Antennas
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Module – 05
Lecture – 23
Circular MSA

Hello and welcome to today's lecture. In the last few lectures, we have been talking about microstrip antennas, what are its advantages, disadvantages and applications. And because of its several advantages, it is finding applications in many different areas. And then in the last lecture we also talked about rectangular micro strip antenna; various feeding techniques and what are the different modes of rectangular micro strip antenna, fundamental mode, higher order modes. We also studied what are the parametric effect, what is the effect of the width, height, substrate thickness, epsilon r and so on, on the performance of the antenna. And then we had just started talking about circular micro strip antenna. So, today we will continue our discussion on circular Micros Strip Antenna.

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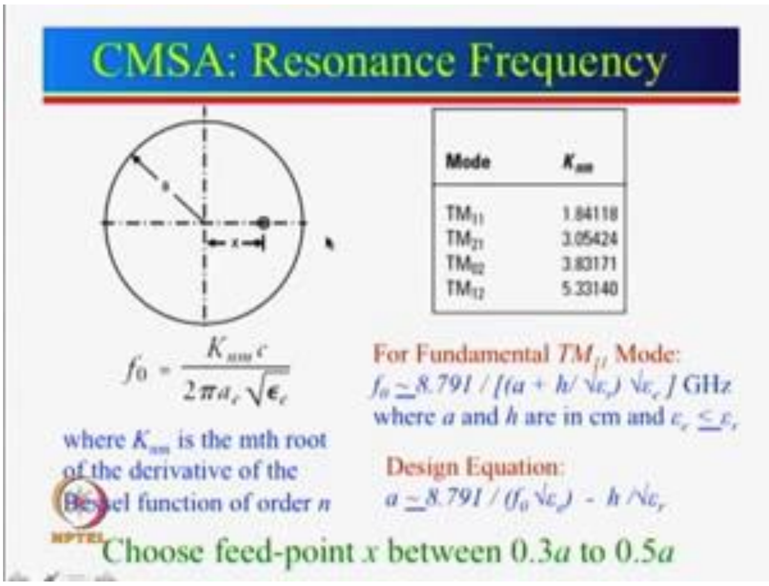

A circular micro strip antenna is defined by its radius a. So, that is governing the parameter and then it is printed on the substrate. So, it is as before for rectangular micro strip antenna, the substrate parameters will be epsilon r, thickness of the substrate h and tan delta equal to 0.001. That will be for low loss substrate and the resonance frequency of the circular micro strip antenna can be obtained by using this particular formula here.

Now here is a one new term compared to the rectangular micro strip antenna which is K nm. K nm is nothing but it is the mth root of the derivative of the Bessel function of order n. Now these derivations come into account because in case of a rectangular patch we had seen Bessel function did not come into because a rectangular patch is defined by length l and width w and along the length the variation was sinusoidal and over here also it is a variation is sinusoidal along the circumference. And in this case where Bessel function come into picture because the sin of sin or sin of cosine function has to be taken which gives rise to the Bessel function.

However, we need not worry too much about it because roots of Bessel functions are available and what we are interested to start with the fundamental mode, which is TM 11 mode. Then the next mode is TM 21 mode. You can see that the K nm is little higher now. Then next mode is 0 2 K nm is increasing. Next mode is TM 12, which is given by 5.33. But we will start our discussion with TM 11 mode, which is the fundamental mode. This is the one which is most commonly used and just to tell you what the first number implies.

So, first number here imply what is the variation along the circumference. This 1 implies that, there is a 1 lambda by 2 variation along the circumference. The second number implies 1 lambda by 2 variation along the diameter. So, in case of a rectangle just to revive so, the first number was the variation along length of the patch. Second number was along the width of the patch over here the first number is along the circumference and the second number is along the diameter. So, since we are feeding at this point here. So, let us say that if I feed here, if we denote this as a positive voltage here, then this positive voltage will keep on decreasing and then it will go to 0. It will go to negative voltage to maximum negative voltage.

So, if I denote this let us say double plus and then this will become plus, double plus means it has more amplitude then plus then, it goes to 0 then, minus then, double minus and minus 0 plus and double plus. And since the voltage here is 0, impedance here is 0, impedance here will be maximum because current is 0 here. So, v divided by i will be maximum again. So, somewhere along this axis here, we can find a feed point location where, input impedance will be 50 ohm.

