Millimeter Wave Technology.
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Lecture-20.
Antennas at MM-Wave Frequencies (Contd.)

Okay so today we will be discussing on antennas. So what happened when we consider antenna design at millimetre wave frequency? What are the challenges we face and then how to solve this challenges?

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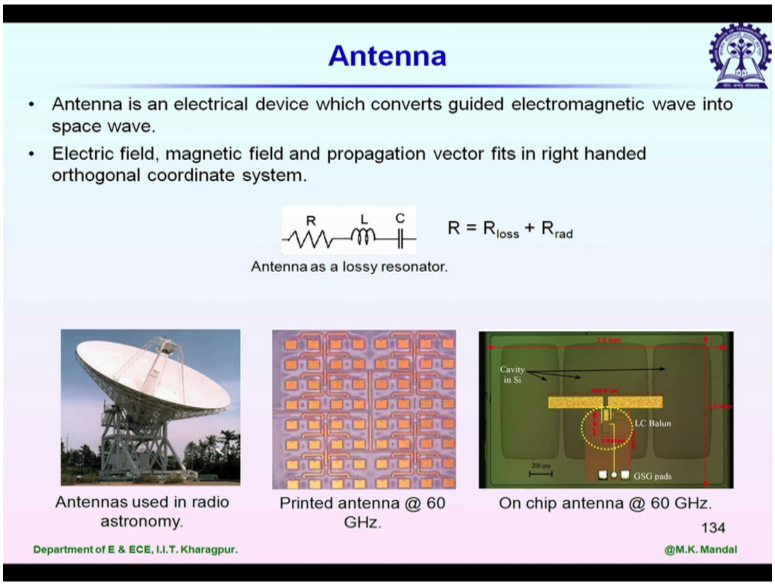

So why we use antenna? So antenna basically we can call it a transducer which will transform the guided wave into space wave. Now in free space so the properties of electromagnetic wave we know that the electric field magnetic field and the direction of propagation they form a right hundred orthogonal coordinate system. And electric field magnetic field they are also in same phase. So for antenna we have to generate then this 2 electric field and magnetic field component which will be in same phase.

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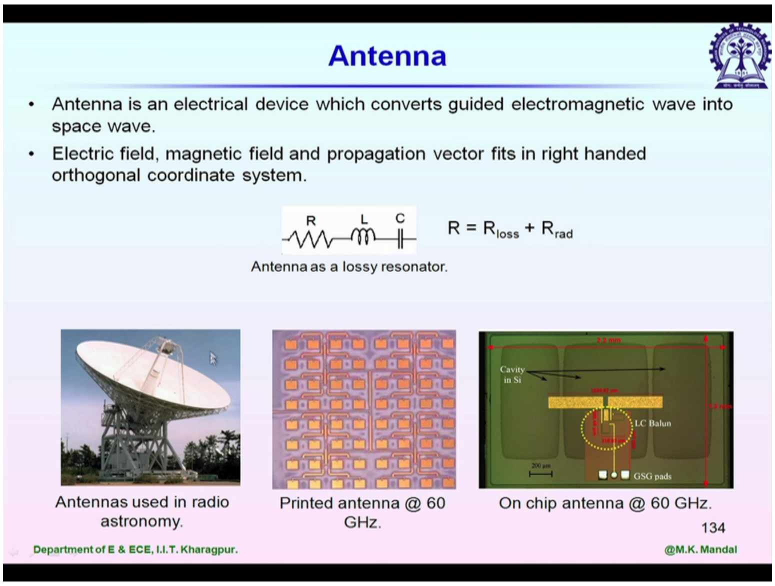

So if I look at the different antennas already available or are being used at millimetre wave frequencies first category it shows a parabolic reflector antenna so where we use 1 feeding antenna we call it feeder. It can be horn antenna or anything else and then the electromagnetic wave is reflected by this parabolic reflector so we use this for astronomy application where we need extremely high gain and very narrow beam width of the antenna.

This is in the second example it showing antennas antenna array it is design on laminates printed in printed circuit board technology. So you can identify 1 single rectangular patch it is a type of a resonating antenna and in this particular example we have 1, 2, 3, 4 so 8 by 8 element array antennas design for 60 gigahertz applications and on the right most we have 1 dipole antenna and it is design on chip.

So at 60 gigahertz already the wavelength is 5 millimetre and when we are designing on PCB substrate approximately we consider wave length is lambda nought by root epsilon R. So antenna dimension it becomes some times 1 millimetre or even less than that. There is a possibility to integrate an antenna on chip itself so we will see some example sometimes even the packaging used for integrated circuit that can be also used to incorporate the antenna structure.

