Millimeter Wave Technology.
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Lecture-17.
Antennas at MM-Wave Frequencies (Contd.)

So let us say how resonant length it varies with the substrate thickness and epsilon R.

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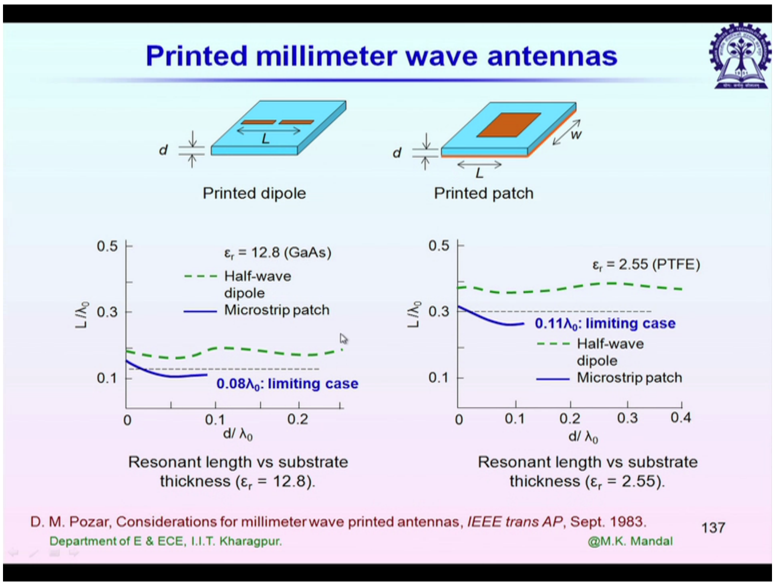

So in this figure we are considering 2 different epsilon R value in the left hand side plot epsilon R equal to 12.8 this is for gallium arsenide substrate and right hand side epsilon R equal to 2.55 this is for the PTFE substrate. Now what we are doing? We are calculating the resonant length so this is normalised resonant length versus the substrate thickness D by lambda not.

Dotted line it is for the half wave dipole antenna and solid line this is for the rectangular patch antenna. this we more we have one more black dotted line it represents the line where it is equal to lambda not by 2 multiplied by root epsilon R that from the thumb rule. Now if I look at the plot what we see with the increasing substrate thickness which is represented by D for the rectangular patch antenna resonating length decreases.

And for dipole antenna increases not only that one more interesting thing we see this curve for printed patch antenna its stops at point 08 lambda not that is the limiting case. After that we cannot identified any resonance behaviour on patch antenna now the reason is why?

Because of the surface wave mode generation when D by lambda not is very small we don't have any surface wave mode as such but as D increases.

We have more and more surface wave mode excitation mode generation. And power is loss to surface wave after point 08 lambda not you can say even we cannot identify the resonance patch is not radiating at all almost all of its power is loss to surface wave. Now if I decrease epsilon R what we expect at least we can increase this limit.

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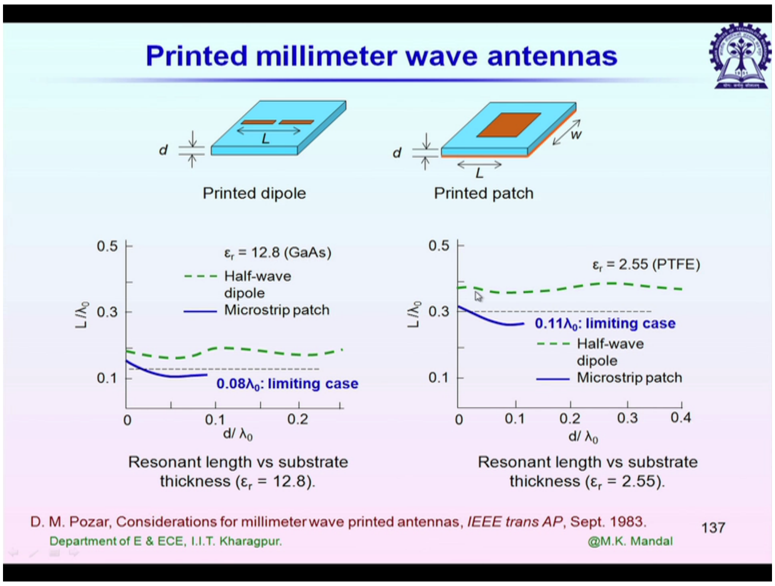

So in right hand side plot you see again same thing dash line for half wave dipole and solid blue line for umm rectangular patch antenna so since here epsilon R is 2.55 we could increase it to point 11 lambda not at least the thickness of the substrate D. For dipole antenna we don't phase as such any problem of course there is surface wave mode generation but even till let us a point 3 or for lower dielectric constant point 4 umm D by lambda not.

We can identify the resonance mode. If you look at this structure surface wave for left hand side and right hand they will be having different characteristics. Why? In left hand side we don't have any ground plane simply the dipole it is printed on a laminate and right hand side we have rectangular patch below dielectric slab back by ground plane. So if I look back to surface wave properties left hand side for the left hand side case we have to consider a dielectric slab simply and right hand side a dielectric slab back by ground plane.

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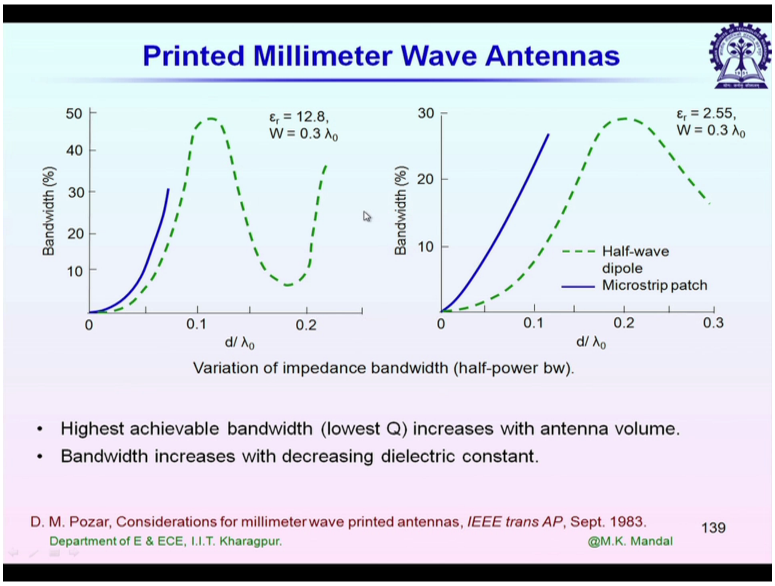

Now let us say how bandwidth varies with the thickness of substrate? In general If we increase the antenna volume in that case Q will decrease this is the radiation Q QR and the bandwidth will increase so if I increased thickness of the substrate.

We are increasing the antenna volume and what we expect that bandwidth will increase look at the plot of 2 different epsilon R for epsilon R equal to 12.8 we are considering width of the antennas for both of the antennas is equal to point 3 lambda not now for patch antenna it increases sharply after point 08 lambda not we cannot identify the resonant mode so we are stopping here.

And for dipole antenna as expected it is first increasing but after that it is decreasing this is due to the surface wave problem but we have 1 transition point here near point 18. Again it is increasing so this increment is due to radiation from surface wave this is not for radiation from dipole antenna. Now you see one thing if we have surface wave generation inside dielectric slab. What are the problems we can face?

