Advanced Microwave Guided-Structures and Analysis
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Lecture 66
Application to the Coupling Problem: Aperture – Coupled, Probe - Coupled and Waveguide Coupled Structures

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Welcome to this session of lecture of week 12 which is essentially application of some of the concepts which we learnt in our previous material over the previous lecture weeks. And in this lecture session we are going to discuss the application of the concepts to the coupling problem. Mainly, we will be addressing the aperture coupled, probe coupled, and the waveguide coupled structures.

So, we will be particularly limiting our discussion to relatively newer form or potentially more advantageous antenna forms like the dielectric resonator antennas which offer notable advantages over traditional architectures like the microstrip patch.

So, we will be essentially discussing the excitation mechanisms of such antenna structures. And we will see how the knowledge of the modes which we learnt in our previous chapters enable us to design and properly come up with an optimized solution to a given problem.

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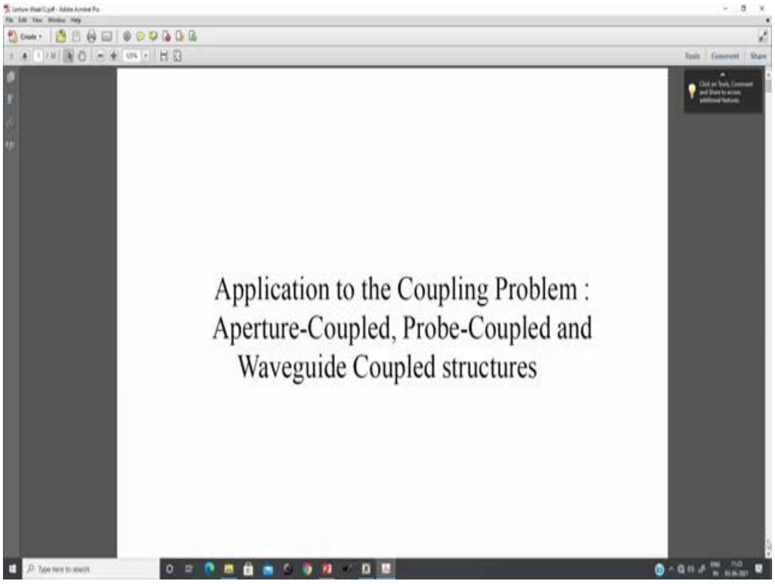

Essentially, it is the application to the coupling, as we discussed with reference to the aperture coupled, probe coupled and the waveguide coupled structures to the dielectric resonator antenna.

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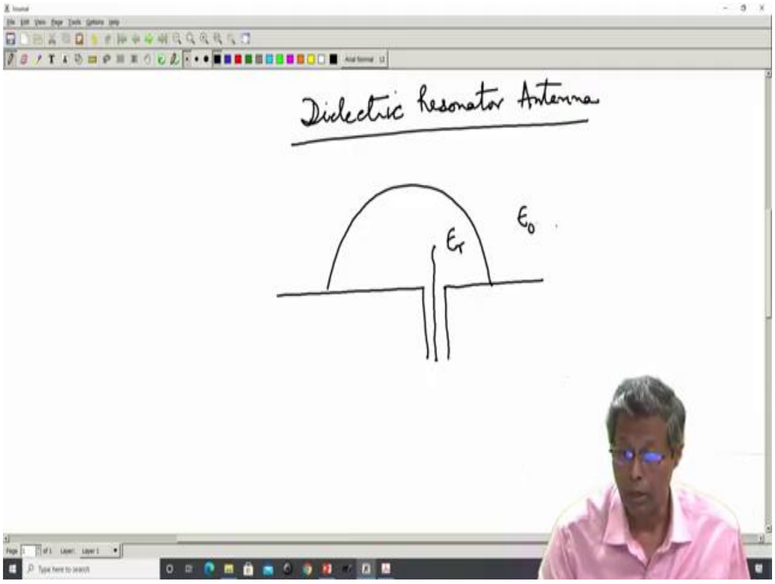

Now, let me give you a brief introduction of this kind of an antenna structure. The dielectric resonator antenna is essentially like a volumetric dielectric material which can be typically excited by a coaxial probe

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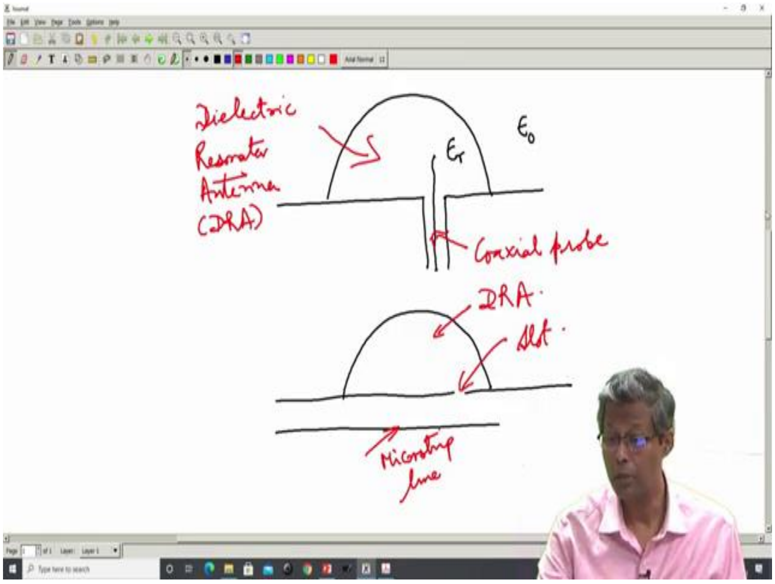

or it can be excited by a slot coupled microstrip line. So, in this case this is the coaxial probe and this is the dielectric resonator antenna in short called the DRA. This is the microstrip slot coupled feed to the DRA. So, this is the microstrip line and this is the slot again this is the DRA.

