Advance Microwave Guided-Structure and Analysis
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Lecture 17
Time – Harmonic Form6 of Maxwell's Equations (Contd.)

So, welcome to this session on the continuation of the time harmonic form of Maxwell's equations.

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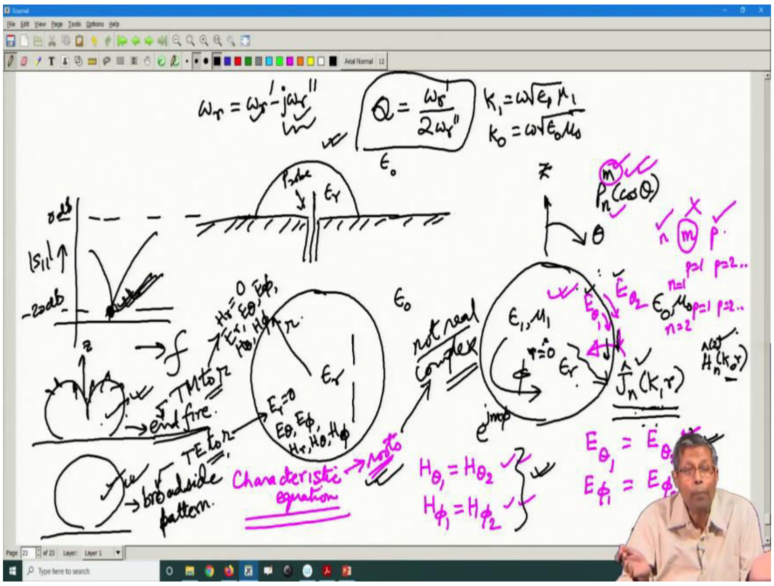

So, we saw that the concept of the loaded resonance and the source free resonance and the distinction between them particularly the loaded resonance deals with the matching aspect of the problem, it enables me to incorporate the presence of the source and thereby match the source to the load.

However, the concept of loaded resonance does not give us a physical insight into the modes that are responsible for the flow for generating that particular resonance. So, in order to find out the modes which are responsible for that particular loaded resonance at that resonance frequency or in the vicinity of that resonance frequency, we go to the concept of source free resonance.

The source free resonance is found by applying the boundary conditions of the problem in the absence of the source, we match the electromagnetic fields and the roots of the characteristic equation give me the source free resonance. Now, in addition to what we discussed previously, these roots are not real, they are not real, there are complex numbers.

So, that might seem strange to you, because, we are always accustomed to think of resonance being a real number that is if you would simulate a structure in H FSS and things like that, you would imagine that the resonance frequency is coming out to be real, but no, if you actually would follow the strict rigour of the analysis of antennas, you will discover that the characteristic equation the roots from the characteristic equation are not real, they are complex, this has to be realised, why this has to be realised?

Because, if I qualify these roots as omega r, I will write this as omega r prime plus j omega double prime. So, this is the real part of the resonance frequency and this is the complex part the imaginary part of the resonance frequency, you have to also understand that any kind of radiating structure any structure will radiate will have imaginary part of the resonance frequency, not only that, the quality factor of the antenna will be given by omega r by 2 omega r double prime the real part of the result is by twice in the unity part of the result.

So, why this quality factor is important? Because we want to excite modes, let us say to couple with another mode.

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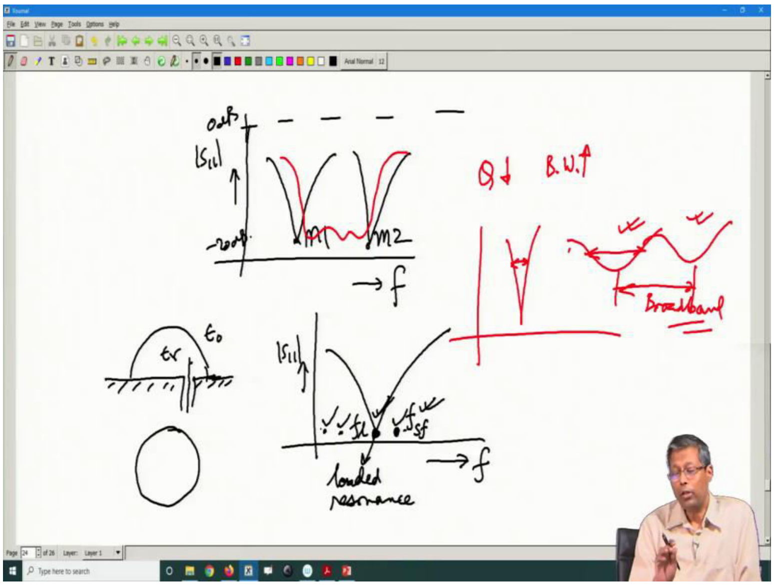