So, now for fundamental mode we have simplified this expression here. So, K nm is 1.84118, c is nothing but 3 into 10 to the power 10 centimeter per second, the 2 pi a e is a effective. So, this term here, these first two terms in the numerator and two terms in the denominator, if we simplify it comes out to be 8.791 and frequency is defined in terms of Gigahertz.

Now, we have used approximate formula for a e. So, a e has been written as a plus delta a delta a is nothing, but h by square root epsilon r. So, it is very similar to what we had done in the case of rectangular patch. In rectangular patch we had said this is length let us say l. So, we had taken l effective which was delta l on this side, delta l on this side, but here we are taking only a effective. So, this is a, a effective will be all around. So, the a effective will be a plus delta a and we have used an approximation of delta a as h by square root epsilon r. And epsilon effective comes as it is here and in general epsilon effective should be less than epsilon r and a and h are taken in centimeters. So, that is how this number comes.

Now this equation can be simplified to become a design equation; that means, if f 0 is given, substrate parameters are given, then we can find out what is the value of a. So, just look into this here; so a plus h by square root epsilon r goes to this side, f 0 comes on this and then plus term here comes to this side here. So, for given substrate parameter which will be epsilon r h and f 0 then we can find the value of a.

And the next thing which will be important is, where to choose the feed point. So as a starting point, we are giving you a good guess, which is x can be 0.3 a to about 0.5 a. So, for a narrow band CMSA, which is circular micro strip antenna you can start with 0.3 a and generally for broadband CMSA, we can choose this as a starting point. Now how do we decide broadband or narrow band CMSA? If you recall in the last lecture I had shown you a curve, which actually showed percentage bandwidth for different values of dielectric constant and substrate thickness. So, those are the parameters will determine then the feed point location.

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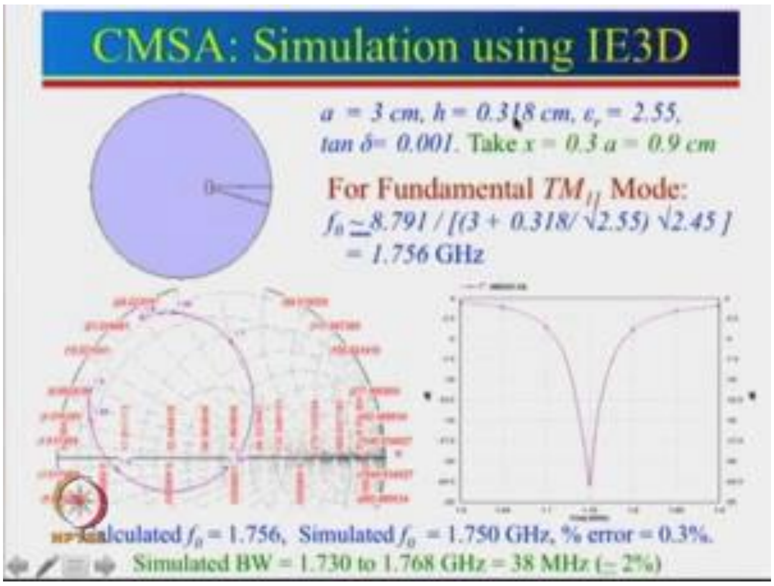

So, let just see the next result. So, what we have done? We have done a simulation. So, we have taken a as equal to 3 centimeter, h is 0.318 centimeter which is actually equal to 1 by 8 inches substrate, epsilon r is 2.5, tan delta is 0.001. So, this is nothing, but a very low loss dielectric substrate. So, as a starting point we have taken x as 0.3 a, which comes out to be 0.9 centimeter. So, corresponding to a equal to 3 centimeter, we substitute various value. Over here, now epsilon e I have taken as 2.45. As I mentioned epsilon e should be less than epsilon r. So, epsilon r is 2.55 I have taken less than that which is 2.45.

Now, the other way to calculate is that we actually equate the area of the circle with area of the triangle, then find out the effective width. From the effective width you can calculate what is the value of epsilon e, but here since we know it should be slightly less instead of 2.55 we have taken a point one less which is about 2.45. If we use this formula we get f 0 equal to 1.756 Gigahertz. So; however, we have done the simulation using IE3D. So, for this particular feed point and these parameter, what we found? This is you can see is a 50 ohm point here. It is very very close to the 50 ohm.