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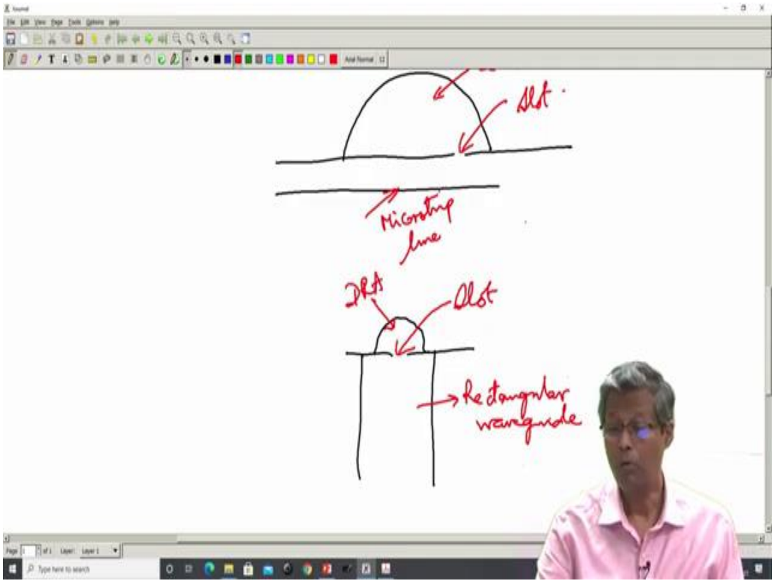

Besides, these two fundamental forms of feed there are other kinds of feed namely the rectangular waveguide feed to the dielectric resonator antenna. So, it can typically take many forms but one of the forms is like this. So, in this case this is the rectangular waveguide, this is the slot and, this is the DRA.

Now firstly, the comparison the between the dielectric resonator antenna and traditional architectures like the microstrip patch. So, we know that the microstrip patch consists of essentially a conductor surface.

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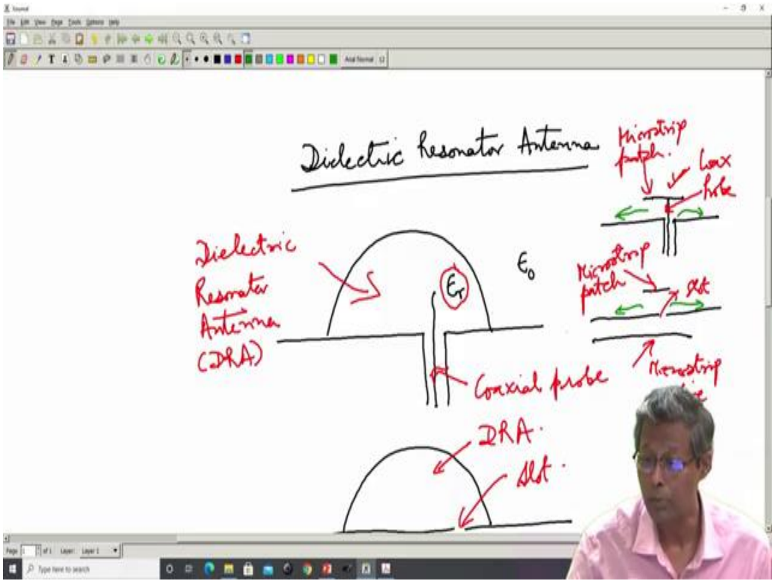

Because, the patch is resident over a substrate and is fed by a coaxial probe like this or by an aperture coupled feed like this. So again, this is the coax probe and this is the microstrip line and this is the slot and this is the patch antenna. So essentially, it consists of a conducting patch and therefore can be compared directly to the DRA in the sense that this will entail more conductor loss. Unlike, that the DRA does not possess any conducting surface. It is a totally dielectric surface of relative permittivity ε_r .

So first of all, the comparison between the two in terms of conductor loss. The dielectric resonant antenna poses no conductor loss. Secondly, the absence of surface waves so you see typically in the probe coupled structure, it is prone to surface waves in the substrate which will limit essentially its size.

The size of the ground plane like it cannot be reduced beyond a particular extent because of the relative predominance of surface waves for reduced size substrates. Both for this architecture and this architecture so surface waves are going to be excited in that substrate.

Unlike that there is no substrate here. The substrate is present in this case, it is only the feed substrate here there is no substrate to the dielectric resonant antenna neither is there any presence of any substrate in the rectangular waveguide geometry. So, you see that there is no substrate in the rectangular waveguide geometry.