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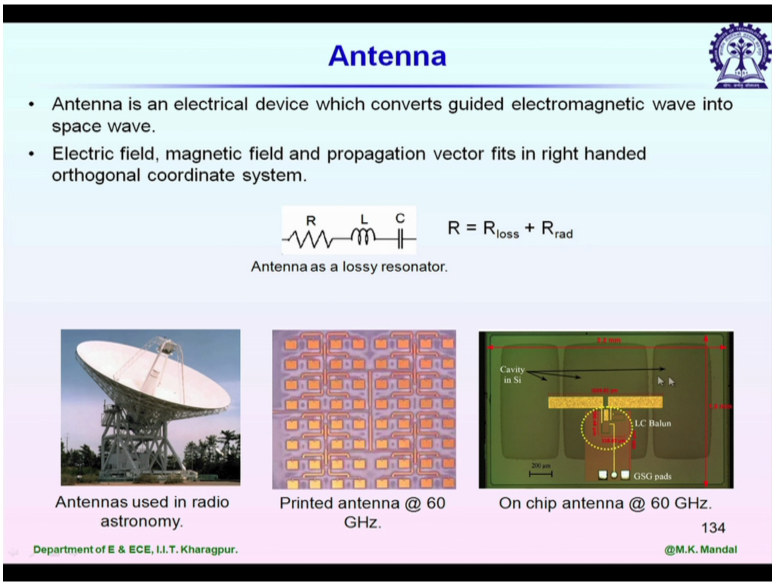

So when we do so we of course face some problem you can identify there are some cavities. So this particular antenna is designed in silicon substrate and silicon it actually we face problem of surface wave in silicon substrate to avoid that the people use some AR cavity which is just below this antenna which will improve the gain of the antenna. So for a resonating antenna then it can be we can represent it by a series resonator or by a shunt resonator.

In that resonator we will be having 1 L component 1 C component and in addition to that we have 1 resistive component. So this resistance it represents loss inside the antenna structure and the radiation so the radiation coming from antenna we are representing by an equivalent resistor we call it R rad or the radiation resistance of the antenna. so as if its a loss for the structure and its coming out in the form of radiation. So R that is equal to then R loss plus R rad.

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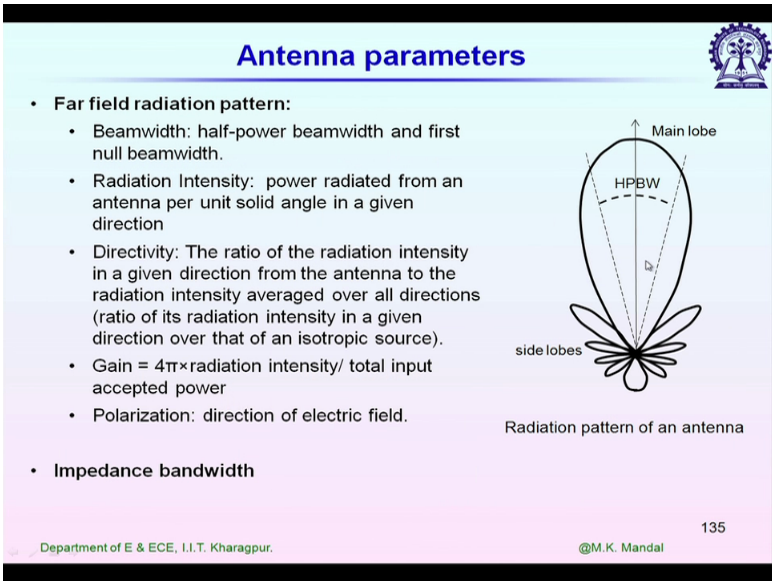

Now for a general antenna structure we have to deal with many parameters. So how we define the characteristics of an antenna? There are several parameters we should know the parameters first. So for example the first important parameter is far field radiation pattern. So what we do? We just measure the electric field or power which is square of electric field its variation with respect to angle and if plot it in R theta pi coordinate then the corresponding plot we call the radiation pattern.

So here you can see a picture it shows the radiation pattern of an antenna. so the desired direction of radiation is shown by this arrow and we call this is the main lobe of the antenna. In addition to main lobe we can see we have some radiation in other direction also. So these are called the side lobes of the antenna and we have also some radiation just in the back side compare to the desired direction we call it the back loop of the antenna.

And now 1 more important quantity that is the beam width of the antenna. so we can define beam width in 2 ways half power beam width and the first null beam width. So how we define half power bandwidth let us say the gain of the antenna in the dire in the desired direction is given by X then we come down by 3 DB and then the corresponding angular separation it is known as the half power beam width of the antenna.

It is an important parameter for antenna for scanning purpose because it defines the resolution of any antenna or 2 object when they are separated and we want to see them as a separated 2 different objects so it the separation it should be more than the half power beamwidth of the antenna. We can define it in another way that first null beamwidth.

So if I consider this particular direction we don't have any radiation in this direction we call this is this antenna has a radiation null in this direction so first null left hand side to first null on right hand side the angular separation we call the first null beam width of the antenna and usually for most of the antennas half power beam width is half of that of the first null beam width of the antenna. Next another important parameter is radiation intensity.

