Millimeter Wave Technology.
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Lecture-12.
Guiding Structures (Contd.)

Okay so welcome back. We are continuing with loss study of microstrip line. Why we are giving so much importance on loss?

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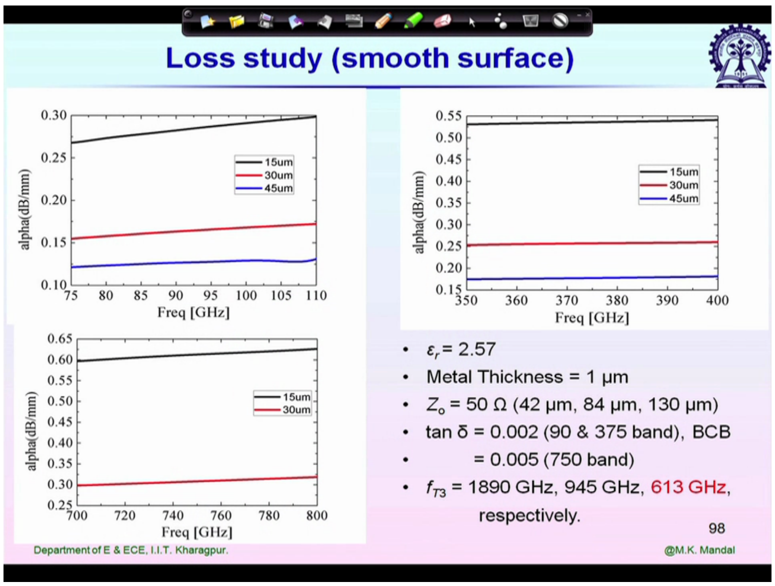

Because at millimetre wave frequencies it creates the main problem in any MMIC. So let us see more studies. So these we are we have calculated these losses by using full wave simulator. So we are considering 3 different thickness of substrates 15 micro meter thickness, 30 micro meter thickness and 45 micro meter thickness of BCB substrate. It is popular at millimetre wave frequencies or even at terahertz frequencies and typical tan delta value for 100 gigahertz and 400 gigahertz is point 002.

Its high but not that bad. And point 005 this is 700 gigahertz to almost 1terahertz and the corresponding epsilon R its 2.57 and it remains approximately constant over 100 gigahertz to 1terahertz and typical metal thickness we are considering for all these 3 cases is 1 micrometer.

Now if I change the substrate thickness 15 micrometer to 45 micrometer and we have only 50 ohm micro strip line in that case obviously the width of the micro strip line will be different. If we have a thicker substrate we have to increase W to make it 50 ohm. So in 15 micrometer the thickness is sorry the the width of micro strip line is 42 micrometer and it increases to 130 micrometer.

When we are considering a 45 micrometer thick BCB substrate and now let us first calculate what are the cut off frequencies? We have 4 expressions and if we calculate FT1 to FT4 for this 3 different substrate what we see in each and every case FT3 what do you remember what is FT3?

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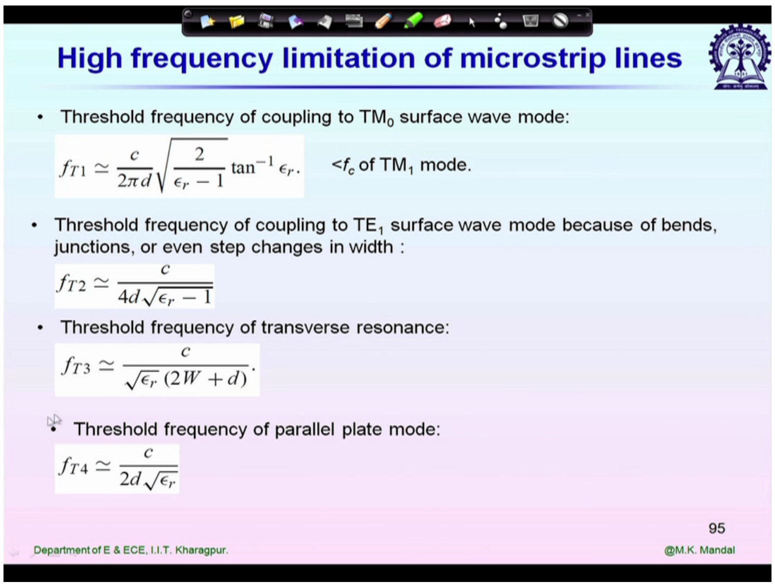

This is the threshold frequency of transverse resonance and we are considering it for that given 50 ohm line in the substrate.

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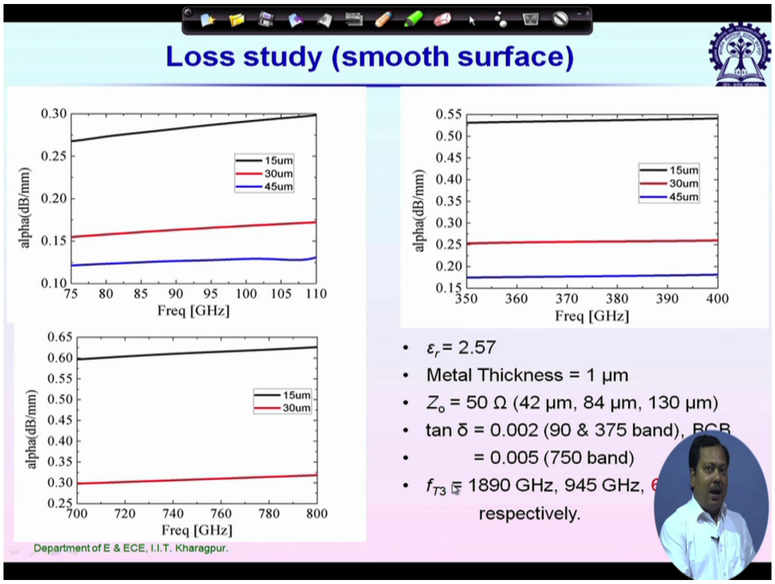

So FT3 it is minimum among all these four for each and every case for the first substrate its coming 1890 gigahertz. For the second substrate it is 945 gigahertz. And for the third substrate with the thickness 45 micrometer since it is having the widest line it is having the minimum FT3. So the third substrate we cannot use let us say about 600 Gigahertz.

Now let us look at the loss plots. So alpha DB per millimetre considering a smooth surface, we are not considering any surface roughness if we add surface roughness so loss will be much more 2 to 3 times than this. Now you see for 15 micrometer substrate loss is much higher compare to that 45 micrometer thick substrate. Why?

For 15 micrometer the width of microstrip line is 42 micrometer. So its thinner. So thats why conductor loss is highest for this 50ohm line on 15 micrometer. This is over 75 to 110 gigahertz. Now if I further increasing frequency we are considering terahertz band 350 to 400 gigahertz. You see for 15 micrometer previously loss was point 25 to point 3 now it increases to almost point 5 DB per millimetre.