So, this impedance is roughly about 54 ohm also. And this is the resonance frequency curve. So, we can actually see that the resonance frequency obtained is 1.75. So, that is the simulated frequency. What we calculated using this approximate formula, is1.756. So, we get a percentage error of 0.3 percent. As I mentioned earlier also these approximate formulas are good, you can get as a very good starting point and the frequency will be within 1 to 2 percent. So, this is a very good you know the value which we are getting.

In fact, now if you want to get let us say if we really want some different frequency. All we can do it is we can actually use the concept from here. We can see that if I take a e on this side. So, f 0 a e will be a constant number for a given substrate parameter and for the given fundamental mode.

So, we can actually say f 1 a 1 is equal to constant is equal to f 2 a 2. So, here if we know what is the value of f 1 which is what we have got here, we know what is the value of a 1 and if you want any other frequency just use the new value of frequency f 2. Find out the value of a 2. So, this way we can actually redesign the antenna very quickly. So, one can actually see that what is the bandwidth over here. So, we have actually written simulated bandwidth and that bandwidth is calculated corresponding to reflection coefficient equal to minus 10 dB which is approximately equal to VSWR 2 and this bandwidth is approximately 2 percent and this can be verified using the design curve, which I had given to you earlier.

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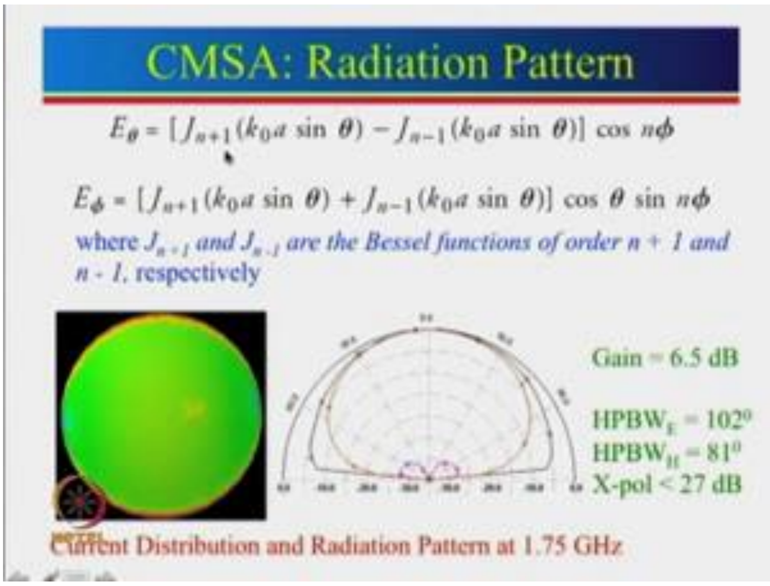

So, how do we calculate radiation pattern? So, the radiation pattern is again very similar to actually rectangular micro strip antenna. We can still find E theta and we can still find E phi, but over here the radiation pattern involves Bessel functions. So, J n plus 1 and J n minus 1 are the Bessel functions of order n plus 1 and n minus 1 respectively. And then these thing takes lot of time to do the computation, but I want to bring one additional point here. If u see E theta here and E phi, then E phi there is a additional term which is cos theta.

So, along the broad side direction theta is equal to 0, so cos 0 will be 1. So, this term will become 1, but along theta equal to 90 degree, cos 90 will be 0. So, this particular component will go precisely equal to 0. I also want to mention these derivations are valid only for infinite ground plane not valid for finite ground plane. So, for the fundamental mode, I have shown here the current distribution. So, we actually saw that the voltage is maximum here and then the voltage goes to 0, then voltage goes to minus. So, current will be opposite. So, current will be 0 here, current is maximum and then current goes to 0. So, just to tell here, the red color here implies maximum radiation, a blue color implies minimum radiation or current density here. So, current is 0, it is becoming maximum, it goes to 0.

And similarly so that actually shows the fundamental mode. One mode along the circumference, along the diameter also we can see that the current is 0, green is little more and yellow is even more slightly red here, which is higher and then it comes back to the zero value. So, that is the current distribution which we have shown at 1.75 Gigahertz. And this is the radiation pattern for circular micro strip antenna. If you actually see this pattern looks very very similar to the radiation pattern of a rectangular micro strip antenna. Whereas, in rectangular micro strip antenna we did not have any of these Bessel function.

