Millimeter Wave Technology.
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Lecture-14.
Guiding Structures (Contd.)

Okay so welcome back. We are continuing with substrate integrated waveguide and for substrate integrated waveguide you have seen that we have one more additional reason of loss and that is the leakage loss from the side walls. So we want to keep it minimum because we introduced SIW for lower loss compare to other printed lines. So here we are plotting in this graph we are doing loss study.

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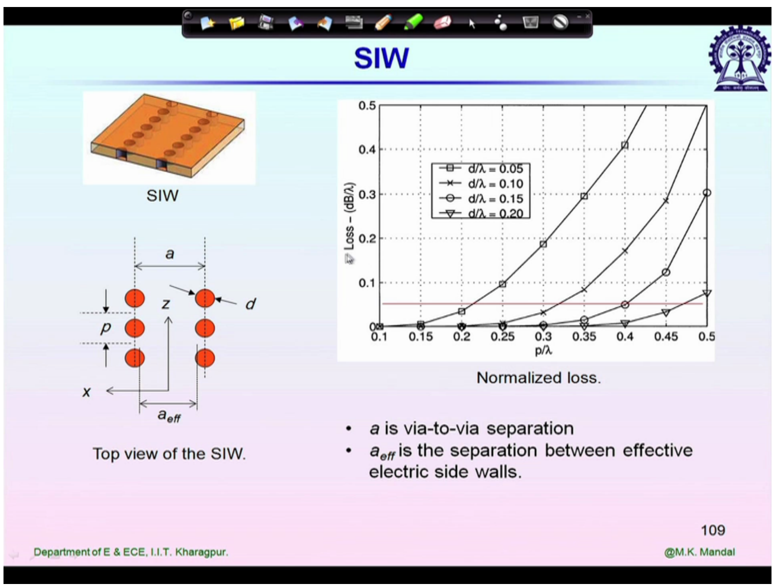

We are plotting the loss in Db per lambda. Lambda is the guided wavelength versus different p values. P by periodicity by lambda for different diameter of this periodic via so for the first case d by lambda equal to point 05 and for this last one D by lambda equal to point 20 so for a given periodicity D is higher so that means what?

We are decreasing the gap or we are expecting lower leakage loss through this gap. So as you can see from this plot, so these plots are obtained by using full wave simulator which gives you very accurate result almost similar to measured result. So for a given periodicity then if I am decreasing D value, the edge to edge separation increases and leakage loss increases so we have higher loss.

So for a given D if I increase periodicity again we will be facing the same problem now if I define the loss by a suggested value let's say point 05db per lambda then we can't consider any value on top of this red line. We have to consider only the bottom of the red line so it determines some design criteria. We have some limiting value of DB so below which we can't use otherwise there will be higher leakage loss through this gap between two metal via.

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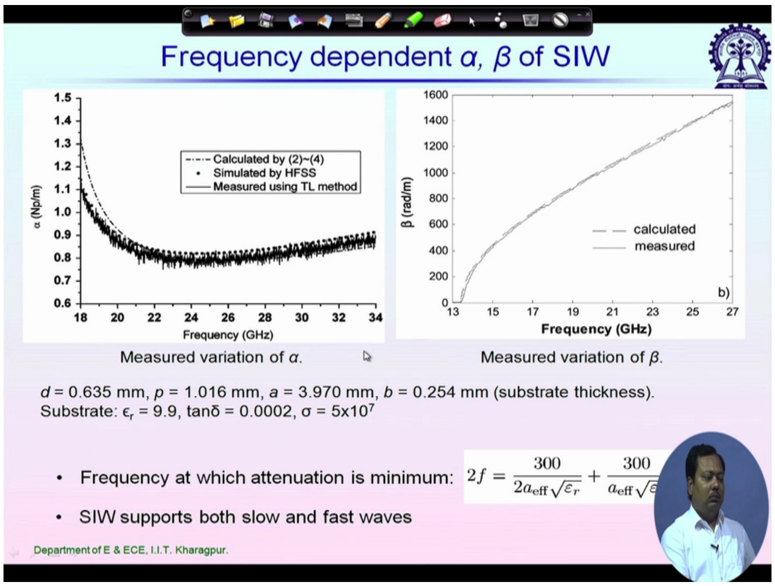

Here is the plot of alpha and beta measured alpha and beta. And also predicted alpha and beta by using full wave simulator so it is strong for a SIW designed in a substrate of dielectric constant 9.9 and tan delta point 0002 and we are using copper as the metal and the dimension you can see here the d diameter is point 635 millimetre. Periodicity is approximately 1 millimetre.

The separation midpoint to midpoint via separation for side walls its approximately 4 millimetre. And thickness of the substrate is point 254 millimetre. And you see the measured response and the predicted response by full wave simulator it's very closed and its cut off frequency nearly 15 gigahertz so at cut off frequency what we expect?

The total loss alpha which is due to the three reasons it will be infinity and then it decreases and not only that do you remember for rectangular waveguide when we have both dielectric loss and conductor loss in that case loss is approximately minimum at 1.5 times of Fc. Here also we are expecting similar effect for SIW.

So alpha has minimum value approximately at 1.5 times of Fc then it slightly increases and the beta so beta is equal to zero at the cut off frequency so it shows clearly the cut off frequency is 13.5 to 13.8 gigahertz and then at higher frequency beta changes linearly so if I consider very close to the cut off frequency this line will be dispersive.