If I further increase the frequency what will happen? It increases to point 6 approximately DB per millimetre. And remember this is without any surface roughness. So if I add same value of surface roughness with these 3 cases then the effect will be more prominent at higher frequencies.

Why? Because at higher frequencies we have smaller delta S and we have seen in the correction factor that if it depends on the surface roughness with respect to delta S.

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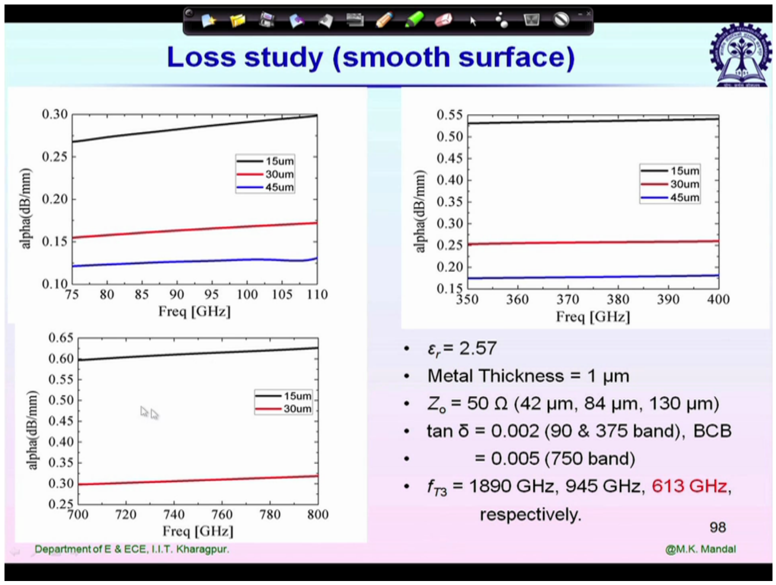

So if I go back here, you can see we are plotting it only for 15 micrometer and 30 micrometer and that 45 micrometer is absent here. Why? Because for 45 micrometer will be facing that transverse resonance phenomenon. Because already we have calculated FT3 is 613 gigahertz for the third case.

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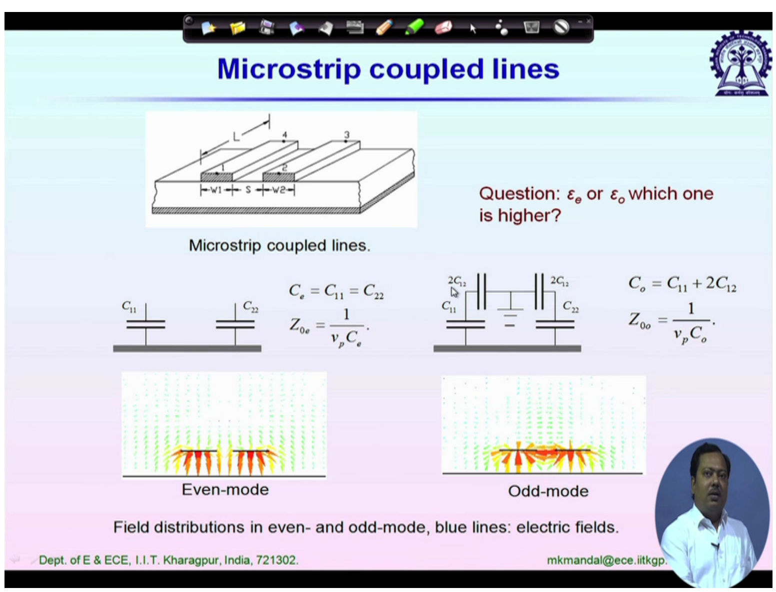

Let us consider a special scenario. Microstrip coupled line. We use microstrip coupled line whenever we go for component design components like couplers, filters and we deal with even mode and odd mode analysis of coupled lines.

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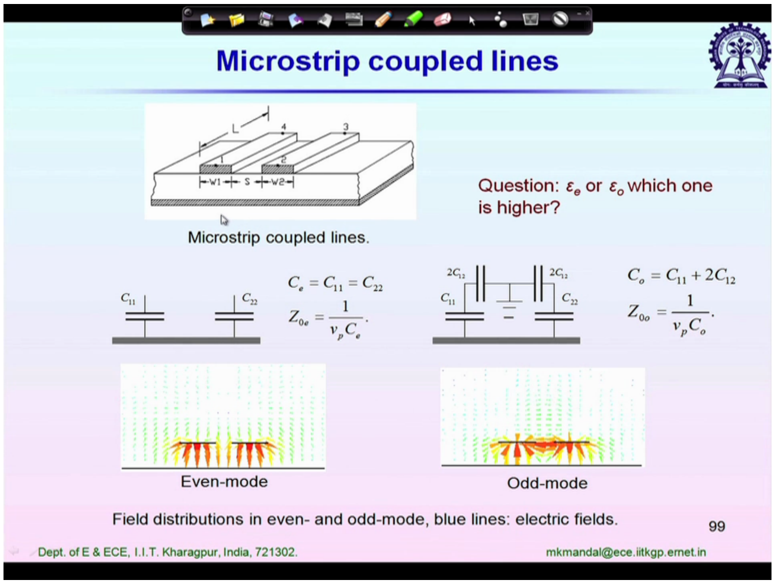

So let us see what is that. We have two coupled microstrip line. We can excite this coupled microstrip line by using 2 RF signals in 1 case it can be in same phase and in the second case it is in opposite phase 180 degree phase difference between these 2 signals. So the first cases when the 2 signals are in same phase we call it even mode condition. And the second case we call odd mode condition.

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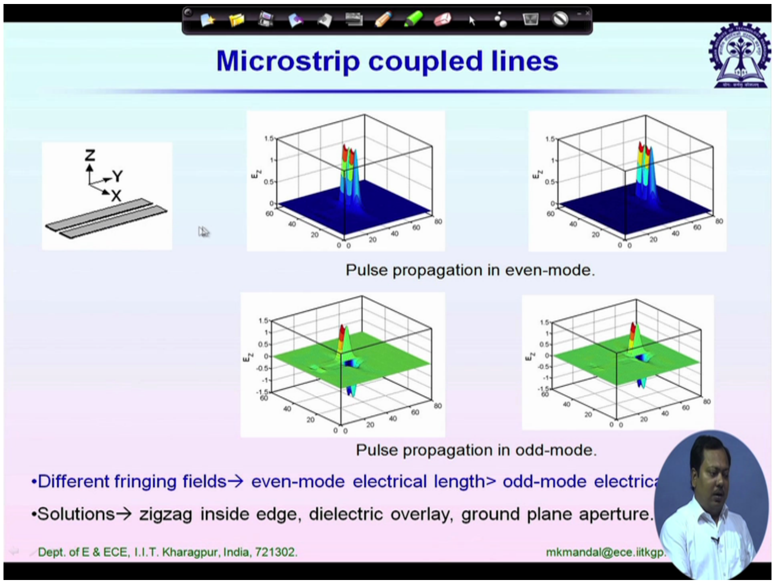