Now just to first tell half power beam width here in E plane, which is shown by the black here is 102 degree of power beam width in H plane is 81 degree and cross polar level is very small, which is about 27 dB here. So, why the radiation pattern of circular micro strip antenna is very similar to rectangular micro strip antenna? We can actually just look at this circle here one more time. So, let us say we actually said the voltage here will be double plus then it goes to plus, then it goes to 0, it goes minus, it goes to double minus.

So, now imagine a rectangular micro strip antenna. In case of a rectangular micro strip antenna fundamental mode, we had a voltage distribution which was uniform along this axis and along the width and for along the length, the variation was from plus to 0 to minus. Now this you can think as an approximation. So, we have a double plus field here and the plus field here, plus field here. So, one can use little bit of approximation assuming that this field is roughly uniform and from plus here it goes to 0 it goes to minus. So, that is a variation along the length in case of a rectangular patch over here along this.

So, if you see if I do some approximation, we can say this is approximately uniform field here and the field varies sinusoidally along this dimension. So, that is why the radiation pattern of a circular micro strip antenna is very similar to that of a rectangular micro strip antenna. And gain is also similar to the square micro strip antenna, I am not using the term rectangle here because circle is to be equated to a square patch because a rectangular patch with larger width will have a larger gain, rectangular patch with smaller width will have a smaller gain. So, this we should compare with square patch.

Then the question comes, if the square patch and circular patch are almost same why should I use a Circular? Or what are the advantages and disadvantages? So in reality as far as the performance is concerned they are very similar, but there is a one additional difference here and that you have to see that the modes of the circular micro strip antenna are given by this here. Whereas, mode for a rectangular patch will be given as say 1 0 mode, 2 0 mode 3 0 mode and. So, 1 0, 2 0, 3 0 mode actually imply; first order mode, second order mode, third order mode. And these three modes will be corresponding to f 0, 2 f 0, 3 f 0.

Now suppose this rectangular micro strip antenna has to be fed by a let us say oscillator, oscillator followed by amplifier. Now invariably all the oscillators will have some harmonics and harmonics will be at 2 f 0, 3 f 0, a patches also resonating at 2 f 0, 3 f 0. So, what really happens in case of a rectangular patch whatever are the oscillator harmonics they also get amplified in the same way, through the amplifier and then transmitted through the antenna but in case of the circular micro strip antenna. If we now see K nm, which is 1.84118, the second mode is at 3.05. You can see that it is not the double the frequency.

Even the third mode is not really exactly the double frequency. The TM 12 mode is also not exactly three times. So, what happens? These circular micro strip antennas will not radiate as efficiently as rectangular micro strip antenna for this higher order harmonic.

So, some time circular micro strip antennas are preferable where we have that problem; however, in general when we cut a ground plane we always cut a patch let us say as rectangular shape or a square shape. So, circular shape will take much larger area. But recently we are doing one project where we are putting antenna inside a circular cavity. So, in the beginning you know by default we started with rectangular micro strip antenna, but when you put a rectangular micro strip antenna inside a circular cavity along the diagonal, the spacing between the cavity and the patch is different then along the length or the width.

So, then later on we took circular patch inside a circular cavity. So, many a times it is not just that what antenna you want to use, it is also where you want to use the antenna. This is very very important and that is why many times I say; antenna design is not just science, not just engineering or physics or math, but it is also to be placed where it has to be placed. So, there is a lot of art involved into it. Sometimes you have to depending upon the where you have to put it. Let us say if you have to put inside a mobile phone, then you would prefer to put a rectangular patch because mobile phone has a shape of rectangular configuration.

If you want to put in the circular configuration, circular box it is better to put the antenna which is of a circular shape or we will discuss some other configuration. For example, if the box of the container has a triangular shape then, we may want to put a triangular antenna. So, depending upon shape and the placement where you need to put it antenna is governed by that also.

So, now let us just look at the circular micro strip antenna operating at a higher order mode, which is TM 21 mode. So, 2 here implies 2 half wavelength variation along the circumference and 1 half wavelength variation along the diameter. So, let us see here, I have shown the current distribution for a given case here. So, we will just look into that also. So, if you see current is 0 here, then it goes to maxima, then it goes to 0, then again goes to maxima, goes to 0. So, that completes two half wavelength variation along this part and the same thing is repeated here. Now let just see here in current you can see here it is going to 1, then goes to 0, then goes to 0, then goes to 0. So, that is basically variation of the current along the center.

