Antennas
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Module – 05
Lecture – 20
Rectangular MSA

Hello everyone and welcome to today’s lecture on micro strip antenna. In the last lecture we talked about micro strip antenna just a very simple rectangular micro strip antenna configuration. Then we looked into what are the advantages and disadvantages of micro strip antenna, and based on it several advantages there are too many applications. In fact, today micro strip antennas are replaced majority of the conventional antennas. Now because of these several advantages it is finding these application of course, there are some disadvantages we looked into the previous lecture, but slowly and steadily many of those disadvantages are also being taken care of and then we also looked into what are the different feed techniques. So, for example, a micro strip antenna can be fed by a coaxial line it can be fed through a micro strip line it can be aperture coupled or it can be electromagnetically coupled.

So, today we will look into how to design very simply and in a quick manner a rectangular micro strip antenna.

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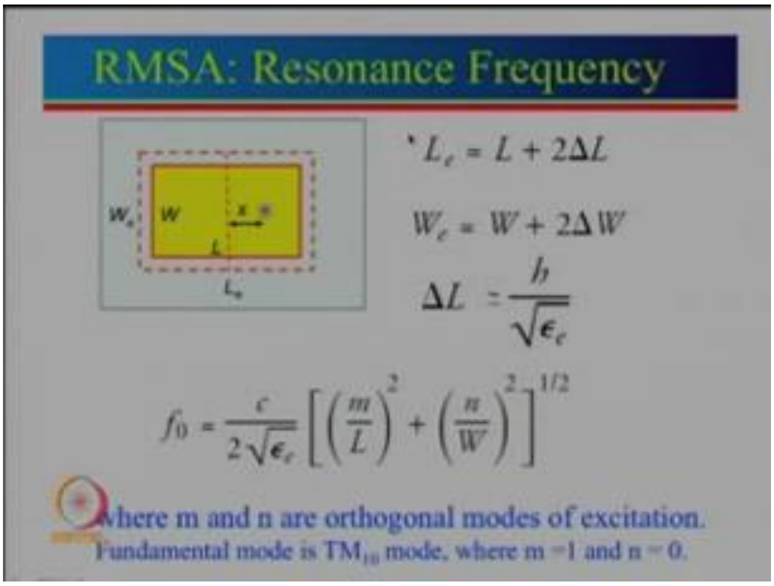

RMSA: Resonance Frequency

$L_e = L + 2\Delta L$

$W_e = W + 2\Delta W$

$\Delta L = \dfrac{h}{\sqrt{\epsilon_e}}$

$$f_0 = \frac{c}{2\sqrt{\epsilon_e}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{1/2}$$

Where m and n are orthogonal modes of excitation.
Fundamental mode is TM_{10} mode, where m = 1 and n = 0.

So, let just see a basic rectangular micro strip antenna. A basic rectangular micro strip antenna is defined by it is length L and it is width W. And what we have here is a we have a substrate. So, it is on one side of the substrate there will be a ground plane so; that means, copper will remain as it is in the backside and on the front side we cut this or etch this patch of length L and W. So, now, we need to design antenna for a given frequency, but before we do design let just look at what are the parameters and what are the things there.

So, first of all if we have a patch here, so that patch will have a fringing field. Just like think about this as a one plate metallic plate and one metallic plate is on the backside. So, there will be fringing fields all around. So, the total capacitance will be the capacitance of the parallel plate plus the capacity of the fringing field. So, what is done actually that to account for those capacitances because of the fringing field, we defined the quantity L effective and W effective. So, L effective is nothing, but total length L plus this delta L that accounts for the fringing field on one side and delta L on the other sides. So, L e becomes L plus 2 delta L. Similarly, we define W e which is W plus delta W and delta W that becomes 2 delta W.

Now, the next part is how do we calculate delta L. And there are several expressions available in the literature and they are fairly complicated expressions available and these expressions have been derived by writing boundary conditions for electric field magnetic field solving all those Maxwell’s equation, but that takes lot of time. And what we would like to do in the real life specially the practicing engineers they would like to design antenna quickly. So, what we have proposed here is a very simple expression to calculate delta e. And that can be calculated from the height of the substrate or sometimes we call it thickness of the substrate divided by square root epsilon i. So, then comes the next part what is the resonance frequency of this particular antenna.

Now, the resonance frequency of the antenna is defined by the expression which is given over here. In reality it is relatively simple thing. I just explain first for the fundamental mode a fundamental mode is nothing, but 1 0 mode. I will explain one by one. So, if we take fundamental 1 0 mode so; that means, m is equal to 1 and n equal to 0 when this is 0 this term will not exist and m by L is one by L square and there is a square root. So, L will come out here. And in reality if you actually see this is nothing, but when L becomes roughly equal to lambda by 2 that is what will be the resonance frequency for the fundamental mode.