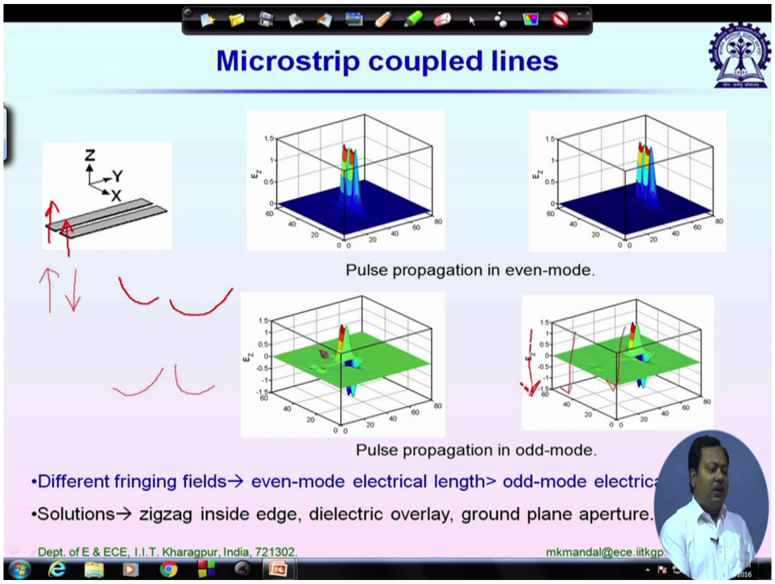

Let me show you the time domain propagation so you can see the strips and in these figure we are showing the propagation direction is Y and we are placing 2 mi millimetre wave sources at these edge left hand side. So here right here so let us first consider the even mode excitation that means these 2 sources they are in same phase.

Now we are considering the electromagnetic wave propagation in Y direction a time frame when these pulse, it just reaches the midpoint of this microstrip line and the shape of the pulse we are considering Gaussian shape. Now you can see the plot of electric field just below the microstrip line in even mode excitation.

This is then we are having mostly EZ component and you can see the Gaussian profile in even mode they are in the same direction and not only that if you look carefully at the tip of this so if I just zoom in the strip points, so in even mode what will happen? The inner tips they are little down compare to the outermost tips.

You can say we have we are facing somewhat repelling effect between these 2 different signals thats why the inner tips are little down compare to the 2 outer tips and in the second case the same mi coupled microstrip line but in this case what we are doing? We are exciting them by using opposite phase signal.

So 1 signal in this direction and the another one having 180 degree phase difference in opposite direction. So now we are plotting the electric field just below the strip. When it reaches the mid plane and you see the electric fields they are in opposite directions one having plus EZ component and another one having minus EZ component.

And if I compare in this case the tip values then inert tips those are at higher potential so in this case the inert tips it will be at higher values and the outer tips that will be lower. So you can say some here we are facing somewhat attractive phenomenon. Now let us go back to the previous one. So what happen here?

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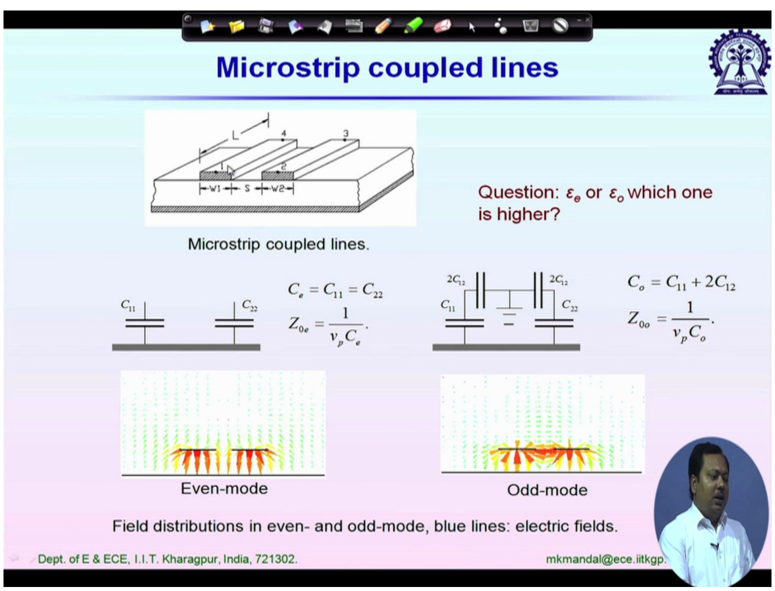

In even mode condition, when we are exciting by the source having same phase component the electric field this is the plot of electric field on a cross sectional plane. You can see the black colours microstrips and this black colour line it represents the ground. So the direction of electric field in same direction and there won't be any coupling between these 2 strips.

So no electric field exists from left to right hand side strip. So we can model this system by using 2 capacitors as C11 represents the first line. And C22 it represents the second line and then effective CE we can consider these 2 lines with ground together as a single transmission line system.

So this single transmission line system obviously it will be associated with some beta, alpha and some characteristics impedance. So we called the characteristics impedance when we are exciting in even mode Z0 E or even mode characteristics impedance. Similarly in odd mode we can define another characteristics impedance obviously which will be different.

Since the electric field orientation its changing and in that case we will call it Z0O or odd mode characteristics impedance. And these 2 different scenario beta or phase constant it will be different. Why? Let us again go back to the circuit diagram.

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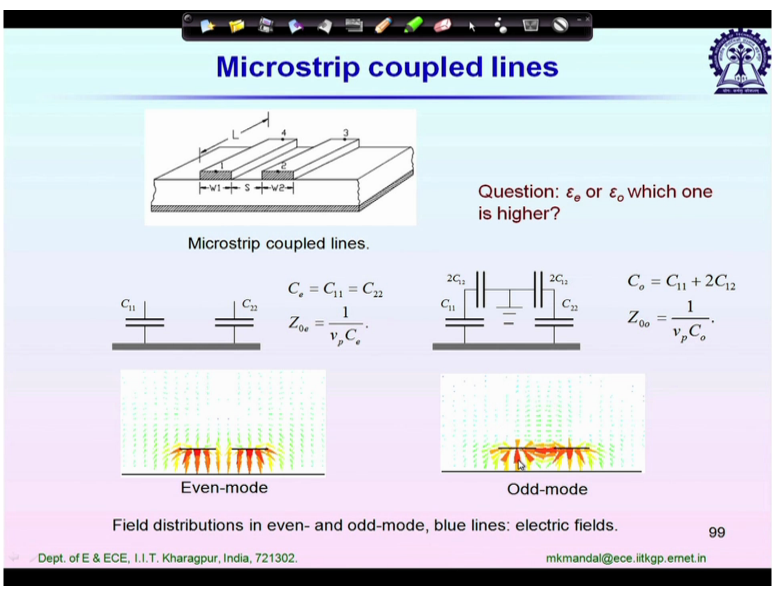