Let us suppose, we want to have a structure in which we have two resonances, these two resonances by mode 1 and mode 2. So, that is my mode is 1. So, they are this is a dual band structure. So, minus 20 dB, let us suppose, and this is 0 dB. So, this is a dual band structure. Now, suppose I want to make these modes come close together and combine to make a broad band structure.

So, in order to make this happen, I will try to identify modes which inherently have a low q factor because a low q factor means the potential bandwidth of such modes is inherently high. So, we want to have modes which low q factor which have also a high radiation efficiency, a high Q mode might look like this, our low Q mode will look like this. So, it has potentially wider bandwidth compared to a high Q mode.

Therefore, it tends to combine with another resonance in order to give me a broad band behaviour. So, therefore, you see that how this source free resonance is very-very important because all these pictures is obtained from the knowledge of the moods which is coming from the analysis, so, it is very important.

So, therefore, this is the idea behind the resonance nature, which is first starting, which has its roots embedded in the power conservation equation. We will just simply also explicitly tell you a little bit about the nature of the feeds in any realistic structure, how the feed effects the matching problem from a practical perspective.

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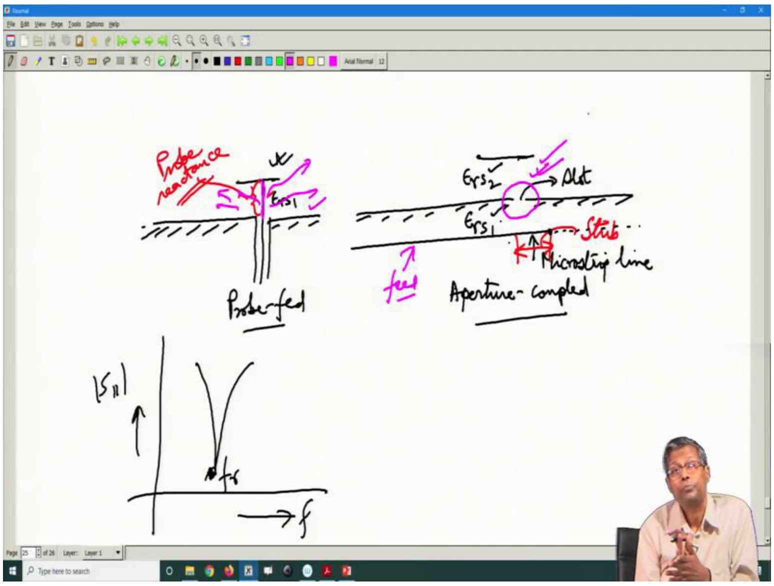