Will see one by one what are the different modes, but let us start the discussion for fundamental mode. So, we put m equal to 1 and n equal to 0, and what is this fundamental mode really imply. So, if it is one then that this length L is equal to lambda by 2. And what does lambda by 2 really mean, that see we have for current let just look from the current point of view. So, we have an open here and we have a open here on this side. So, along the open current will be 0. So, since the length is lambda by two. So, current will be 0 it will go to the maximum it will come back to 0, that is what is a half wavelength and that is what's the variation is known as 1. Since we have talking about n equal to 0, but n equal to 0 means that along this axis there is low variation so; that means, if the current is 0 here maximum here 0 here then current is 0 here maximum here and 0 here.

Now, since effective length is slightly more than the physical length. So, in reality current is absolutely 0 here goes to maxima and then comes back to 0 here. Now voltage distribution will be reverse of that. So, open circuit means voltage will be maximum and then it will go to 0 and then it will come back to the minus this thing, plus 0 minus. So, what it really is again this is nothing, but equal to lambda by 2 lengths which is the variation of the waveform.

Now since voltage is maximum here current is closed to 0 well here it will not be exactly 0 here it is 0, but this one we do not see we only see the physical dimension, but nevertheless current is small voltage is maximum. So, v by i which is impedance will be maximum at the center voltage will be 0 current will be maximum. So, impedance will be v by i. So, impedance will be 0. So, along this length here, either you think this length or along the center or along the top the impedance will be 0 here it will be maximum. So, we feed at the center point here specifically it is known as a symmetrical feed. So, if we feed in the center here. So, then this is 0 impedance and at the edge it is a maximum impedance. So, between 0 impedance and maximum impedance we want to find a point where impedance will be equal to 50 ohms because coaxial feed which we are using those will be coaxial line or connector which are 50-ohm line or 50-ohm connector.

So, our next problem would be is to find out the value of x, so that we can get a good match. So, now, let just see systematically one by one, how is the field distribution going on.

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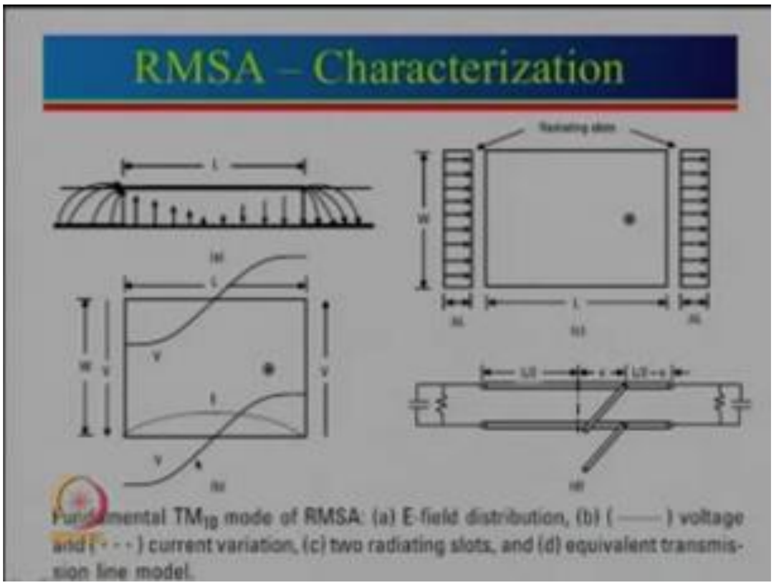

RMSA – Characterization

Fundamental TM_{10} mode of RMSA: (a) E-field distribution, (b) (——) voltage and (- - -) current variation, (c) two radiating slots, and (d) equivalent transmission line model.

So, along the length will just start from here. So, I have already told you that at the end current is 0. So, that is the maximum and then current is 0 along this here the voltage is maximum, and then voltage is becoming 0 over here. So, if we plot this voltage distribution along here. So, voltage is maximum. So, the field will be going from here to here this is the electric field and then the field will be going here and along the edges there will be fringing field. And this amplitude which is maximum here and gradually it is reducing to 0. So, gradually it is reducing to 0 and then it changes the direction. So, now, the arrow directions are there, now, at this point if you see. So, the field is going towards the patch which is a negative and these are the fringing fields.

So, now this whole thing can be represented in this form here. What we are looking at we are looking at 2 set here one is the field beneath the patch. Now the radiation takes place from the edges because the field is confined within the patch here. So, now, these fields here can be represented in 2 component horizontal component and vertical component. So, horizontal component will be in the right hand side direction. So, this is where is the horizontal component.