Obviously its a loss of power or wastage of power into surface wave mode. Now if the dielectric slab is infinite in XY plane then surface wave it will propagate X and Y and the electromagnetic wave it will spread over the surface of the dielectric slab. In that case from radiation point of view we don't have any problem only problem is power loss to the substrate and as a result antenna efficiency will decrease.

But in practice always dielectric slab is finite we cannot use infinite dielectric slab in that case what will happen? If we use finite dielectric slab then we will be having radiation from surface wave and it comes at the dielectric air boundary. So this radiation it can be random direction we don't have any control over this radiation. Polarisation of the electric field it can be in random orientation.

Variation of radiation intensity from the surface wave that can be also in random direction as a result if I look at the radiation characteristics of the antenna cross pole level will increase and side robe level will increase which is not desired. At millimetre wave frequencies then we have to be very careful not to excite this surface wave.

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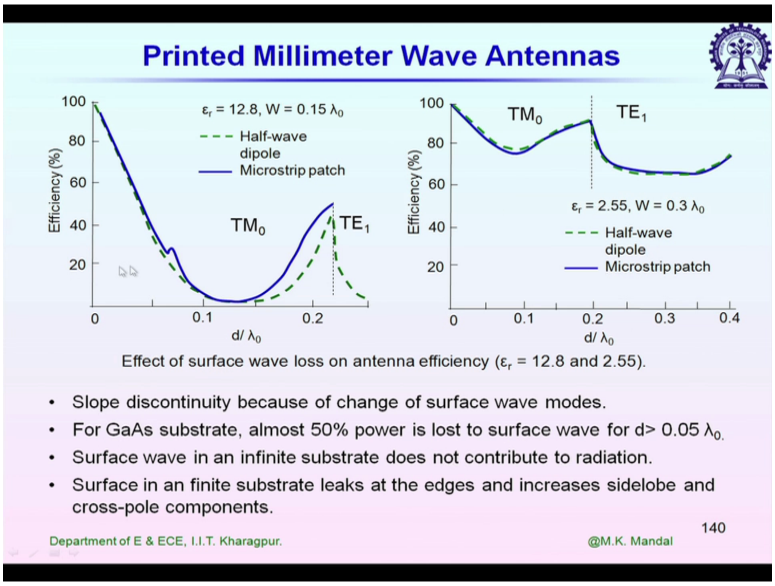

So next, we see the antenna efficiency variation with the substrate thickness for epsilon R equal to 12.8 its shown by blue and dash line for the micro strip patch and half wave dipole. As expected due to surface wave they all decreases and they are umm decrement almost have similar value. Now after point 11 we are again plotting the efficiency for micro strip patch.

So this radiation or increment in antenna efficiency it is not due to radiation from the patch but this is due to the radiation from surface wav. And if you remember for micro strip line we cannot avoid coupling with TM 0 mode and the radiation is mainly coming from the TM 0 surface wave mode for patch antennas as well as for the half wave dipole antennas.

After this transition we have one more second transition here then for the dipole power is loss to TE 1 surface wave mode and antenna efficiency again decreases because for the TE 1 surface mode we don't have sufficient radiation from the structure. We have similar variation for lower dielectric constant also. So you see first the antenna efficiency decreases so only for this first part which is showing negative slope we can say radiation is due to the antenna resonance.

After that radiation is mainly from the surface wave mode. So we can see some observation for gallium arsenide substrate almost 50 percent power is loss to surface wave for D greater than point 05 lambda not. You can calculate it if the substrate thickness is just i i is more than point 05lambda not where lambda not this is wavelength in free space then 50 percent power is lost for gallium arsenide substrate.

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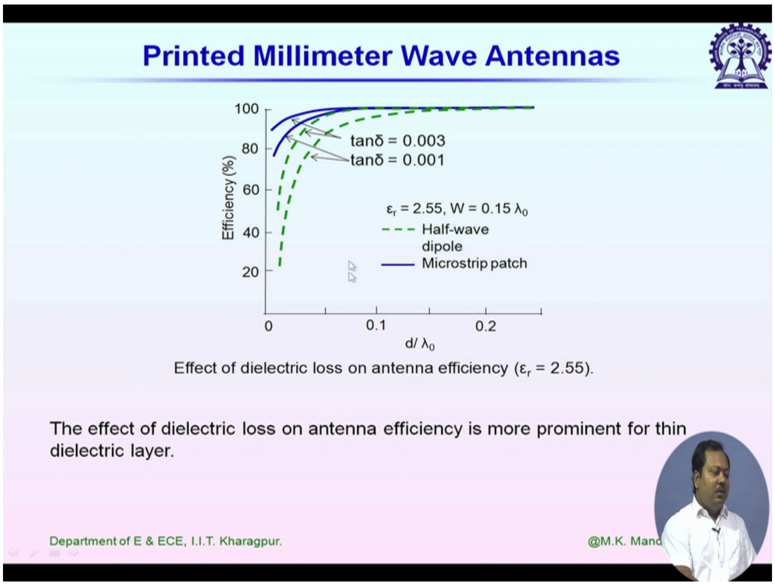

Next we plot efficiency variation versus the substrate thickness for different loss tangent value. If we increase the loss tangent of the dielectric slab obviously we will expecting more loss. And if we consider now a thinner substrate and let us say feeding the same power to one rectangular patch antenna so for thinner substrate obviously electric field intensity will be higher inside dielectric and will be expecting more loss for thinner substrate. This loss is the dielectric loss.

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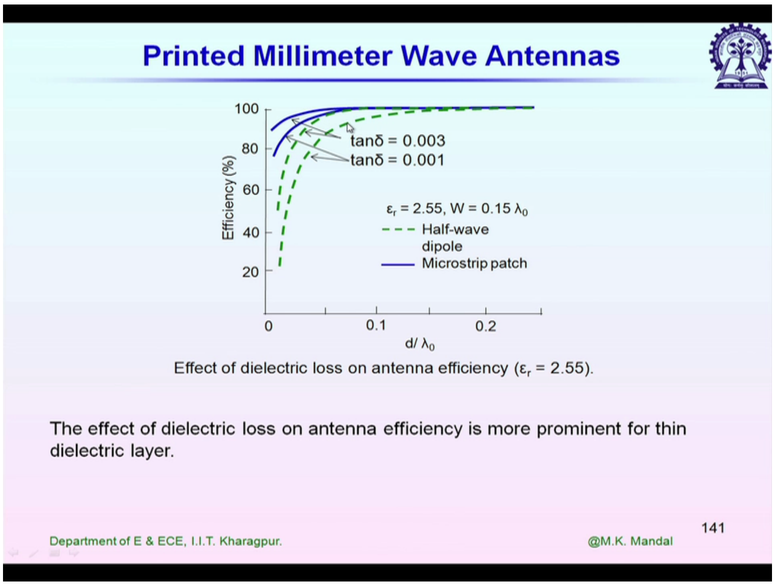

So look at the plot then, when D is small compare lambda not loss increases sharply this loss is due to the dielectric loss and this is because of the increased electric field intensity value but if we increase the thickness of the substrate to some point then the dielectric loss is negligibly small and as we expect higher tan delta value is providing higher loss compare to the smaller one. And the effect is more prominent for half wave dipole. Why?

