Microwave Theory and Techniques
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Module – 10
Lecture – 49
Microstrip Antennas

Hello and welcome to today's lecture on Microstrip Antennas.

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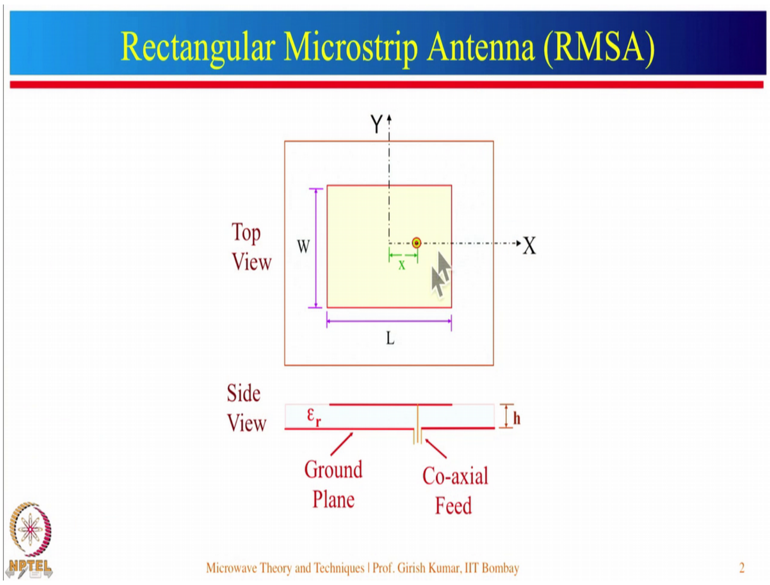

This figure shows a rectangular Microstrip Antenna. So, we have a ground plane over here then a substrate and on top of the substrate, we have a rectangular patch. If, you really see this looks very similar to the circuits which we have discussed earlier like power dividers, couplers, filters and other things.

Now, in case of microwave circuits, what we do we try to send signal from point a to b on the PCB itself, in that particular case we do not want any radiation to take place whereas, in case of microstrip antenna we want this patch to radiate in the free space.

So, how do we achieve this? There are 2 things which we need to do. So, that a microstrip circuit behaves a better microstrip antenna and these 2 things are we should try to choose epsilon r value, as small, as possible and we should choose the thickness of the substrate as high as possible. That does not mean you can take very thick substrate there is a limitation that h by lambda 0 should always be less than 0.06. Now, as you can see it is a very simple geometry. So, it has lots of advantages.

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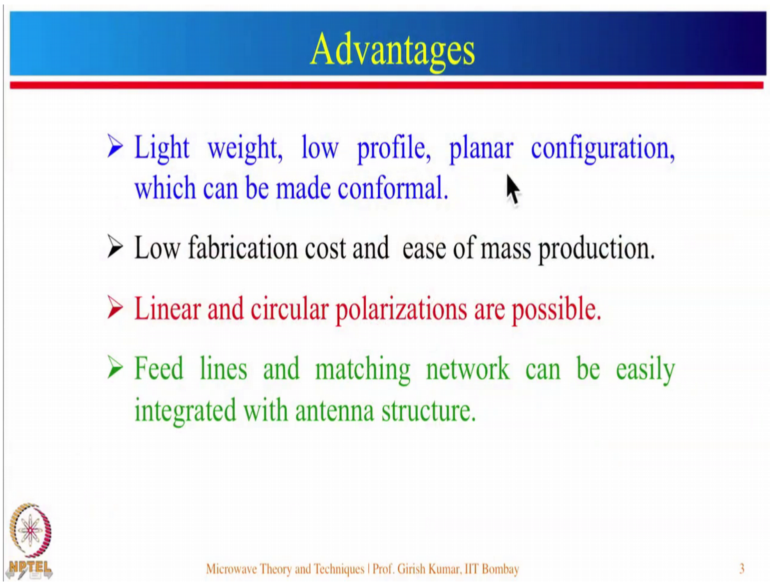

It has lightweight low profile, planar configuration, and which can be made conformal to let us say the host body which could be even a missile helicopter, plane, satellite and so on.

Since, it uses of PCB technology. So, fabrication cost is very low and also mass production can be done very easily. Both linear and circular polarizations are possible, we will show you some of these cases later on. Also feed lines as well as matching network can be easily integrated with antenna structure itself. I am going to show you an example of microstrip antenna array, where feed lines as well as matching network both are integrated on the same substrate. However, microstrip antennas have few disadvantages 1 of the main disadvantage is narrow bandwidth.

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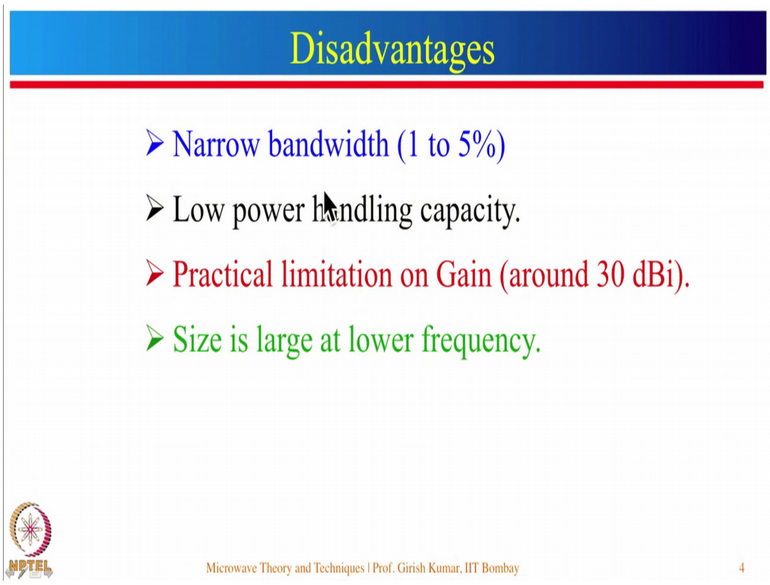

Typical bandwidth of a microstrip antenna is of the order of 1 to 5 percent. However, I am going to show you the techniques, how to increase the bandwidth of microstrip antenna?

It has typically low power handling capacity after all it is fabricated on a PCB. So, it cannot handle very high power, but again I am going to show you 1 example which can handle very high power. There are practical limitations on the gain. So, 1 can obtain gain of around thirty dBi also. For larger gain it is better to use parabolic dish antenna, which I am going to cover after 2 lectures. Now, size of the microstrip antenna is large at lower frequency, you can think about if we are designing antenna let us say at 100 megahertz. What is going to be the wavelength, 3 meter and if we design a lambda by 2 antenna that is going to be a very large antenna.

However, I am going to show you some configurations, where we can reduce the size of the microstrip antenna. So, because of so, many advantages microstrip antenna finds several applications.