The vertical component will be going down, but from this side now if you see the horizontal component is also in the right side which is shown over here. And the vertical component will be in the opposite direction of this one here. So, if we look at a broad side direction since these 2 are in the opposite phase they cancel in the broad side. The only addition comes is from these 2 things which are in the same direction. So, this whole thing can be thought about as that there is a one radiating slot there is another radiating slot, and now we need to find out what is the radiation pattern so. In fact, we can apply the array theory. So, we can actually see that there is a one radiating slot on one edge another radiating slot is on the other edge and the distance between them is approximately lambda by 2 why because that is what is half wavelength corresponding to which is resonance frequency is there.

So, now if we look into here then, in order to find the radiation pattern what do we do, we already know how to calculate the radiation pattern of a dipole antenna. Compliment of a dipole antenna is slot antenna. And then we apply the array theory to find out the overall radiation pattern in this plane and then these can be integrated along this axis to give the H-plane pattern. Now the simplified way of the analysis is also that we can think of this whole patch as a transmission line and since the field is uniform, we can neglect that particular part there. So, we assume that this is a simple transmission line fringing fields are represented by capacitance on both side. And the radiation resistance is modeled over here.

Now, how do we calculate radiation resistance, well we know that there will be electric field here. So, the electric we can find out what is the power radiated and then power radiated is equal to v square by 2 r. So, from that we can find out the radiation resistance. And as I had mentioned earlier this radiation resistance is not the physical quantity it is just a representation of radiated power. So, now, we can actually look at how to design the antenna.

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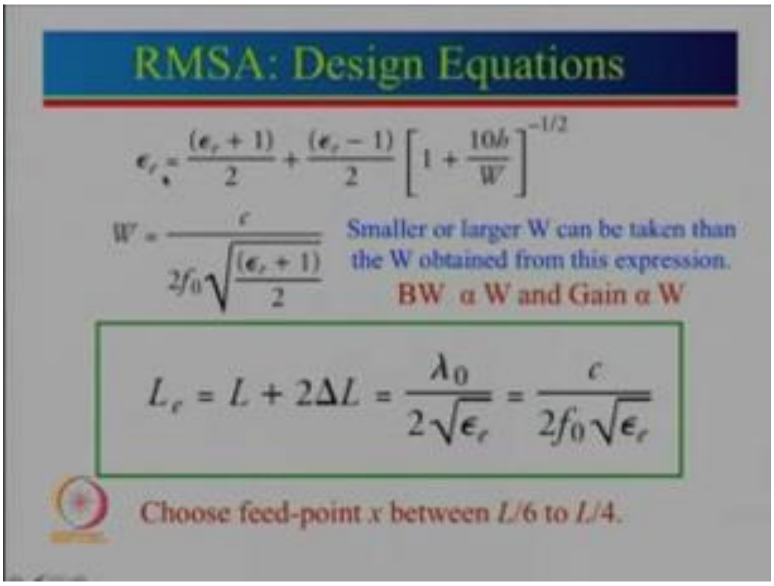

RMSA: Design Equations

$$\epsilon_e = \frac{(\epsilon_r + 1)}{2} + \frac{(\epsilon_r - 1)}{2}\left[1 + \frac{10h}{W}\right]^{-1/2}$$

$$W = \frac{c}{2f_0\sqrt{\frac{(\epsilon_r + 1)}{2}}}$$

Smaller or larger W can be taken than the W obtained from this expression.

BW α W and Gain α W

$$\boxed{L_e = L + 2\Delta L = \frac{\lambda_0}{2\sqrt{\epsilon_e}} = \frac{c}{2f_0\sqrt{\epsilon_e}}}$$

Choose feed-point x between $L/6$ to $L/4$.

So, first of all for the design, what we need we need to calculate what is the effective dielectric constant. Why effective dielectric constant let just go back and see the distribution. So, we can see that most of the field is confined in the substrate, but part of the field is going up in the air. So, because of that the effective dielectric constant is not really only epsilon r, but is slightly less than epsilon r because part of the fringing field is in the air. So, we can use this particular formula calculate what is epsilon effective.

Now, again for this there are so many different expressions are given this we found out is reasonably good expression which can be used for rectangular patch antenna. So, one can actually see that if W is going towards infinity; that means, patch is very long and if W is infinity this term will be equal to 0 then this whole term becomes 1, and if you look into here then this entire term becomes epsilon r. So, which is expected if the patch is spread to the infinity epsilon effective will be equivalent epsilon r; however, if the width is very small if it is tending towards 0 if you put this expression epsilon e will be nothing, but equal to epsilon r plus one by 2. Why? Because epsilon r is below the patch and one is the above the patch, we need to take effective dielectric constant, but majority of the time for a rectangular patch we take a larger width. So, epsilon e is given by this particular expression and where we can also say epsilon e is slightly less than epsilon r.

