Millimeter Wave Technology.
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Lecture-21.
Passive Components

Okay so toady we will discuss about millimetre wave passive components like filters, resonators there basic properties.

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And couplers, power dividers and finally different types of transitions so passive components like band pass filter or coupler it is very popular in any wireless communication system. For example if we design any trans receiver system so in trance receiver system then the first component will be the antenna and then we have to use a band pass filter. So band pass filter it not only eliminate the noise it will also eliminate undesired bands.

So after band pass filter if we use a single antenna for both transmission and reception so in that case we have to use 1 isolator or some SPDT switch or may be orthomode transducer so after that we can use different types of receiver architecture. If we use homodyne architecture it does not involve many passive components but if we use super hit train receiver technology it involves many passive components particularly band pass filter. So here I am going to show you 1 more receiver architecture its known as mixer less receiver architecture or 6 port architecture which use many passive components.

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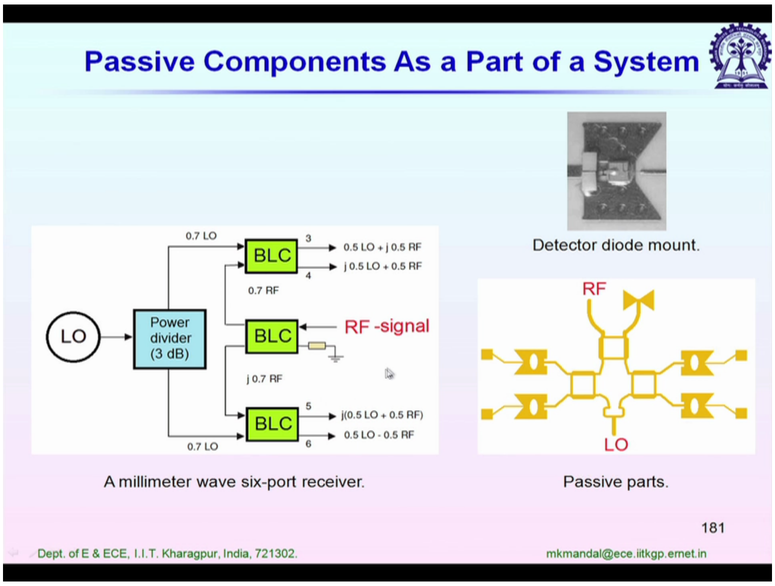

So this the schematic circuit of the 6 port receiver so here you can see the RF incoming signal it is fade to 1 branch line coupler BLC so this is 1 type of coupler which will divide the power into 2 ports when we face difference of 90 degree so this architecture its using 3 branch line coupler so not only that 1power divider usually (())(2:38) power divider and local oxilator signal it is fed to this power divider.

So all of this are passive components right side you can see the micro strip line footprint or layout so this is the PCB part PCB layout of the 6 port receiver and the only RF active device is used detector basically detector diode at millimetre wave frequencies they are connected to this first branch line couplers output port. Prt 3 port 4 and bottom 1 port 5 and port 6.

So we need basically for RF detectors and with this we can demodulate any signal and it works as a receiver so you can see so many different types of passive components are being used in this particular receiver architecture so the size of this receiver architecture in terms of lambda its quiet big that is why its not popular at lower microwave frequencies but its very popular at millimetre wave frequencies because the accuracy of this receiver is much higher compare to super heterodyne or homodyne receiver technology.

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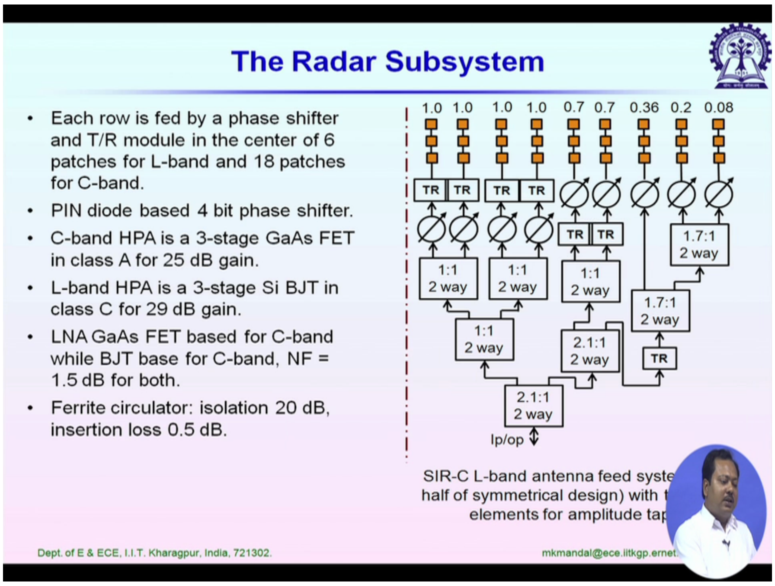

I will give you 1 more example so this is a typical antenna array with accessories used for synthetic aperture radar system so this orange colour patches you can see they form one arrays antenna it is being used for both transmission and reception. So it is followed by TR module so inside TR module we have isolator on passive component and also bandpass filter that is again passive components and just before it we have a pin diode paste for the phase shifter.