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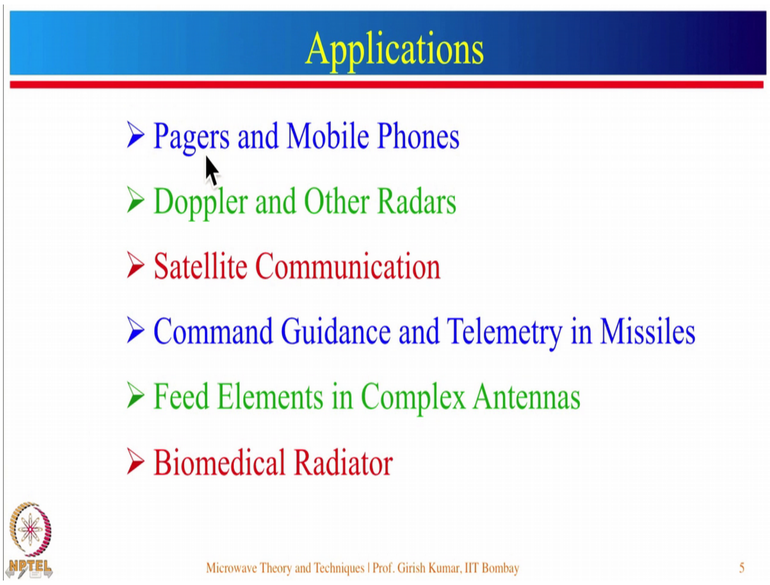

So, these were used in pagers of course, now days there are no pagers, but it has been used in mobile phones microstrip antennas find application in Doppler and other radars, satellite communication, missile guidance systems, feed element even in complex antennas and biomedical radiator. By, the way this is not the complete list of applications there are many other applications of microstrip antenna.

So, I have shown you the configuration only of a rectangular microstrip antenna. However, there are so, many different shapes, which have been reported in the literature.

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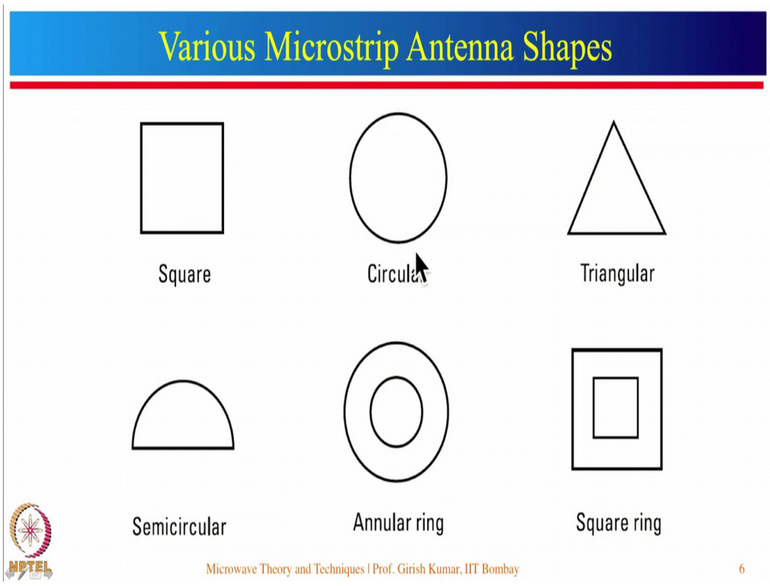

So, these are square, circular, triangular, semicircular, annular ring, square ring in fact, there are shapes like pentagon, hexagon and so on also, but today in my lecture I am going to focus mainly on rectangular microstrip antenna.

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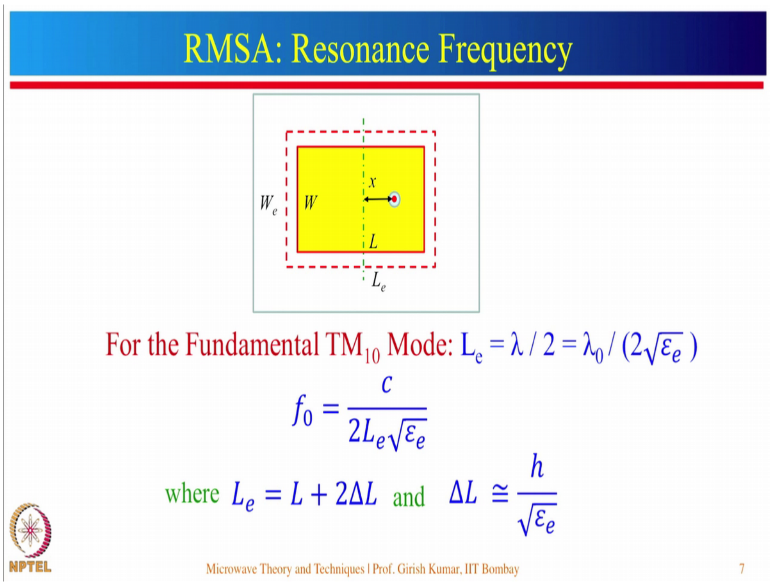

So, let us see how we can find the resonance frequency of a microstrip antenna? So, here we have a rectangular patch whose length is L width is W. You can see that I have shown dotted line over here which actually represents effective length as L e, effective width as W e. So, where is this effective length coming into picture?

So, just recall now I showed you there is a microstrip patch, which is on top of the ground plane. So, there will be fringing fields from the edges. So, these fringing fields account for additional capacitance. The additional capacitance can be compensated by simply extending the length outwards. So, here I am just going to show you that L e is nothing, but equal to L plus 2 times delta L, where delta L is the extension in 1 direction delta L is extension in the other direction.

So, total L e will be L plus 2 delta L. Now, for the fundamental TM 1 0 mode, what is TM 1 0 mode? Well, 1 actually implies that there is a 1 half wave length variation along the length ok. I am going to show you these things in more detail in the next slide, but 0 implies no variation along the width.

So, now recall dipole antenna, what is the effective length of the dipole antenna it should be lambda by 2. So, here also effective length of the rectangular patch L e should be equal to lambda by 2, but since it is printed on a substrate lambda is nothing, but equal to lambda 0 divided by square root epsilon e. So, why there is a epsilon e and not epsilon r? The reason for that is most of the field will be confined within the substrate material, but part of the field will be going in the air. So, to account for the field in the air we use effective dielectric constant.

So, over here, so if we now substitute the value of lambda 0 as C divided by f 0, where C is velocity of light. So, we can write the expression for f 0 just note it is C divided by f. So, f 0 will become C divided by 2 times L e square root of epsilon e. So, L e is given by L plus 2 delta L and the value of delta L can be approximately calculated as h divided by square root epsilon e L, will also show you later on what is the expression for epsilon e? But right now let us see the characterization for TM 1 0 mode.