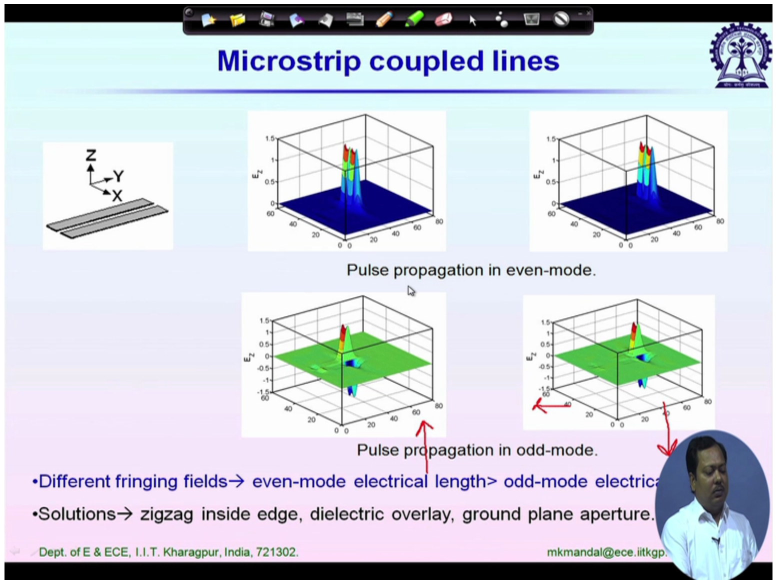

So in odd mode excitation you can see in 1 case, this for the left strip the electric field below strip its in this direction and for the right strip it is in bottom direction and not only that we have electric field coupling between these 2 strips. For this figure it shows that electric field right to left strip.

So we can model this system by 3 capacitors C11, C22 in addition to that due to this coupling electric field coupling we can represent it by 2 more capacitors C12 twice C12 actually the capacitance is C12, we are just breaking it into 2 parts. So now 1 interesting phenomenon we see if I compare the electric field plot for these 2 cases, left hand side we have electric field mostly confined inside the substrate.

And right hand side fencing field is more in air. Now if I calculate epsilon E for both of these 2 cases obviously it will be different. So effective epsilon for the even mode configuration it will be higher compare to that in odd mode excitation. Why? Because we have mostly the electromagnetic wave propagation through dielectric.

And here right hand side as the field plot shows we have fencing fields also which we cannot neglect in air. So the conclusion is that epsilon E in even mode it is much higher compare to the epsilon O in odd mode. What is the problem we face due to that if epsilon E is different that means lambda g will be different, if lambda g different phase velocities will be different. We will be having dispersion effect.

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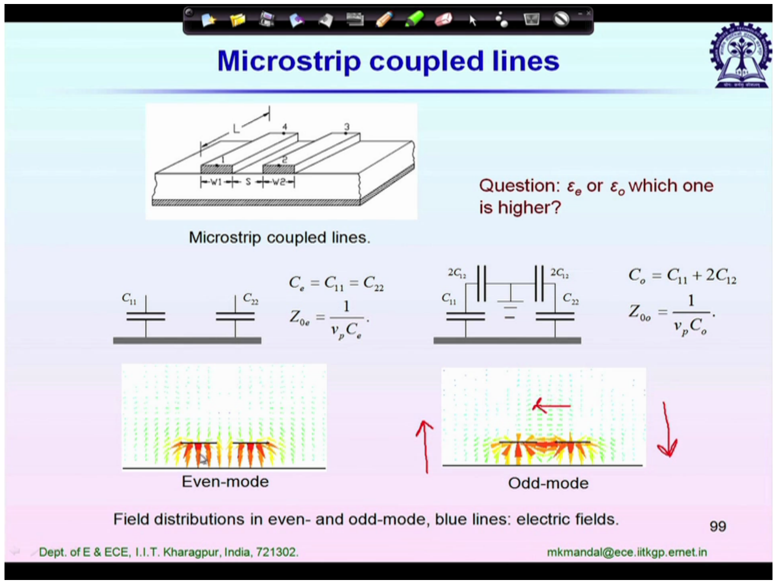

So for even mode since epsilon E is higher small length will show more beta so if I consider let us say a fixed length of 5 millimetre microstrip line For left hand side case and right hand side case so for left hand side if the 5 millimetre length it represents some electrical length equivalent electrical length let us say 180 degree at some given frequency.

For the right hand side since epsilon O is smaller, it will represent smaller length its not 180 degree at that frequency but something much smaller than that. So due to that we face problem when we design components. Because in practice if we have if we excite a coupled line system we can always divide it into 2 parts even mode component part and the odd mode component parts. And these 2 excitation they co exists and we will be having dispersion 1 more interesting observation here.

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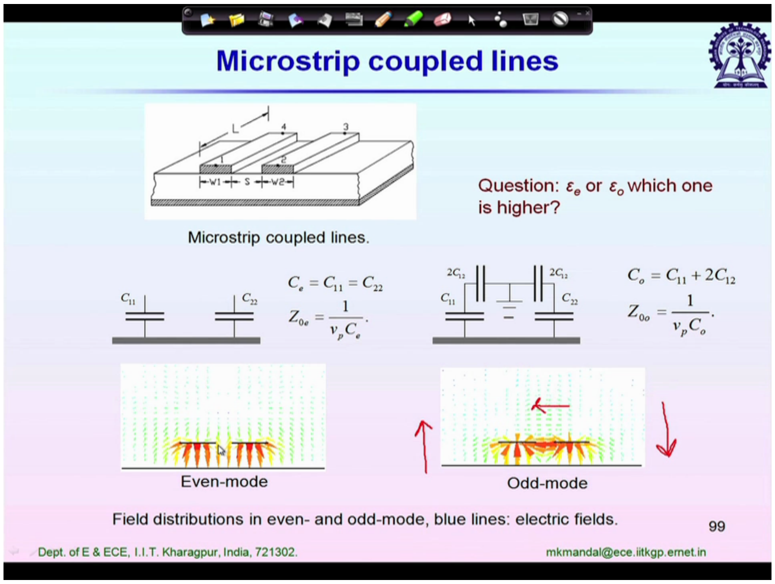

For the even mode case we don't have any electric field from left strip to right strip. So if I consider a mid plane which is perpendicular to this and it is placed just in between these 2 strips then no electric field is passing through that plane. Not only that the electric field left hand side and right hand side it becomes parallel. So we can call this plane a PMC or open circuit condition.