If we move away from the cut off frequency dispersion dis dispersion effect will decrease. So we have a closed form expression where attenuation is minimum. So approximately it is F nought where the attenuation is minimum. It is 1.5 times of the cut off frequency. And one more interesting thing that SIW it supports both slow wave and fast wave. So if I plot beta by K nought instead of beta so then how the plot it looks? Let me plot it.

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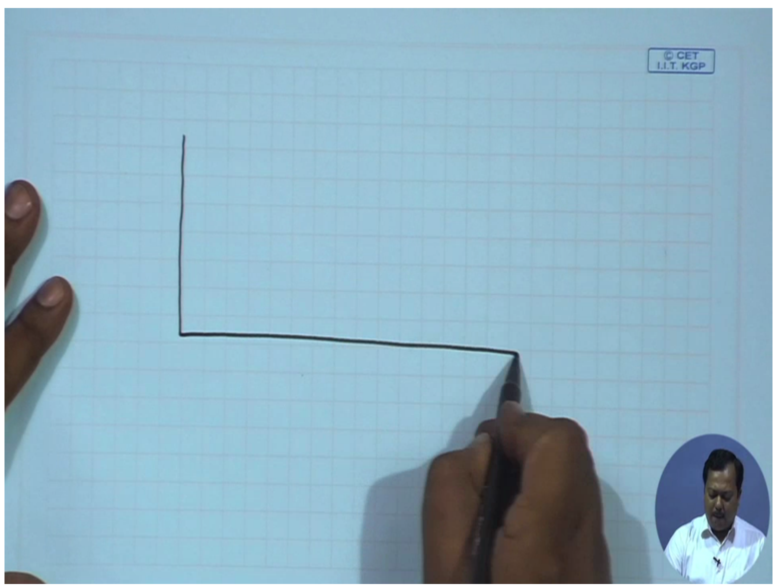

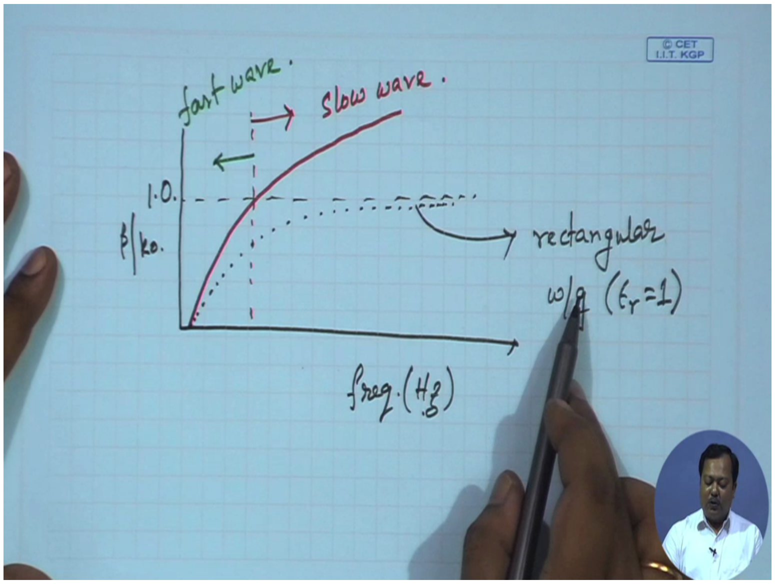

So we are going to plot beta by K nought normalized beta versus frequency in hertz so beta by K nought. Let's say it represents equal to 1.0 line. So if beta by K nought is less than one, that represents Vp is higher than C or first wave. So for rectangular waveguide if I plot beta by k nought, so this is the Fc then it varies according to this dotted line. It will be always a fast wave.

This is for a rectangular waveguide air filled without any dielectric or epsilon R this is equal to one. Now for SIW structure we have some dielectric material always present so we are loading it by epsilon R and now let's say we have adjusted the width so that they are having similar cut off frequencies. Now for SIW if I plot beta by K nought then it supports both slow wave as well as fast wave.

So for this plot beta by K nought is more than one so it represents the slow wave region. And the left hand side part for which beta by k nought is less than one. So it represents the fast wave region. So what we see then? SIW it supports both fast wave and slow wave. So this is not just for SIW for air filled rectangular waveguide if we load it with some dielectric material for that case also we will see that it supports both fast wave and slow wave.

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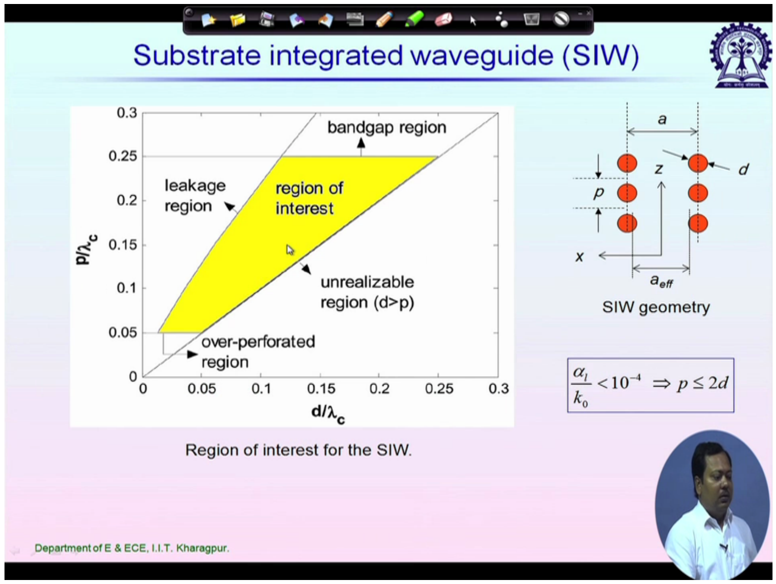

Now the design drop. It showing P by lambda C versus D by lambda C plot. P is the periodicity, D is the diameter of metallic via and lambda C it is the wavelength at cut off frequency. Now this right hand side bottom part you see in this plot in this region it represents D is more than P that can't happen for physical realization D is it always should less should be less than P. S

o the limiting factor D is equal to P and we have a straight line for that. So this design drop it shows we have solution only in the upper half of this plot. Now one more factor, if we increase P for a fixed D that means we are increasing the separation edge to edge separation leakage will increase if we if we use some suggested value of leakage.