So this is for scanning purpose and you can see there are many Wilkinson power divider so this a 2 way 1 is to 1 Wilkinson power divider this is 1 more so there are so many passive components import any radar architecture or any actual wireless system. So before going to the coupler and filter let us discuss about a basic resonator which is dielectric resonator.

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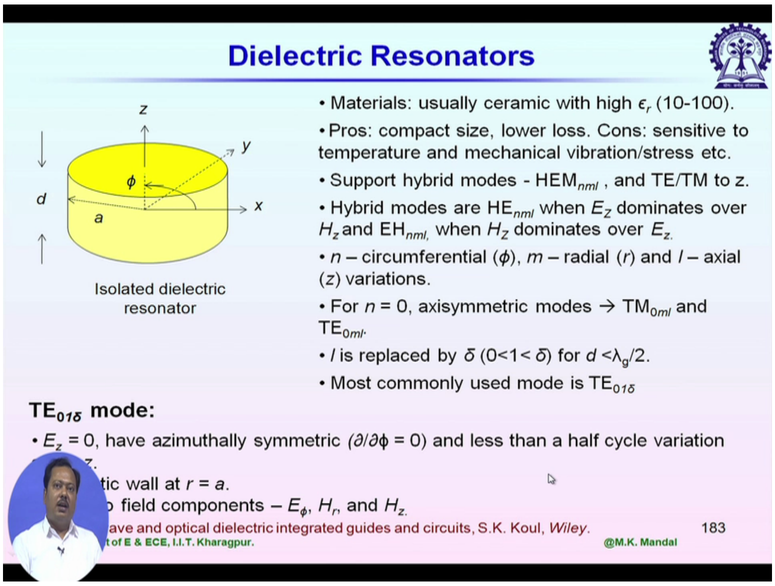

At millimetre wave frequencies metal loss is very high so we usually try to avoid any metallic structure at millimetre wave frequencies and if we can make some resonator based on dielectric wave guide in that case we can avoid metal loss to some extend and the only loss will be facing is dielectric loss so that is how we can minimize loss from in structure and resonators. Where are they used?

They used in filter design as well as they used in antenna design. So when we will be using in antenna design then in that case we expect radiation from the resonator or the quality factor due to radiation QR should be smaller and when we use similar resonator in filter design.

So what we expect that all of the electromagnetic energy it should be confined inside the resonator or quality factor should be as high as possible there are different shapes of dielectric resonator like cylindrical resonator, rectangular resonator, hemispherical resonator so most popular design is cylindrical resonator and let me discuss quickly the some basic properties of a cylindrical dielectric resonator.

Usually different types of dielectric materials are used to make this dielectric resonator. So epsilon R is high usually typically its more than 10 and the only thing we have to keep in mind that the loss tangent value or dielectric loss should be as small as possible. Because we are using dielectric resonator to minimize losses so let us start with the dielectric cylindrical dielectric resonator.

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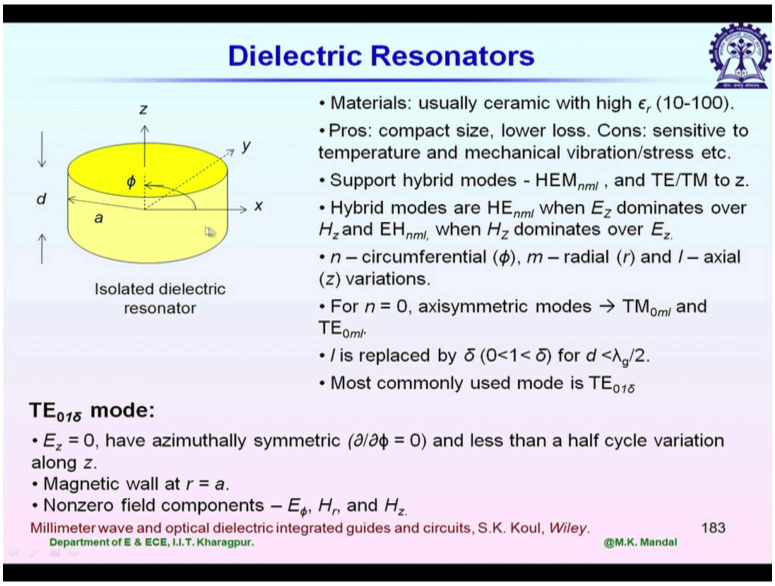

As you can see in this figure we have a cylindrical dielectric resonator let us consider it is isolated from rest of in space and Z axis represent the axis of the cylinder and typical materials we use with epsilon R 10 to 100 so it is of compact size but only problem we face is that it is sensitive to temperature to temperature variation and mechanical vibration so that is why it is not very popular in space application.