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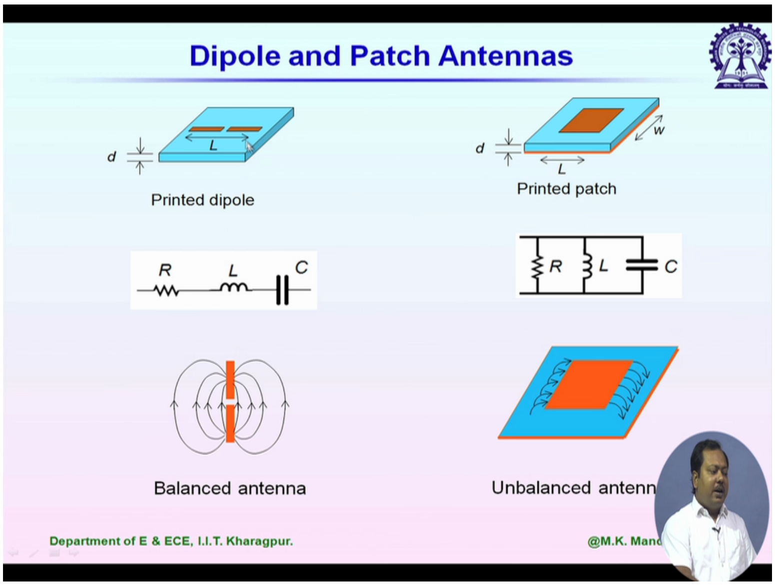

If I go back and look at the structure the half wave dipole its radiating in umm upward direction as well as in bottom slide. And it has to radiate through the substrate so thats why the effect of dielectric loss is more prominent for dipole antenna.

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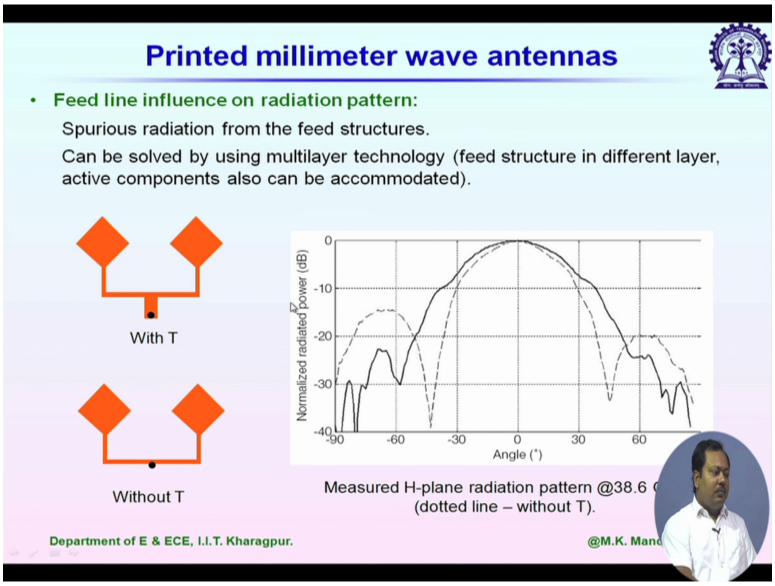

Next let us say we are going to design some arrays at millimetre wave frequency in printed circuit board technology then what are the problem we faced at millimetre wave frequencies? When we design some array we have to feed the antennas so we have to design some feed networks for that and for the feed network we use different guiding structure in PCB form most popular guiding structure as the feed network is micro strip line.

Now already we know that micro strip line is lossy at higher air frequency so obviously loss will increase from the feed network at millimetre wave frequency and not only that we may face also (())(12:53) radiation from the feed network and that will be great the radiation characteristics of any antenna. Degradation in terms of it can be cross pole level and increased side lobe level.

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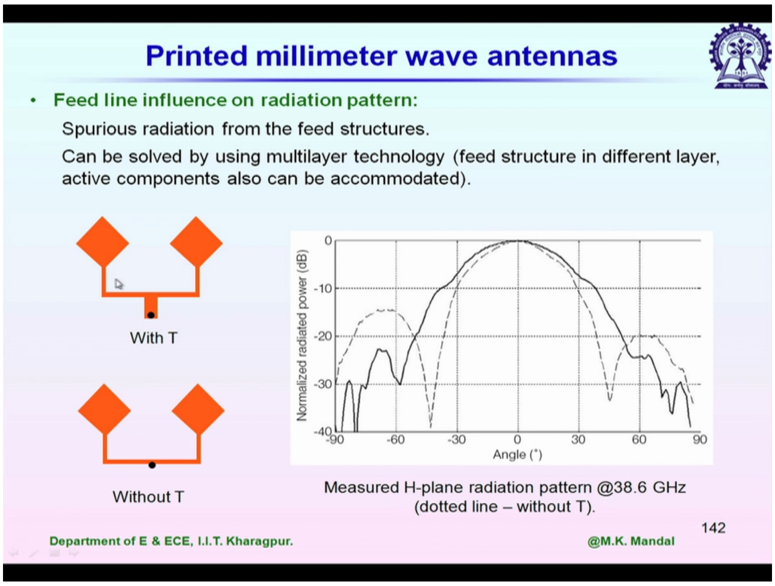

So let us see the first example (())(13:110) we have umm an array of 2 resonating patch antennas now we are feeding it in the first example it is using 1 key network this solid black dot it represent the tip of a coaxial prob. So its being fade from below the substrate by using one coaxial cable. And in the second example we are calling it without D. We are not using this extension.

Directly connecting the tip of coaxial cable to this point and then we are plotting the normalize radiated power versus angle for this particular example. It was design at 38.6 gigahertz. You see the radiation characteristics its significannotly different so this dotted line this is without T and the solid line with T. So being with it changes with T and this is due to the spurious radiation from just this extension its very little even then we cannot the neglect the effect of this in radiation radar.

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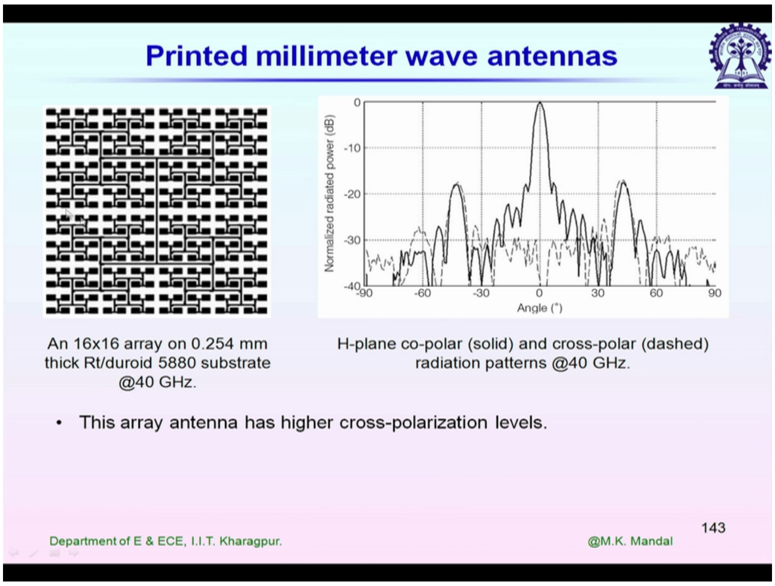

Let us take some more example here one big array antenna you can see and this line straight line they are nothing but feeding micro strip line we are using one corporate feed network here. Its a 16 by 16 array antenna and design on point 254 millimetre thick RT duroid 5880 substrate so RT duroid 5880 substrate umm at 40 gigahertz. Its RT duroid has a loss tangent of point 0009 at 40 gigahertz.