Let's say the normalized leakage constant alpha l by K nought it should be less than 10 to the power minus 4 to keep this leakage smaller than this value we can't use this left hand side part. Because for this part this gap between two metallic via is too weak and we will face leakage. So then the region of interest is shown by this yellow line.

Now this we have a limiting factor again which is coming due to the band gap effect. You remember P it should be less than lambda by 4 at upper edge of my band of operation. So this upper region is limited by band gap region. Similarly we define one lower region, so this is it represents the over perforated regions because if we drill too many vias, it will become fragile.

So it is not mechanically rigid so to avoid that we are defining one more forbidden region and so as a result you can choose any D and P value to realize your SIW structure. The solution you should take from this yellow part only.

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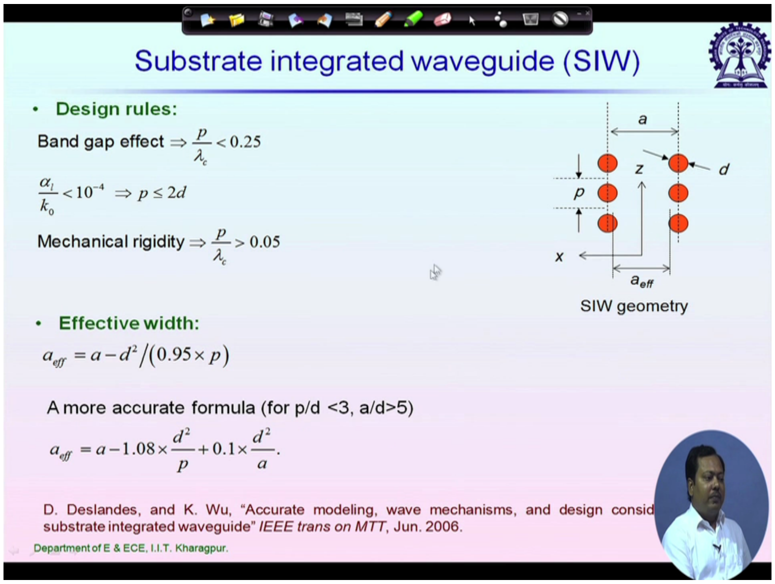

So now we know enough theorems. So let's see then what are the design criteria. So designed rules are described here. First rule it comes from the band gap effect at the band edge upper cut off frequency. P by lambda C it should be less than point 25 already we discussed and then to keep the leakage loss minimum smaller than the suggested value 10 to the power minus 4.

It can be shown P should be less than equal to twice D. So at least D should be half of P then and for mechanical rigidity P by lambda C it should be more than point 05 we defined it. So basically this design rules

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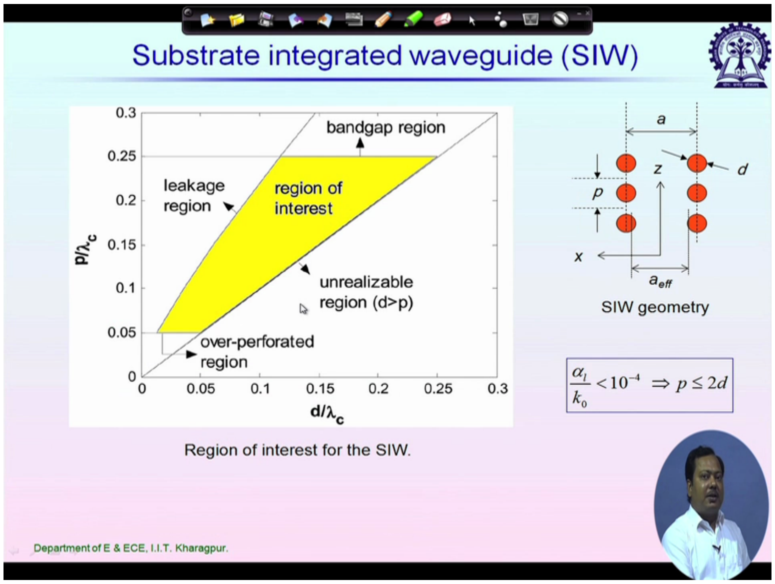

It describes this region of interest.