Where we may have to deal with large temperature variation now since we have dielectric air boundary so we will be having hybrid modes so typically it supports hybrid mode HEM suffix NML NML is the mode no and if you recall image guide so almost similar analysis we can follow here and HEM NML in addition to this we have TE or TM to Z so almost transverse electric or transverse magnetic with respect to Z axis.

It also supports hybrid modes HE when EZ dominates over HZ and EH when HZ dominates over EZ now how we fix the mode designation so N it represents no of extrima maxima or minima along circumference so phi direction M it denotes very the number of extrima in along radius and L it denotes along exis axis so if N equal to 0 that means there is no extrima along phi or no variation along phi.

So we will call this mode as axis symmetric mode for example TM0ML mode or TE0ML mode this modes are axis symmetric mode and in some cases we will see L or along Z we will be facing less than half wavelength but there would be 1 maxima or minima so that is why sometimes L is replaced by delta to represent that its length is less than Lambda g by 2 and we call it then TE01 delta mode for the fundamental mode.

So for TE01 delta mode then it is axis symmetric mode we don't have any variation along phi we have only 1 extrima along radius and along Z the dimension is less than lambda g by 2 so characteristics of TE 01 delta modes its written here so we don't have any del del phi radiation and less than a half cycle variation along Z and not only that on the dielectric air interface electric field is parallel.

So that means we can replace this dielectric air boundary by on magnetic L or magnetic wall so the non 0 feed components mainly we have E phi components and both the radial components and Z direction component of magnetic field vector H.

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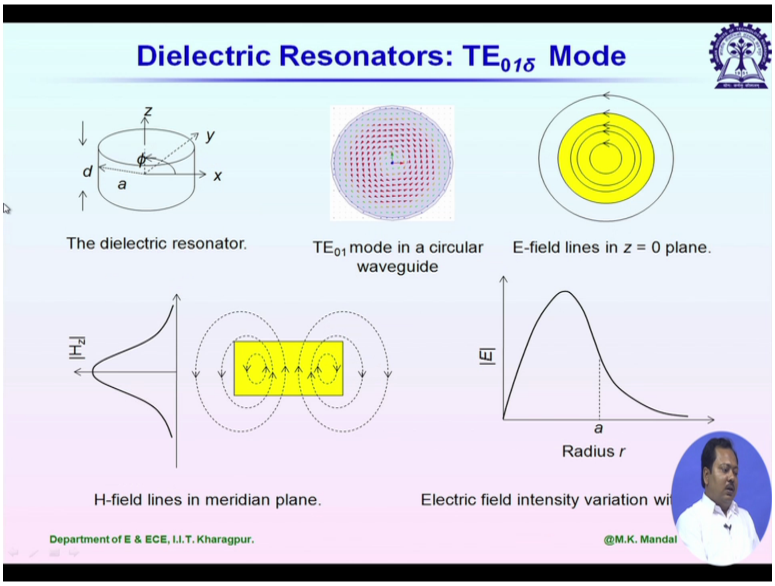

So let me show you the field plots so remember the axis its in Z direction then right hand top right figure it shows the electric field variation it clearly shows that we have only 5 components of electric field and not only that at centre electric field component is 0 so this bottom figure it shows the electric field strength variation along radius starting from centre.

So you can see that at centre it is 0 then its increasing having a maximum inside the dielectric and R equal to A represents air dielectric boundary so above A that means in air it decays exponentially. And we don't have any EZ component or ER component of the electric field you can compare this electric field variation with the TE 01 mode in a circular wave guide this is also a axis symmetric mode in circular wave guide.

So almost similar field variation but only difference is that in circular waveguide all this electric field is confined within the structure but for the dielectric resonator in air it decays exponentially so we have some fencing fields and the amount of fencing field it depends on the dielectric constant of this material and now if I want to use this resonator as an antenna in that case we will have radiation due to the fencing field.

And we will expect that the electric field and magnetic field they should be in same phase otherwise we will not have any radiation and for feeder application the whatever electric field or magnetic field we have in air they should be in phase quadrega so that almost there is negligible radiation and now look at the magnetic field variation so magnetic fields they forms loop and we have both the radial component and the Z component. So on the central plane of this dielectric resonator magnetic field is maximum.