Now loo at the radiation pattern, solid line represents the co pole pattern and dash line represents the cross pole pattern. What we can see? It is having high cross pole level left hand side and right hand side and this is due to this (())(15:41) radiation from the feed network. So this feed network is also radiating some power and for that we don't have any good control over the electric field.

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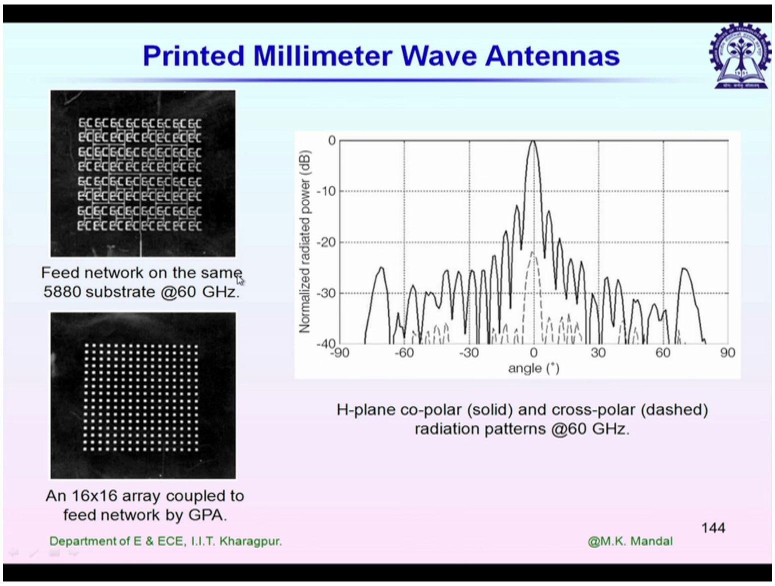

So how we can avoid this then? We have to separate somehow the feed network and the radiating patches. How people do? They will place the radiating patches in 1 layer and design the feed network in another layer then we have to couple power from the feed network to these radiating patches and for that we can use ground plane aperture the GPA. So some slots basically which are (())(16:32) in the common ground plane of the antenna and feed line structure.

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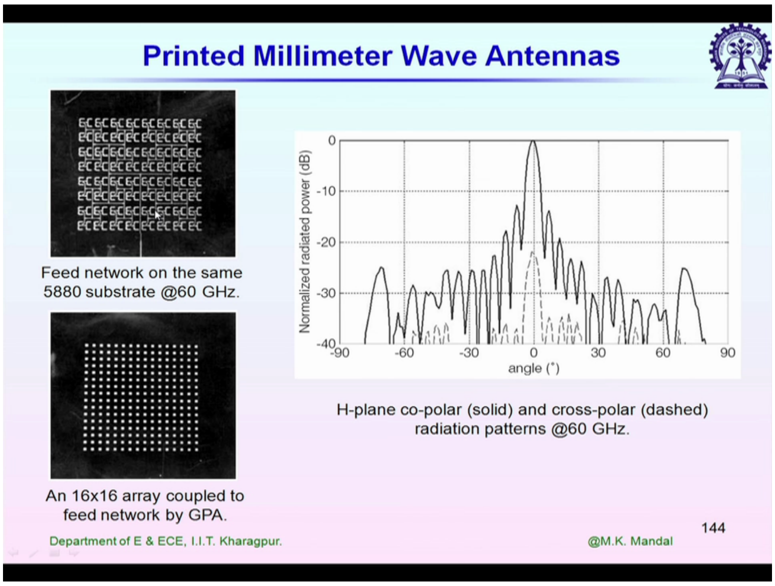

Let us see there is one example, this antenna array is designed for 60 gigahertz application you can see the feed network and this elements are the radiating patches these are the square radiating patches16 by 16 array on top plane and in the common ground plane we have slots that is not shown here. So power is couple from the feed network to these patches through these slots and now look at the radiation pattern.

Co pole and cross pole level so cross pole level shown by this dash lines they are now much below in comparison to the previous figure so we can improve the cross pole level significannotly by using separate substrate for the feed network and the radiating patches.

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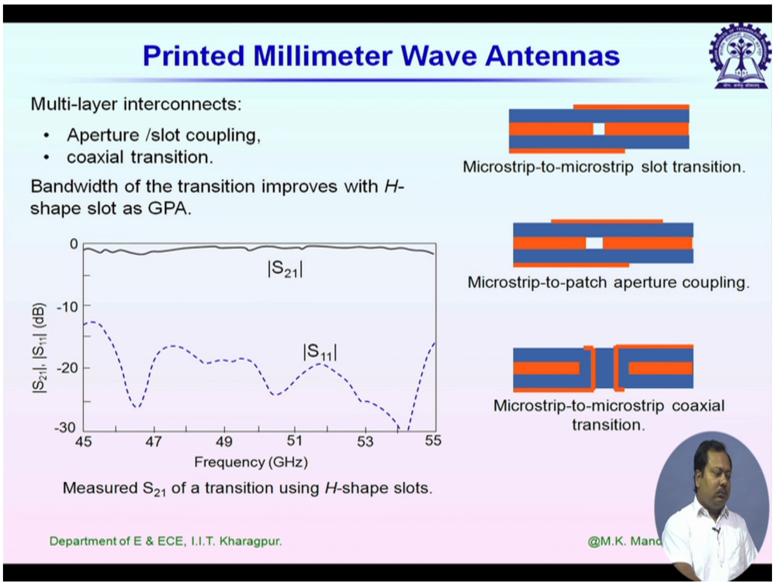

Now when we design at millimetre wave frequency we have seen that we have to use a thinner substrate people are using typically 10 mil or 5 mil substrate for 60 gigahertz application since the substrate thickness is very small its fragile and mechanically not rigid structure.

We have to use some supporting structure usually people use brass plate with that then how to design this tangition through bras brass plate? From feed network to patch antenna that becomes another challenge. Let me show you some examples here.

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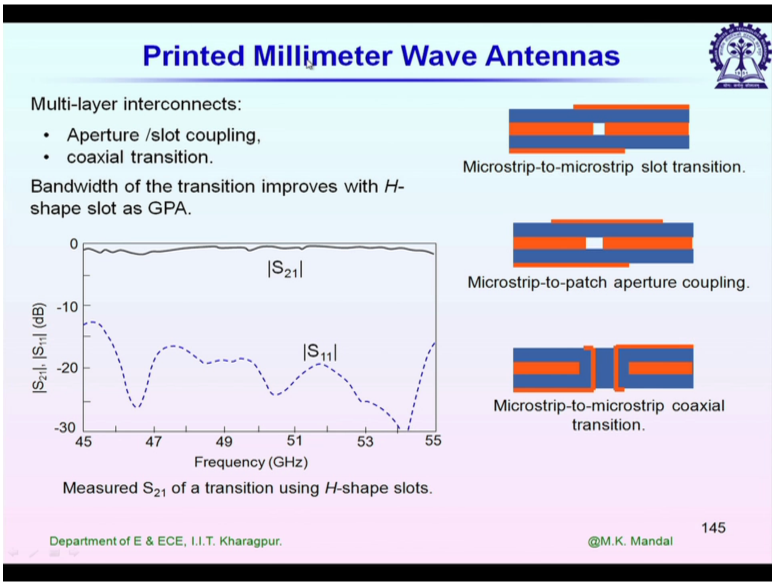

How to couple power from the feed network to antenna. We are showing the cross sectional view we have 2 substrate the bottom blue line it showing the dielectric slab 1 and this top one it is dielectric slab 2. You can see the feed network micro strip line it is design on the bottom most plane and top most plane it can be the radiating patch in between we have thick brass plate and now we can design that GPA or ground plan aperture to couple power for micro strip line to patch its showing the cross sectional view.