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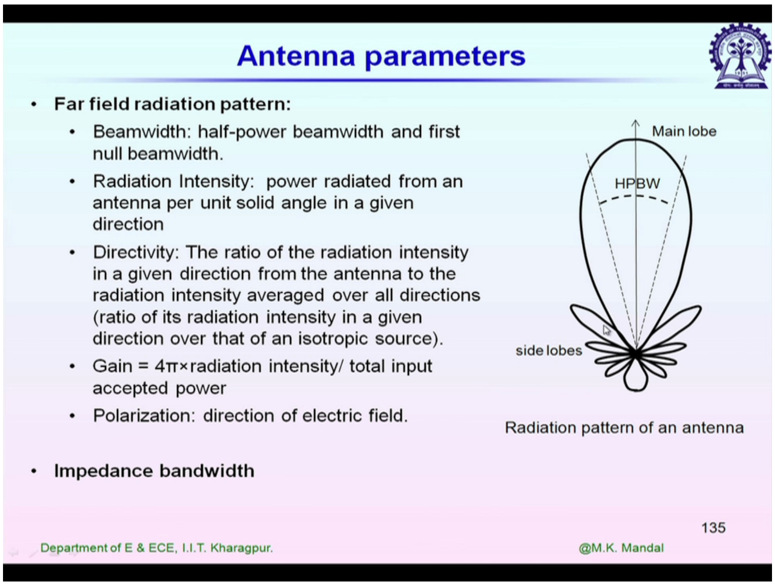

So how we define it power radiated from an antenna per unit solid angle in a given direction so in my desired direction obviously radiation intensity will be higher other direction radiation intensity should be as small as possible so the third parameter is directivity. The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions called the directivity of the antenna.

We can also define it in another way ratio of the radiation intensity in a given direction over that of an isotropic source or isotropic radiator. 1 isotropic radiator if it does not have any loss ideally it radiates power in each and every direction. Next we consider another parameter gain when we define electricity of an antenna we did not consider any loss inside the antenna structure but in practice we have to face this loss.

So if we want to incorporate this loss in directivity definition so we have to use this definition we call gain of the antenna. This is define as 4 pi into radiation intensity divided by the total input accepted power. Now usually gain definition it does not consider the loss due to input reflection.

Whenever we feed any antenna at the feeding port obviously there will be some input reflection loss due to the impedance mismatch between the guiding structure and the antenna input impedance. So if we want to also incorporate these input reflection loss. Because if there is any input reflection loss that power is going back to the source.

And its not being accepted by the antenna sometime we define 1 more parameter realise can or absolute can of the antenna and in that case we also incorporate what is the input reflection loss in calculation? Next another important parameter is polarization so basically by polarization we means what is the direction of electric field it can be in a straight line in that case we call it linear polarization it can be circular polarization.

Electric polarization and till now we are discussing about the radiation characteristics of the antenna from input impedance point of view there is 1 more definition of antenna band width we call it impedance band width of the antenna so by impedance band width then we can understand how much power antenna will be accepted over which range of frequency. Now impedance band width it can be define in many ways.

So for impedance bandwidth what we do we plot S11 or the input reflection coefficient of the antenna versus frequency. So let us take 1 example.

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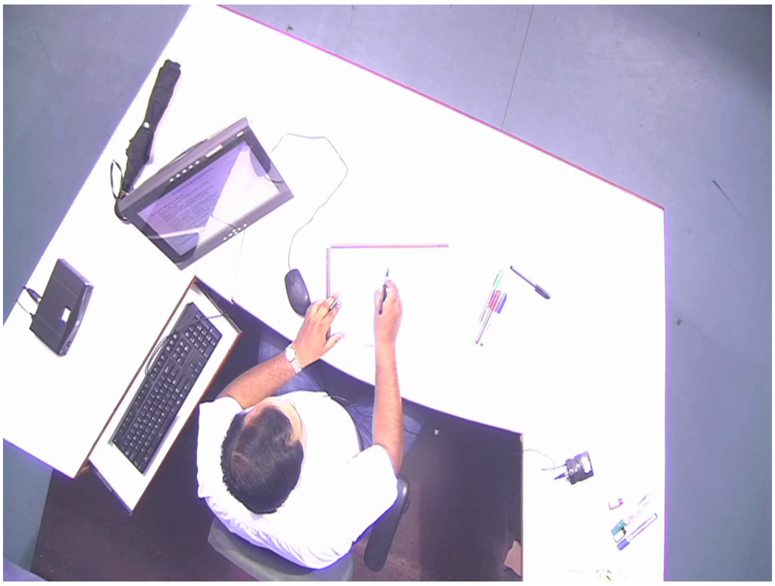