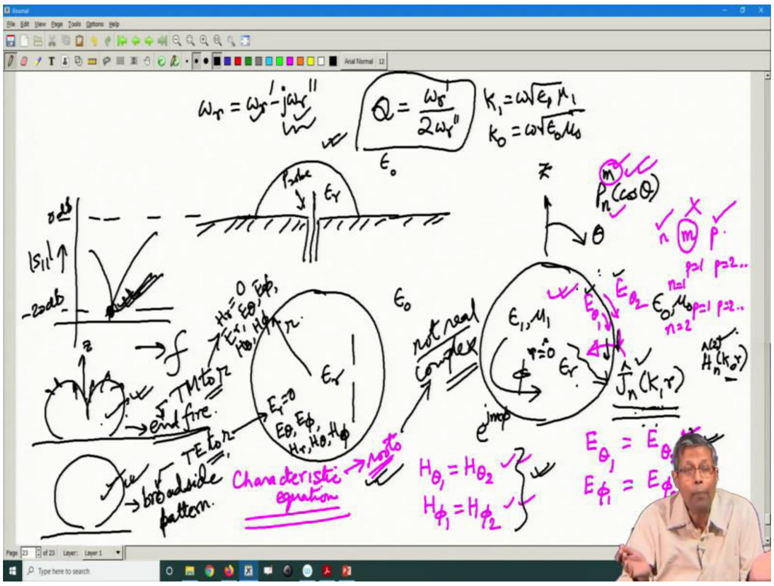

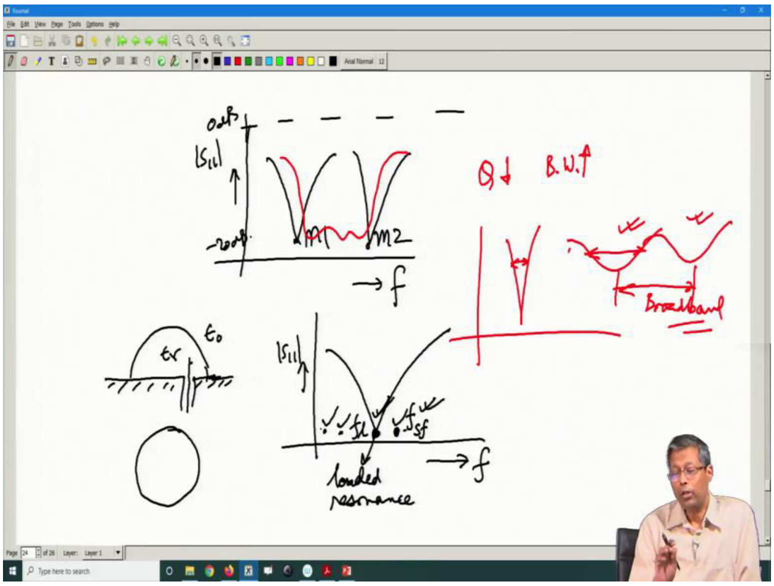

So, let us suppose I have a patch which is excited by a coaxial probe and I have the same patch which is excited by a slot couple feed. So, you see that this feed has two different types of substrates rs1, rs2 while I have only one kind of substrate here. So, this is the ground plane, this is the microstrip line and this is the slot.

So, see after you have done this kind of what is the comparison between the probe fed patch and the aperture coupled patch after you had made the design, the probe fed patch cannot be changed because you have made the design in HFSS you are stuck with that design if you get a little bit fabrication error as you will always get tolerance due to tolerance your design your fabricated design will change from the simulation design.

So, there you are stuck you because you cannot change anything after fabrication. But, therefore, you see here also you have to drill a hole through the substrate and this length of the probe will lead to the probe reactance as I told you the difference between loaded and source free resonance if you look at that, if you look at the slide.

If you compute the source free resonance of this kind of a structure, which is excluding the probe, let us say this is our dielectric resonator antenna and you have computed the source free resonance of these and you have also performed a simulation with the probe and found out the S11 so, that S11 is here. So, this is the resonance.

So, this is the loaded resonance which is with the probe. This is the loaded resonance with the probe, loaded resonance. Now, when you calculate the source free resonance by applying image theory as I said and take this as a whole sphere and without the presence of the probe, then you are going to compute the source resonance to be here.

So, the source free resonance will differ from the loaded resonance in general. In fact, at a particular level loaded resonance there can be it can be contributed by 2 or 3 modes, which are located close by. Locate the radiation at this point can be contributed by this mode it can be contributed by this mode and this mode in conjunction with each other.

Now, the next question is how to find the relative contribution of this mode and this mode how to calculate it we cannot get this by simulation? Will come to these aspects when we particularly deal with the modes here I will give you a rough idea, but before that we will talk about this one as we are talking that your probe reactance is going to shift it is going to cause a shift in from the source free resonance.

So, your source resonance is what you identify that this is the resonant frequency I want to design this patch in, but when you actually design the patch due to the presence of this probe reactance your resonance frequency that is the frequency at which the S11 is giving you a dip this resonance frequency is going to shift this fr is going to shift from the source free resonance frequency.