So, let us say we have taken an example here where a is same as 3 centimeter earlier one 0.318 at the same substrate, but here we have to use a different feed point to do the matching. Now first let just see the calculation here. So, TM 21 mode, K nm value is now 3.054 again the rest of the things are similar I have taken epsilon effective as point 2.45. So, if you use this very simple formula, we get a frequency of 2.912. Whereas, what we stimulated is 2.94. So, you can see that the error is about 28 Megahertz which is less than 1 percent. So, again this simple formula is pretty good and in this particular case what we get? We actually get a conical pattern.

So, for TM 11 mode we were getting a broadside pattern, but now it is a conical pattern why? Because let just see here. So, this is now plus voltage point of view. So, plus voltage then, 0 voltage, then minus, then 0, then plus, then 0, minus 0, plus.

So, what really is happening? So, this plus field here will be in this particular direction. And this plus will be in the opposite direction. Since the two fields are in the opposite direction, they will cancel in broadside direction. And hence there is a null and one can see that the null depth is almost more than 15 dB along the broadside direction and the maximum radiation is in this particular fashion. See this kind of a pattern is also required many a times, when we actually want to send the radiation in the conical direction. In that case this will be very useful configuration.

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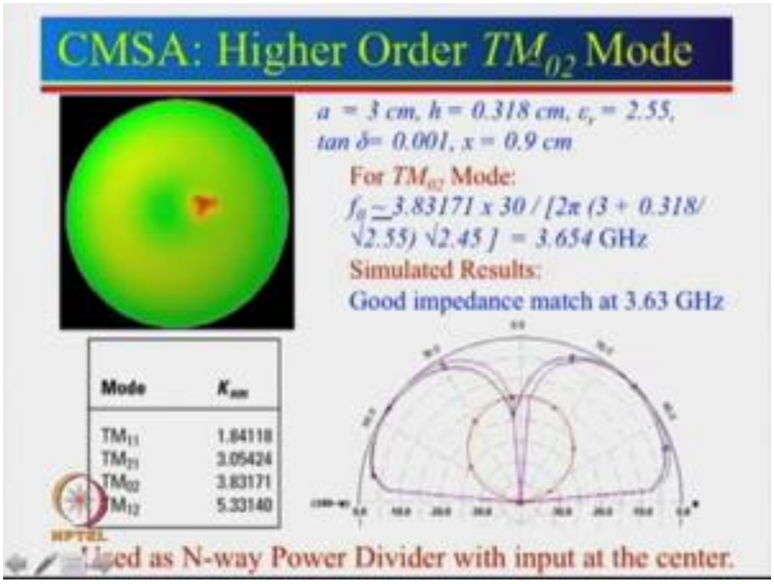

Then let just look at another mode which is a TM 02 mode. Beforehand, only I want to tell you this mode is generally not used for antenna application, but it has a very good application as a N-way power divider, but we will come to that one by one. So, again the case is same a is 3, h 0.318, epsilon r, tan delta same as before x is also very similar to the TM 11 mode. So, x is 0.9, now since this is a 0 2 mode, we have to see what is the K nm value. So, K nm value is 3.8, we put it over here, epsilon effective again I have taken as 2.45 and that gives me a resonance frequency of 2.654. So, we stimulated this here we got a good matching for epsilon, for x equal to 0.9. So, that matching was at 3.63 Gigahertz. So, what is the error here? The error is about 24 megahertz again that is less than 1 percent error.

Now, how we can see the current distribution? Let us see over here. So, 0 means there is a no variation along the circumference. So, you can see that the color of the current distribution remains almost same and there is a 0 2 mode here; that means, two half wavelength variation. So, you can see that the current starts from the lower value goes to the maximum, goes to 0, then goes to maximum, goes to 0. So, that is a 2 lambda by 2 variation, but now let us think from the voltage point of view.

So, what it really means current 0 means voltage is maxima and since current is uniform; voltage is uniform all along the circumference. And what is the voltage here? Again at this point also voltage is maxima because it is plus 0, minus 0, plus. So, minus or plus will only imply a phase difference of 180 degree, but as far as amplitude is concerned both are showing maxima. So, now, let us see an application were we want to use this particular configuration as a N-way power divider. So, let us say if we feed here, now if I take the output let us say from here and here. This actually becomes a two way power divider we feed here; you take one output here and here.