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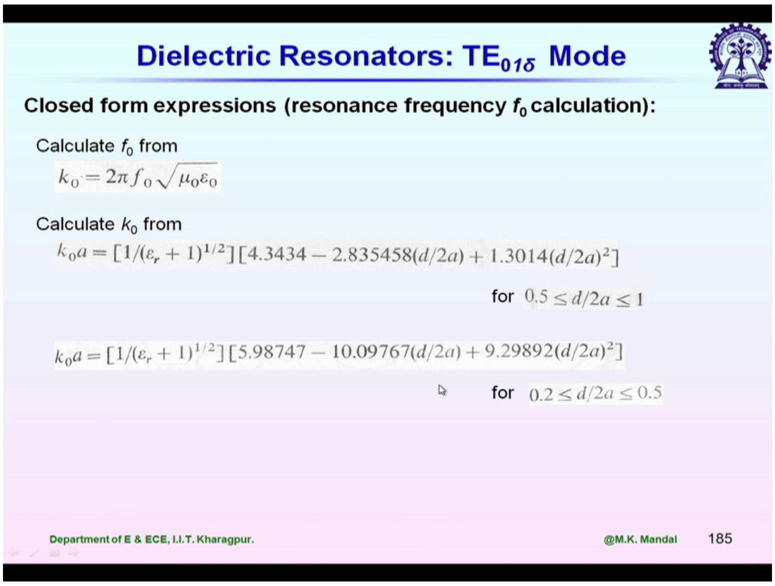

Some there are many closed form expressions available in literature so this is one of them it is accurate within plus minus 5 percent you can say if the resonator dimension is given that means the resonator height D its diameter twice a dielectric material epsilon R then we can calculate its resonance wave no K not.

So we have 2 closed form expression of 2 different cases 2 different as aspect ratios when D by 2A it is within point 5 to 1 you can use this fist formula to calculate resonance frequency. So you recall that K not this is equal to 2 pi by lambda not so from that you can calculate then what is F not and the second one when D by 2A is within point 2 to point 5.

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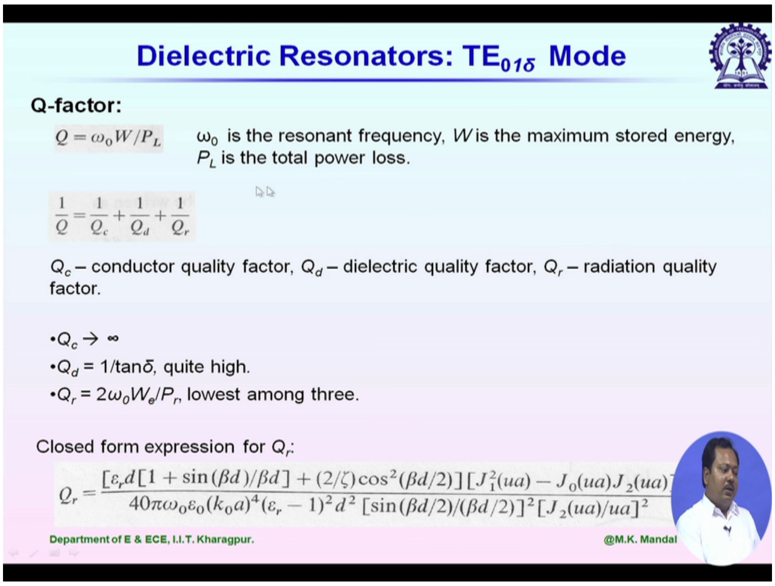

Now the quality factor this is one of the important parameters will frequently use to represent loss Q in general this is equal to omega not into W by PL where omega not represents the resonance frequency w is the maximum stored energy inside resonator and Pl is the total power loss so if loss is minimum in that case quality factor will be much higher now what are the sources of losses for any structure passive struct component.

The losses it can be due to conductor loss it can be due to dielectric loss or it can be because of radiation so then we can define 3 quality factors which will represent this 3 different losses and then the overall quality factor Q they are related to this quality factors like this expression as can be given 1 by Q equal to 1 by QC plus 1 by QD plus 1 by QR. so where QC represents conductor quality factor.

QD this is dielectric quality factor and QR this is radiation quality factor. So if we want higher radiation QR should be small if we want to use dielectric resonator in filter application this overall quality factor should be as high as possible so that we can we can say that the loss inside the structure is minimum and it stores almost all of the given energy inside the structure now whatever resonator we are considering here we did not consider any conductor.

So QC that means it is infinite we don't have any conductor loss equal to 0. And QD it depends on loss tangent of the material this is equal to 1 by tan delta so its a property of the material and now choosing a dielectric material which has very low dielectric loss it can be made very high and QR it is approximately twice omega not into WE by PR so it is lowest among this 3 so mainly the loss term will be facing is due to radiation.

We have a closed form expression to calculate QR its given here Q so its a function of D height of the resonator epsilon R dielectric constant whatever being used inside the material and also the diameter twice A.