Now bandwidth of this transition it depends on the slot with and the slot length is approximately lambda g by 2 at the design frequency. We can improve the bandwidth of this transition by using different shapes of the slot 1 such technique is instead of using 1 simple line you use H shape slot.

You will be having higher bandwidth in this third example the bottom line umm the bottom most micro strip line it is being directly connected to top most patch or top most let us say we have one more micro strip line by using co axial umm by using via metal pin. So if you look at this structure this mid layer somewhat its looking like one co axial cable so the brass plate we have to drill a hole inside the brass plate to insert this metal pin.

So this metal pin its look like the inner conductor of co axial cable and the hole which is (()) (20:36) in the brass plate its look like one outer conductor of the co axial cable and we can model it by a co axial cable. Here we are showing umm the simulation result of a transition using ground plane aperture but the aperture shape is H shaped. You can see it is quiet good transition and the operating band is 45 to 55 gigahertz S11 is almost below minus 15 DB. So for array design design of transition is another important factor.

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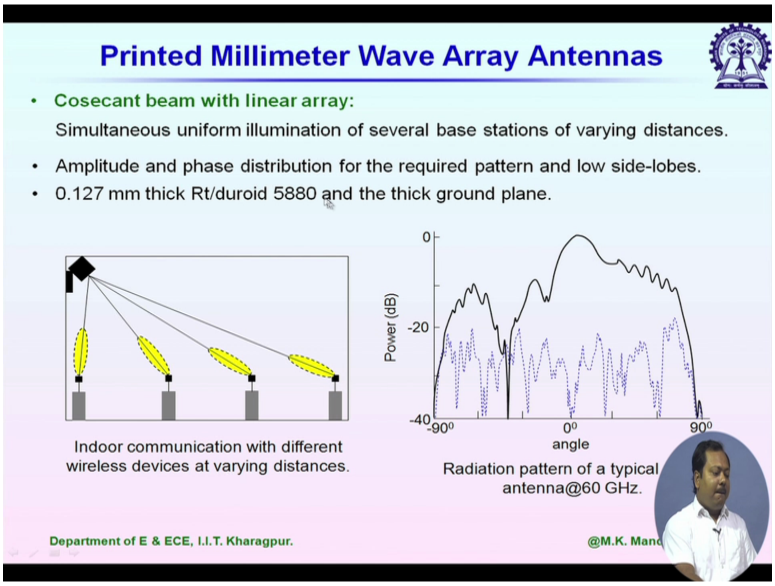

Now arrays we design for different types of applications for some application we want very narrow beam let us say for line of sight communication in that case we don't want any radiation in other direction other than the desired direction so the beam which should be as narrow as possible. Side of levels should be as down as possible and gain should be aa high as possible in the desired direction.

Now consider another application let us say 1 transmitter millimetre wave transmitter it is placed at 1 corner of the room and we want to communicate with different people sitting inside the room. Now we know (())(22:21) transmission law so the man who is very close to the transmitter he will get maximum power.

And the man carrying device which is far away from the antenna he will get much lower power level if I consider uniform radiation pattern so we can denote the radiation pattern for such application so that the gain will be higher for that longer length and gain is smaller for the shorter length and the resultant pattern it is usually we call the co second pattern this is 1 example of such application.

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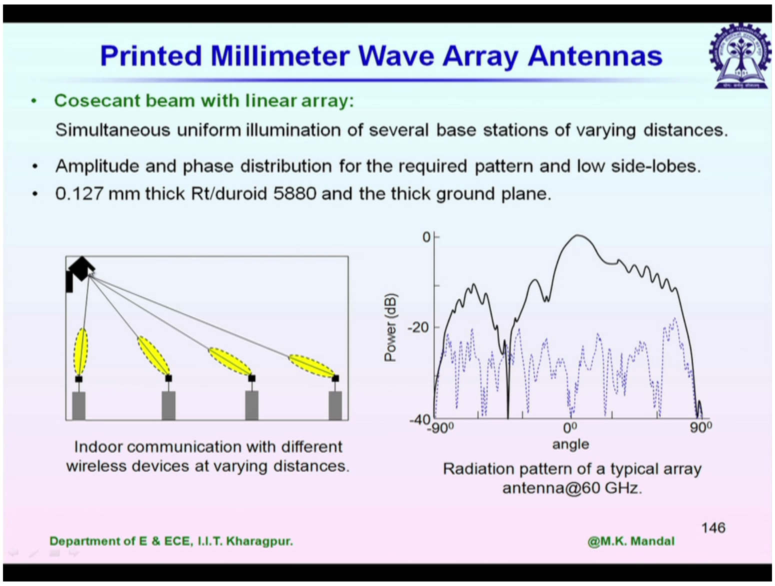

You can see millimetre wave transmitter it can be even for base station application it wants to communicate with umm different devices and varying length varying distances and for this type of application instead of a very narrow beam with we want a co second beams.

And we can actually tailor this radiation pattern by changing the power level fade to the array antenna so that is a subject of array antenna and we are not going to that we are just discussing what are the challenges we face at millimetre wave frequency.

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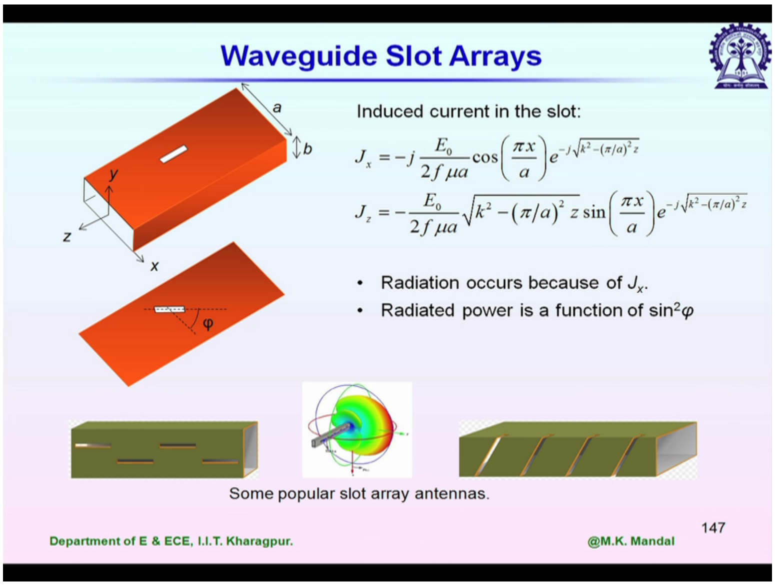

Another example this is slot antenna in rectangular wave guide already we know that rectangular wave guide it provides minimum loss and it also have highest power handling capability. So for many defence application and space applications people till now using rectangular wave guide and we don't have any other choice, other alternative at millimetre wave frequency even in near future.

Then how to design antennas in rectangular wave guide technologies there are 2 different categories 1 is by using resonant antennas and the second category travelling wave antennas we will discuss later so for resonant antennas we have to use some sort of radiator or open structure which will be resonating at the radiating frequencies.