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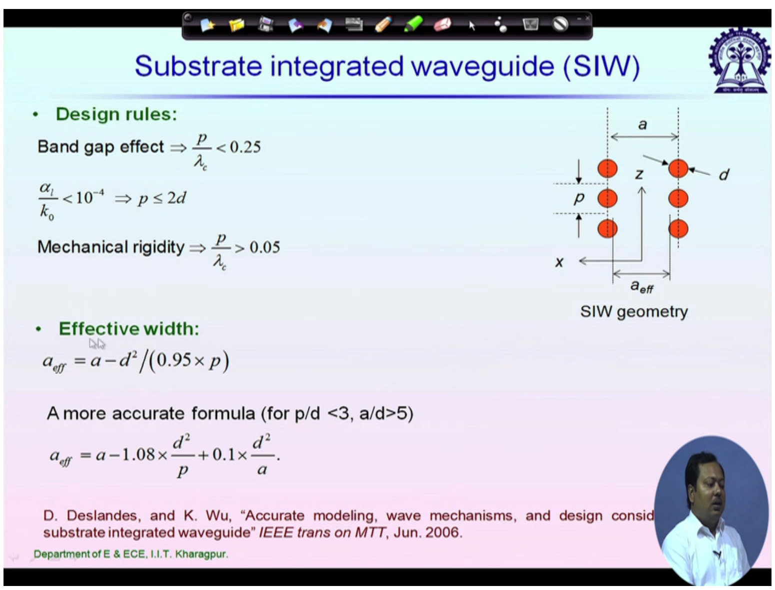

Next we have to calculate the effective width. Once we have the effective width A effective then we can use the rectangular waveguide formula. So umm it represents the physical separation midpoint to midpoint separation and A effective it represents the effective separation between the two effective electric side walls.

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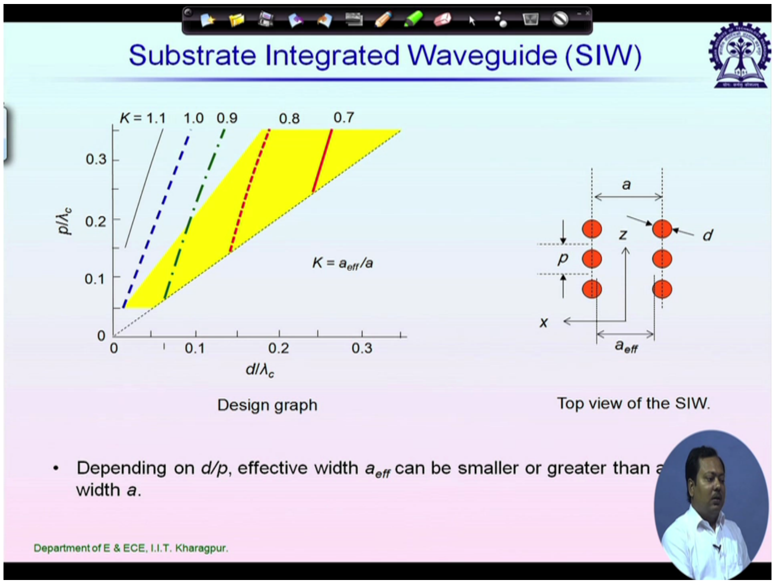

Now lets see how this a effective it varies with a it varies with the periodicity P and the via diameter D. So we are plotting again P by lambda C versus D by lambda C and you remember this is the region of interest. So left hand side in some regions it shows that A effective by a it is actually more than one.

But we are not using this region because we know if we choose any P and D from this region then we face high leakage loss. So we have to choose a solution from this yellow region and in this yellow region, we see that K, A effective by a it is always less than one as we predict from this formula.

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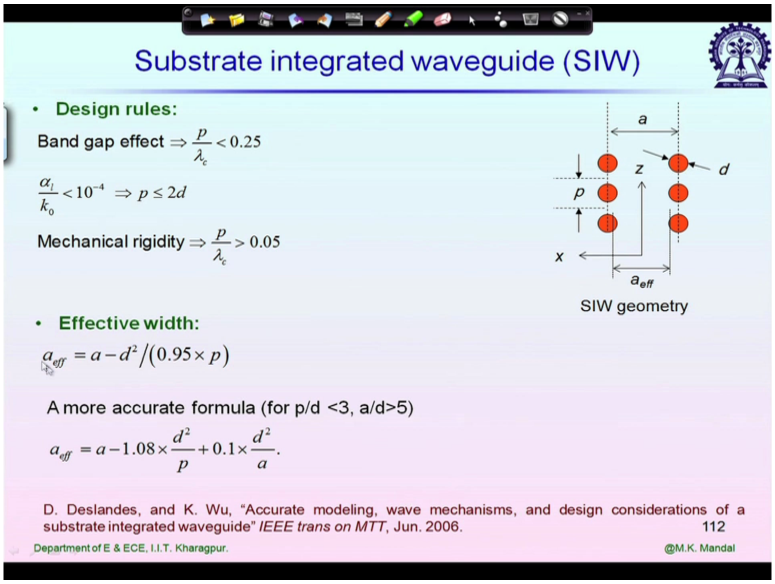

A effective it should be always less than one.

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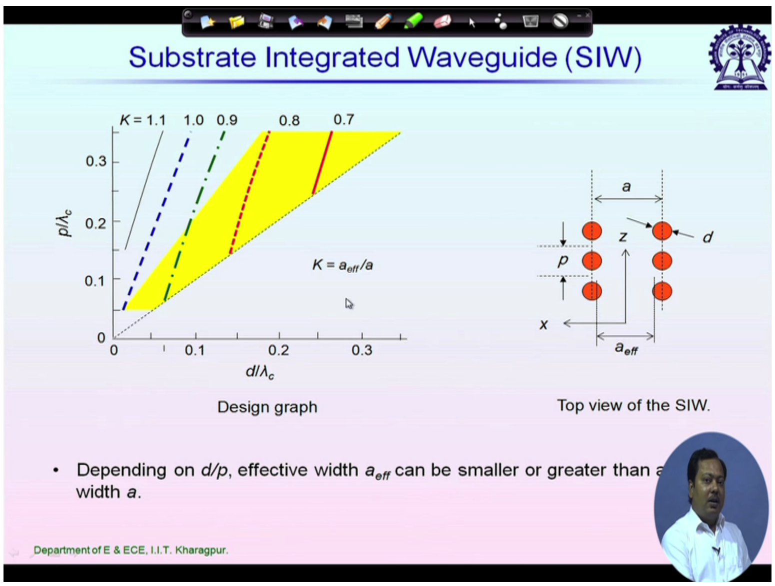

So why the calculation of A effective is so important? Because once we have the expression or the actual value of a effective then you can use all the formula you learnt for rectangular waveguide.