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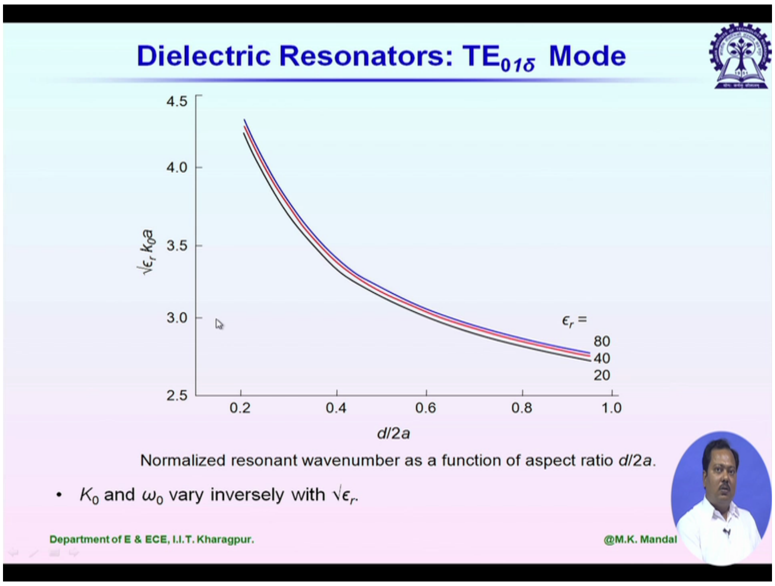

So let me show you 1 graph how the resonance frequency it varies with aspect ratio D by 2A and the dielectric constant. So in this particular graph we are expecting 3 different values of epsilon R 20, 40 and 80 X axis represents the aspect ratio D by twice A so an Y axis represent normalized resonant wave number K not A is twice by lambda not and epsilon R this is the dielectric constant of the material so it becomes as a whole it becomes a frequency parameter.

We can see then if we increased the aspect ratio D by 2A then this resonance this resonant wave number it decreases or in other words you can say resonance frequency of the dielectric resonator it decreases. So K not and omega not it vary inversely with root epsilon R it also depends on epsilon R if we increased epsilon R then for given dimension obviously resonance frequency will increase but change in resonance frequency due to epsilon R its very small.

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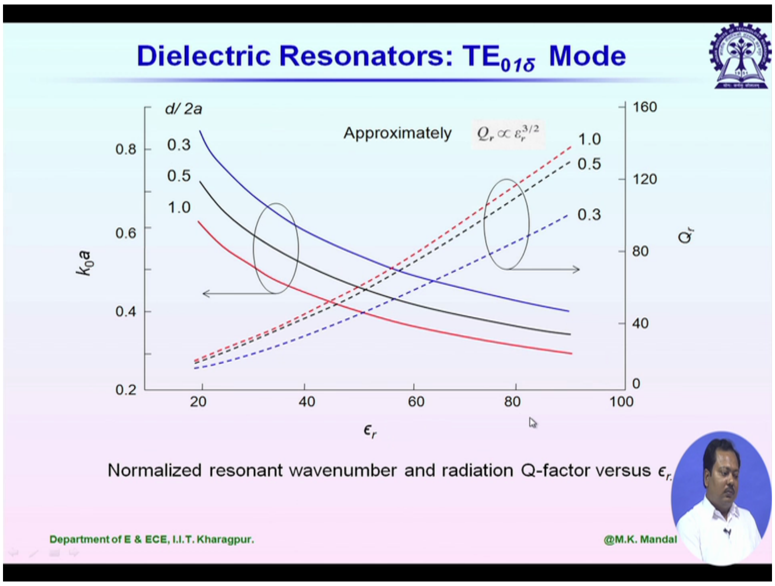

Now since QR is minimum among the 3 different quality factors so let us see QR depends on which parameters again we are considering 3 different aspect ratios D by twice A equal to point 3 for this blue line D by twice A equal to point 5 for this black one and 1 this is for this red one. We are plotting K not A that normalised wave number versus epsilon R so epsilon R we are considering 20 to 90.

And you see when we increased epsilon R then this normalised wave number it decreases and also it varies with D by twice A what we expected from the previous graph and the interesting thing is that QR which is shown on right side it also increases with increasing epsilon R approximately QR is proportional to epsilon R to the power 3 by 2 so if we increased epsilon R then QR will increase in other words there will be less radiation.

And radiation bandwidth will decrease and if I we have now 3 curves for 3 different aspect ratios so we see that smaller aspect ratio this point 31 it provides lower QR that means higher bandwidth so If I want to design 1 antenna using cylindrical dielectric resonator we have to use then lower epsilon R and lower aspect ratio.

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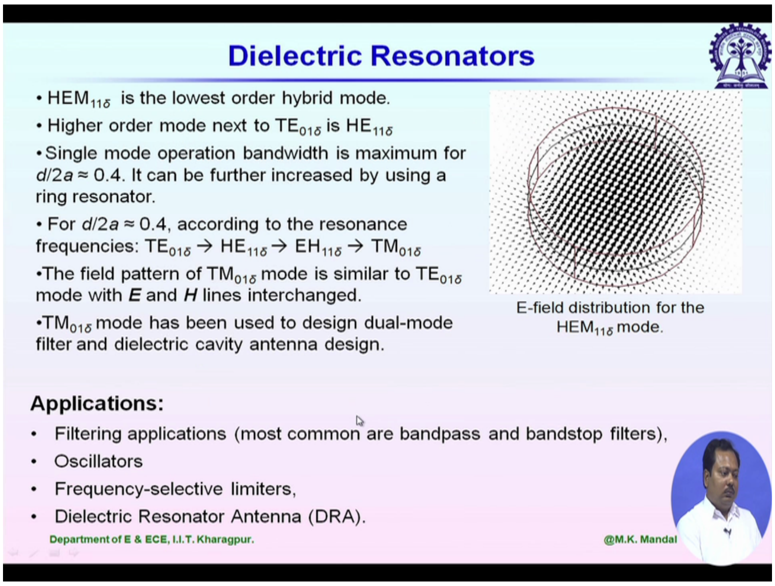