So, you see now therefore that the dielectric resonator antenna poses no surface wave loss. So, this is another very important criterion which distinguishes the dielectric resonant antenna from the patch and enables its operation at higher frequency ranges in the millimetre wave frequency ranges.

Though much of the research on the dielectric resonant antenna has happened in the lower frequency ranges in the 2 to 5 gigahertz band or in the x band but this is potentially an antenna candidate which can be translated or effectively operated at the millimetre wave frequency ranges because of these one or I mean these two important advantages. In addition, the modes of the dielectric resonator antenna enable it to realize potentially wideband structures. The bandwidth of a microstrip patch is limited and it can be compared to the wide band using the dielectric resonator antenna to the order of 60 percent or beyond using multi-layer architectures.

Even with a single DRA a bandwidth of 30 percent can be realized. So, you can see that the potential wide band nature of the dielectric resonator antenna which is contributed in part to the low Q DRA modes, the ability of the DRA modes to couple with each other as we will see and also to couple with the source resonance or to couple with any other forms of resonance. So, this enables us to realize wide band structures. So a structure for example which is used to satisfy one kind of requirement can also be used to realize a wideband DRA antenna structure by coupling to the relevant resonance with the DRA resonance.

This happens because the DRA modes are essentially low Q DRA modes and they are prone to couple with other resonances. One more important advantage of the DRA in addition in comparison to the microstrip patch is that the radiation characteristics of the DRA over the entire bandwidth can be made absolutely uniform. So, this is a very remarkable advantage of the DRA. So if the DRA excitation of the DRA modes are properly chosen we can use the wide band nature of the DRA to additionally realize antenna structures where the radiation bandwidth is exactly the same as the impedance bandwidth of the antenna.

So, this can be compared to the microstrip patch where the radiation bandwidth may be a fraction of the impedance bandwidth which can like typically be of the order 15 percent or at most 20 percent.

Now, so we will essentially deal with the excitation problem or the coupling problem to the DRA in relation to the probe coupled, the aperture coupled and the waveguide coupled structures.

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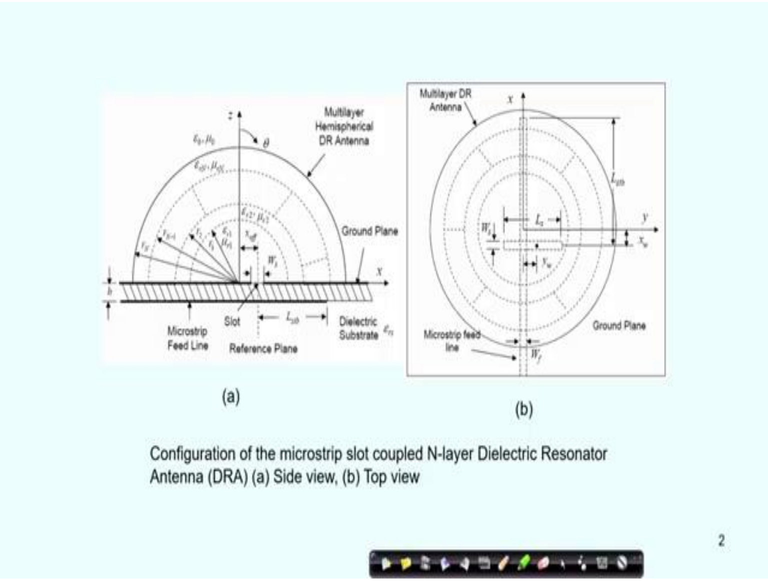

So, we start with the multilayer dielectric resonator structure which is aperture coupled to the microstrip line at first. And the reason why we would consider a multilayer structure is that as we discussed previously that it offers relatively much wider bandwidth compared to a single layer DRA.

In addition, it helps us to establish a matching or enable a matching in environments which are more challenging to match using a single layer DRA. So, those things we are going to see as we progress through. But it will also elucidate or it will also explain why the knowledge of the modes which we have learnt in the context of the wave guide or in the context of the circular waveguide is important and how it can be more generalized to the modes of an antenna and enable us to arrive at an optimum design.

So, these modes of the DRA so they are of the TE to r where r is the radial direction or the TM to r. But we will come to that but unfortunately a rigorous analysis of this kind of antenna structure in terms of the modes is actually beyond the subject matter of this course. It involves a rigorous greens function analysis and our in-depth understanding of the greens function which is outside the course topic and it is quite a big a huge research area on its own.

So, what we will concentrate more in this material is the application of the knowledge of the modes in order to arrive at a suitable solution to the dielectric resonator antenna problem. Which will lead us to a scientific understanding of the dielectric resonator antenna, which will complement our knowledge when we use our simulation tools.

So, it must be remembered that the simulation tools which we use for the simulation are extremely important for antenna design. But they do not replace the rich knowledge which we get or the deep insight which we get from a rigorous modal analysis of the structure. Rather it complements and enables us to use our simulation tools in a much better and a much more scientific manner. So, we will see the structure of the dielectric resonant antenna. In this case because we dealt with the analysis of such structures we considered an N layer dielectric resonator.