However, for this design you see that one of drawbacks of this design is that it using two substrates and substrates are like a costly business at microwave frequencies. But how does this accomplish the match, you see this length of stub. This is called stub it is an open-ended transmission line. So, this substrate is not ending yet. So, this is the substrate, the substrate below the ground plane.

So, this stub is used to match this patch with the feed line. So, even you can post trim after you have manufactured these after it is fabricated, you can trim this a little bit in order to fine tune your match. So, you have the flexibility of adjustment after the design. In addition, you see that while this probe radiates the thicker the substrate the larger the length of the probe, the stronger the probe reactance effect of the probe reactance and the more the probe radiation. But here the slot length does not depend on the thickness of the substrate. So, it is less susceptible to vary the inherent patch resonance.

It is not that the slot does not radiate the slot also radiates and it causes spurious radiation but the spurious radiation from the probe is larger because it is dependent on the height of the substrate. In addition, you have to drill a hole to the substrate there is no hole to be drilled here. So, all these features contribute to the positive sides of this design.

So, this is how the resonance phenomenon play an important role in the practical design of the circuits. In addition, you will see that the feed radiation. This is the feed and the feed radiation is shielded by the presence of these ground plane. So, the effect of the feed radiation does not come there while the feed radiation is an important part here.

So, besides the shifting of the resonance, the effect of the feed radiation and everything. So, you have to make a judicious choice versus the simplicity of the design that you are using a single substrate. Here it is not that the probe coupled design is not used it is very popular in antennas in antenna design. So, it is very popular in antenna design. So, as the aperture coupled it depends on the situation you are at hand and the amount of money you want to spend and the other factors which you may or may not want to mitigate.

So, the resonance behaviour plays a very important role in these in the practical implementation of the circuits. I will now describe to you how the concept of power where is the concept of power flow as we are discussing E cross H star the real part of it where does it work? How do we use the power flow, besides these various use that is, you know like finding out the power flow through a surface in numerical problems, but one very important thing is that I will take the same problem.

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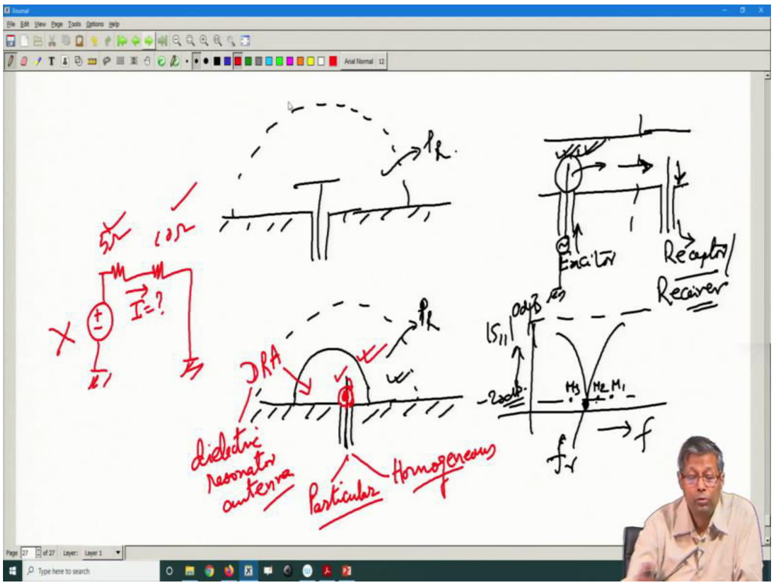

Let us say a coax fed microstrip patch, I want to find the power radiated or a dielectric resonator antenna I want to find the power radiated. So, I will find I will surround these by an imaginary surface and find out the integration of S dot dS is over the real part of S dot dS over the surface in order to find out the radiated power

So, this is how we can find out the power radiated by an antenna, in a waveguide scenario. For instance, I am exciting a mode in a waveguide and I have a receptor here I am collecting the power here. So, the power is travelling down and this is listening to this power or listening to this wave. So, this is the electromagnetic energy coupled here.

So, this is the exciter and this is the receptor or the receiver. So, here you because if this receiver or the receptor or the receiver is there in the far field, I need only calculate the radiated power from this probe, I do not care about his reactive part because its reactive part does not reach this far field.