Some properties of dielectric resonators in general HEM 11 delta mode this is the lowest order hybrid mode. Higher order mode next to TE 01 delta is HE 11 delta. Now single mode operation bandwidth is maximum for D by twice A equal to point 4 so actually it can be shown that the mono mode bandwidth it depends on aspect ratio.

And when we used any guiding structure or even a resonator we expect that it should be excited only in single mode and then the bandwidth is limited by the cut off frequency of next higher order mode so we have to increase the cut off separation of this 2 cut off frequencies to increase the effective monomer bandwidth of any given resonator or of any guiding structure and it can be shown that approximately for TE 01 delta mode it is maximum.

When D by twice A equal to point 4 it can be further increased by using a ring resonator. So what is ring resonator? If we simply drill 1air via inside this dielectric resonator we call it a ring resonator. Now how it increases the mono mode bandwidth? Let us concentrate on the electric field plot so the next higher order mode HEM 11 delta mode the electric field plots for this mode is shown here.

You can see electric fields its having maximum on centre on axis of this cylinder so if I drill 1 air via it is going to affect this HEM 11 delta mode most. You compare this with the electric field configuration of TE 01 delta mode.

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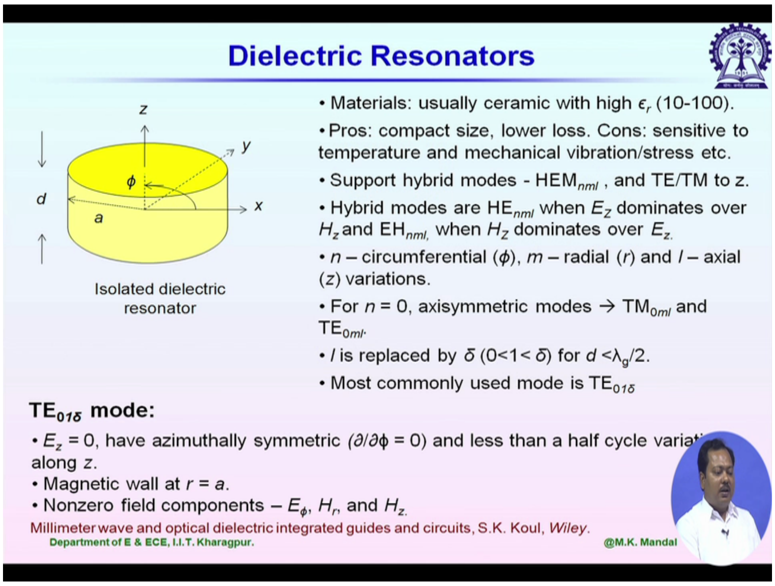

Let us go back to the previous slides so for TE 01 delta mode we have electric field minima so if we drill 1 AR via inside it will not affect this TE 01 delta mode as much or in other words we can say the cut off frequency it is less affected by AR via place at the centre of this dielectric resonator but cut off frequency for the next higher order mode.

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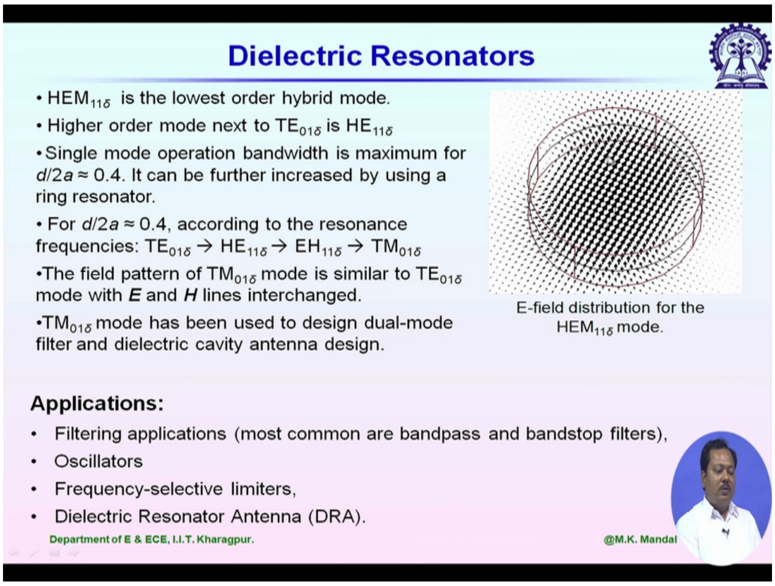

Which is HEM 11 delta mode it will increase if I place 1 AR via on along the axis of this dielectric resonator so that is how mono mode bandwidth of the resonator can be increased. Now if I choose aspect ratio D by 2A equal to point 4 then according to resonance frequencies the fundamental mode is TE 01 delta mode so next higher order mode will be HE 11 delta mode then EH 11 delta mode will appear then the TM 01 delta mode.