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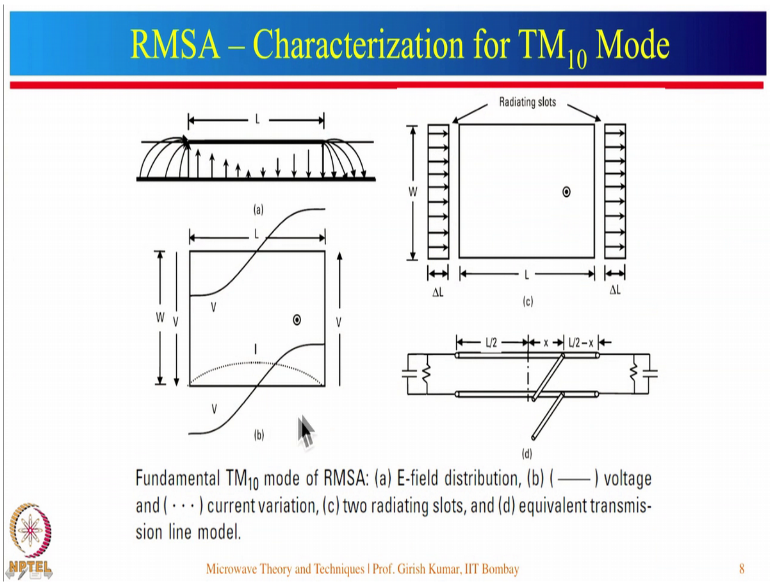

So, for TM 1 0 mode as I mentioned there is a 1 half wavelength variation along the length. Now, you can see that this is the voltage distribution, this is the current distribution. The reason for that it this is an open end, at open end current will be equal to 0, it will go to maxima and come back to 0, why? Because, the total length is equal to lambda by 2 and since it is open circuit here, voltage is maxima here, it goes to 0 and then it goes to the negative maxima.

And, field is uniform for TM 1 0 mode field is uniform along the width. So, you can see that this voltage will remain constant and voltage will remain constant along the width. So, now let us see how the fringing fields will vary. So, from here you can see that the fringing fields are going outward to the ground.

Since, we are feeding at this particular point over here we are assuming this voltages positive. So, for positive voltage field will be going from here to the ground. And, as we move along the length, you can see that the field intensity will keep reducing as you can see the amplitude will keep on reducing. And, then the direction changes and you can see that now the field will be like this here. Now, you can see here most of the field is confined within this dielectric medium, but part of the field is actually in the air. And, that is why we use the term epsilon effective for characterizing, rectangular, microstrip antenna.

Now, these field distributions can be resolved into 2 components vertical and horizontal component. You can see that this vertical component is going upward, this vertical component is going downward. So, these 2 field cancel out in the broadside direction. However, if you look at this particular thing the direction of this is in the right hand direction, you can see it is going in this direction, if you look at the direction of this one here, it is also going in this particular direction.

So, the analysis of rectangular microstrip antenna can also be done by assuming that there is a 1 slot antenna over here, there is a another slot antenna over here, and the amplitude of these 2 fields are equal the reason is this is plus V this is minus V.

And, we can apply array theory to find out the radiation pattern. So, just think about 1 slot antenna another slot antenna. And, we can actually find out the total pattern by multiplying the slot pattern with the array factor, rectangular microstrip antenna can also be modeled as a transmission line. The fundamental mode of rectangular microstrip antenna can be modeled as transmission line, reason for that is there is a no field variation along the width.

So, this length is approximately lambda by 2. So, we have a radiation resistance in parallel with capacitance, which is nothing, but fringing field capacitance, this is the radiation resistance corresponding to this particular slot here, and then there is another one on this particular side.

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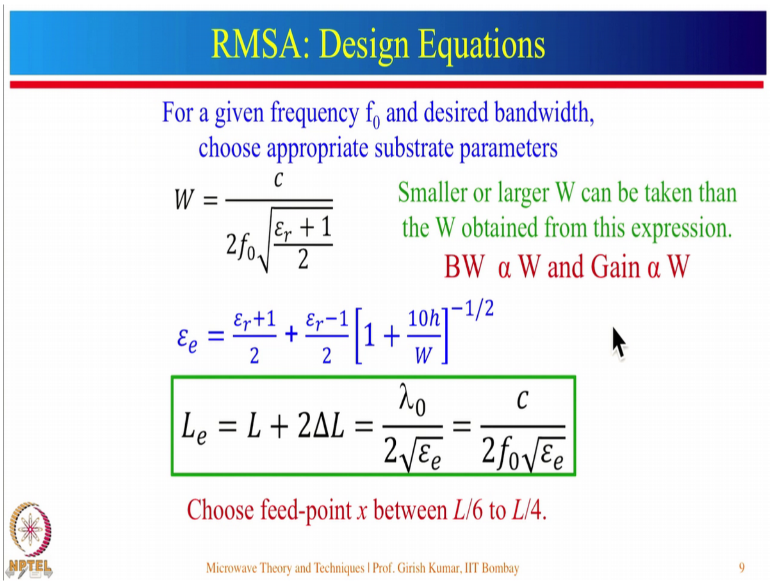

So, now let us see how we can design rectangular microstrip antenna? So, generally speaking design problem will be that frequency is given to us and desired bandwidth will be given to us and then we have to design the length and width of the rectangular patch, but before we do that we have to choose appropriate substrate parameters. Later on I am going to show you, how to choose these appropriate substrate parameter, but let us just assume that we have chosen substrate parameters as epsilon r and h then first step is to calculate the width.

So, width can be calculated using this particular expression over here. Now, in this particular case I just want to mention, you can take smaller or larger W, then the W obtained by using this particular expression depending upon what is the requirement?

So, just want to mention, if you take a larger W, then what will happen bandwidth will be more as well as gain will be more. So, bandwidth is proportional to W as well as gain is proportional to W, why gain increases, because total aperture has increased. Why bandwidth is increasing? The reason for that is that as W increases fringing fields will increase. If fringing fields increased; that means, there will be a more radiation and hence q will be small and if q is small bandwidth will be a large. Epsilon effective can be calculated using this particular empirical formula, there are many different formulas are there, but I have found this formula to be best suited for designing rectangular microstrip antenna. Epsilon e can be calculated for chosen value of subset parameters epsilon r and h and whatever the W value you have chosen substitute over here. And, then we can find out the value of L e for given frequency value. And, then after we have calculated L e find the value of L, I have given already expression for delta L.

Then, comes the next point what should be the feed point location. So, I am just giving you a simple rule of thumb that choose feed point x between L by 6 to L by 4. Generally we choose L by 6 for narrow bandwidth antenna and L by 4 for broadband antenna. So, let us take a designed example.