The most popular structure is slot (()(24:56) on the broad side of a rectangular wave guide. Now let us say we are edging on the broad side of a rectangular wave guide.

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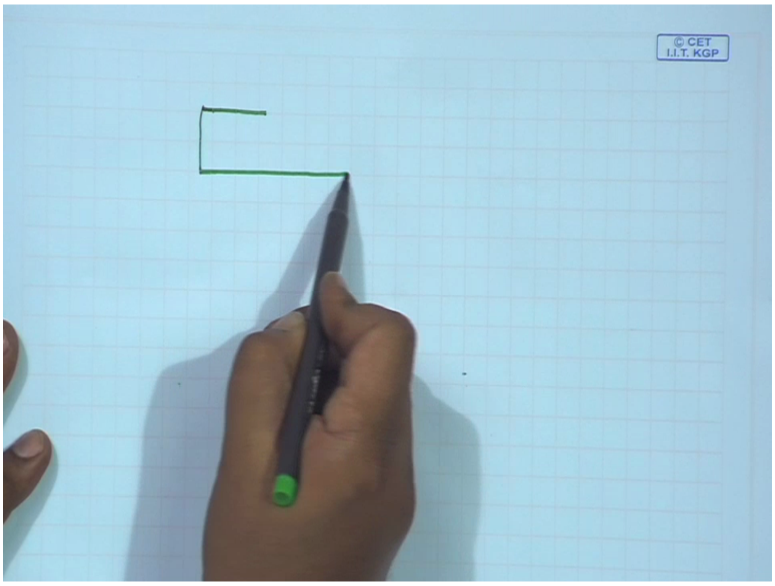

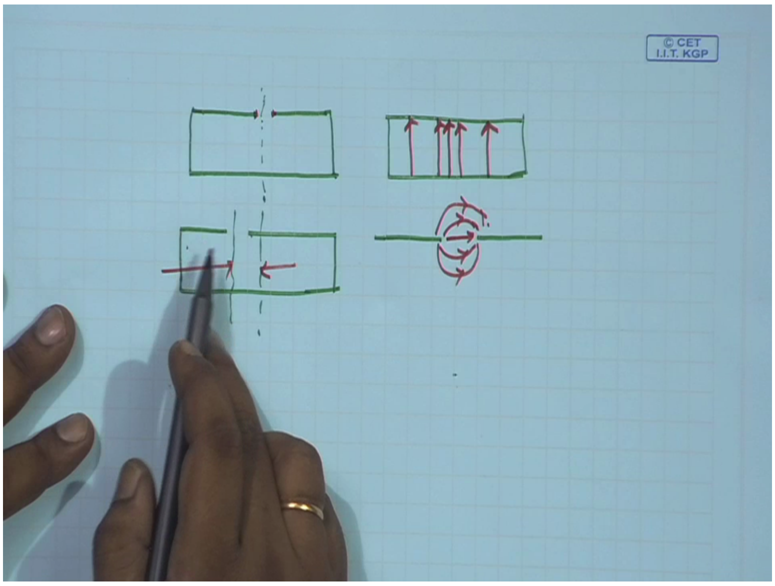

If I plot if I draw the rectangular wave guide if I plot if I draw the cross section of 1 rectangular wave guide so where to place this slot? If I place this slot symmetrically about the central axis then it will not excite this slot the TE 10 mode. If it propagates through the wave guide it will not excite this slot. Why? Let us see the field configuration of TE 10 mode we have electric field maximum on the central plane.

And it varies sinosidally on the side planes side walls its zero. Now if I draw a slot here may be on an infinite ground plane I am showing the cross sectional view then for slot we know the electric field configuration in odd mode excitation its like this and its radiates from this odd mode perpendicular field component. So if I place a slot on the mid plane you see the potential difference between this 2 point is 0 simply.

So this field cannot excite the slot in other word we can say the impedance seen by the slot is infinite. If I H a slot along the central line of any wave guide on the broad walls even though we are disturbing the current distribution it will not radiate thats why in micro wave lab when we use micro wave bench you might have noticed that we use long slot cut just on the central axis through which we monitor the power inside the rectangular wave guide by using a (()) (27:04).

So what we have to do then we have to use some offset to excite this slot. So that means slot it is not on central axis but with some offset. If I change this offset distance then accordingly the excitation of slot will change if I place slot more near to side walls we will have more radiation from the slot but at the same time it will change the loading of the wave guide finally we have to feed the power to rectangular wave guide over which we are hatching the slots.

Now when we place the slot on the central axis there is no effect on the rectangular wave guiding mode or you can say in other way that for the feeding port to the rectangular wave guide there is no change due to the slot. But when we use some sort of offset then the input impedance changes and this change is maximum when we place the slot near to side wall.

So then the final placement of slot this will be a compromise and because we have 2 opposite behaviour when we place this slot near side wall we will see maximum input impedance miss match. But maximum radiation from the slot so let us go back.

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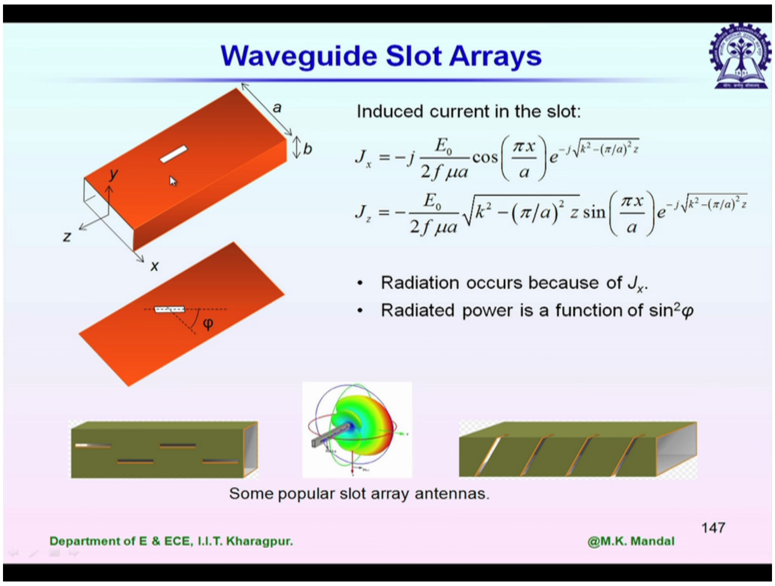

This is one example of wave guide slot antenna you can see this slot edged on the broad side of a wave guide now if I look at the field component inside slot we may have we will be having JX component and JZ component of current and JZ this is negligibly small and the radiation it mainly comes from the perpendicular component or JX component. Which is maximum on the central line of a slot, we can use some tilt also as shown in this figure.

In that case radiation it becomes a function of phi. And approximately it can be shown radiated power it is proportional to sin square phi. When it is perpendicular very little power is radiated by this slot almost 0. Now for the array antenna we have to repeat this slot structure. In this figure it shown umm such array antenna 1 interesting thing you can see. When we repeat this element it is in the opposite side of the central line. Now the question is why? Again let us go back to basic structure.