Let us say you want a four way power divider. So you put one output here, one here, one there and one here. So, that will become a four way power divider. In fact, we have used this particular configuration even for 16 way power divider. So, you can put the things at different places. So, in general you can design N-way power divider in a very simple way. All you do it is you locate all those N-way at an angle of 360 by N. So, for example, four way 360 by N will be by 360 by 490 degree. So, 1, 2, 3, 4; if you want let us say 10 way power divider. So, 10 way will be every output port will be at 36 degree. So, it is a very nice simple power divider.

In general otherwise suppose if I wanted to realize a 16 way a normal way to design is you take a one way, then one way will become two way and then two way each of them will be split again into 2. So, that will give 4 way power divider and then each 4 will be further divided into 2. So, that will give 8 way power divider and then those are again further divided we will get a 16 way power divider. But here by using this very very simple configuration, we can actually design a very nice power divider and which will divide power equally to all the ports and all the ports will be at the same phase also.

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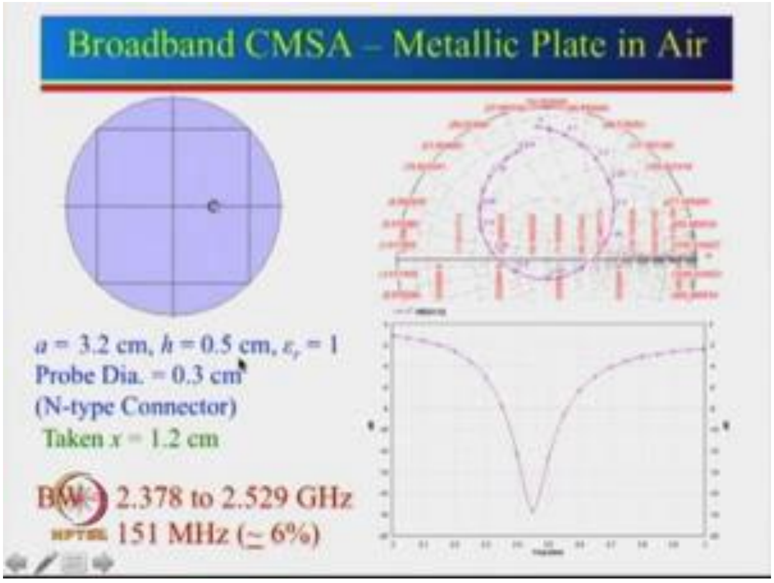

So, now we can actually design a broadband circular micro strip antenna. So, that is nothing, but realized by a metallic plate in air. So, here we have taken a equal to 3.2 centimeter, h equal to 0.5, epsilon r one. In fact, this we have designed to cover the Wi-Fi frequency range. We know that Wi-Fi is from 2.4 to 2.483. So, over here we have taken N type connector, probe diameter is 0.3. We have taken x as 1.2, if you recall I gave a starting point as 0.3 a to 0.5 a. Since it is relatively broadband, 0.3 a will not be a good solution, so 1.2 is roughly close to 0.4. And for this here we can see the impedance plot 50 ohm matches somewhere here.

Instead of 1.21 could have taken a 1.15 also for a little better match, but this is still good enough and over here the bandwidth what we are getting for VSWR less than 2, is 151 Megahertz. So, you can see that this covers the entire band from 2.4 to 2.483. We have a margin on the left side; we have a margin on the right hand side. So, that if there are some tolerances in the manufacturing that will be taken care of. Now of course, one additional thing is you cannot float this metallic plate in air, you need some supporting structure also. So, how we did that? And how we obtained the real performance? We will tell you in our next lecture.

So, today we just looked at quickly how to find out the resonance frequency of circular micro strip antenna? And then we looked at the current distribution for fundamental TM 11 mode and then higher order modes of TM 21 mode as well as 02 mode and we also saw that for fundamental mode radiation is in the broadside direction and for TM 21 mode radiation is in the conical direction. So, even though TM 02 radiates conical direction, but we never ever use, but TM 02 is very good and useful for power divider application. And then towards the end we also looked at how to realize a broadband circular micro strip antenna. However, in the next lecture we will see how to do the practical implementation of broadband circular micro strip antenna.

Thank you very much. We will see you next time, bye.