Now, we can see that there is a W here, and we need to calculate the value of W. Now here again a starting point has been given and this starting point can be used to calculate

W, and where is the starting point coming into picture well just think about c by f 0 is nothing, but lambda 0 lambda 0, divided by 2, which is a approximately half wave length. And then this is being divided by the effective dielectric constant between the dielectric layer down below and one above there. Now again this is just a starting point now it does not mean always that you have to choose this value of W, you can take a larger value than this W or smaller value of W it all depends upon just to tell you right now that if you take a larger value of W, then what will happen aperture area will increase. So, aperture area increases; that means, gain will increase. So, if you require a larger gain you can take larger W.

Also if W increase fringing fields will increase and if fringing fields increase; that means, there will be more radiation. From circuit point of view; that means, there will more losses and more lossy means q will be low and if q is low bandwidth will be high. So, one actually choose and, but sometimes we may have to take a smaller than this W because we need to fit the antenna into a certain area. Suppose let us say you want to design an antenna for a mobile phone you can’t use a very large W, because of the size of the mobile phone is small. So, you may end up taking a small W which will then compromise on the bandwidth as well as on the gain. And once we W and epsilon then we can actually find out the value of L e which is effective length, let us say L e should be equal to this here what is this here that is lambda by 2, and what is lambda, lambda 0 is lambda is nothing, but lambda 0 divided by square root epsilon e.

So, then this basically is nothing, but lambda by 2 and that is what we had same for fundamental mode 1 0 the length should be equal to lambda by 2 and L e is nothing, but L plus 2 delta L and what is lambda 0 c by f 0.

So, now let us say we want to do the design. So, design we need to use this equation. So, let us say frequency is given to us. So, for a given frequency we can choose first W. So, W will be used f 0 is known epsilon r is known because we have chosen a substrate we can calculate W. For this given value of W substitute over here find out the value of epsilon, then this value of epsilon e we can put over here and find out what is the effective length and then from that we can calculate the physical length will take a design example; however, we also need a another thing where should we feed. So, in order to feed I have given a general guideline the feed point can be between L by 6 to L by 4. So, if it is a narrow band antenna start with L by 6 if it is a wide band antenna start with L by 4. So, let just take a design example.

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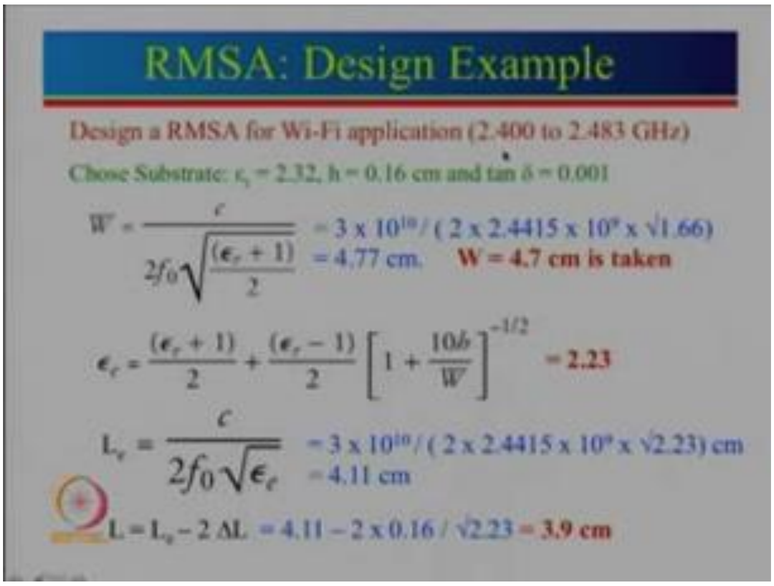

RMSA: Design Example

Design a RMSA for Wi-Fi application (2.400 to 2.483 GHz)

Chose Substrate: $\varepsilon_r = 2.32$, h = 0.16 cm and tan δ = 0.001

$$W = \frac{c}{2f_0\sqrt{\frac{(\epsilon_r + 1)}{2}}} = 3 \times 10^{10} / (2 \times 2.4415 \times 10^9 \times \sqrt{1.66}) = 4.77 \text{ cm.}$$