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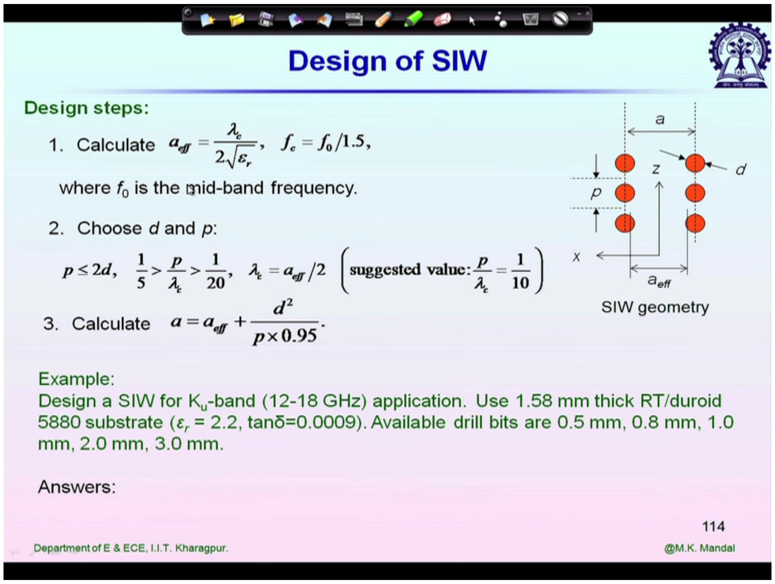

Next is design steps. So let's say for any given application now you are asked to design one SIW that means you have to choose a substrate first and then you choose our periodicity, you choose your d and you choose the via to via side wall separation a. So already we have the design rules, we can use those design rules to obtain the physical parameters for fabrication.

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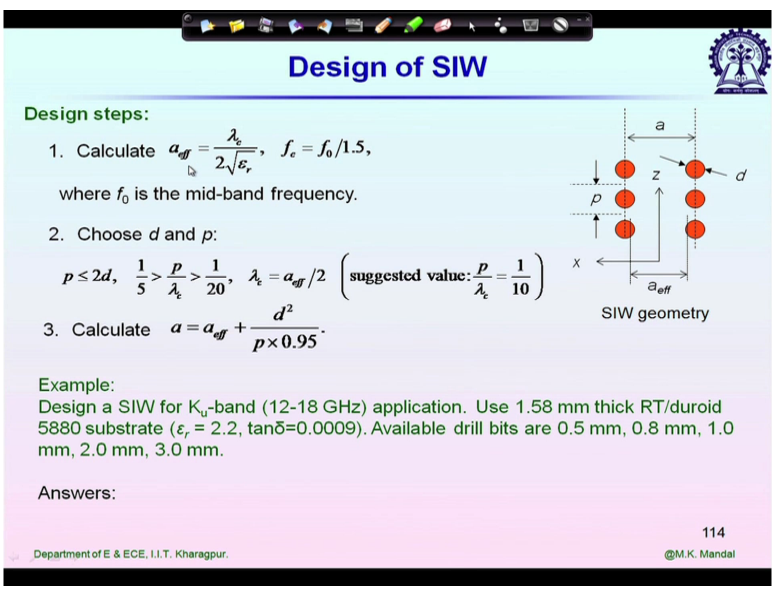

So lets start with the first step. Calculation of A effective. Once we have a effective from that we can calculate the physical separation a. So how we calculate A effective? Lets say the suggested band given lower frequency and upper frequency you already know, then you can calculate the mid band frequency of interest that is simply upper cut off plus lower cut off divided by two.

Then we keep the minimum attenuation point at the mid band frequency. So if your mid band frequency is F nought in that case then we can choose Fc value, that is equal to F nought by 1.5. Once you have Fc, you can calculate a effective. So A effective equal to approximately lambda C by two square root of epsilon R.

Now we have A effective so we can use these formula to calculate what is the physical separation a. Next we have to choose D and B. So already we know the requirements P should be less than equal to twice D and P by lambda C we have a lower limit and upper limit, it will be it should be within one by five to one by twenty.

If nothing is specified, we choose a midpoint value B by lambda C value one by ten and then already we calculated a. So now we have all the parameters A, P and D. How to choose the substrate? If I increase epsilon R, the structure will compact will be compact because A effective will be smaller. But at the same time its power handling capability will decrease.

And loss will increase because with increasing epsilon R you are decreasing cross sectional area. Not only that if I choose a higher thickness that means we are increasing cross sectional area. So we are increasing the power handling capability as well as we are decreasing loss.

So depending on the substrate available to you and requirement application requirement you have to choose your substrate wisely. What it should be the epsilon r? What should be the thickness of the substrate? Let us take one example.