So, layer one is you see the inside layer of permittivity epsilon r1 and permeability mu r1, the next layer is permittivity epsilon r2 permeability mu r2 and the last or the Nth layer is permittivity epsilon rn where N is the number of layers and permeability mu rn and it is followed by the radiating free space. The multilayer dielectric resonator antenna is fed by a micro strip line which is aperture coupled to the dielectric resonator through this slot. So, the footprint of this dielectric resonator antenna on the ground plane is shown here. So you see the dotted lines correspond to the different layers of the DRA and this is the slot its length is Ls and its width is Ws.

So, we all know that the length of a slot has to be much larger. We all know that the length of a slot has to be much larger than its width otherwise we are going to have an electric field component along the length of the slot.

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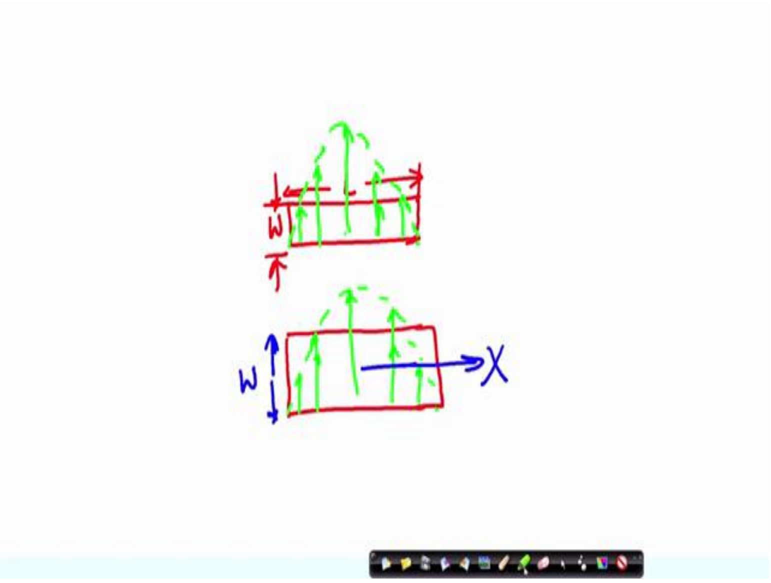

So, as we said the if this is the slot if this is the slot length L and this is the slot with W the electric field of the slot is essentially maximum at the centre and it reduces like that so it has a typically sinusoidal distribution so it reduces steadily and it is 0 at the edges.

So, this is essentially the electric field of the slot. So, what happens if you make the width larger is that in addition to this field component of the electric field as we drew in addition to this component of the electric field, electric field in this direction would also develop.

So, an electric field in this direction would develop and this is undesirable. So, we always make the length of the slot much larger than the width. So, let us go back to the presentation.

So now we have the slot of length Ls and width Ws. The slot x offset along the x direction you see this is the x direction this is the microstrip line coming so this is the microstrip line and Wf is the width of the feed i.e. microstrip line and xw is the x offset of the slotand this is the y direction so yw is the y offset of the slot. So, the slot is offset at xw and yw so if xw equal to 0 and yw equal to 0 it means that the slot is at the center so it is center coupled slot if xw equal to yw equal to 0.

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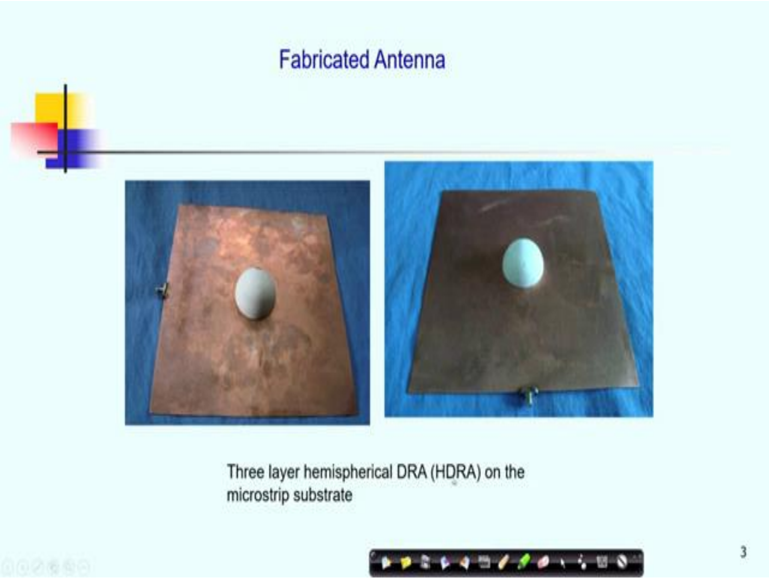

So now, so this is our fabricated antenna structures which was the three layer hemispherical dielectric resonator on the microstrip substrate.