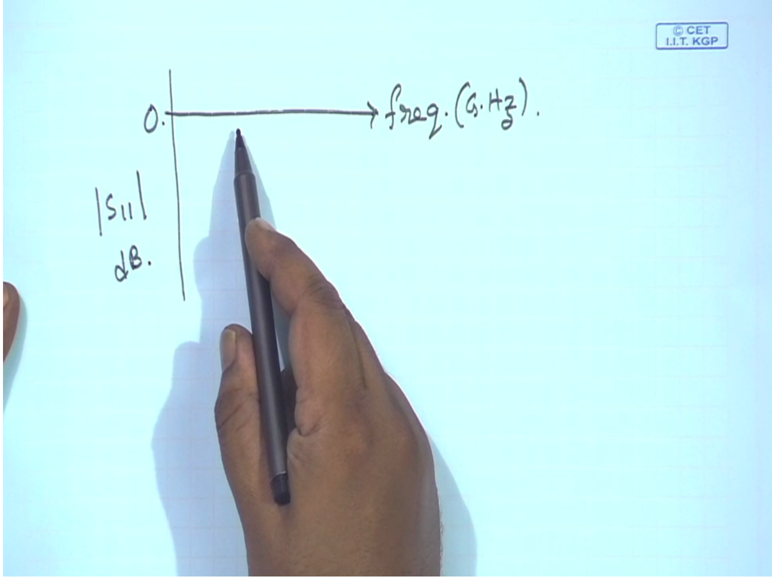

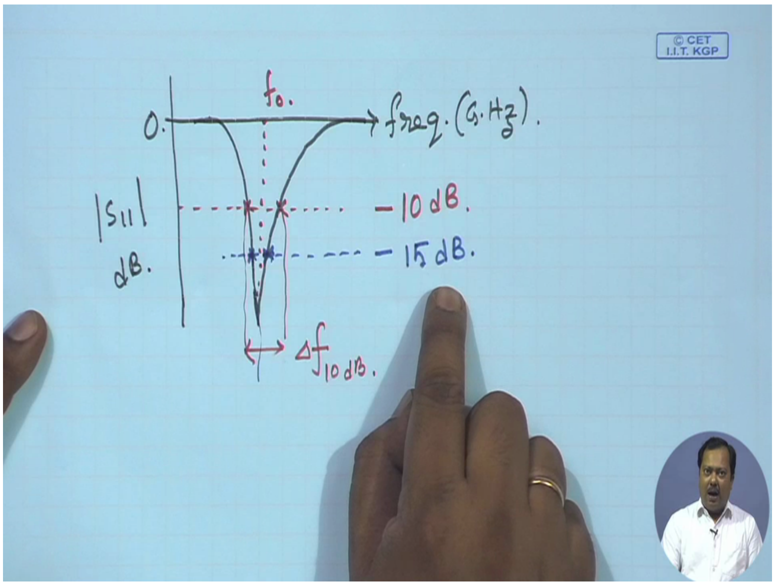

If I plot frequency let us say in gigahertz versus S11 which is in decibel scale if S11 in DB is 0 DB that means whatever power I am feeding to antenna it is being reflected back 100 percent power is being reflected back to source. Now if the antenna accepts power then we have some negative value of S11 so let us say we have measured the S11 or we have simulated the antenna structure from that we have a knowledge on S11 and when we plot it.

It looks like this so this is we call the mid band frequency of the antenna where it accepts maximum power and now we can define the impedance band width in many ways. In some definition mostly for handheld devices and small antennas we consider 10 DB matching point so we will see where this values the value of S11 is minus 10 Db then the corresponding band width delta F we call it sometimes 10 DB band width so over this band width.

If I calculate what is the reflection coefficient at this point? And from that what is the power being accepted by the antenna? so approximately 90 percent power is being accepted by the antenna if I consider S11 is minus 10 DB but in some application a more stringent definition is used in that case they don't want even this 10 percent loss so we further decrease it to another level let us say minus 15 DB we call it minus 15 DB band width of the antenna.

And if I convert this minus 15 DB to input power loss due to reflection it comes approximately 5 percent so over this band then we can say that at least 95 percent power is being accepted by the antenna port. So with this definition now let us say what are the problem we faced at millimetre wave frequencies?

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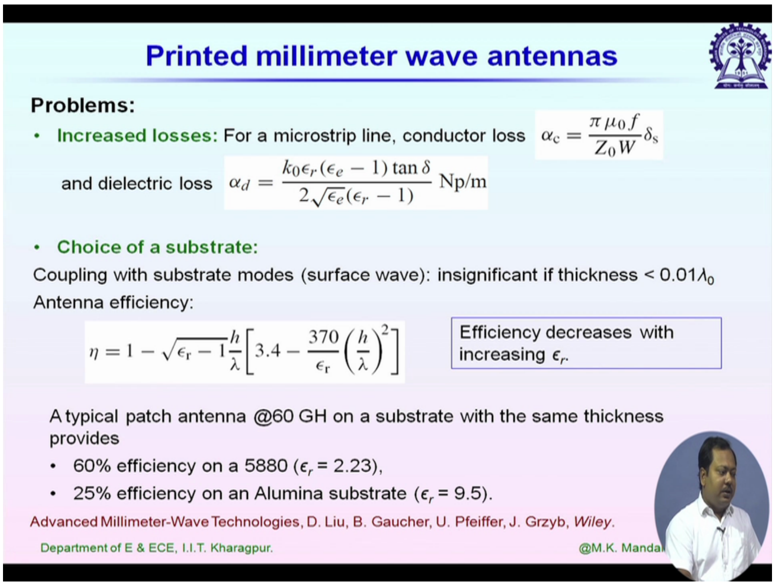

At millimetre wave frequencies if we want to design any antenna on printed circuit board or laminates then the losses what are the sources of losses already we know and this loss increases with frequency. So do you remember the 3 sources of losses? The first 1 is dielectric loss second 1 conductor loss and third 1 loss due to surface wave generation.

And this third components surface wave loss it also increases significantly at millimetre wave frequencies. So all of this power lost to this 3 reason due to this 3 reasons they are not being radiated by antenna so its a total loss or wastage of my power so we have to avoid this loss somehow and we will see what are the solution? And what are the methods people used to minimise this loss?