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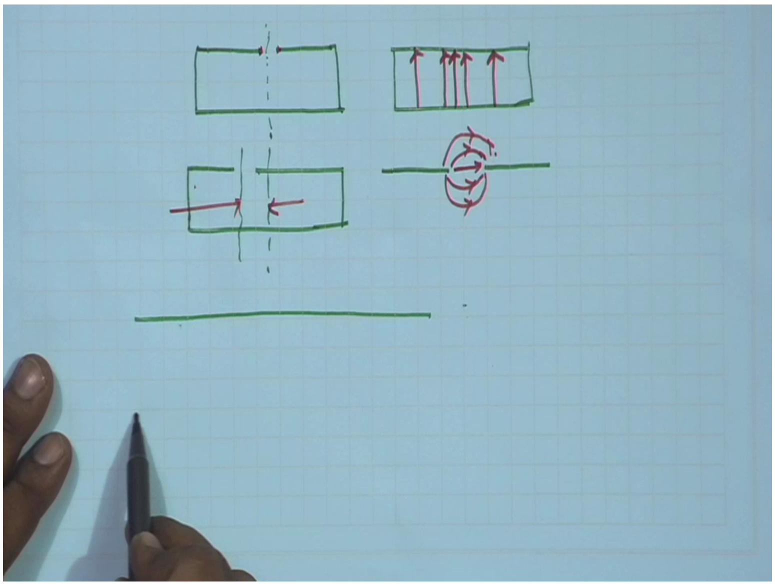

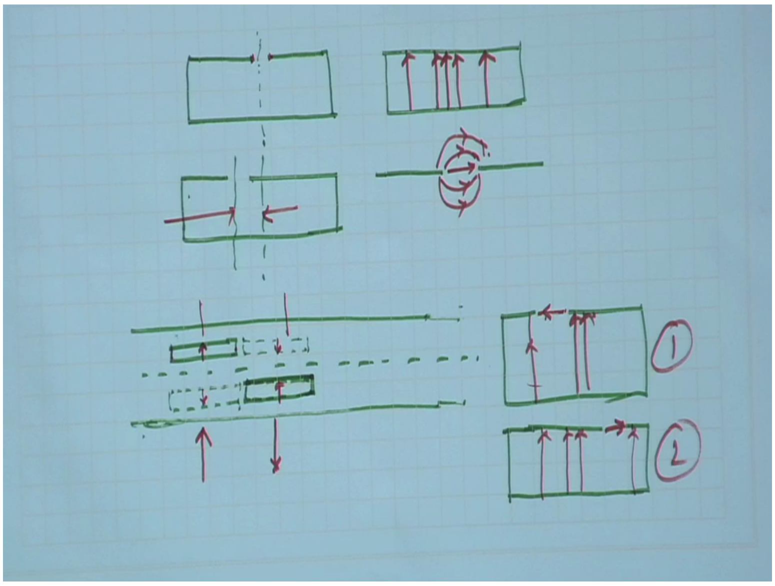

Now we are considering top view of a rectangular wave guide so that you can see 1 broad side let us say we are having 1 resonating slot here which is on top of the central axis. Now if I plot the electric field variation inside this slot obviously it will be having maximum here and minimum on the edges of the slot. Now inside if I plot the electric field considering the cross sectional view.

We have TE 10 mode inside so on the central plane we have maximum and on the side walls we have minimum so looking at the electric field inside the wave guide we can say for this slot electric field will be from right to left as shown here. If I edged another slot at the same position but opposite side of the central line then what will happen?

We have electric field in the same direction but in this case you see maxima on left hand side then the electric field it will be from left to right inside the slot. So if I slot if I edged one more slot here inside this slot electric field will be in opposite direction now if I look from broad side they cancel each other effects so we have broad side null. But this is the desired direction so we cannot a place a slot like that its called slot droplet.

Similar problem we will be facing if I place another slot just after this in the same direction now along the propagation direction here if the electric field is upward after lambda g by 2 it will be downward. So in this figure figure 1 and figure 2 the direction of electric field will change so this slot electric field it will change its direction so again we see if I place this slot here with a lambda g by 2 separations between this 2 electric field will be in opposite direction.

So we cannot again place this slot here. So only solution is then we have to plot we have to edge this slot here so that electric field in the same direction. Sorry, so thats how this array is designed the right hand side figure it shows the slot edged on the narrow wall its not actually an example of umm resonant antenna.

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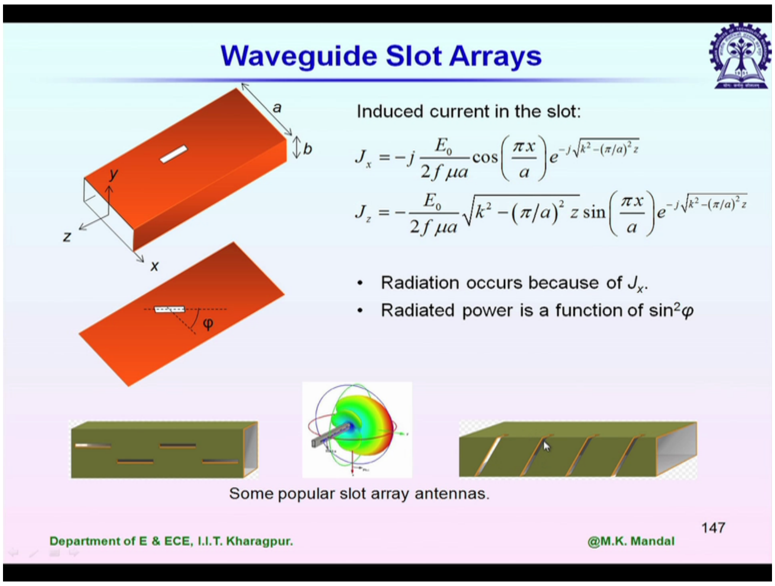

Its an example of leaky wave antenna we will discuss it later.

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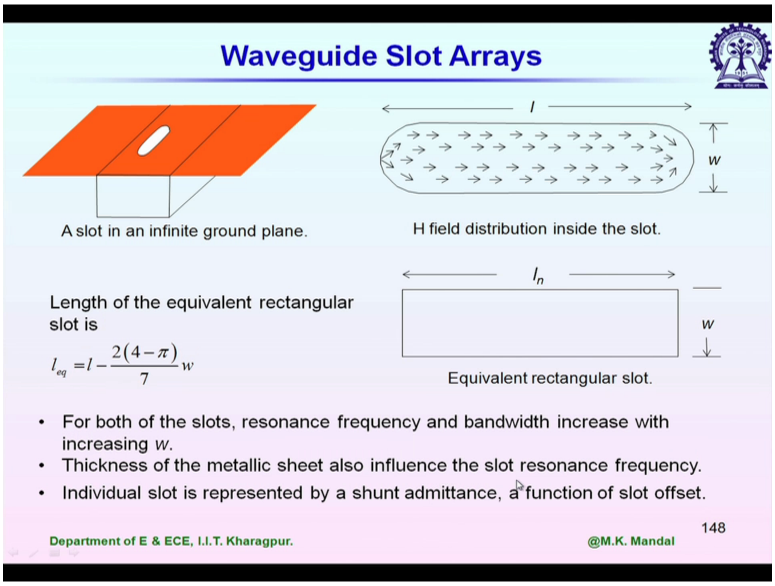

Now at millimetre wave frequencies fabrication of slot is a problem. why? its dimension becomes very small then how to drill slot in brass plate? Usually its done by laser drilling and we can control the cross sectional of the laser beam. So when we go fabri go for fabrication the problem we face with laser drilling is that we cannot achieve, we can obtain this sharp corner of this you can see the rectangular shape of the slot.