However, the design we spent all this time to discuss the reactive part of the power to say that it is contributed by the imaginary part of the complex pointing vector and the stored energy term both together which is a purely real number is to match this excitation or the source of excitation to the waveguide because for matching this I will need to tune out the reactance here.

So, the input impedance of this probe is very very vital, finding the input impedance the input impedance in order to find out the input impedance, I have to find out the near field of the probe, how does the probe? What is the reactance of the probe? The resistance of the probe, the total impedance of the probe the complex impedance of the probe which is exciting this waveguide.

So, that is where the input impedance plays a very vital role in the excitation and when we are receiving when we are you know like getting the received power in order to find out the power received we have to again calculate the power received using the Poynting's theorem.

In additional cases for example, this kind of case as I said we might have a resonance here mod S11 versus frequency and I may be interested to know if there are multiple modes nearby as I told you which mode so mode M1 mode M2 mode M3 which is contributing which kind of power here how much power whether mode M1 is predominantly contributing here or mod M2 is contributing here or mode M3 is predominantly contributing here.

So, I want to find out a chart, a chart listing at this resonance frequency fr how much power is being contributed by all these modes, how do I do that? We will come to what we call the Greens function of this problem when we discuss the magnetic current source and the source problem inside in the the wave equation and there we will see that the solution to this problem is obtained through the input impedance and what is the Greens function.

So, the Greens function is particularly just to give you a rough idea, if I take a unit impulse source here, I find the fields due to this unit impulse source. Why do we do this because I do not know the current on this probe to start a priori. It is like giving you a circuit like these with two resistances r1 and r2 5 ohm and 10 ohms and asking you to calculate the current without the battery being unknown.

This is the battery which is driving this network I have given you the boundary conditions here and if there are any other layers the boundary condition at the probe itself those boundary conditions are like the resistances but this is microwave frequency, we do not have resistances we have boundary conditions, but I have not told you what is the current flow in this probe. So, without this information you would not be able to calculate the fields.

So, in order to start the process, we need to assume the source of excitation and that source of excitation is the unit impulse and from that unit impulse I find out the radiated fields by applying the boundary conditions on the probe and by applying the boundary conditions on the surface, we expand the fields inside the probe. And we expand the fields inside this antenna structure, which is also called a Dielectric Resonator Antenna or DRA for short. And we break up the problem into two parts one is called the particular part, another is called the homogeneous part.

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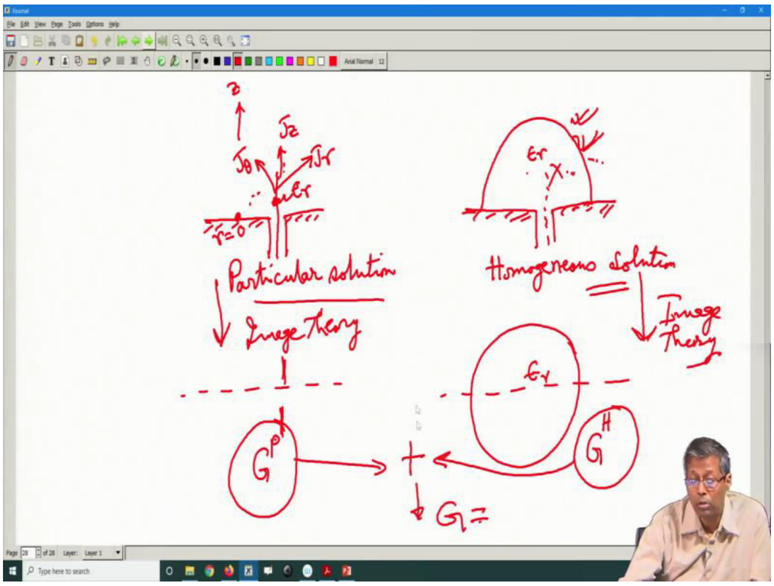

The particular part is the part where I have only the source present the source is radiating like this. So, this is r is equal to 0 and this is the source radiating. So, the source will be broken up into source currents will be broken up into two components. So, if this is the z direction, so, if this is the current in the z direction, this is broken up into the theta direction and the R directions. So, this is the particular solution.

The homogeneous solution is this probe is absent it is not there and you have the dielectric resonator. So, the boundary conditions of the problem work without the presence of the source. So, this is the homogeneous solution. In reality, this is the particular solution with applying the image theory removing the ground plane and this is the homogeneous solution removing the ground plane and applying image theory.