W = 4.7 cm is taken

$$\epsilon_e = \frac{(\epsilon_r + 1)}{2} + \frac{(\epsilon_r - 1)}{2}\left[1 + \frac{10h}{W}\right]^{-1/2} = 2.23$$

$$L_e = \frac{c}{2f_0\sqrt{\epsilon_e}} = 3 \times 10^{10} / (2 \times 2.4415 \times 10^9 \times \sqrt{2.23}) \text{ cm} = 4.11 \text{ cm}$$

$$L = L_e - 2\,\Delta L = 4.11 - 2 \times 0.16 / \sqrt{2.23} = 3.9 \text{ cm}$$

So, will start with a design of a rectangular micro strip antenna for Wi-Fi application, you know that Wi-Fi works around 2.45gigahertz, but the exact frequency ranges from 2.42 to 2.483. Now till now we have not really looked into what controls the bandwidth what controls the gain and other thing. So, what we will do will just take one of the standard substrate. So, this is a substrate whose parameters are epsilon r 2.32, h is 0.16 which is really equal to 1 by 16 inches and tan delta is 0 point 0 0 1 which is a low loss substrate now we know the frequency take the center frequency of this as 2.4415 which is in between center value.

So, our first task is to calculate W. So, we know the parameter c, c is nothing, but 3 into 10 to the power 8 meter per second, but here we have represented in terms of centimeter. So, 3 into 10 to the power 10 centimeter per second, here is the 2 which is coming here f 0 is 2.4415 into 10 to the power 9 gigahertz. And 2.32 plus 1 3.32 divided by 2 is 1.66. So, we do the calculation it turns out to be 4.77 centimeters. Now as I mentioned it is not necessary that you take this value of W you can take any different value. So, I have just taken a value which is 4.7. You can take 4 take also you can take 5 also you can take 3 also depending upon the requirement. For this value of W, we substitute the value of epsilon r which is 2.32 h is known 0.16 put W here do the calculation epsilon effective is

2.33 you can see that this 2.33 is slightly less than 2.32. So, that tells that you are on the right path. If this is more than this, you know definitely it is not correct.

So, from here now once we know this we can find out L effective. We know c we know f 0 now we know epsilon e substitute the value we got 4.11 centimeter. And then the next part is to calculate L which is a physical length. So, we use this expression now delta L as I mentioned this is h by square root epsilon i. This this is the approximate value and that comes out to be 3.9 centimeter, but one thing I can assure you, if you just use these simple 3, 4 lines I can assure you that majority of the time your antenna will be designed within 1 to 2 percent of the accuracy absolute maximum error you take any case will not be more than 5 percent. In fact, most of the time we have found out the error is less than one percent. So, let just take an example here. So, what we did the same design?

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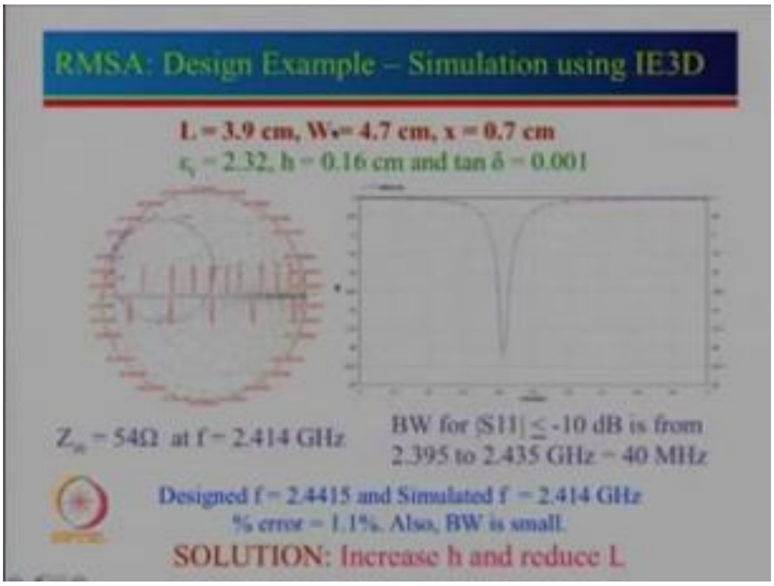

RMSA: Design Example – Simulation using IE3D

$L = 3.9$ cm, $W = 4.7$ cm, $x = 0.7$ cm

$\varepsilon_r = 2.32$, $h = 0.16$ cm and $\tan\delta = 0.001$

$Z_{in} = 54\Omega$ at $f = 2.414$ GHz

BW for $|S11| \leq -10$ dB is from 2.395 to 2.435 GHz = 40 MHz

Designed f = 2.4415 and Simulated f = 2.414 GHz

% error = 1.1%. Also, BW is small.