Similarly for the right hand side if I place a mid plane here which is the plane of symmetry so electric field on that plane it is perpendicular. That means it behaves as a short circuit or a PEC. So even mode condition we call it sometimes the open circuit condition and odd mode condition we call it sometimes a the short circuit condition. One more observation since no electric field is from left to right then the coupling effect there is coupling effect.

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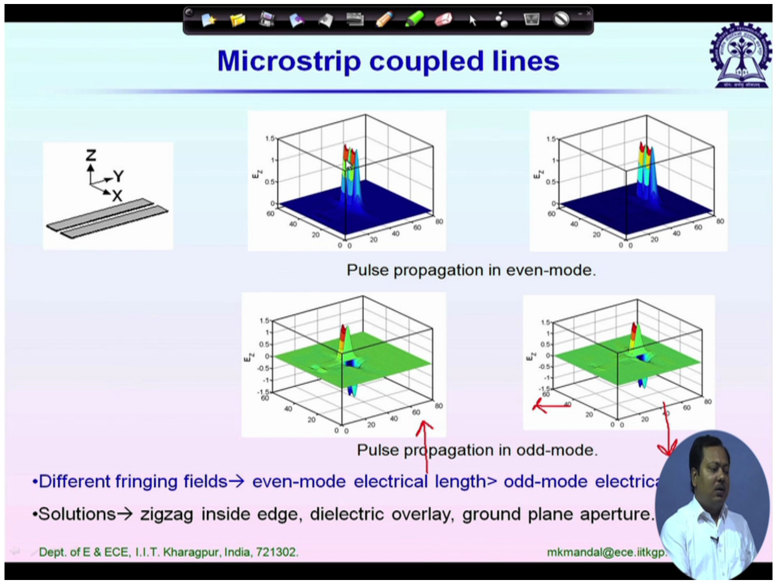

Because if I look at this plot the outer tips are higher compare to the inner tips so there is coupling effect.

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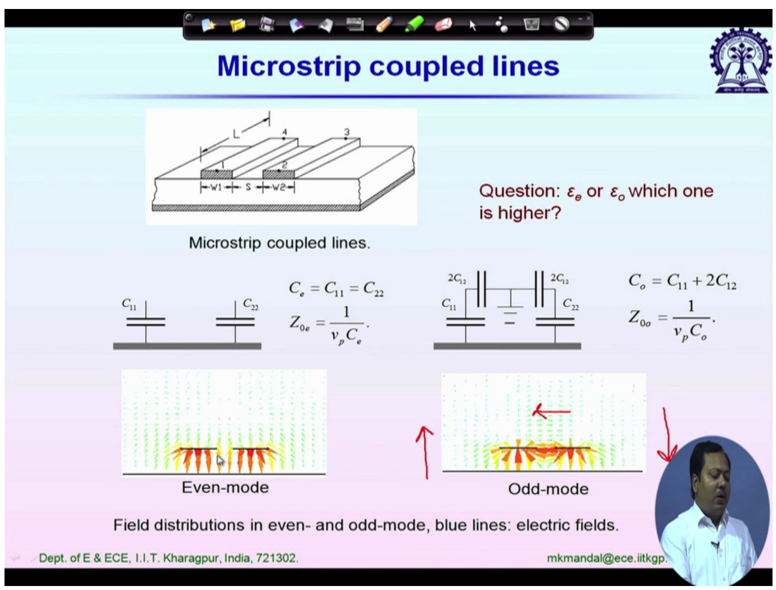

And for this one then this coupling it might be through magnetic field so for even mode we called it magnetic coupling. And right side we can see it clearly we have electric field from right strip to left strip so the coupling is due to electric field and we call it electric coupling.

So 2 important conclusions 1 in even mode we can place 1 PMC between these 2 strips and in odd mode it should be PEC and not only that in even mode the coupling is due to magnetic field so we call it magnetic coupling and for odd mode we call it electric coupling so in practice then how we can improve it? That how we can avoid the dispersion problem? There are some remedies so let me discuss one of them.

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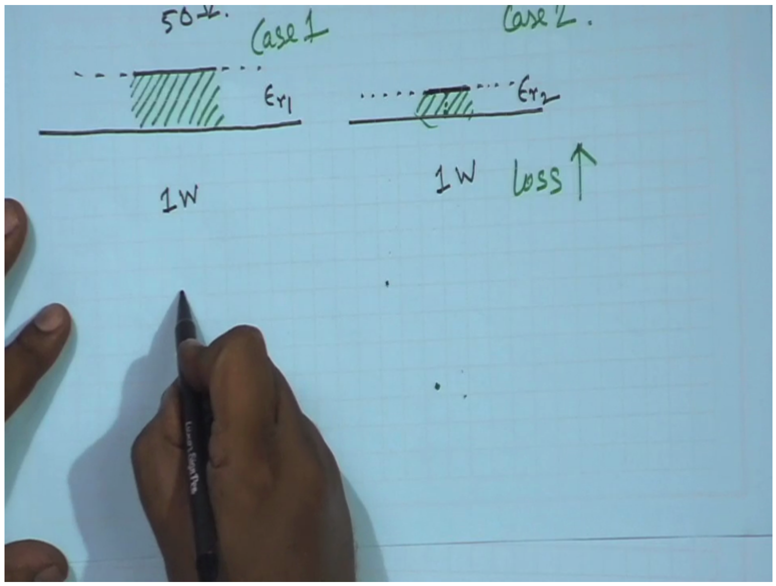