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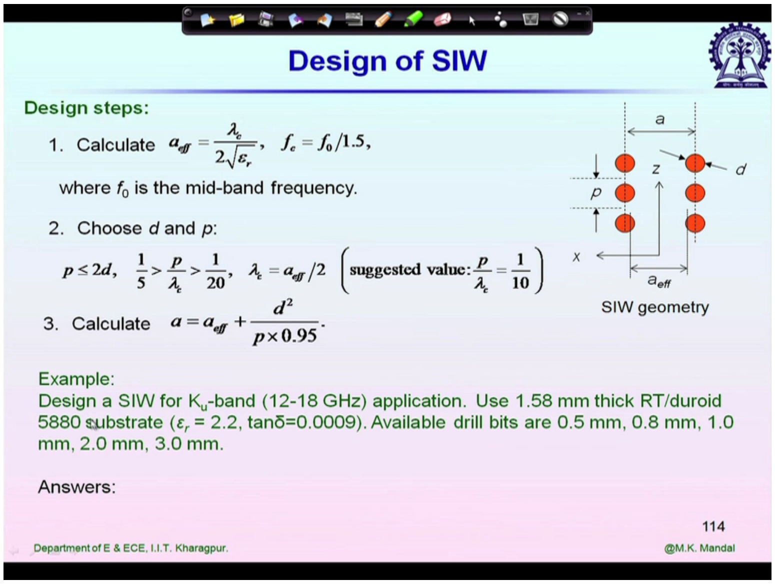

You are asked to design one SIW for ku band application. So my band of interest is Ku band 218 gigahertz and the substrate already given its the available substrate is 1.58 millimetre thick RT duroid 5880 substrate for which epsilon R this is equal to 2.2 and tan delta point three nought nine. Now we are going to fabricate it by using mechanical drilling and the drill bits available are point 5 millimetres, point8, 1, 2 and 3 millimetre. So you have to choose a proper drill bit and then fabricate your structure. So for that you have to calculate then D, P and A. We can utilize these three steps and then one by one you can calculate. So what should be the first step?

The first step is the calculation of A effective. Now the band of operation is given 12 to 18 so mid band where we will keep the attenuation minimum its coming then 15 gigahertz. So Fc is 15 by 1.510 gigahertz. Then calculate what is a effective at 10 gigahertz? So once you have that you can calculate D value and P value.

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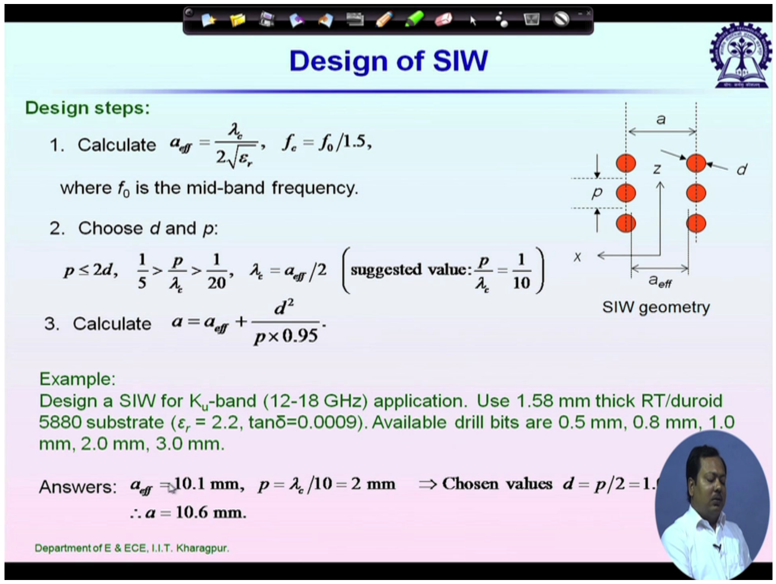

So here I am showing the calculated values. A effective is 10.1, P we choose lambda C by 10 it's coming approximately 2 millimetre. Then the chosen values are D equal to P by 2 to keep the leakage loss minimum. We are considering the limiting value and the drill bit then we have to use 1 millimetre and the corresponding a according to this formula its coming 10.6. So midpoint to midpoint physical separation it should be 10.6 millimetre. So if you fabricate the structure in this substrate it should support 12 to 18 gigahertz band applications.

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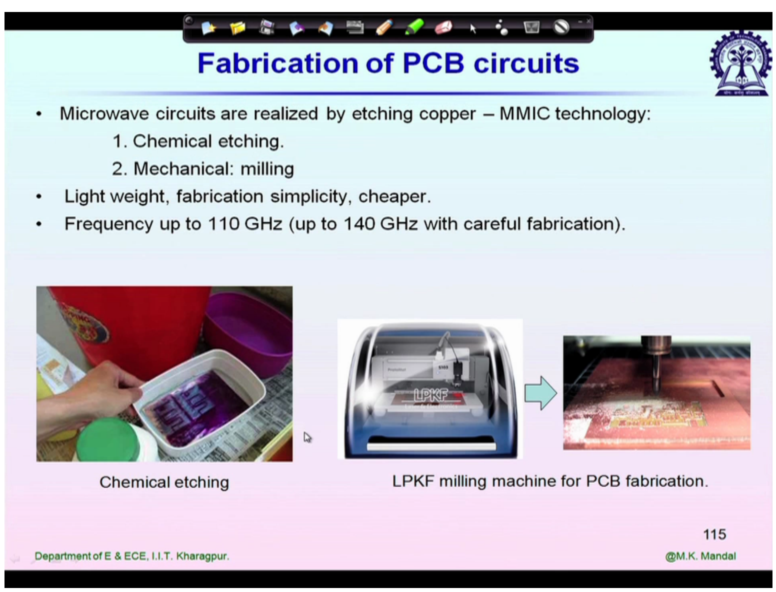

So before going to next topic which is waveguide dielectric waveguide? Let me discuss out the fabrication procedure. How we fabricate in printed circuit board technology? We can fabricate SIW structure and as well as we can fabricate microstrip or CPW structure. So two methods usually we use. One is chemical etching method and another one is milling method.