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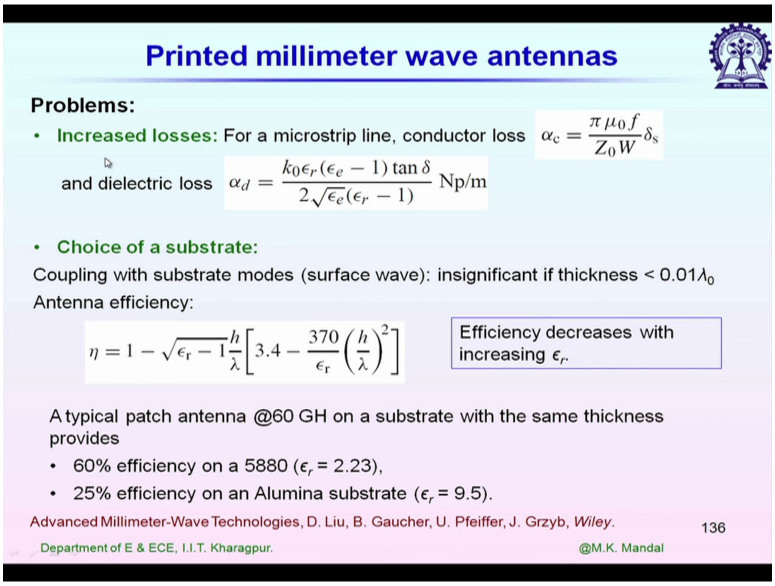

So first 1 already we know at millimetre wave frequencies for example for a micro strip line the conductor loss is given by this which we already learnt at it increases with frequency dielectric loss it is also a function of frequency it also increases at millimetre wave frequency. Next important point comes choice of a substrate. What should be the dielectric constant of the substrate? What should be the tan delta of the substrate?

What should be the thickness of the substrate? So coupling with substrate modes or in other word we also called surface wave it is insignificant only if the thickness is less than point 01 lambda nought otherwise we have to consider the effect of the surface wave mode. Now if I consider a frequency 60 gigahertz lambda already 5 millimetres so point 01 lambda nought it too small too thin most of the substrate will be more than this.

And we cant avoid the effect of surface wave generation. Antenna efficiency considering the effect of surface wave it can be given by eta equal to 1 minus square root of epsilon R minus 1 into H by lambda where H represents the thickness of the substrate and you see its a function of H by lambda so thickness with respect to the wave length or operating frequency.

And 1 more term 1 more epsilon R term is here now if I plot eta versus epsilon R for a given thickness let us say H is fixed and frequency is also fixed that means lambda is fixed in that case eta it decreases with epsilon R why antenna efficiency decreases with increasing dielectric constant?

Because when we increase the dielectric constant it generates more surface wave because the thickness of that substrate is fixed but in terms of lambda it is effective thickness it is increasing with increasing epsilon R.

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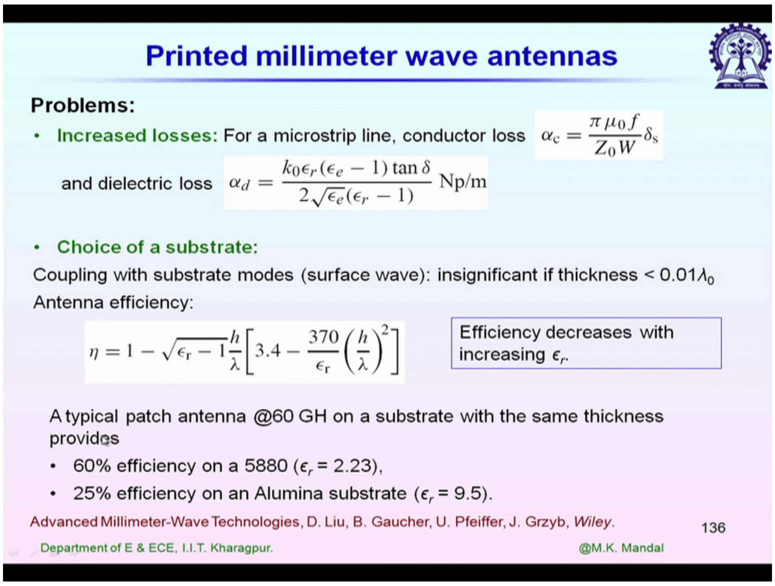

So for 1 typical example a patch antenna designed at 60 gigahertz on a substrate with the same thickness but in 2 different substrate with different epsilon R. When we design it on a 5880 substrate where dielectric constant is approximately 2.2. at 60 gigahertz it antenna efficiency it comes 60 percent and it reduced to 25 percent when the same antenna is designed on alumina substrate which has higher dielectric constant epsilon R equal to 9.5.

So what do we expect then? If we use higher epsilon R antenna efficiency will decrease. So the conclusion is that when we go for millimetre wave design we have to use lower epsilon R as well as smaller thickness.