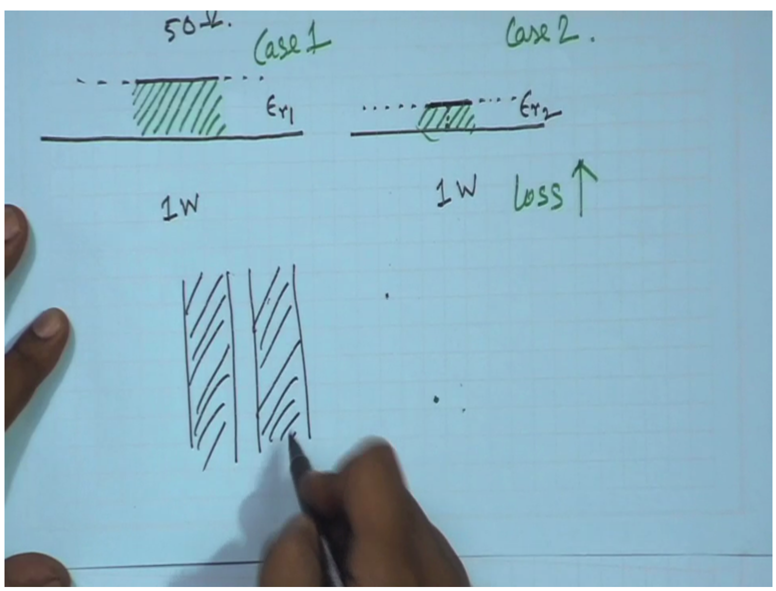

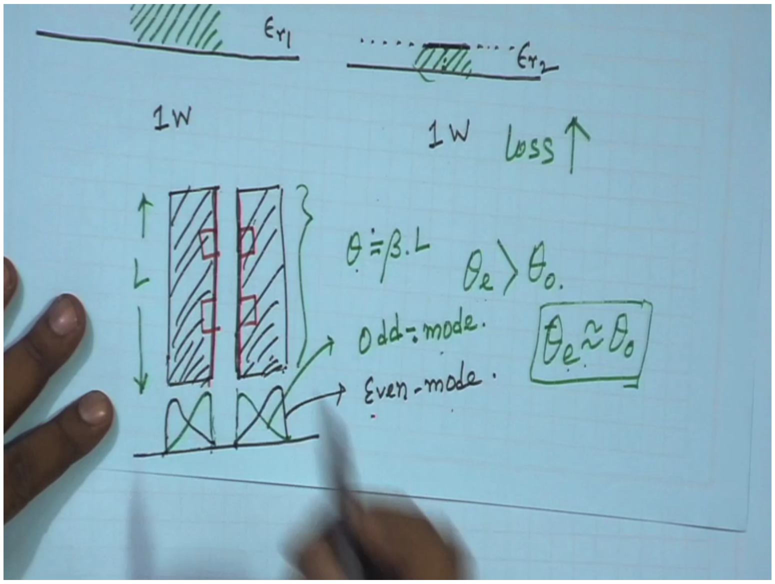

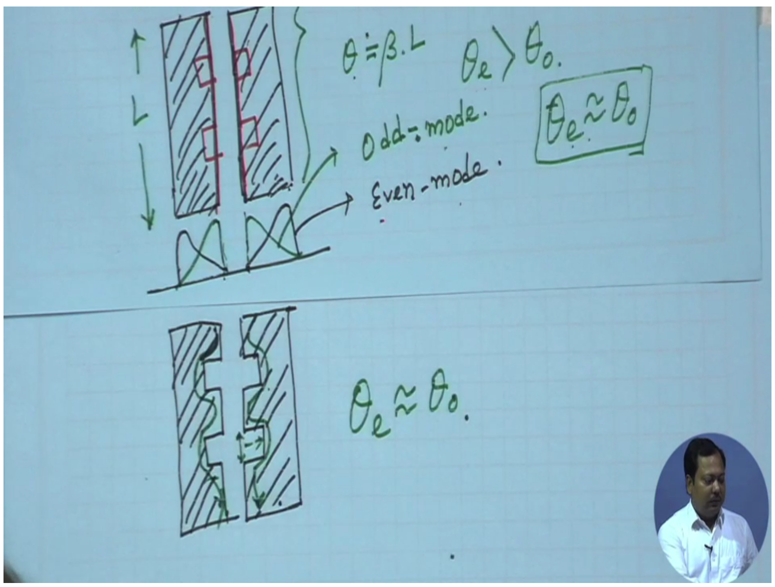

Let us say we have a coupled line system. I am drawing the top view so this is the left strip and this is the right strip. Now if I plot the surface density of surface current component on left strip and right strip for even mode and odd mode they will have different variation. So in even mode this current will be more concentrated on outer edge so this is for the even mode scenario and in odd mode we have some sort of attractive effect.

So the current will be more on the inner edges. So this green line, this is the current distribution for odd mode excitation. Now what we have seen that for a given length the equivalent electrical length theta which is beta into L. So L is the length of the strip. So this theta will be higher for even mode excitation. So theta E is more than theta O.

We have to if we can increase theta O so that theta E it becomes equal to theta O. In that case we can avoid dispersion. Hoe we can do it? There are many ways one of them noting down that electric field inside air is more in odd mode configuration. What we do? We use some dielectric overlay on this strip. So that in even mode there will be some field inside this overlay.

Now depending on the dielectric constant of that overlay we have to control the thickness by using any full wave simulator. So that theta E it becomes equal to theta not. This is one way another popular way noting down that the current distribution is different so you can say it in different way. Since the current distribution for the odd mode is higher at the inner edges so if I partnered the inner edge most probably it is going to partnered the odd mode characteristics. Right?

If I do any perturbation if I add any perturbation on the outer edges it is going to effect mainly my even mode characteristics. Now noting down theta E is more than theta not what people do? Intentionally they will cut some groups. So the structure resultant structure it looks somewhat like this with groups. So what we are doing here?

We are introducing some groups here so that the effective current path in odd mode it increases. You can see now it becomes longer. Right? So we have to then tuned the depth of this group and the width of this group so that this theta E it becomes nearly equal to theta not and it is not going to affect my even mode excitation since we are doing at the inner edges. So this is another popular method to avoid that dispersion effect.