So in chemical etching method what we do? First we use some auto sensitive material on the copper cladding and then we print some mask. It can be negative as well as positive. So here in IIT Kharagpur we design negative. So you have some metal patterns you want to obtain it and the unwanted copper part we have to etch. So that the only required or desired metal part will be remaining.

So now for this undesired metal part will print in black colour then will keep this mask on that auto sensitive pasted copper clad and then we keep it under UV ray. So the all the open part it will be exposed by the exposed part. It will be its chemical property will change under UV ray and then we use some sort of dye and that will change the colour of this exposed part. So here we are showing some examples here.

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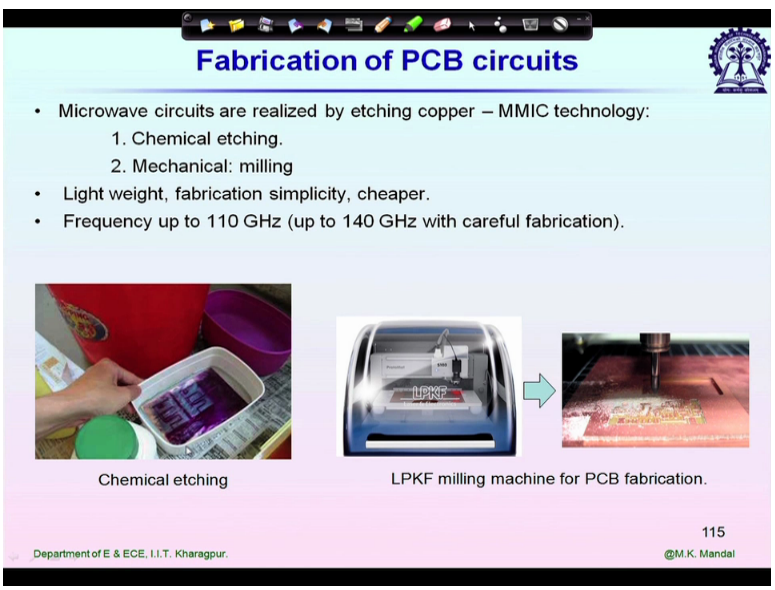

So this is a chemical bath and when we immersed this copper clad structure inside dye, you can see the microstrip part which is actually desired. So its colour is changing and then once we keep it in a etching solution like ferrite chloride then the unexposed part copper from this unexposed part from this etch away and only the copper in this pot will remain.

That’s how we can realize the top metallic pattern. We have one more method. It’s using mechanical milling. We have some computer controlled machine like this. In IIT Kharagpur we are having one LPKF and one MITS machine. So inside this machine what we have we have a drilling machine like this and it can also do milling. We have different types of bit for different purpose.

For milling we have milling bits for drilling we have drill bits and to cut away a substrate part we have also substrate cutter and what it does simply it milling it mill or it simply rub away the unwanted copper from the top surface. So thats how we can obtain the mid required metal pattern. And this is fully computer controlled and the fabrication procedure is very accurate even we can fabricate a thin line as thin as 50 micrometre and with a metal to metal edge separation as small as 50 micrometre. So frequency up to 100 10 gigahertz or even up to 140 gigahertz is possible.

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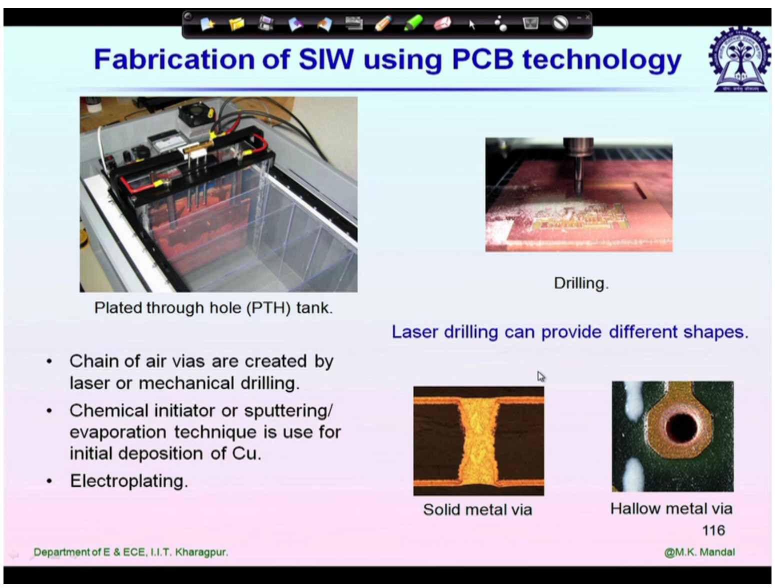

Now how to obtain the vias for SIW or for CPW lines, so what we do? Again we will be using those now drilling bits. So we will be having some air vias by using these drilling bits. Now once a fabricate air vias will be having exposed dielectric. We need some metallization on this dielectric.

We can’t use electro plating technique directly on dielectric because as a starting material we need some metal for electroplating. So we use some initiator which will deposit a thin layer of copper. A few nanometre on the surface of this dielectric then we put it for electroplating.