SOLUTION: Increase h and reduce L

Now, we have simulated using a commercially available software which is IE3D earlier it was available from Zealand, now it is available from Vector Graphics. So, what we have done here we took 3.9 centimeter, W 4 as we calculated x as 0.7. Now just recall I said starting point can be L by 6 now 3.9 divided by 6 L is 0.65. I have taken slightly more than that. And there is a reason also here W is more than length and if W is larger; that means, bandwidth will be larger; that means, impedance variation will be small will see the parametric study also. So, because bandwidth is large impedance variation will be relatively less. So, we have taken slightly more than 0.65. So, this is 0.7 epsilon r h tan delta you have to specify these things in the simulation. And in the beginning we have done the simulation for infinite ground plane. Now these are the results this is the smith chart plot and that is a S11 plot.

So, we can see here that what we have got here is a center frequency as 2.414 impedance is 50 ohms. So, this 50 ohm is reasonably close to 50. So, we can leave that here and if you at the S11 that is the S11 plot, but if you look for bandwidth for S11 less than minus 10 dB you can actually just go through and draw a line at minus 10 dB and one can see that the bandwidth obtained is about 40 megahertz. Now this is really not our objective. Our objective was from 2.4 up to 2.483 we require 83 megahertz, but we have got only 40 megahertz.

Do not be disappointed because this is just the starting point we just took some arbitrary substrate which has an epsilon r and this n h is given by this value. We will see how to design a real antenna, but this is good starting point, but what we would like to show you here that our designed frequency was 2.4415, which we took that. And simulated came out to be 2.414. So, if you calculate the percentage error it is only about 1.1 percent which is a very good thing, you do not have to solve Maxwell’s equation you do not have write boundary conditions you do not have to do e field h field double integral and. So, on just by using simple calculator you can do the design and how much time it took may be less than 10 minute.

So, now the question comes then what do we do next. So, we got the value which has a percentage error of 1.1 percent. So, what we simulated is 2.414, what was desired was this here. So, if we reduce the value of length L. So, what will happen frequency will increase. And to increase the bandwidth what we need to do we need to increase h. So, that band width will increase. So, let us remember this 13.0.

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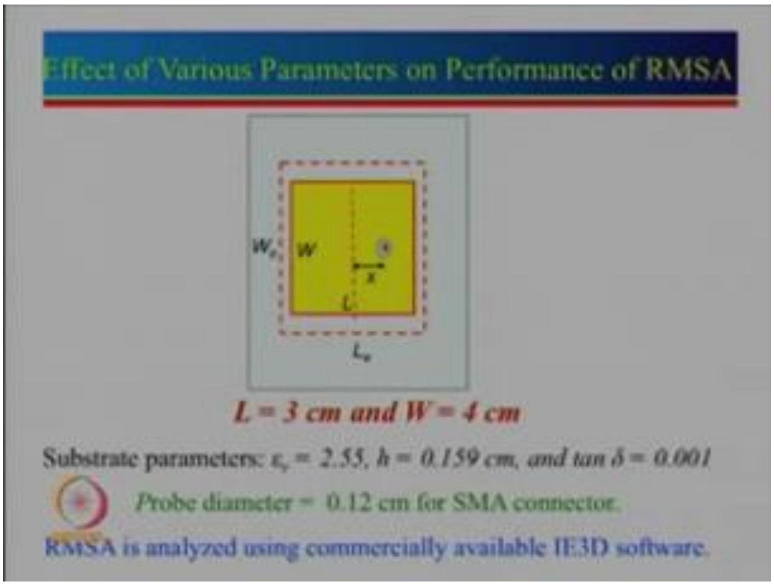

Effect of Various Parameters on Performance of RMSA

$L = 3$ cm and $W = 4$ cm

Substrate parameters: $\varepsilon_r = 2.55$, $h = 0.159$ cm, and $\tan\delta = 0.001$

Probe diameter = 0.12 cm for SMA connector.

RMSA is analyzed using commercially available IE3D software.

And now what we will do we will study the parametric study. So, will take a case one by one will see the performance of each and every parameter and see what really happened. So, as I starting different design example we have taken L equal to 3 centimeter and W equal to 4 centimeters. And these are the substrate parameters. And for the simulation we have taken probe diameter as point one 2 centimeter this is the diameter for SMA connector there are 2 most popular connectors actually one is SMA connector another one is a n type connector, will show you the results one by one. Again all these antennas have been analyzed using IE3D software.