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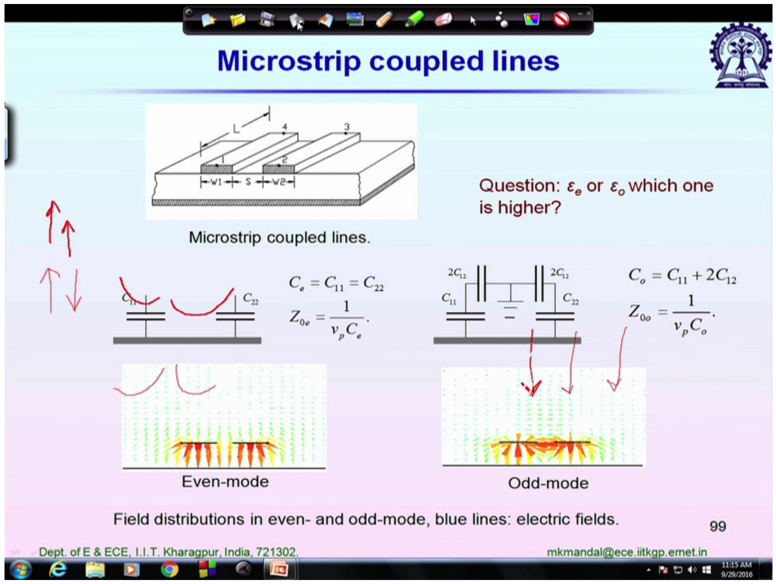
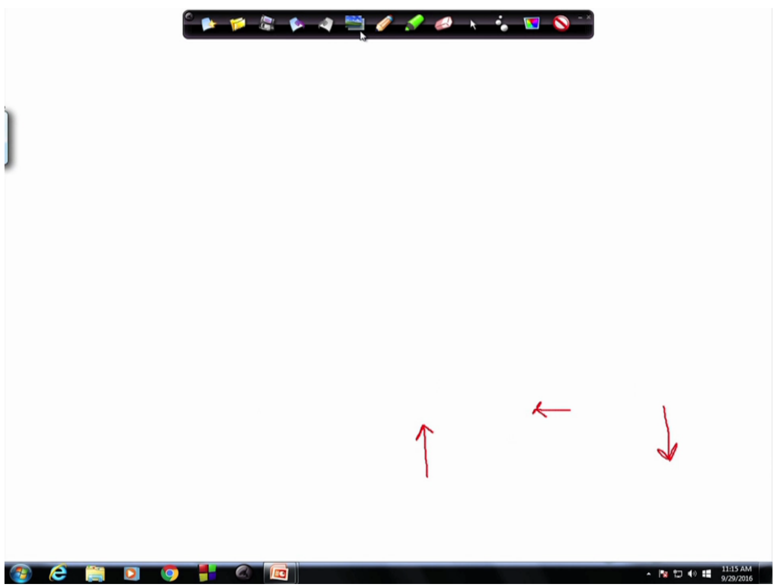
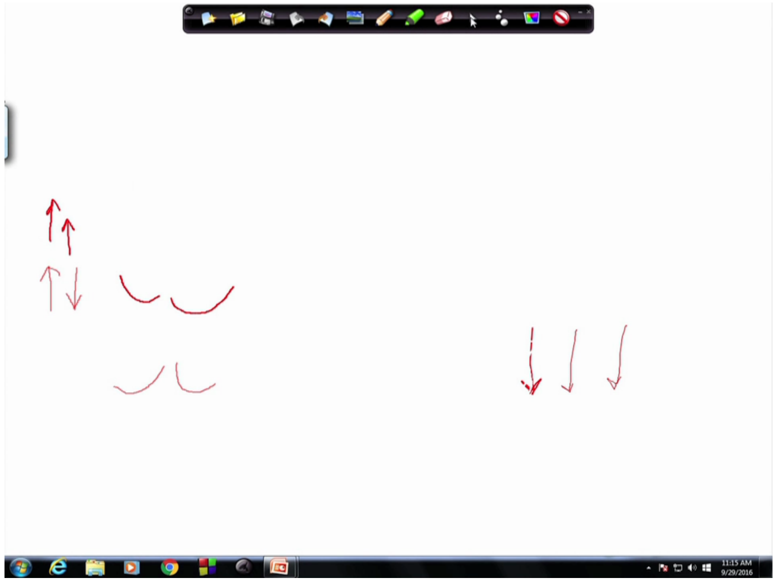
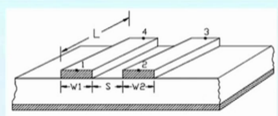




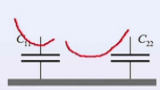


Microstrip coupled lines



Microstrip coupled lines.

Question: ε_e or ε_o which one is higher?

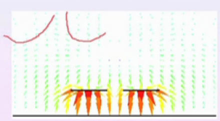


$$C_e = C_{11} = C_{22}$$

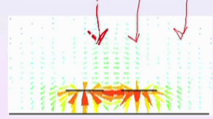
$$Z_{0e} = \frac{1}{v_p C_e}.$$

$$C_o = C_{11} + 2C_{12}$$

$$Z_{0o} = \frac{1}{v_p C_o}.$$



Even-mode



Odd-mode

Field distributions in even- and odd-mode, blue lines: electric fields.

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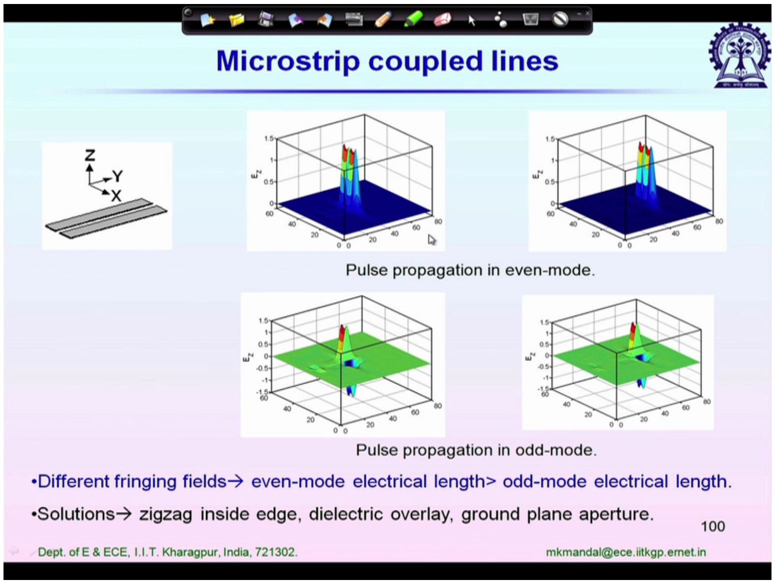

Okay so next.

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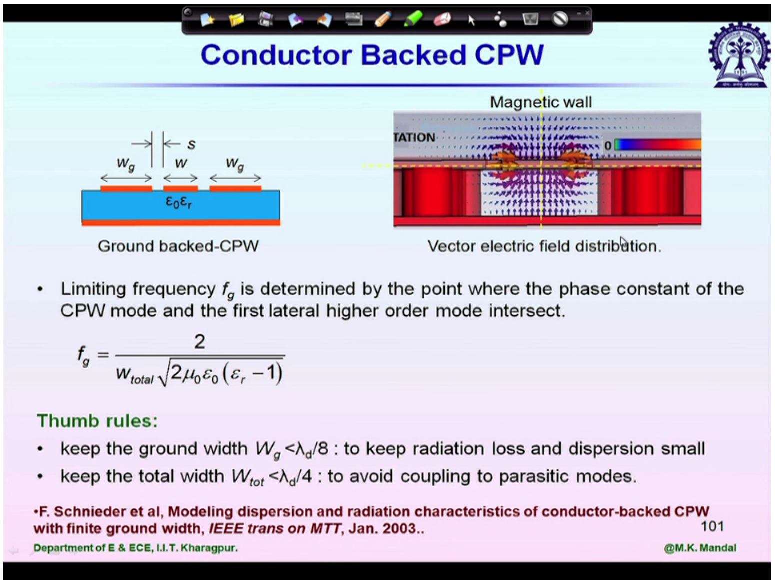

Let us start CPW line Coplanar waveguide. It cames in 1960s. Let me draw a coplanar line first. How it looks?