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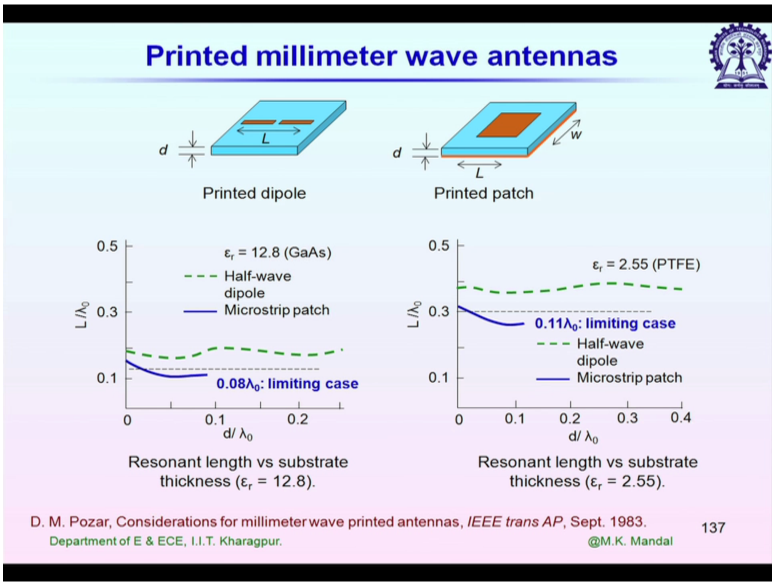

Next I am going to show you some studies which will which can be used as the guide lines when or where we are going for antenna design at millimetre wave frequency? Here what I am going to show some results obtain for 2 different types of antenna the first 1 is printed dipole which is 1 example of balanced antenna and the second 1 is printed patch antenna so both of these antennas they are printed on laminates using printed circuit board technology.

Now in this plot we are going to show the resonant length versus substrate thickness variation. So before this study let me discuss a few points on printed dipole how it radiates and the printed patch how it radiates and what are their basic characteristics because both of them are resonating antennas and the fundamental resonance frequency their length will be lambda g by 2.

But they represents 2 different groups dipole antenna is an example of balanced antenna and printed patch antenna it is an example of unbalanced antenna.

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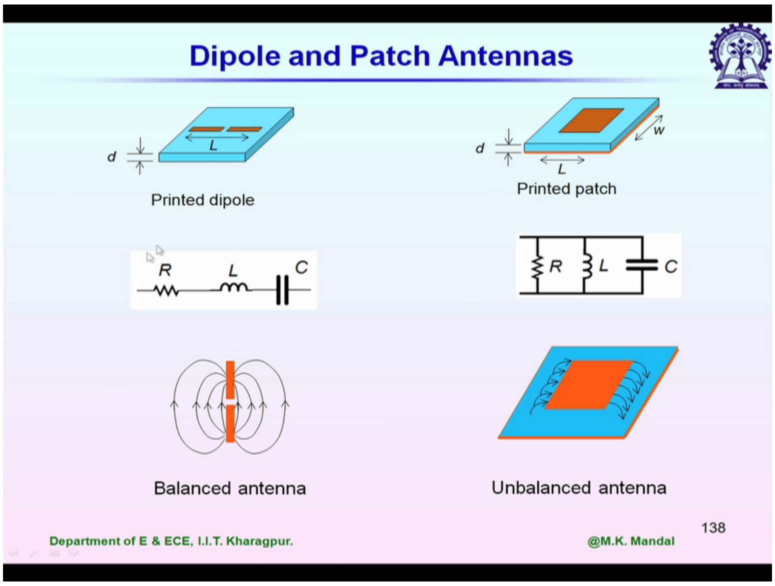

So if you look at this equivalent circuit for printed dipole and printed patch both are resonating antennas but in the equivalent circuit printed dipole is represented by a series resonator where this capital R it includes both the radiation resistance and the loss in the antenna structure itself where as for the printed patch its a parallel resonator and R represents same things.

Now how we determine that printed dipole it should be represented by a series resonator and printed patch by a parallel resonator so what we do? We can simply calculate the input impedance or if the calculation is too complex we can use any full wave simulator or electromagnetic simulator to simulate this structure and thats how we will be having the input impedance.

And then we plot the imaginary part of input impedance at resonance frequency it should be 0. And now at below resonance frequency if its negative that means below resonance frequency input impedance is capacitive and above resonance frequency input impedance is inductive so for a series resonator we know that below resonance frequency it is capacitive and above resonance frequency its inductive.

So thats why for a dipole antenna the equivalent circuit we can determine that it should be 1 series resonator. Similarly for any unknown antenna structure we can plot the input impedance its the looking at the imaginary part variation we can determine what should be the equivalent circuit it should be 1 series resonator or parallel resonator.

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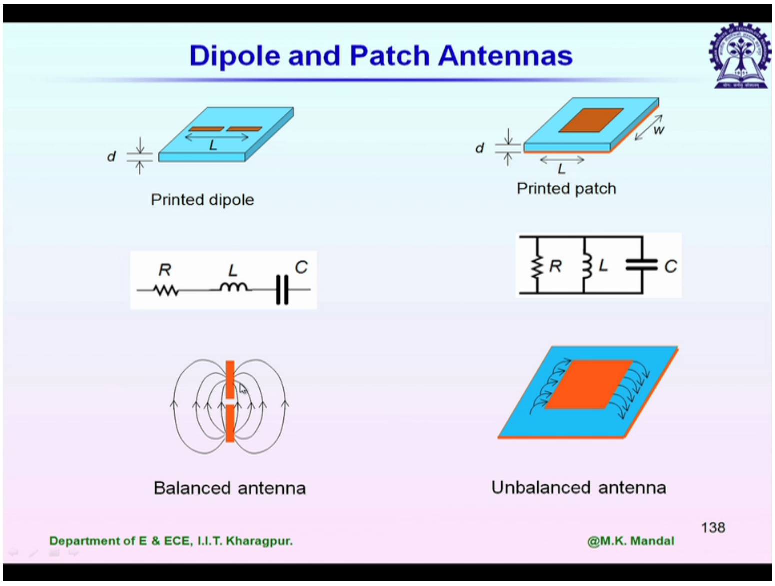

Now if I look at the electric field plot of any resonating dipole antenna it looks like this. So the length of this antenna is lambda g by 2 at resonating frequencies and if you look at the electric field it is maximum on the central plane and we have in the far field radiation electric field is parallel to the wire or this line of this dipole antenna we have linear polarisation.