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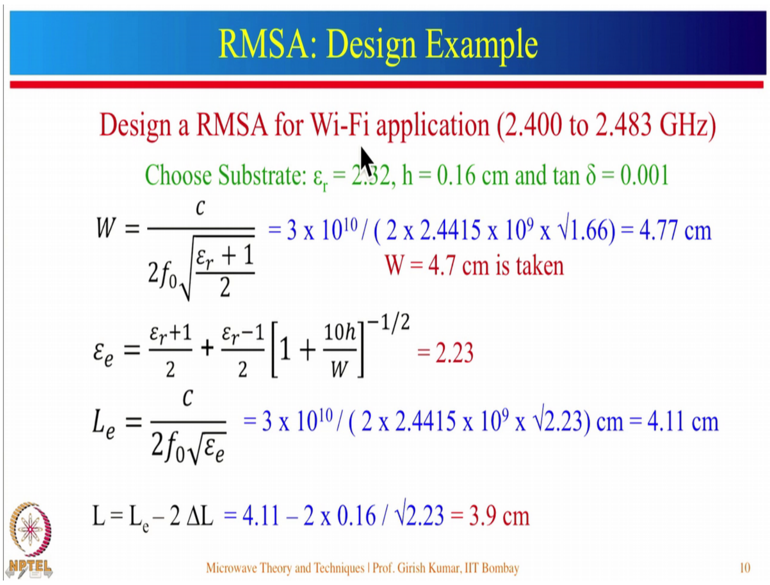

So, I am taking a practical design example of Wi-Fi application. Now, Wi-Fi works from the frequency range of 2.4 to 2.483 gigahertz. So, we choose some substrate parameters epsilon r is 2.32 h is equal to 0.16 centimeter and tan delta is 0.001. Now, you might wonder why we have chosen these parameters. In fact, I will tell you beforehand only these are not the optimum parameters for this particular application, but sometimes you know we learn better if we make mistakes.

Then I will take some substrate parameters see what we get then I will tell you how to improve the design? So, first step is to calculate W I had given the expression in the previous slide. So, C is equal to 3 into 10 to the power 10, this is in centimeter not in meter if in meter, it will be 3 into 10 to the power 8. So, 3 into 10 to the power 10, that is in centimeter then down below is 2 into f 0.

So, the center frequency of this is 2.4415 into 10 to the power 9 and epsilon r plus 1 by 2 is equal to 1.66 it comes out to be 4.77 centimeter. So, we have chosen W equal to 4.7 centimeter.

For this value of W, we can now find the value of epsilon e, which comes out to be 2.23 you can see this value is slightly smaller than the value of epsilon r. So, now, we can find the value of L e. So, by substituting various values it comes out to be 4.11 centimeter, after that we can calculate the length L equal to L e minus 2 delta L. What is delta L, h divided by square root epsilon e? So, that comes out to be 3.9 centimeter. So, now, we are going to take these values and do the simulation.

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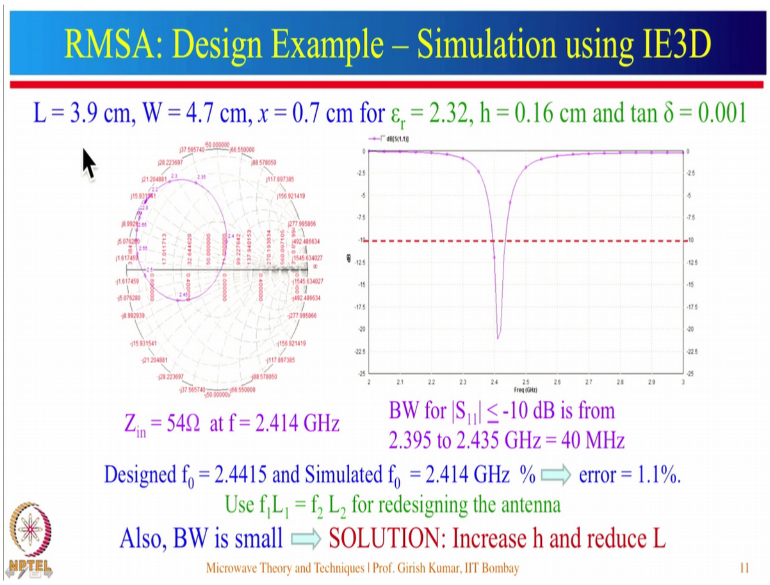

Now, we take these design values 3.9 centimeter, now we will start with the, now we take these designed values of l equal to 3.9 centimeter W equal to 4.7 centimeter, and as I mentioned take x between L by 6 to L by 4. So, L is 3.9 centimeter. So, we choose x equal to 0.7 centimeter.

And, these are the substrate parameter. So, simulation has been done using IE 3 D software. So, you can see here this is the input impedance plot and this is the reflection coefficient plot. Z n is equal to 54 ohm at f equal to 2.414 Gigahertz. As, you can see this frequency is slightly different than, what we had done the design for. Now, let us see what is the bandwidth for S 1 less than minus 10 d B is from 2.395 to 2.435 gigahertz, which is equal to 40 megahertz. In fact, the desired bandwidth is much more than 40 megahertz. So, let us see what needs to be done now?

So, first start with the analysis. So, we had designed this antenna for f 0 equal to 2.4415 whereas, simulated value comes out to be 2.414 gigahertz. That means, percentage error is about 1.1 percent. In fact, we have given you very simple design equation and if you are getting error of only of the order of 1 percent. In fact, it is the very good starting point. Now to improve the design of the antenna all you need to do it is use this particular thing f 1 L 1 equal to f 2 L 2. So, for example, in this particular case we had taken L as 3.9. So, L 1 is 3.9 centimeter, what we have obtained here that is 2.414. So, put 2.414 here.

And, then what is the desired frequency 2.4415 calculate the value of L 2 use this value to do the simulation, you will get nearly perfect result now comes the next part bandwidth is small. So, what do we do if bandwidth is small solution is increase the height. So, just to tell you bandwidth is proportional to the substrate thickness. So, if you double the substrate thickness bandwidth will also increased by almost 2 times. And, if you increase h remember you have to reduce the value of L slightly, why because if you increase h fringing fields will increase; that means, delta L will increase. So, L has to be reduced slightly.

So, I am going to now show you how to properly choose substrate parameter?