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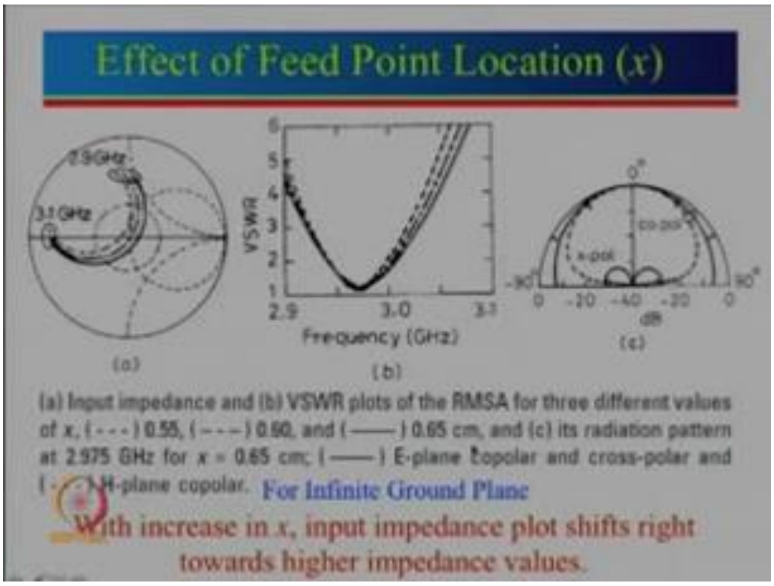

Effect of Feed Point Location (x)

(a) Input impedance and (b) VSWR plots of the RMSA for three different values of x, (- - -) 0.55, (— — —) 0.60, and (——) 0.65 cm, and (c) its radiation pattern at 2.975 GHz for x = 0.65 cm; (——) E-plane copolar and cross-polar and (- - -) H-plane copolar. For Infinite Ground Plane

With increase in x, input impedance plot shifts right towards higher impedance values.

So, let us see one by one effect of this. To start with we have given effect of feed point location. So, what we have done kept the L W constant epsilon r h r also constant all we are doing it is changing the value of x, and what we have taken x as 0.55 0.65 and 0.655 these are the 3 values. And we can actually see the plot for x equal to 0.5. This is the impedance plot and then this is for 0.65 and then this for 0.65. So, what we are effectively doing by increasing the value of x, we are moving towards the edge of the rectangular micro strip antenna. And we know that at the center impedance is 0 towards the edge impedance is maximum.

So, that is why when you are shifting the feed point towards the edge impedance is increasing. Now by changing the feed point location resonance frequency does not change much. So, that is why you do not see much difference in the VSWR plot as far as the resonance frequency is concerned; however, one can see that the bandwidth is slightly different, if we draw a horizontal line for VSWR 2 here then we can see that the bandwidth for the solid line is slightly more than this here.

So, how that can be explained again let just look at here. So, what we have we have these 3 impedance plot. So, what you need to do, you need to draw a line from this edge to this one cut here and that is chord and then we see that the line which is going through the 50-ohm line again that is a chord, but for this particular feed point if you look at, then we can see that it is almost passing through the diameter of the VSWR equal to 2 circuit. And that is where it is more important. And that is where this one gives a better bandwidth. In fact, I would like to tell my audience that it is not always important that you design antenna for exactly 50 ohms. In fact, most of the time when I design antenna I design antenna for 55 ohm or 60-ohm impedance which will be something like this plot here and that will give me a slightly larger bandwidth. And here also let us look at the radiation pattern.

Now, since it is simulated for infinite ground plane. So, there is a no radiation in the backside, but what we have here. We have 2 things which are co polar this is a E-plane pattern and this is a H-plane pattern. So, you can see that this E-plane pattern how does that E-plane pattern comes into picture. So, you look at the slot antenna. So, slot antenna will have a omnidirectional pattern. So, let us say we have a 2 slots here, there is an omnidirectional pattern here omnidirectional pattern here, but below there is a ground plane. So, it will not radiate in the downside. So, the pattern will something like this pattern will be radiating in the upper hemisphere. Now we apply the array theory and the separation between the 2 is lambda by 2. This is not lambda 0 by 2 which we studied in array theory.

So, compared to lambda by 2 this is actually lambda 0 divided by 2 square root epsilon e. So, this length is still small. So, the radiation will be in the broad side direction and that is why when we look at the pattern here you can see that it is not exactly 0, because of the array factor it is coming slightly less than that, but the main is in the broad side direction what about this plane H-plane. So, for H-plane again you have to think about the slot antenna radiation. So, let say this is the slot here radiation is maximum around this. So, this is giving me e field, but h field is perpendicular to the e field. So, this side here if you look at the slot we see the maximum, but if you look from here the radiation is actually equal to 0. So, that is why for H-plane the radiation is starting from maxima it is going towards 0 here. So, what is this component coming here this is actually a cross polar component.