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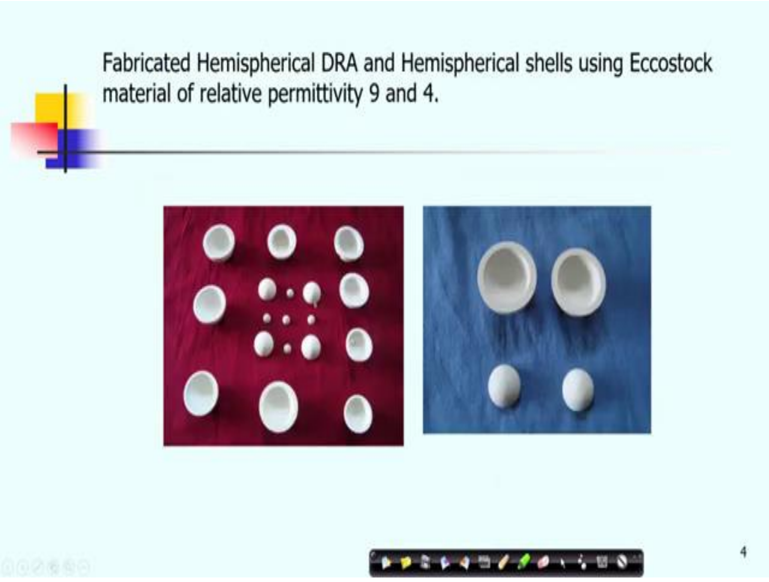

And these were the shells the inner shells and outer shells typically we use the permittivities of 9 and 4 using eco stock materials so these are the photographs of this.

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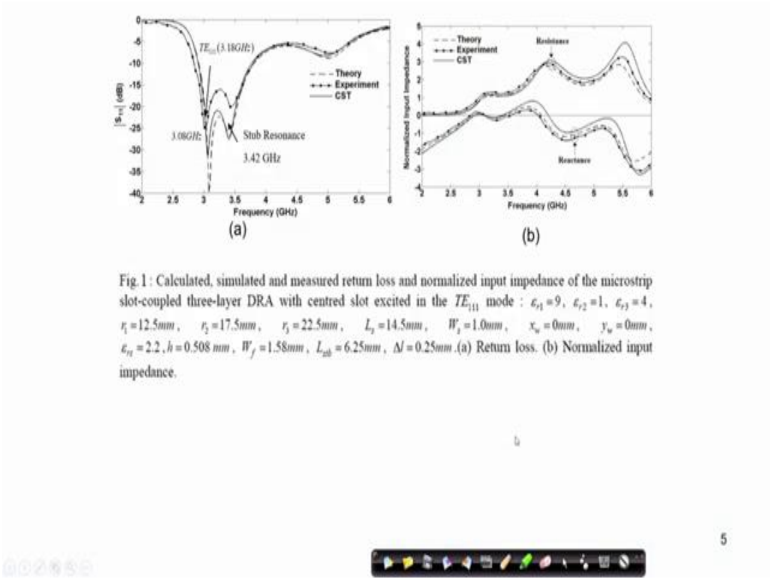

Now, the first figure shows the return loss characteristics or the reflection coefficient characteristics of the dielectric resonator antenna. The multilayer dielectric resonator antenna fed by a centred slot you see xw equal to 0 yw equal to 0 so this stands for the centred slot.

The first layer permittivity is 9, the second layer permittivity is 1 and the third layer permittivity is 4 so it is a three layer dielectric resonator antenna. The r1 the inner layer radius is 12.5 millimetre the radius of the next layer the second layer is 17.5 millimetre and the third layer radius is 22.5 millimetre.

So, if you go back to the figure you would be able to see the radius so r1 is here, r2 is here so from the centre to here and from the centre to the n minus 1th layer is rn minus 1. So now, if we go back there so here epsilon rs is the substrate permittivity of the microstrip line h is the height of the microstrip substrate Wf is the feed width Lstb is the length of the stub. Now, we know that this is Lstb from here to here. Now, we know that this stub you see here, this kind of open circuited here so if you neglect the radiation loss or the like the surface waves from here you can approximate that this region as an open circuit.

So, this open circuited stub allows us to enable an impedance matching for this slot. Because, it cancels out the slot reactance so this kind of open circuited line it will offer me a capacitive load or an inductive load if this line length is less than lambda by 4 it will offer a capacitive load.

Because, it is an open circuited line and if this line length is more than lambda by 4 it is going to offer me an inductive load. So, this length of the line is used to cancel out the reactance of the slot and enable the matching of the slot. So, this Lstb that is here given as 6.25 mm so this was some like the simulation parameter which we used.

So, let us not dwell on this. So, first of all this is the return loss and this is the normalized input impedance. Now, you see in the return loss characteristics the first dip is due to the TE_{111} mode. Now, first of all we need to understand what is meant by TE111. So, let us go to the notes.