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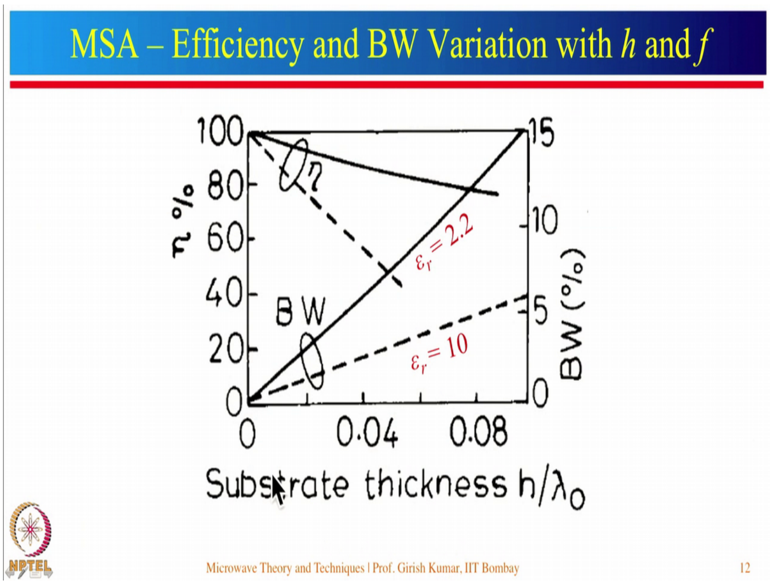

So, here is the plot substrate thickness is plotted along the x axis, this axis shows the efficiency of the antenna and this axis shows bandwidth of the antenna. So, plot is for 2 different values of epsilon r this is for epsilon r 2.2 this is for epsilon r equal to 10. So, you can see that as substrate thickness increases, for this particular case let us say bandwidth keeps on increasing. And, bandwidth keeps on increasing for this case also, but you can see that bandwidth is much more for epsilon r equal to 2.2 as compare to bandwidth for epsilon r equal to 10.

However, let us see what is happening to the efficiency? As, we keep on increasing the substrate thickness you can see that the efficiency is decreasing. And for epsilon r equal to 10 efficiency is relatively poor. So, in general I want to tell you please do not use very high value of epsilon r for designing rectangular microstrip antenna, or any microstrip antenna.

Generally, choose lower value of epsilon r. So, that you can get better bandwidth as well as better efficiency, I just want to also mention if you take epsilon r equal to 1, you can just think about extrapolating this result. So, for epsilon equal to 1, this curve will be going something like this. So; that means, you can get much better bandwidth also efficiency curve instead of going like this, efficiency curve will be almost like this here.

So, by choosing lower value of epsilon r you can get better bandwidth as well as better efficiency. You can see that typically bandwidth is of the order of 5 to 10 percent. Even though you can see here bandwidth is 15 percent, but corresponding to this particular case, you can see efficiency will be relatively poor.

So, that is the reason majority of the time people say bandwidth of the microstrip antenna is relatively small. So, that you can get a better efficiency, but later on I am going to show you lot of broadband antenna configurations.

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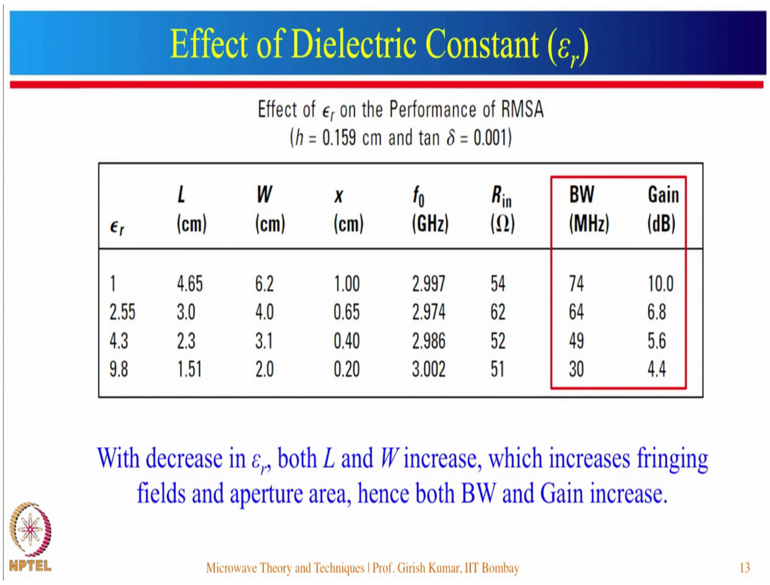

ϵ_r	L (cm)	W (cm)	x (cm)	f_0 (GHz)	R_{in} (Ω)	BW (MHz)	Gain (dB)
1	4.65	6.2	1.00	2.997	54	74	10.0
2.55	3.0	4.0	0.65	2.974	62	64	6.8
4.3	2.3	3.1	0.40	2.986	52	49	5.6
9.8	1.51	2.0	0.20	3.002	51	30	4.4

So, this table shows effect of the dielectric constant. So, here are multiple cases of epsilon r starting from 9.8 to 4.3 2.551.

Now, when we reduce the value of epsilon r, length will increase correspondingly, width will also increase correspondingly, we have designed all of these parameters for f 0 approximately equal to 3 gigahertz. And, you can see that bandwidth increases as epsilon r decreases. So, epsilon r decreases size increases. So, bandwidth increase, as well as gain increases. Why gain is increasing, because total aperture has increased both L and W have increased because of the low value of the epsilon r.

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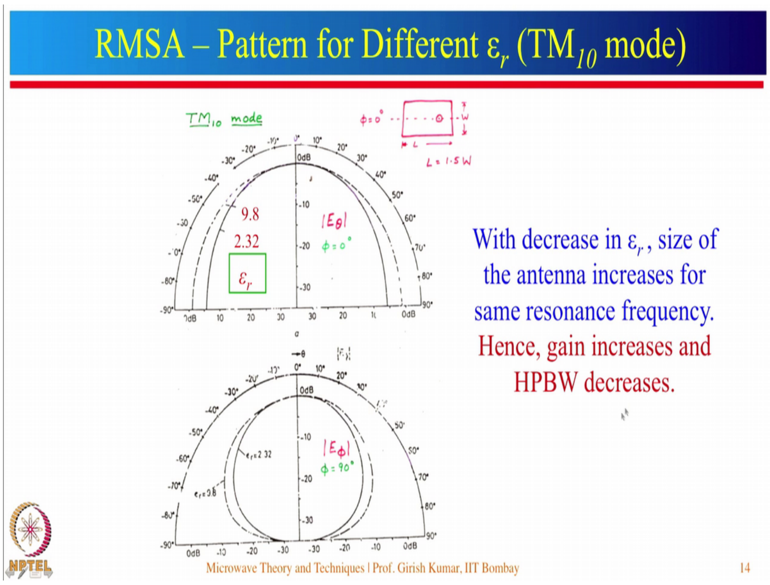

So, let me show you the radiation pattern of the rectangular microstrip antenna for TM 1 0 mode. So, this is the e plane pattern this is the h plane pattern do not get confused it shows here E theta in phi equal to 0 degree plane. So, E theta phi equal to 0 degree plane is this one here. So, this is E plane and perpendicular to that will be e phi in phi equal to 90 degree plane. So, that corresponds to h plane radiation pattern.