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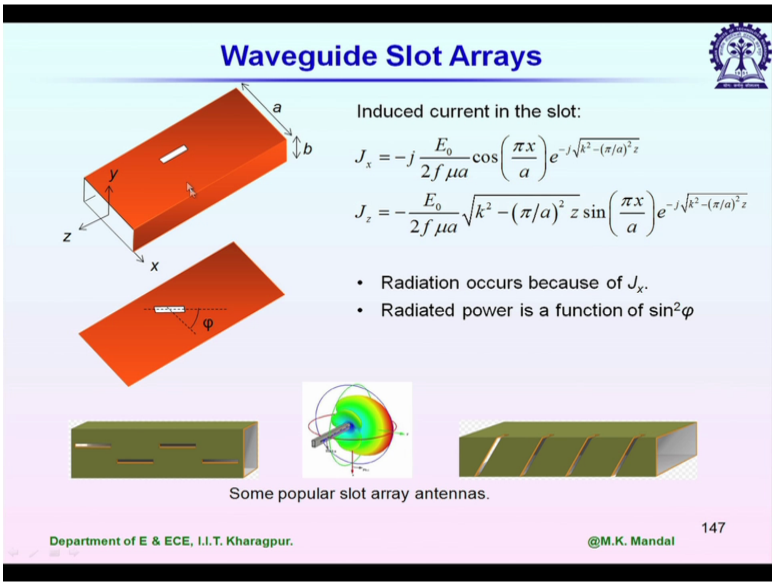

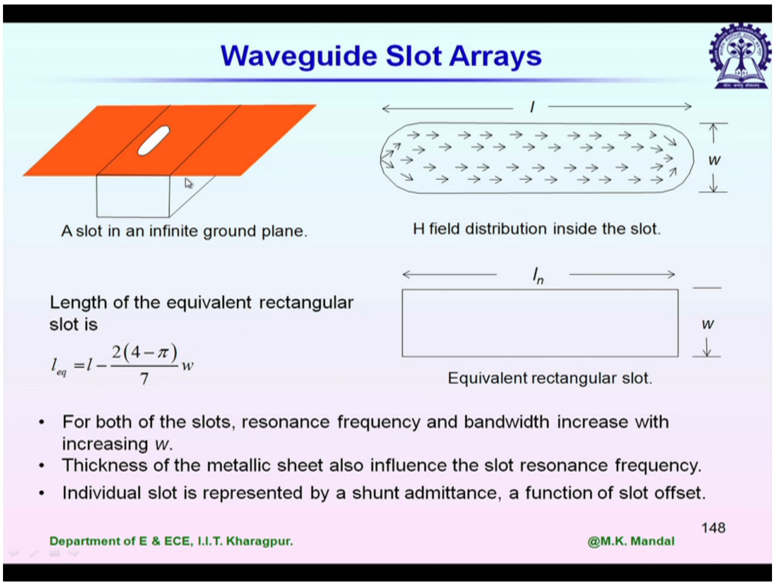

So we have a sharp corner here. We cannot fabricate that structure so in practice if I fabricate it at millimetre wave frequency of 90 gigahertz application or even more than that. Then we will be having rounded structure and for that if you plot the umm current density it will have different distribution.

But we have a thumb rule for that L equivalent it can be represented by an equivalent rectangular slot whose length can be given by L minus 2 into 4 minus pi by 7 into W. Where L is the length of umm this first slot and W is the width of the slot. Once we have this equivalent length then we can use all the formula derived for rectangular slot structure.

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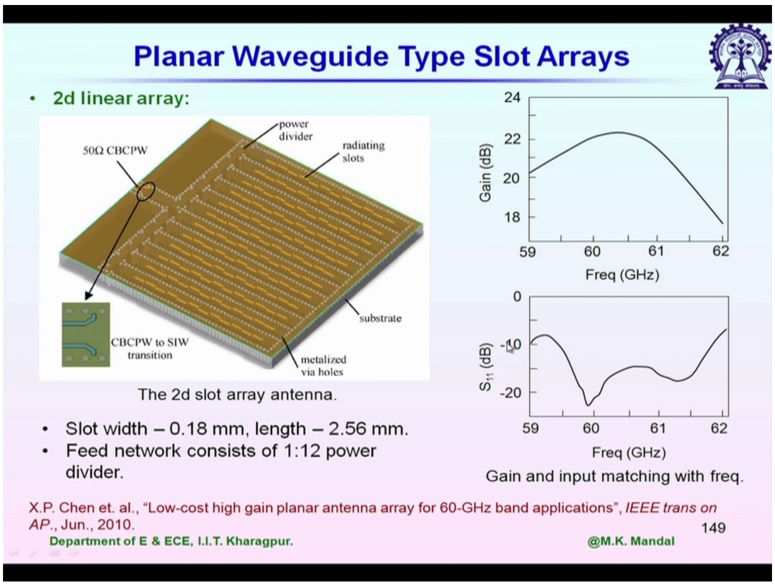

Here is one example of 2 dimensional slot arrays. If we want 1 beam then 1 dimensional slot array is sufficient but if we want pencil like beam. Beam with this narrower in both theta and phi in that case we have to use 2 dimensional array antennas. This is 1 example of 2 dimensional array antennas and in addition to simple feeding we have to also use some sort of distribution.

So the power whatever being couple to this array it will be different for different umm rectangular wave guide structure. So that we can minimize the side lobe level there are some standard technique one such is called tailor distribution and that is being done by using different gaps here feed lines. So this this the plot of input impedance is 11 in DB its fro 60 gigahertz application and this is the plot of gain so for this particular array slot with umm is point 18 millimetre length 2.56 millimetre and gain you can see almost 22 DB.

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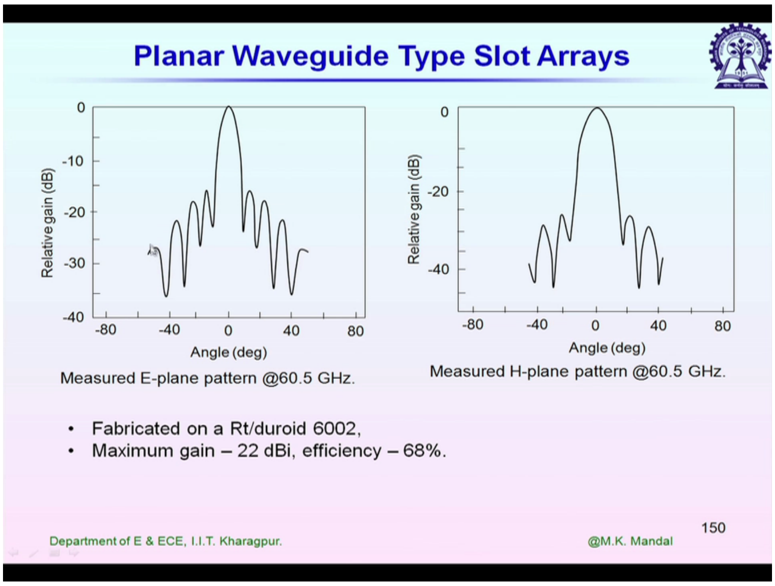

This is the measured E plane and H plane radiation pattern both of them are showing pencil like beam and typical radiation efficiency obtained is 68 percent it is quiet high if I compare with rectangular patch antennas. This is the advantage of umm rectangular wave guiding structure. So next we will take a break then we will start on chip antennas.