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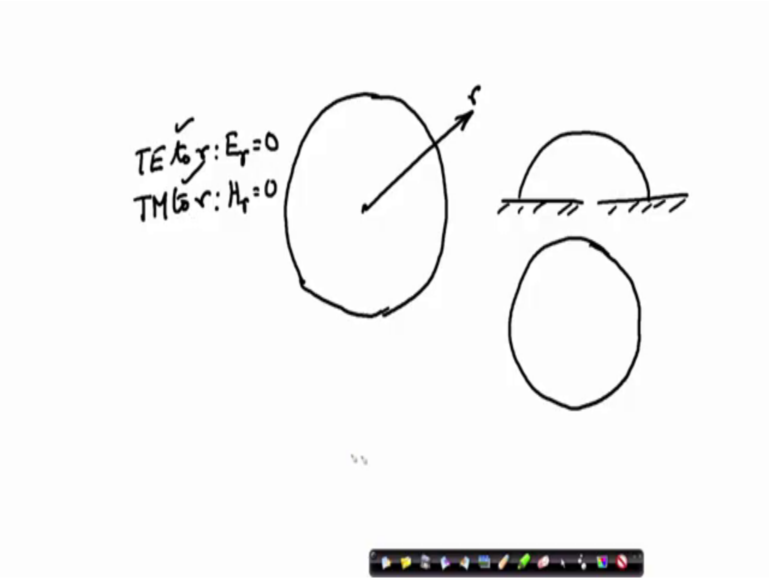

So, the modes of spherical resonator actually for the analysis the dielectric resonator is considered spherical. Because, this is the ground plane this is the slot so if you consider a single layer this is the ground plane so the dielectric resonator is reflected in the ground plane. So, it becomes a full sphere using image theory.

So, the modes of this kind of a spherical or so to say the hemispherical resonator are in the form of TE to r or TM to r modes. So, this is the radial direction r so the TE to r modes poses Er equal to 0. That means there will be no radial component of the electric field.

And for the TM to r modes Hr equal to 0 so that means there is no radial component of the magnetic field. So, the modes of the spherical resonator can be expressed as a combination, as a combination of the TE to r and TM to r modes, any field inside a spherical resonator can be expressed as a combination of TE to r and TM to r modes.

There are no other sets of modes unlike in the rectangular coordinate system we saw that TE to z TM to z the TE to x TM to x or the TE to y TM to y. And when we also explained the use of these different kinds of mode sets with relationship to the partially fill waveguide. Unlike that in the spherical coordinate system there is no other mode sets other than the TE to r or TM to r.

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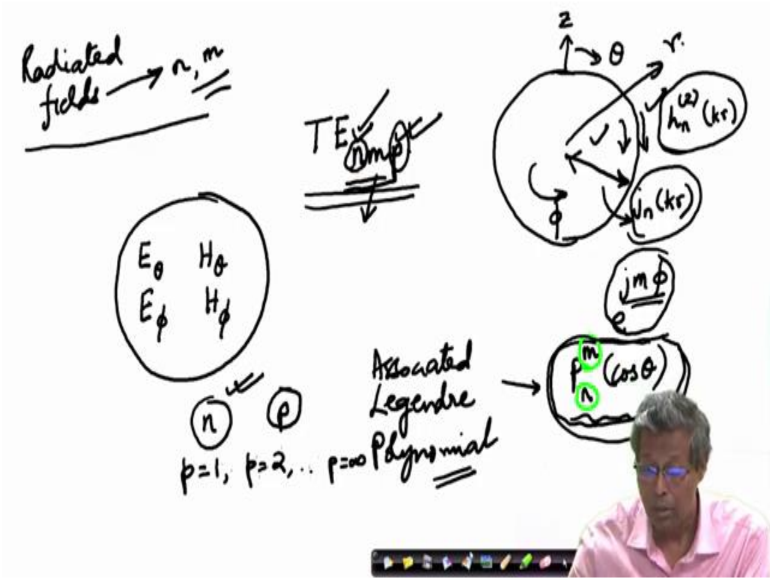

So, the first mode is the TE111 mode. Now, what does this 111 stands, the TE n m p. So, this stands for the order of the Bessel function. You see the dielectric resonator is like this. So, inside the fields are expressed in this region, in this region the fields are expressed by functions jn kr the radial variation of the fields along the r direction are expressed in the form of the spherical Bessel functions jn kr.

So, n is the order of the Bessel function which is used. In the outside region the fields can be expressed in the form of hn 2 kr which are the spherical Hankel functions. Actually, the functions which are used more are the schkelnuoff type Bessel function or the schkelnuoff type Hankel functions which are also closely related, they are closely related to the spherical Hankel functions and spherical Bessel functions.

But they are also having they also have the order n. So, this n refers to the order of the relevant Bessel or Hankel functions for the modes m refers to the azimuthal variation of the fields e to the power j m phi. So, if this is the phi direction m will refer to the azimuthal variation of the fields.

In addition, if this is the z direction so this will be theta. Along the theta the description of the fields for the hemispherical resonator are in the form of associated Legendre polynomials. So, this is an associated Legendre polynomial. This describes we have to have like a generic description of the modes without going into the wave equation for the spherical coordinate system.

But all these come just like in the rectangular coordinate system or the cylindrical coordinate system which we have rigorously covered these come as solution to the spherical wave equation. The solution to the source free spherical Helmholtz equation. So, just like in the cylindrical coordinate system.

So, these associated Legendre polynomials describe the variation of the fields along the theta direction. So, there also you see the subscript n and the superscript m. So, there also we see that. Now, p stands for the ordered roots.

For example, p stands for the ordered roots of the resonant frequencies. For example for a given value of n there can be many roots to the transcendental or the characteristic equation. So, what is the characteristic equation? Again, we cannot go to a lot of detail but essentially what happens is we match the tangential electric and magnetic fields inside the dielectric region and outside the dielectric region.