Ideally we would like there should be no cross polar component a perfect linear polarized antenna should not have any cross polarization, but; however, as one can see the cross polar component is this is 0 minus 10 minus 20 minus 30 that is about 27 28 dB down compared to the maximum radiation in this direction. So, we can almost say cross polar is very less, but; however, from where this cross polar is coming, actually this cross polar is coming if you look at the patch. There is this probe here, from the bottom when you are feeding the patch. So, what we see here there is a ground plane and this probe is coming out and then there is a patch so. In fact, this probe can be thought about as a top loaded monopole antenna. So, basically this is a more like monopole antenna, what is the radiation pattern of the monopole well it will be 0 in this direction maximum in this direction.

So, if you actually look at this radiation pattern. So, the cross polar is really speaking coming because of that monopole antenna or because of that probe which is radiating. So, if the probe length is more the radiation will be more. In fact, we will see that the cross polar level component increases. So, this is the effect of the feed point location.

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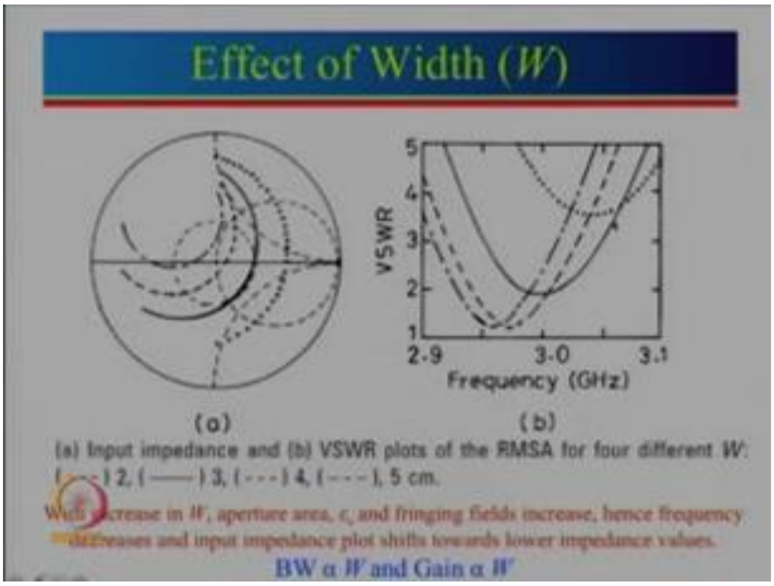

Effect of Width (W)

(a) Input impedance and (b) VSWR plots of the RMSA for four different W: (- - -) 2, (——) 3, (- - -) 4, (- - -), 5 cm.

With increase in W, aperture area, ε_e and fringing fields increase, hence frequency decreases and input impedance plot shifts towards lower impedance values.

BW α W and Gain α W

And then we can also look at the next one which is effect of the width. So, we can see here that results are given for different values of the width 2 3 4 and 5. So, this is the case for the width equal to 2 this is the 4 3 this is for 4 and that is for 5. So, also there is a VSWR plot this is for 2 3 4 5. So, why we are this kind of fringes think about, if the width is increasing we saw the expression for epsilon i larger is the width epsilon effective will keep on increasing. So, if epsilon effective increases resonance frequency will decrease.

Also if the width is large fringing fields will also increase and now coming to this here. So, this can be explained as the width increases there will be more and more fringing fields; that means, there will be more radiation. So, more radiation means more losses and that is radiation losses. From antenna point of view, it is very good, but from circuit point of view we think it is losses, but that is not correct from antenna more radiation is actually a desired quantity. So, when there is a more radiation. So, what will happen q will reduce and that increases bandwidth and if the bandwidth is increases; that means, that the impedance variation will reduce.

So, impedance variation reduces means impedance will reduce. So, that is why when we shift from W equal to 2 to 3 to 4 to 5 we can actually see that the impedance is changing. And one can choose a proper feed point for doing the impedance matching for any these cases here. So, we can actually note that bandwidth is proportional to W. So, as you keep on increasing the value of W we will see that the bandwidth increases and gain is directly proportional to W, because W increases aperture area increases hence gain increases.

So, will continue from here in the next lecture, today we just looked into how to design a simple rectangular micro strip antenna, for a given different frequency range, but in the next lecture will first study what are the parameter effect of different components also for substrate parameter and then will see what determines the bandwidth of the antenna. Then we take a real example to meet the exact requirement.

Thank you very much and will see you soon.