this metal part.

So the operation or mode characteristics almost similar for both of this 2 cases we can have lower loss even lower than air filled rectangular wave guide. but they are not being used currently because of fabrication problem and because of high radar modes. So this all from umm different types of dielectric guides next we will discuss about how to excite this guiding structures.

Because at the end of the day we have to measure the structures whatever we design. And already we discussed the measurements instruments coaxial cables so we need some adapters or some excitation came that so that you can measure it measure your structure which may be design in NRD SIW or micro strip line. But you have to measure it by coaxial cables. Okay thank you!