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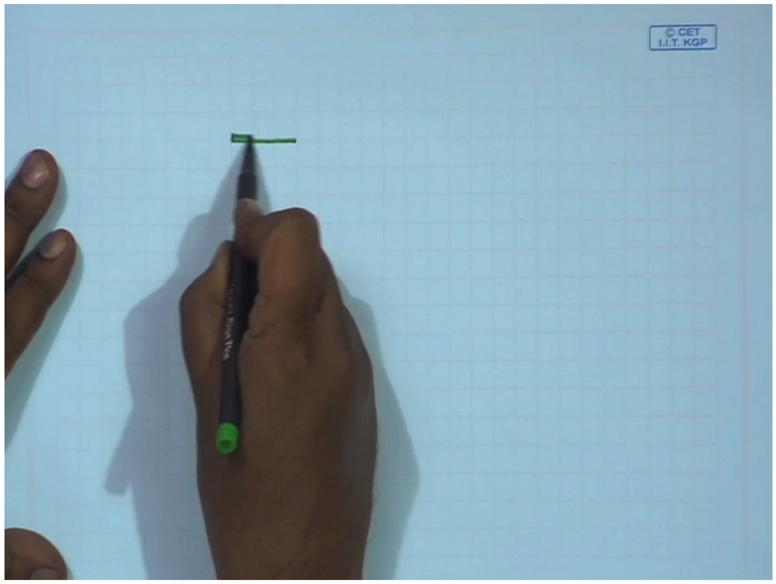

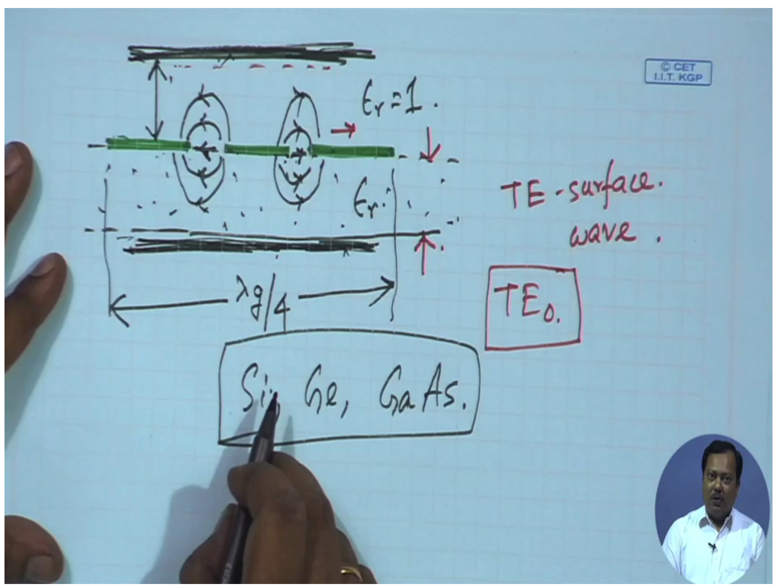

So we have a central conductor which is a central strip and its separated by from 2 ground strips and together they sits on a dielectric layer. You can consider it as a couple slots. This is the cross sectional view. So inside we have electric field if you remember that odd mode and even mode excitation so we prefer even mode excitation so that this 2 extreme ground they will be at same potential and in that case the electric field configuration will be like this.

So again we see that we have some fencing field in the air. And some fields inside the dielectric so we will be facing dispersion problem just like microstrip line. And in this case if I change frequency again just like the microstrip line epsilon E it will be changed, we can also control the characteristics impedance. We have some standard closed for expressions.

So if I decrease this slot with characteristics impedance it decreases. We have similar FT1, FT2, FT3 and FT4 for this CPW line as well. So in most of the cases what we do? Its width effective width including the ground left to right it should be less than lambda g by 4 to avoid any transverse resonance and to avoid any parasitic mode.

What do you see if I use a open structure its a semi opened structure that supports quasi TEM mode. Now if you remember that transverse electric surface wave mode in that case we have the dominant electric field component which is in this direction and so we will be having coupling from CPW mode to TE0 surface wave mode.

Which has no cut off frequency and this coupling will increase if I increase the thickness of the substrate. So how to avoid this? So in most of the time for MMIC the CPW line is not preferred since you have to maintain this spacing for this fencing field as well as for the dielectric because finally at the end of the day we have to go for some packaging and packaging we do by some metal box.

And now if the metal wall let us say it represents the metal wall of the packaging. If it is close to CPW line then obviously there will be coupling between this CPW mode and this metal and the mode characteristics will change so we have to maintain a minimum separation for that and that separation depends on the signal line width.

The slot width and as well as the dielectric constant and the thickness of the substrate. Similarly bottom side we cannot place the packaging wall just attached to the substrate so we have a problem due to packaging. So usually a pure CPW line it is used in semiconductor industry like for in silicon fabrication, germanium fabrication or gallium arsenide fabrication again silicon, germanium or gallium arsenide they have they follow different fabrication process for example gallium arsenide fabrication it starts with backside metallization. Silicon, germanium it does not have any back plane metallization.

It starts with bulk P type or N type material. So in PCB form using laminates usually we don't use open CPW line like this. So what we use? We use a grounded CPW line or ground back CPW line as shown in this fig.

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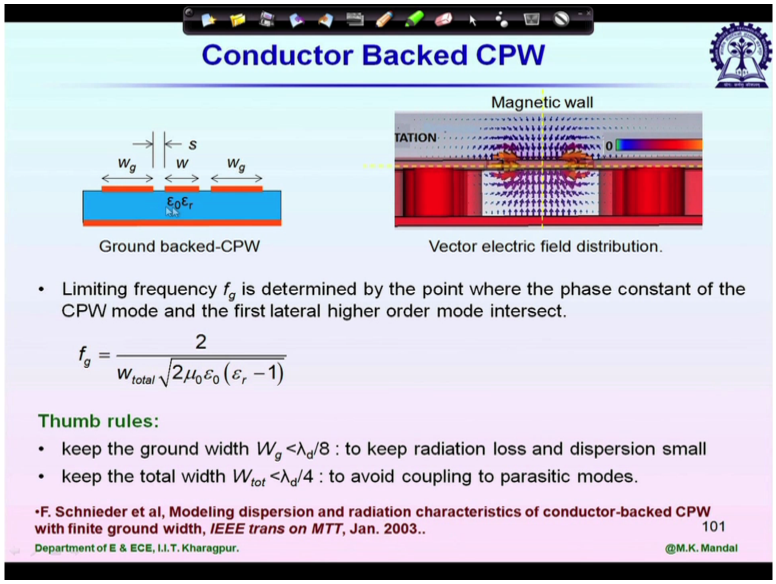

So you can identify the top layer CPW line. W this is shown as the width of the signal line. WG this is the width of the ground and we have 1 additional metal layer. It is the ground plane of the CPW line. And now you see at least in 1 side we can directly place our packaging wall and on top of this of course again we have to maintain some minimum separation. So we will take a short break. Then we will discuss on the ground back CPW line. Thank you.