Now this field pattern for this TM 01 delta mode it is very similar to TE 01 delta mode so only thing is that we have to repress electric field by magnetic field lines simply we have to interchange that. Otherwise it looks very similar TM 01 delta mode it has been use to design dual mode filter and dielectric cavity antennas. So we have many applications in filter we can use resonators in oscillators design for the tank circuit we can use dielectric resonator. Dielectric resonator also used for antennas and frequency is selective limiters.

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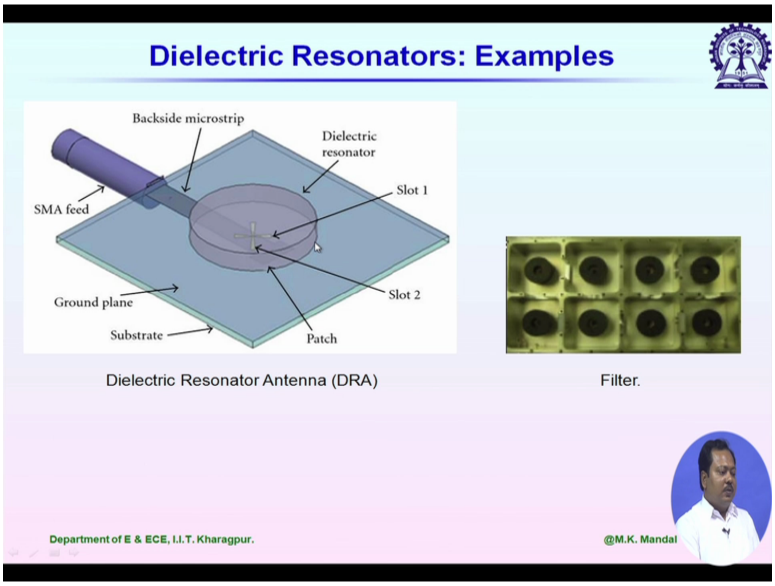

So since its also popular in antenna design let me discuss.

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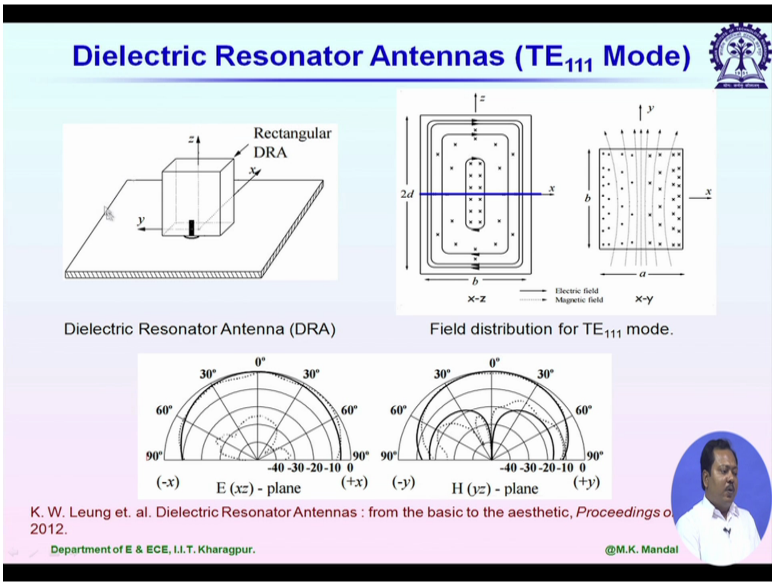

Some basic properties when we use it as an antenna. Again when we use as an antenna different shapes are popular it can be rectangular shape, it can be hemi spherical, it can be cylindrical also. But if I compare the QR or compare the bandwidth in impedance matching bandwidth of the antenna it is observed that the bandwidth is maximum for rectangular dielectric resonator so here in this picture I am showing one rectangular dielectric resonator and the fundamental mode is TE 111 and it is the most used mode for DRA.

Rectangular DRA and so it actually shows half of a full resonator it is placed on a ground plane you can see it is being fed by 1 SMA connector and the inner conductor of SMA connectors it is drilled inside this DRA and you can see also 1 slot edged in the ground plane this is to couple power from SMA cable to DRA now if I consider a full resonator so ground place is ground plane is placed in middle.