Here, there are 2 plots are there 1 plot is for epsilon r 2.32 another plot is for epsilon r 9.8. So, one can see that as epsilon r is reduced from 9.8 to 2.32. So, what has happened half power beamwidth has reduced? So, why is that because as we reduce the value of epsilon r size increases? Size increases mean gain increases and gain increases mean half power beamwidth will decrease. So, same thing you can note for h plane pattern also this is for epsilon r 9.8 this is for epsilon r 2.32.

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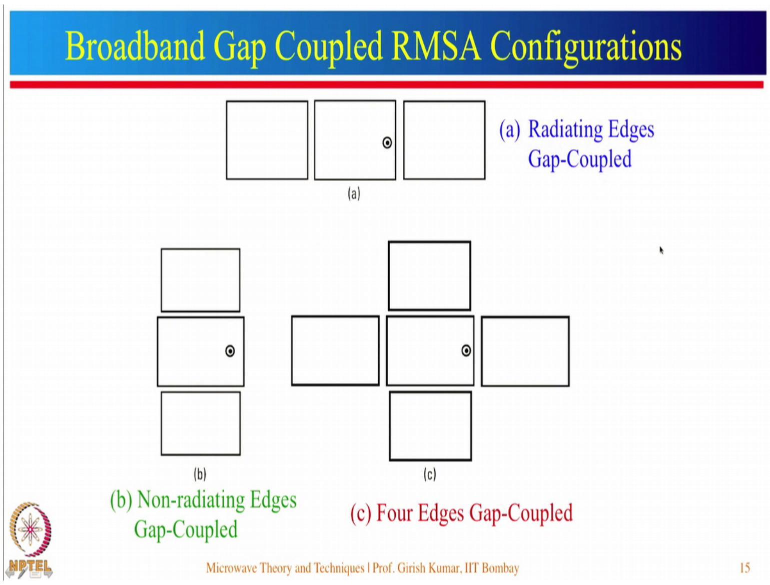

Now, we will talk about various broadband techniques. So, first technique which I am going to talk about this gap coupled rectangular microstrip antenna configuration. So, here only 1 patch is fed other patches are parasitically coupled. In this particular case these patches are coupled along the radiating edges of the rectangular microstrip antenna. This is the configuration where, parasitic patches are placed along the non-radiating edges of the fed patch. Here 4 patches are placed along the 4 edges of the rectangular microstrip antenna. You can see that only 1 patch has been fed and all other patches are parasitic patches.

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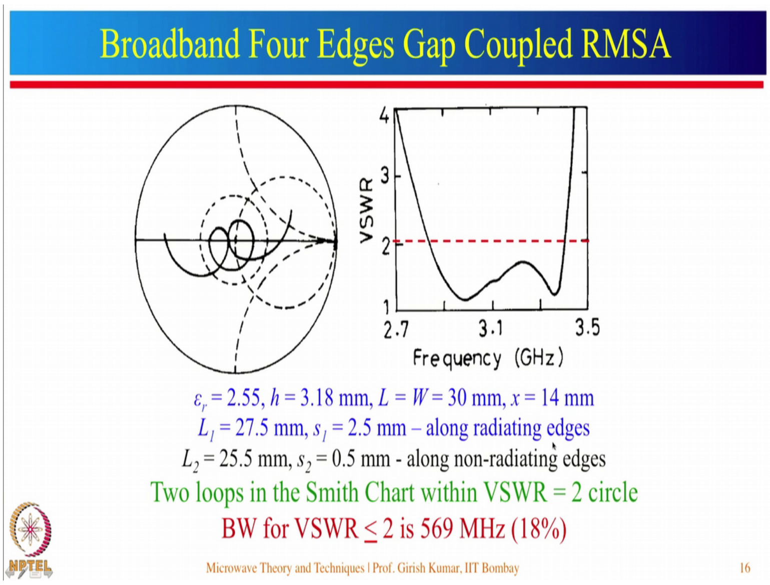

So, let us see the result. So, I have actually shown the result for 4 edges gap coupled rectangular microstrip antenna, I have shown all the parameters over here epsilon r h L equal to W equal to 30 mm or you can say 3 centimeters. Feed point is almost at the edge which is 14 mm from the centre. So, these are the dimensions for the parasitic patches along radiating edges.

So, both the parasitic patches along the radiating edges are taken identical equal to 27.5 mm the gap between the patches is taken as 2.5 mm. However, along the non-radiating edges length of the parasitic patches again taken equal, but equal to 25.5 mm in this particular case gap is much smaller. The reason for that is along the radiating edges field is uniform. However, along the non-radiating edges field is varying sinusoidally. Since field is varying sinosoidally coupling will be relatively weak. Hence we have to take smaller gap to increase the coupling.

You can see 2 loops in the smith chart over here this is lowest frequency. This is the highest frequency as frequency increases this particular patch becomes resonant. So, this loop corresponds to length L 1. And, then you can see another loop here this loop corresponds to the length L 2, which is happening at a higher frequency. You can see that both the loops are within VSWR equal to 2 circle, and that you can see from VSWR plot versus frequency and you can say that the bandwidth for this particular configuration is almost 18 percent. So, you can see that it is not 1 percent, 2 percent, or 5 percent it is a very large bandwidth and in terms of megahertz it is 569 megahertz bandwidth.

Now, this is the another configuration, where patches are electromagnetically coupled.

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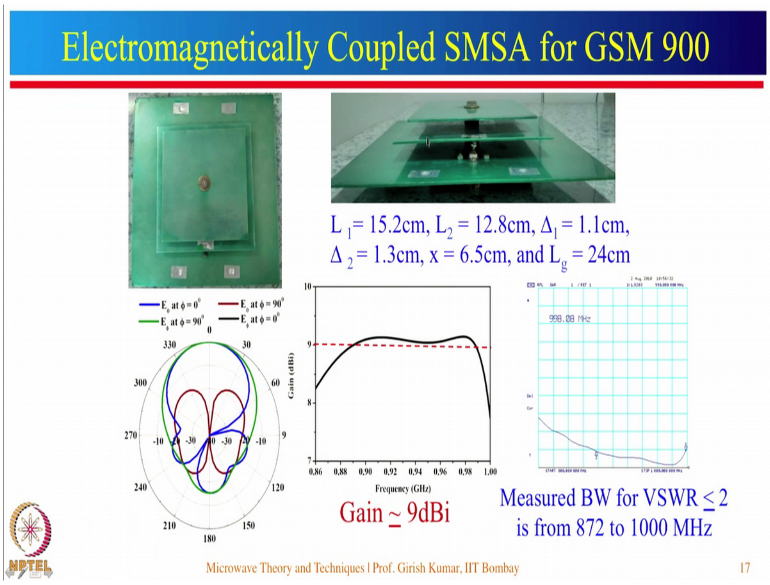

So, there is a one patch at the bottom layer there is a another patch which is put on the top of the bottom patch over here. Here, we have used thick metallic plate and these are suspended in the air by using a central shooting posed over here, you can see this is the feed point for this particular antenna configuration. So, let us see what are the dimension? So, L 1 is 15.2 centimeter we have taken square microstrip antenna. So, L 1 is equal to W 1, which is 15.2 centimeter that is the dimension of this one here. L 2 is the top patch dimension is 12.8 centimeter; delta 1 is the gap for the bottom patch which is 1.1 centimeter, delta 2 is the gap between the top patch and the bottom patch, which is 1.3 centimeter. And, in this particular case L g is equal to 24 centimeter L g corresponds to length of the ground plane.