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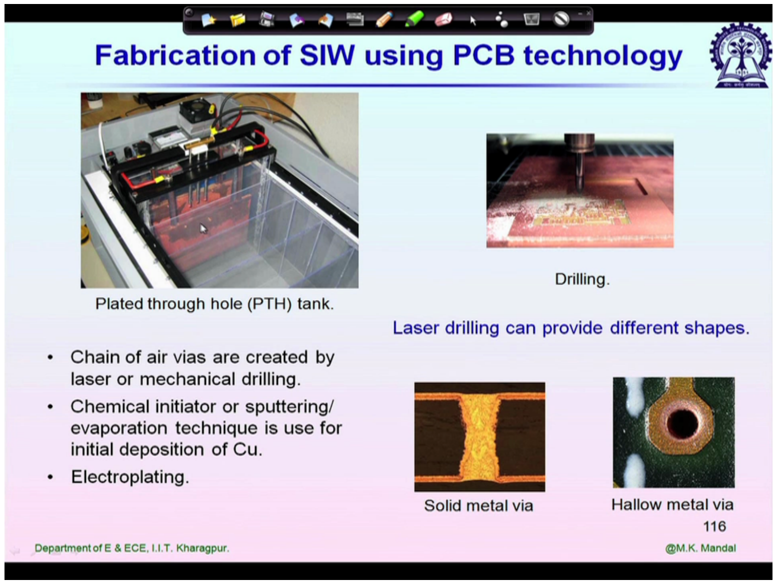

So here this figure is showing how we fabricate plated through pole or it calls PTH tank. So once we have the drill vias we have we use initiator on it and there is one more technique. We can also use sputtering or evaporation to deposit a thin layer of thickness a few nanometre of copper or aluminium or gold.

So once we have that thin layer of metal then we put it for electroplating inside this tank and what is the minimum thickness of copper we need that should be at least five times of the skin depth at the lowest frequency of operation. So here we are showing two different types of via. By using this PTH, basically what we obtain a via like this right side so you can see the hole.

So from one side of the substrate you can see the other side inside we have air and on this cylindrical surface we have copper deposition. You can see this copper layers from top view and left hand side one more via fabrication procedure. In this case we use some metallic paste. We have some silver paste or gold paste so inside we put them and then put it in oven.

Keep it for a few hours then it will become solid. So left hand side it shows solid metallic via but its fabrication procedure is expensive and time consuming. So next topic we are going to start wave guiding structure using dielectric only. Already for the surface waves we have seen that a dielectric slap itself can support electromagnetic wave propagation.

And dielectric slab back by ground plane that can also support electromagnetic wave propagation but if I use say dielectric slab the wave is not confined to any channel. It will spread throughout the surface. So that's why we call it surface wave. Now the waveguide if I want to design any guiding structure in dielectric technology so we need to design a channel first.

We can simply a thin layer of dielectric material instead of slab we have to consider a rectangular cross section and then it can support wave propagation. What is the advantage? So for this case we can minimize conductor loss. So that was the main problem for printed lines. So instead of then printed lines we can use this different types of dielectric guides with reduced loss. So here are some examples.

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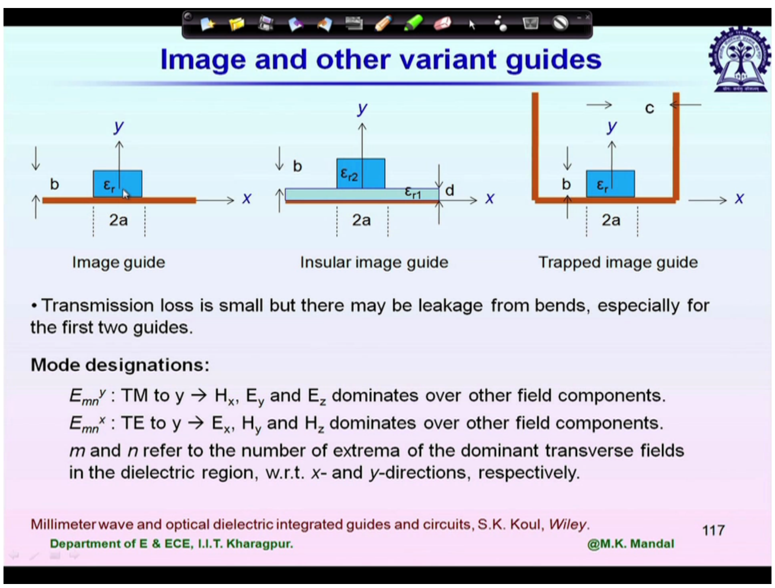

The first one is called the image guide. You can see one dielectric channel it seating on a metal plane which is used as the ground and the second example we have actually two different layers of dielectrics the first layer of dielectric material dielectric constant epsilon R1 over it we have that channel of dielectric constant epsilon R2.

And in the third example we have trapped image guide. So in this case only change with the first one is that we have packaging. So we can minimize the cross talk between two different channels. So for all this dielectric guides we always face with dielectric dielectric boundary. For the first example we have air dielectric boundary.

In second example we have air dielectric boundary in addition to that dielectric dielectric boundary separated by this interface. Right? So what is the problem we face it supports hybrid mode. So that means in the direction of wave propagation we have both electric field component and magnetic field component.

And not only that we have to deal with all the six components three components for the electric field and the three components for the magnetic field. But fortunately for different wave guiding structures mainly we have three dominant components.

In some cases we will see two dominant component of magnetic fields and one dominant component of electric fields and in other cases two dominant components of electric fields and one dominant component of magnetic field. So we use some approximation to simplify the analysis and we deal with only these dominant components of magnetic or electric fields. So we will take a break then we will start again. Thank you.