So, this is after applying image theory, from here applying image theory, from here applying image theory. So, the particular solution the response of a source here, response of the source here to this probe which is considered as a boundary that response is called it is encompassed or it is the information is contained in the particular greens function named GP.

And the information regarding this boundary without the presence of the probe is contained in the Greens function enable GH the homogeneous green green’s function, these two greens functions are added together to form the total Greens function G. How does it happen, we will again discuss it in more details, but now roughly we match the basically the basic thing is that expand the fields right down the potential functions involving the woods step one.

Expand the write down the fields from the potential functions match the fields at the discontinuity in the case of the particular solution, the discontinuity is located at the source. So, you match the fields across the source in the case of the homogeneous solution, the discontinuities along the dielectric surface, you match the fields at the dielectric surface.

So, these greens function is going to contain a summation or infinite summation over the modes. Now, if I want to find the current on this probe, however I do not still know the current on the probe, I know that if only a source is present here a point sources present here what will be the electric and magnetic fields due to this point source?

And the presence of this probe only immersed in a material of permittivity epsilon r which is the same as the dielectric resonator material, that information is in GP, I removed the probe I castaway the probe have the dielectric resonator only present and again the response is contained in this term GH, but I still do not know the current on this probe.

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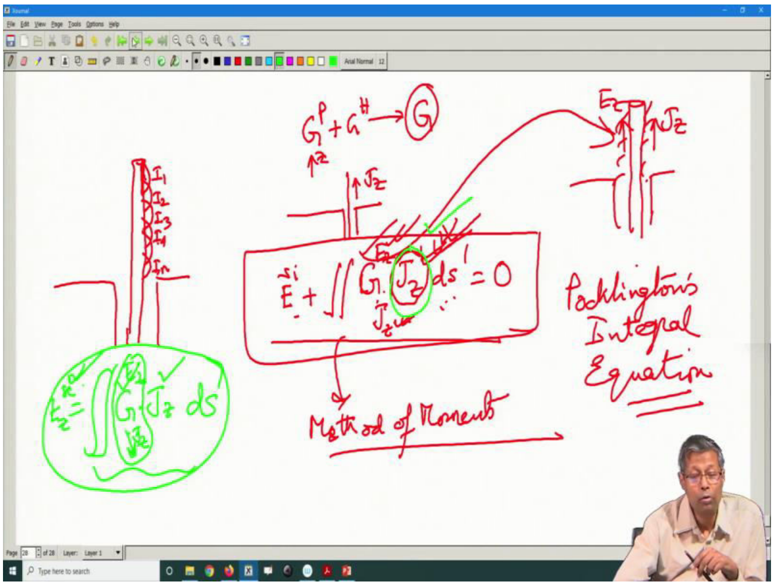

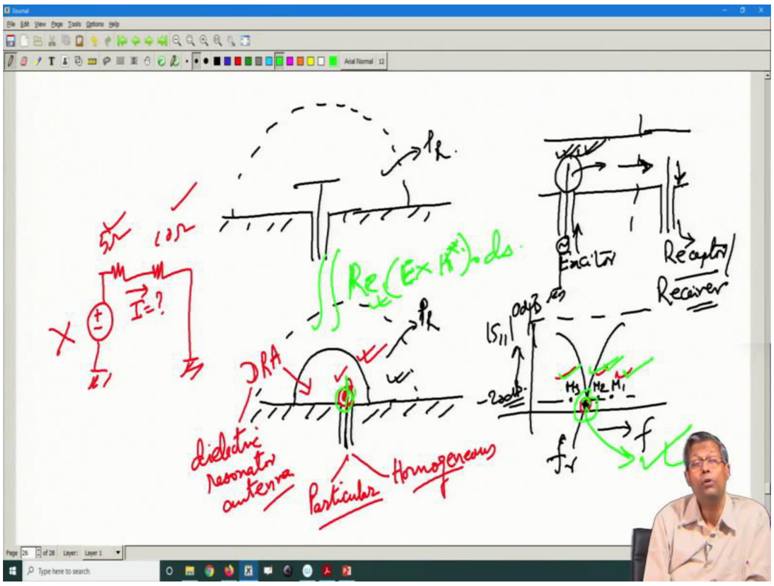

In order to find out the current on this probe, I have to find out as I said GP and GH and add the two find the total greens function and apply the Pocklington's integral over the probe and that is incident on the probe plus is scattered which is the Greens function times Jz because the current on the probe is along the z direction, so, this is the z direction. So, this is Jz times ds prime that will be equal to 0 on the surface of the probe because the probe is a conducting surface. So, this is the probe.