So, there are the field components E theta E phi H theta H phi these are the tangential field components inside the resonator and outside the resonator. So once we match these field components we arrive at the transcendental equation or the characteristic equation.

The solution to the characteristic equations yields the different modes of the resonator. So, that solution that transcendental equation actually is dependent only on n. The characteristic equation which is obtained by matching the tangential electric and magnetic fields on the inside surface and on the outside surface of the resonator that equation is a function only of n.

So, for every value of n the characteristic equation will have many solutions actually an infinite number of solutions and we label the solutions in terms of p is equal to 1, p equal to 2, p equal to 3, up till p equal to infinity. So, these are the infinite modes for a particular value of n, the ordered modes corresponding to a particular value of n then we go to the next value of n.

Then, we again order or label the roots of the characteristic equation. So, those roots are labelled in terms of p equal to 1, p equal to 2, up till p equal to infinity. So therefore, you see that the resonant frequencies are going to depend on n and they will be labelled by p.

However, the value of n is also going to determine the field distribution that is the radiated fields by this resonator, the radiated fields that will be determined by these indices n and m. Because, they are entering inside the harmonic functions m is entering here and n is entering here so they are entering inside the harmonic functions and therefore they will determine the radiated fields.

But you see here there is no value there is nothing called p so p is not going to determine the radiated fields it is only going to determine the resonant frequencies. And therefore, this enables us this knowledge of modes this behaviour of the modal indices enables us to design an effective antenna structure. Why?

Because, let us say I want to have a multiband structure so we see that the field distributions are going to be determined by n and m and the resonant frequencies are going to be determined by p and n. So, how is this important how is this knowledge important for antenna design?

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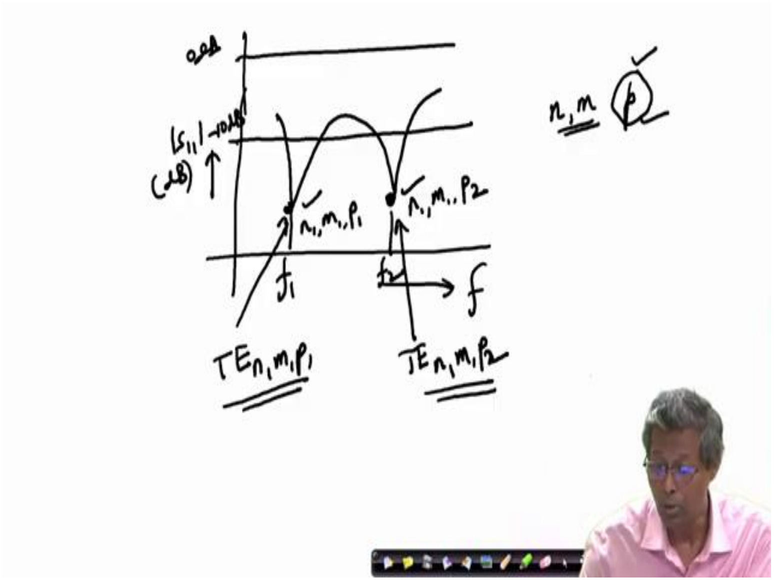

So, let us as we said look at like a structure where we have two resonant dips these two resonant dips can be used to generate a multiband structure. So, if this is mod s11 in dB and this is frequency. So, let us assume that this is the 0 dB line and this is the minus 10 dB line.

So, if this is a minus 10 dB line so this can be used to generate dual band behavior at frequencies f1 and frequencies f2. And frequently we would like to have similar radiation characteristics at f1 and f2. How do we have similar radiation characteristics? If the radiated fields are the same so we know that the indices n and m determine the field distribution outside the resonator or inside the resonator.

So, if we change the value of p if the value of p is changed keeping the values of n and m same then we will have the same field distribution but a different resonant frequency because the value of p will determine the resonant frequency. So, if we go from here let us say indices n1 m1 p1 to n1 m1 p2 let us say a TE n1 m1 p1 mode here and TE n1 m1 p2 here.

So, we can, we will have the same field distribution here and here but we will have different resonant frequencies corresponding to f1 and f2. So, this by this way we can generate a dual band behaviour having the same radiation characteristics at f1 and f2.

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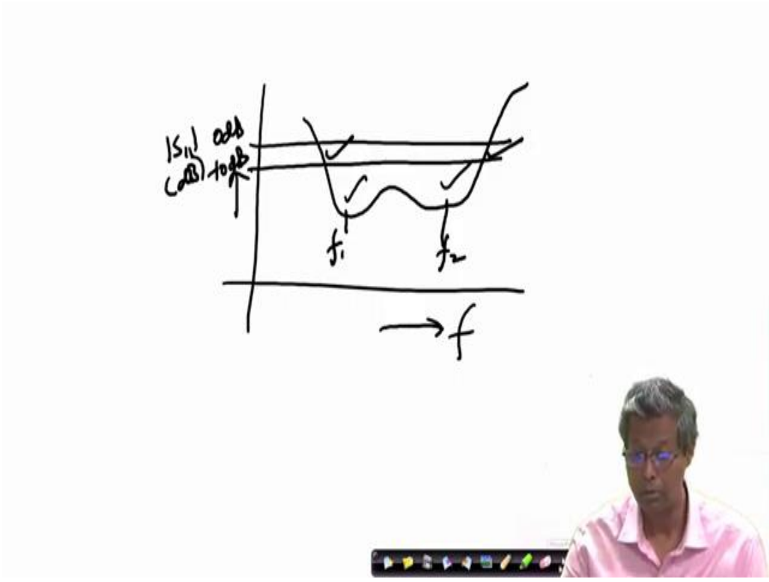

We can use the similar topology to have a wideband feature with stable radiation characteristics. Because, if this is S11 dB and this is the frequency f we can couple two resonances at f1 and f2 these two frequencies these two resonant frequencies say this is the 0 dB point.