So, you can see this is the radiation pattern of this particular antenna you can see that radiation is mainly in the broadside direction and there is a very little radiation in the back side. So, we can define front to back ratio as this value subtract this value in terms of dB. So, that is approximately 15 d B this is the gain plot versus frequency you can see that over this particular bandwidth gain is almost flat which is of the order of 9 dBi. And, measured bandwidth for VSWR less than equal to 2 is from 872 to up to 1000 megahertz it covers the GSM 900 band from 890 to 960 megahertz.

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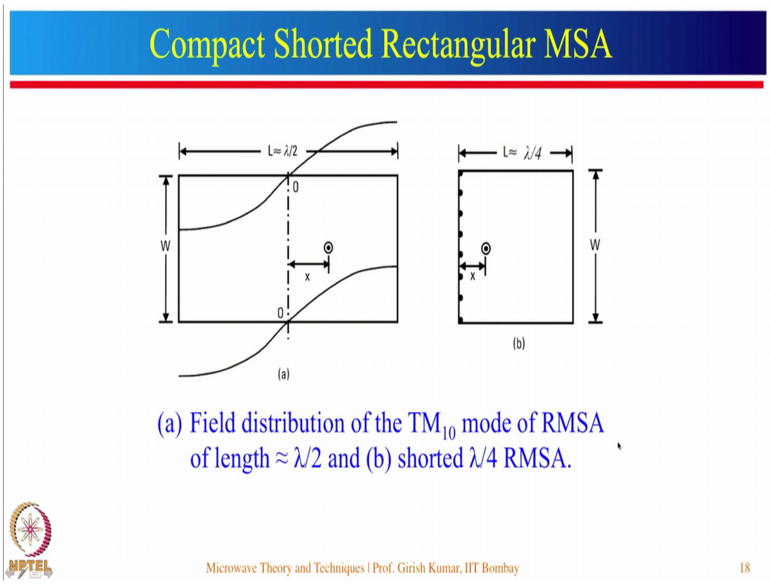

Now, let us see how we can realize a compact microstrip antenna as I mentioned earlier at lower frequency size of the antenna becomes large. So, here let us see the field distribution of TM 1 0 mode again. So, field varied from minus to 0 to plus and along this width field is uniform. So, you can actually see that along this particular thing field is 0 and if the voltage is equal to 0 that can be replaced by a short circuit. So; that means, instead of using a lambda by 2 length RMSA, we can actually use lambda by 4 length shorted RMSA. So; that means, we have reduce the size by almost 50 percent. In fact, instead of shorting this entire width if we just put single short over here size will reduce even further, in that particular case what will happen if there is a single short then this length will become lambda by 4.

One can also realize compact antenna by cutting slots within the rectangular patch.

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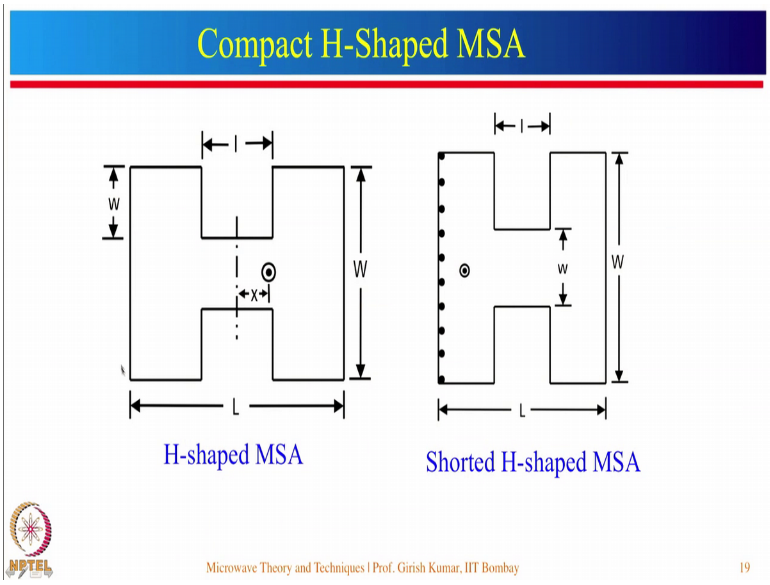

So, just think about this was the original rectangular patch we have cut 1 slot over here, we have cut another slot over here, it looks like the shape of a edge. Now, in case of rectangular microstrip antenna length was from this point to this point which was equal to L, but; however, for h shaped MSA effective length will be now equal to average of the lengths from this point to this point and going around up to this here, then another path over here then another path over here. So, we have to take average of these path; that means, total path length will be definitely more than the length l and hence frequency will reduce.

So, we can realize that compact antenna simply by putting shorted over here. So, if we do short circuit over here. So, now, we can say that this particular length will be approximately equal to lambda by 4. So, size is reduced further. In fact, I have just shown 1 slot over here, one can use multiple slots. So, that effective length is increased thereby reducing the frequency of operation. Now, we can also obtain circular polarization using square microstrip antenna. So, what we need to do it is?

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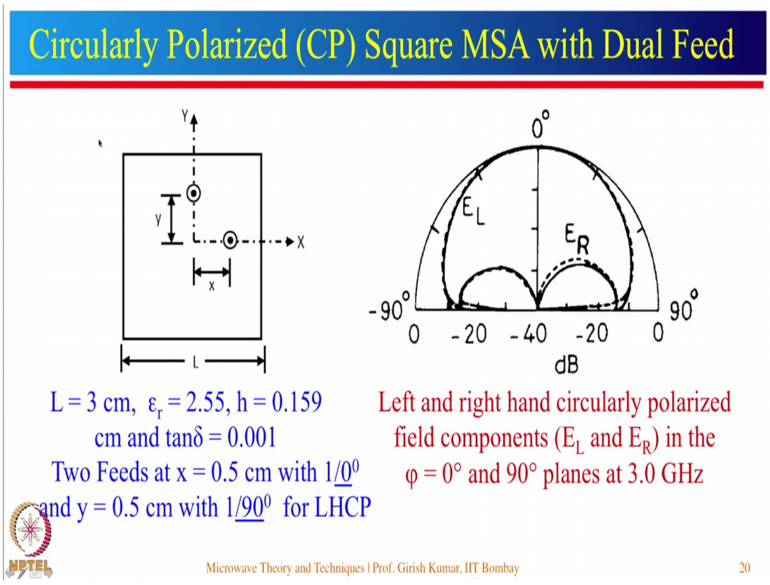

This is a square microstrip antenna. So, we feed along X axis let us say with 1 angle 0, we feed along Y axis by 1 angle 90 degree for left hand circular polarization. Now, I just want to mention again for this particular feed this is actually null ok; that means, 0 field. So, hence any feed over here will not affect the performance of this particular feed here.