And this dipole it radiates its maximum radiation in the broad side direction and we have radiation null along the wire and now look at the electric filed plot for a rectangular patch antenna for a rectangular patch it radiates from its fencing field. Okay let me discuss a little more on this fencing field how it radiates?

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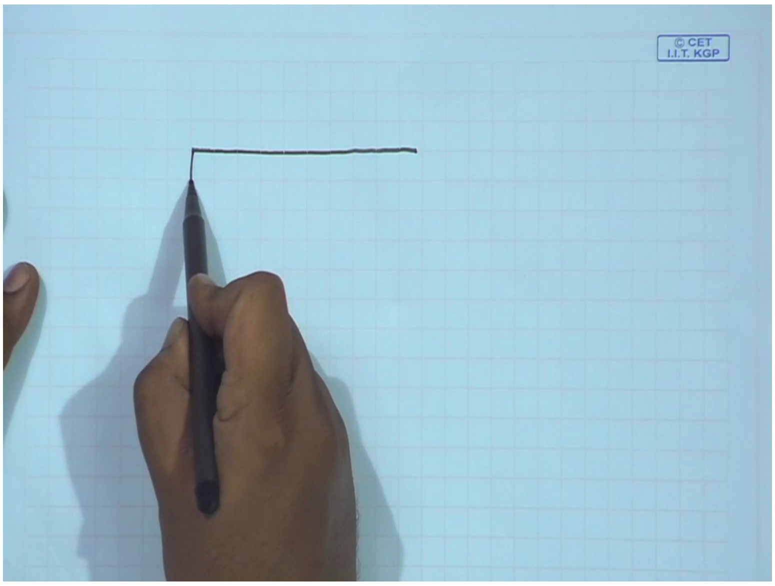

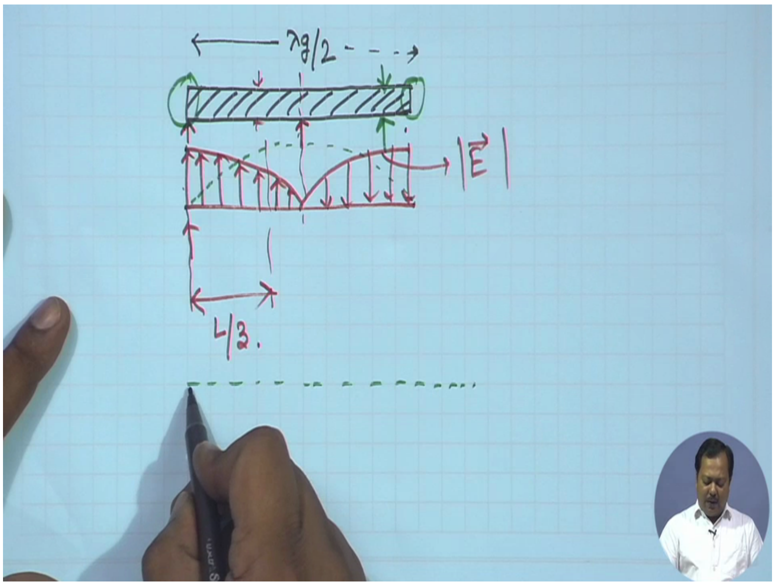

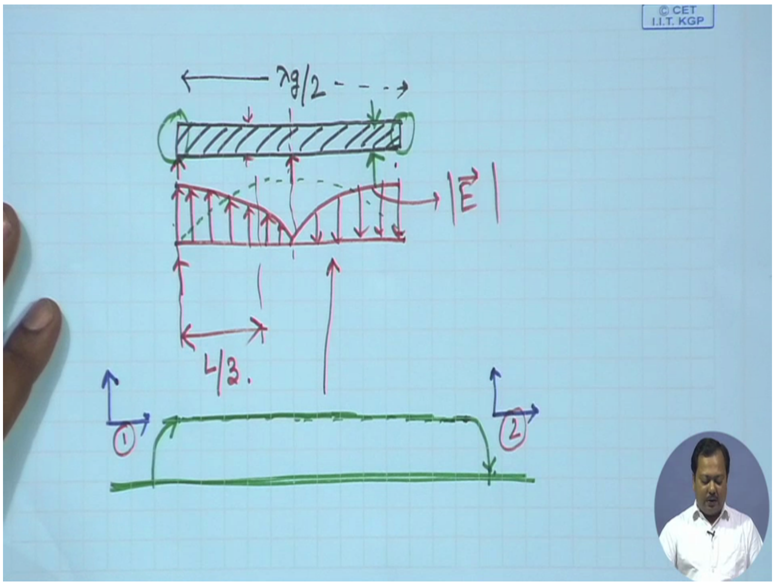

Let me start from a very basic resonator let us say we have a micro strip line resonator of length lambda g by 2 obviously at the resonance frequency. Now both of this 2 ends they are open circuited so at resonance frequency if I plot electric field along the line then we will be having maximum left most and right most edges and if I plot current distribution so this is the plot of electric field and if I plot the current distribution it will have just opposite variation.