So for this full resonator look at the electric field plot it looks like 1 loop Z is the top direction and this DRA it is placed in the XY plane so magnetic field it is perpendicular and it forms loop in XY plane you can look at the field plots in XY plane the electric field it is perpendicular and magnetic fields they are parallel so again if I go back to this XZ plane so on this mid line shown by X axis.

And blue line here electric field this is exactly perpendicular or you can say we have 1 we can place 1 PEC here or you can simply cut this resonator and use half of this resonator backed by a metal or ground plane. So if I place a ground plane here at the mid plane then we are having this DRA dielectric resonator antenna shown at the left side now its radiates mainly the X component due to the X component of electric field.

So electric field in space it will be parallel to X mostly in Z direction and this is the radiation pattern E plane radiation pattern and H plane radiation pattern so E plane this is the XZ plane and we have highest cane in both side both in XZ plane or E plane and YZ plane or H plane. So you can see how this DRA is being excited by using SMA.

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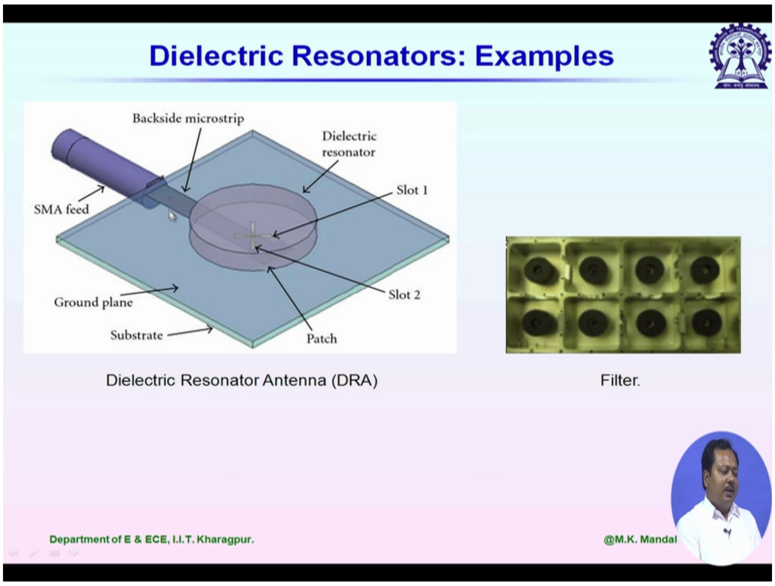

I will show you another example. Here DRA is being excited by using a micro strip line the inner conductor of this SMA is connected to strip of the micro strip line and here we have a printed circuit board on substrate so the micro strip is placed bot at bottom most layer and top layer is the ground plane of the substrate and slot is edged in the ground plane. You can see it looks like on plus sign and then DRA it is placed on that.

So that is how we can excite DRA by using micro strip line. This right figure it shows uses of DRA in filter application this is a rectangular ca rectangular wave guide cavity filter and inside 1 cavity so here you can see we have actually 8 cavities and coupling between 2 cavities controlled by Irises. It is the cut (())(29:20) view and this dielectric resonator basically its a ring resonator.

Where we have AR via at the centre of this resonator it is placed inside the cavity because of this dielectric resonator the overall dimension of the filter it decreases at the same time quality factor increases or in other words you can say loss (())(29:48) loss it decreases. So this is the use of dielectric resonators cylindrical dielectric resonator in filter applications.

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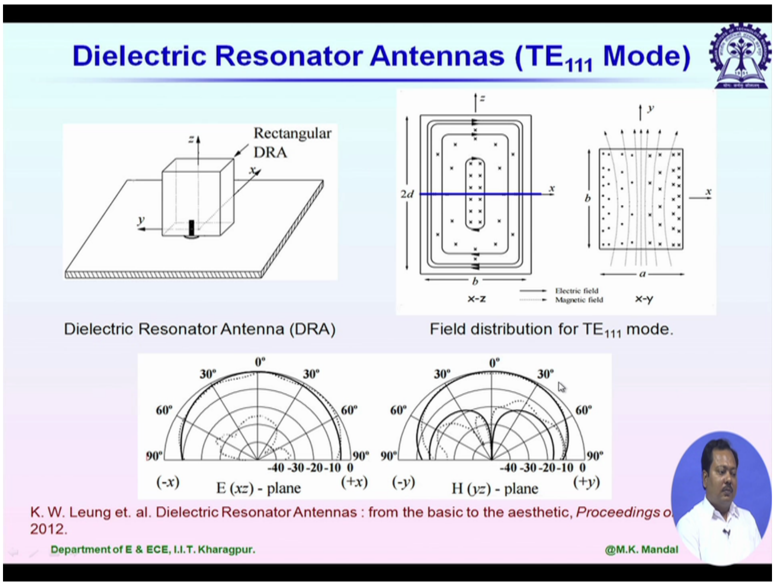

So we will take a break after that we will start filter. Thank you!