This is a conducting surface over which this equation is applied, I know these which is G Jz that is due to Jz due to a z directed current flowing here, what is my Ez because the z directed current E is going to produce Ez so, this contains the cause and this count on the source and these contains the effect that is the grammar of the Greens function. So, this equation is called the Pocklington integral. This is the Pocklington integral equation.

This is fed to the method of moments. This is fed to the method of moments. Which solves for these unknown current Jz, essentially we take this probe surface which is here and break this up into piecewise sinusoidal basis functions. So, we find the unknown current in each of these basis functions by assuming by applying the Pocklington's integral equation over each subsection.

So, for this subsection for example, the current i1 the electric field due to the current i1 plus the electric field with the current i2 plus the electric field with the current i3 plus due to i4 plus the electric field with the current in is going to be 0, added with the incident field, this will give me the first row of the equation.

So, anyways so, I will you know, like using the using the method of moments, it will be solved, we are not going to the details of the method of moments, but right now, it is important to know for us that this current will be solved using the Pocklington's integral equation, after the Greens function is found out.

Now, the most important here is after this current is solved, I can make this equation work in reverse gear, what is called making this equation appear in reverse gear, I told you I want to quantify the amount of radiated power due to these modes, what are the power radiated by these modes at this frequency, in order to find out that once I have evaluated my current once the current is evaluated using the Pocklington's equation, I can find out G Jz ds because this current is known and these greens function is known.

These greens function is a summation over all the modes as I told you earlier, so, I can stop these greens function if I am interested in one particular mode, I can stop the summation in the Greens function and make it applicable for only that mode and find out the radiated field due to that particular mode

So, if this is Jz is it, this is going to give me the scattered field Ezsc. So, this is the scattered field Ezsc. Once this Jz is known, I can integrate with any relevant Green's function and find out any relevant component of the field. So, I can find out my radiated field at this imaginary surface as I told you before I can find out the radiated field at this imaginary surface for one particular mode.

Because I have already the Greens function and I know this probe current the Greens function is a summation over all modes convolving the Greens function, this process is called convolution. This process is called convolution it is called convolving the Greens function with the probe current.

So, once this greens function is convolved with a probe current and I can stop the summation of the Greens function at restricted at one particular mode convolve this with the probe current I can find the scattered field due to that particular mode and therefore, I can find out therefore, I can find out E cross H star, I can find out E cross H star or real part of E cross H star, real part of E cross H star, double integral ds for that particular mode and thereby I can quantify the power radiated by each of these modes.

And I can have a chart showing at this point what are the powers radiated by the individual modes and which mode therefore, is dominantly contributing to the radiation here. So, these are all applications of how I use the pointing vector in the efficient design of guided structures or antennas.

This is the basic idea here is not to go to the details of how the Greens function is formed, or it is an elaborate process and it runs through hundreds of pages, but that is not the main point, the main point here is how the concept of the power the pointing vector enables us to find out design better devices and not only that to give us a deeper insight into the design of efficient devices.

We do not want to be you know like a try by luck that I want to you know, like design one particular make my antenna one can particular design frequency without any clue as to what is happening to the modes and how much power is being coupled to the desired mode. I can have a quantitative estimate nothing qualitative, a quantitative estimate of the power radiated at different modes and it will give me a rigorous perspective.

Because there is no approximation in the Greens function it is a rigorous technique it is a full wave technique with no approximation, I mean there are a couple of steps in it and any method will have a number of assumptions in that sense, but otherwise it is a very full wave and rigorous technique all the modes are considered and everything is taken into account.

So, that way I can find out, I can have greater insight into any given results or as is here a deeper insight into any given resonance of an antenna. So, thanks for attention. So, we stop here.