And let us suppose that this is the minus 10 dB line. So, we can couple these two resonances to generate a wideband behaviour as we see that this is a wideband structure. Because, the reflection coefficient characteristics are below minus 10 dB. So similar, to the previous case we can ensure that similar radiation characteristics will happen at f1 and f2.

And therefore, the pattern will stay uniform across the impedance bandwidth which is from here to there the pattern is going to stay the same across the impedance bandwidth. So, these are the ways in which we can design a better antenna structure and we can have a control over the radiation characteristics of the antenna.

By utilizing the nature in which the modal indices affect the modes and the modal indices affect the design. Let us go back to our slide. So, the first resonance is given by the TE111 resonant mode which is actually the fundamental mode of the dielectric resonator.

And the second resonance is given by the stub resonance. Now, what is the stub resonance, we have said the effect of the stub the use of the stub. It is to enable matching of this slot to the DRA. To cancel out the reactance of the slot by using the reactance of the stub.

That is the way the stub is used also in the microstrip slot couple structures. But here we are going to use the resonance of the stub and couple it to the TE 111 mode so you see the TE 111 mode has a tendency a high tendency to couple with the stub resonance and offer me an enhanced bandwidth.

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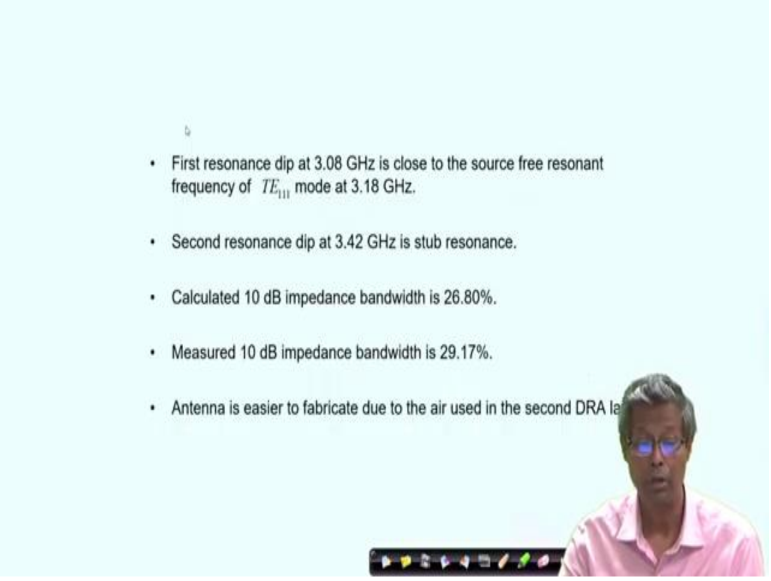

So, the first resonance dip is at 3.08 gigahertz it is close to the source free resonant frequency of the TE 111 mode at 3.18 gigahertz. So now, comes what is source free resonance what we understand by source free resonance.

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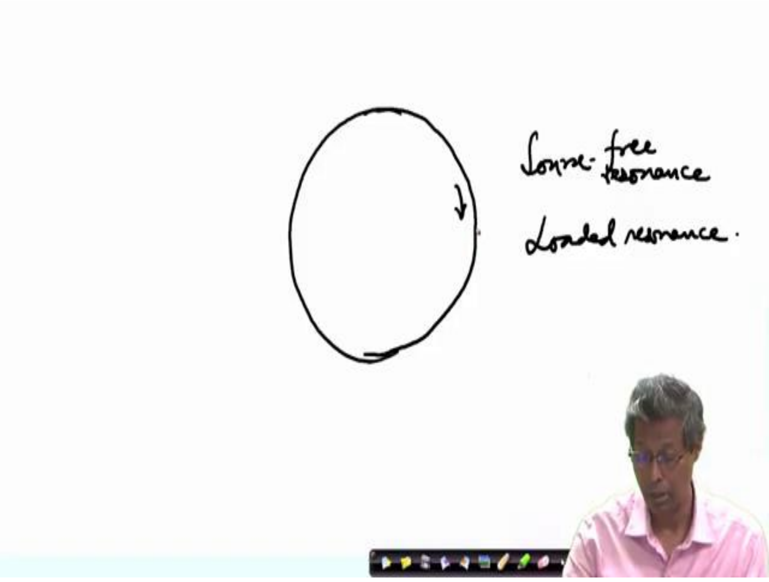

Let us continue with this material in our next slide. So, where we will have a more detailed idea or a more in-depth idea behind the source free resonance and the loaded resonance.