It will be having maxima on the central line and 0 since the ends are open circuited. Now if I want feed this resonator at this edge we see that electric field is maxima so corresponding potential difference it will be also maximum between the strip and the ground plane. But current having minimum value so the impedance seen by the feed line if I connect it here it will be infinite now on the central plane we have current maxima and electric field minima.

So if I feed at this point we are expecting input impedance is 0 for microwave circuit mostly we use 50 ohm system so for impedance matching then the feed point will be somewhere in between this Z equal to infinity and Z equal to 0 plane. And the thumb rule is that you consider one third length from left hand side so if the length is L of this resonator then we have to consider approximately length from left hand side is L by 3.

This resonator when its width is very small it will not radiate but if we keep on increasing the width of the resonator its starts radiating and this radiation comes from the fencing field at this 2 sides so if I look at the fencing fields plot so this is the direction of electric field I did not show it in this diagram so since it radiating so if left this is in left hand side if this is in upward so here it will be downward and at the end we have fencing field.

So now how we have radiation from the fencing field obviously some of this component it has to be the for that electric field and magnetic field it has to be in same phase. So let us say this is the fencing field components so I am drawing this side view at bottom we have the ground plane and this is the top plane strip now I can represent the fencing field along to orthogonal axis.

So in that case we see that this 2 electric field component let us say this is 1 this is 2 they are in same direction looking from broad side and we will be having electric we will be having maximum radiation intensity in broad side direction from this 2 field. So to increase the radiation what we have to do? We have to increase the width of this resonator and thats how we obtain a rectangular patch resonator.

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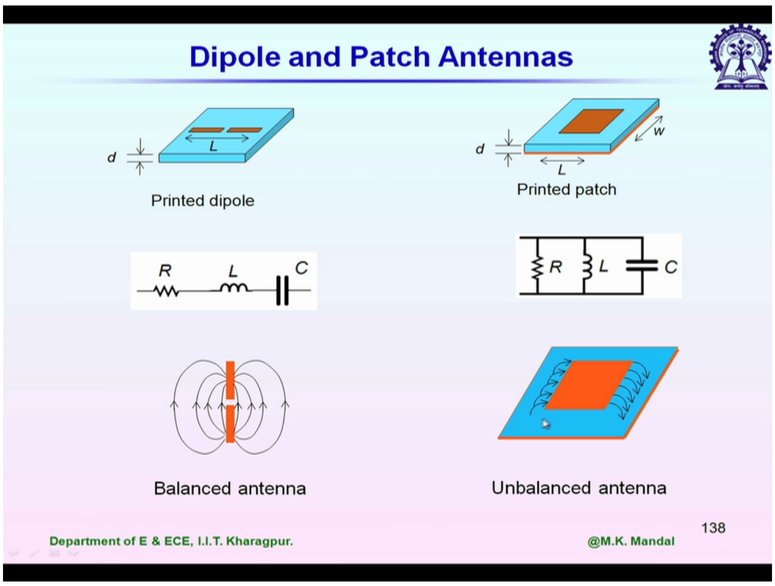

So now look at this electric field plot. We have fencing field left hand side and right hand side so it represents the length of this antenna in this direction. Now this length it should be lambda g by 2 at the resonating frequency and we will be having maximum radiation intensity in the broad side direction of this antenna.

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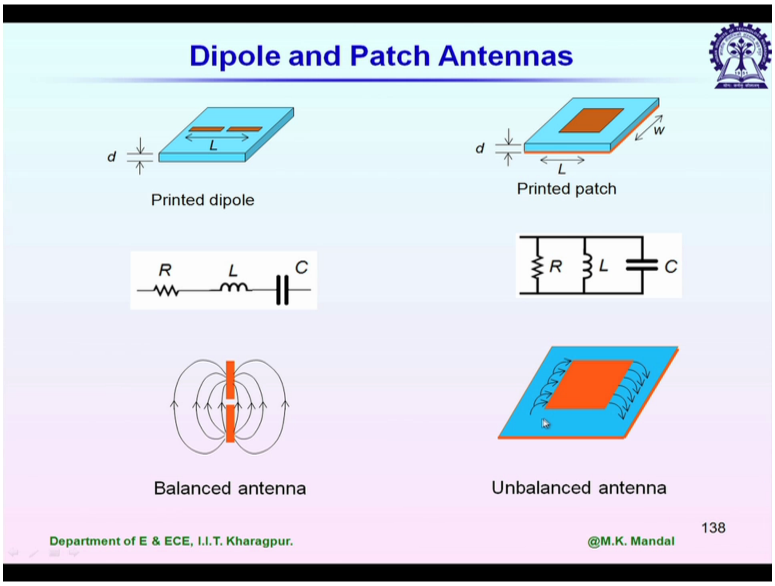

Next we will see resonating length of the antenna its a function of frequency not only that it also depends on epsilon R off the substrate. Why? Because of this fencing field component but different epsilon R will be having different fencing field components so we have different length correction factor because of that. So we will take a break then we will start again. Thank you!