Similarly, for this particular feed this is orthogonal point. So, that will correspond to the null or short circuit. So, hence this will not affect this particular feed. So, both the feeds will be isolated from each other. So, let us see the radiation pattern of this particular antenna. So, I have shown here not normal E theta or E phi pattern, but I have shown here E L and E R. E L is left hand circularly polarized components; E R is right hand circularly polarized component. So, you can see that it is a good left hand circularly polarized radiation pattern and the orthogonal component here is relatively very small.

Now, let us take an example of array to increase the gain of the antenna. So, 8 by 8 corporate fed microstrip antenna array is shown in this particular slide over here.

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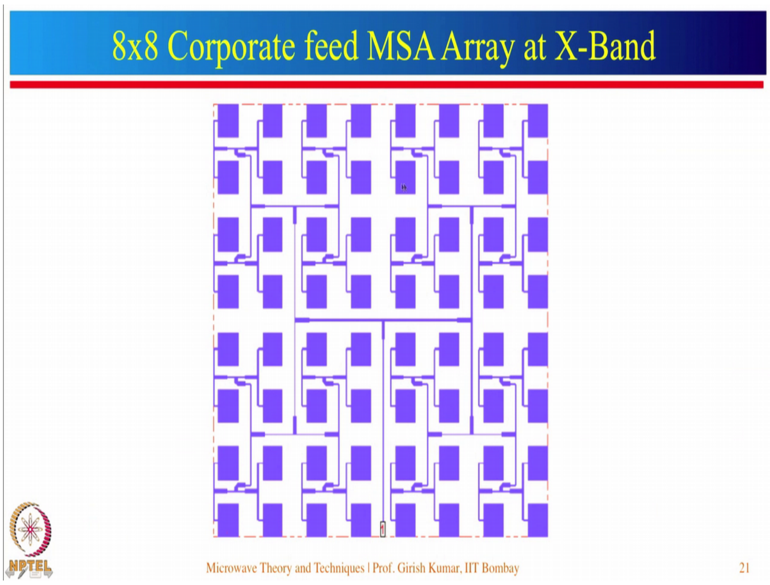

So, you can see that the entire feed network is also integrated along with the patches. So, let me start with this 2 by 2 array first. So, we will start with the 2 by 2 Array first. So, you can see that there is a feed at the edge at the edge impedance will be relatively high. So, hence we have to use a quarter wave transformer at this particular point quarter wave transformer we put it over here. And, then another quarter wave transformer has been placed over here to transform this impedance to about 100 ohm. Now, this is identical to this particular portion. So, 100 in parallel with 100 will be 50 ohm.

So; that means, if you just use this 2 by 2 Array feed over here you will have a 2 by 2 matched Array ok. And, that will of course, have a more gain compared to a single patch. Now, this 2 by 2 array is extended to 4 by 4 array you can see this is repeated over here. So, another 2 by 2, another 2 by 2, another 2 by 2 and now these are connected together. So, again as before what we do we transfer this impedance using quarter wave transformer. Another quarter wave transformer to transfer this impedance to 100 ohm 100 in parallel with 100 will become 50. So, just this particular thing will become 4 by 4 array this particular concept is extended to 8 by 8 array. So, let us see the result of this particular array.

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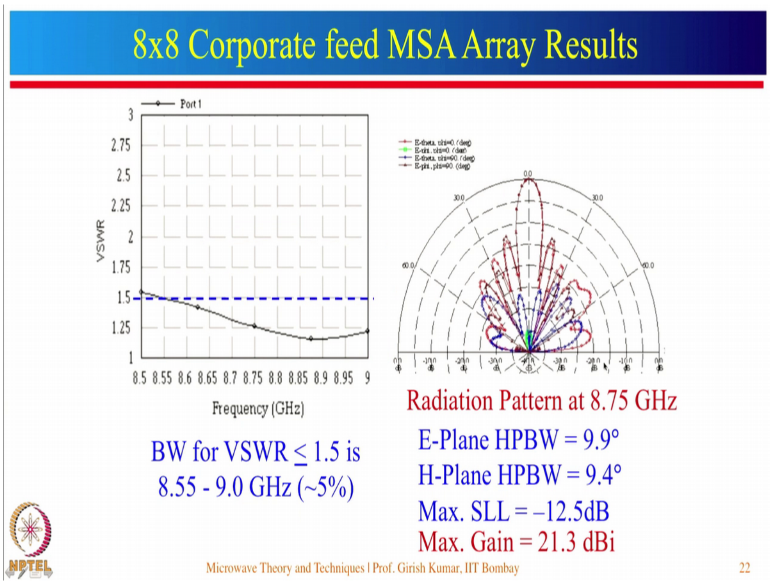

So, we have again simulated using IE 3 D software you can see that this is VSWR plot versus frequency. So, you can see bandwidth for VSWR less than 1.5 is from 8.5 5 to more than 9 gigahertz, which is about 5 percent bandwidth. Let us see the radiation pattern at 8.7 5 gigahertz, which is approximately the centre frequency of this particular antenna.

You can see that this is the main beam and there are multiple side lobes are there, please recall array theory when we talked about linear array and planar array I did mentioned to you there will be side lobe levels. So, here there are 2 plots are there they look kind of identical, but there is a 1 plot for E-Plane and another plot is for H-Plane. So, E-plane half power beamwidth is 9.9 degree, which is almost same as that of H-plane half power beamwidth which is 9.4 degree.

Side lobe levels you can see that they are below 12.5 d B, other side lobes are below this particular value here. And a gain of this particular antenna is 21.3 db. So, just think about for a single patch we had a gain of 6 d B for a dipole antenna we had gain of only about 2 dB, but by using an 8 by 8 microstrip antenna array we can obtain a gain of about 21 d B.

Of course, this concept can be extended to 16 by 16 array or even 32 by 32 array to realize much larger gain. So, just to quickly summarize today we talked about microstrip antenna which has several advantages that is why it finds lot of applications. There are certain disadvantages such as small bandwidth, but we talked about 2 different configurations to increase the bandwidth, it has the disadvantage of higher size at lower frequency.

But, we talked about compact antenna to reduce the overall size of the antenna, it has the disadvantage of low power handling capacity, but we showed you 2 metallic plates which was suspended in the air and supported by metallic post at the centre that can handle kilowatts of power. It has a disadvantage of small gain, but we use 8 by 8 corporate fed array to realize gain of 21 dBi of course, gain can be increased by using larger number of elements so.

Thank you very much.