Antennas
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Module – 03
Lecture – 14
Slot Antennas

Hello, and welcome to today's lecture on Slot Antennas. Now, in the last few lectures we have actually talked about dipole antenna, monopole antenna, and loop antenna. Today we will actually start with the slot antenna and we will see that slot antenna is nothing but complementary of a dipole antenna.

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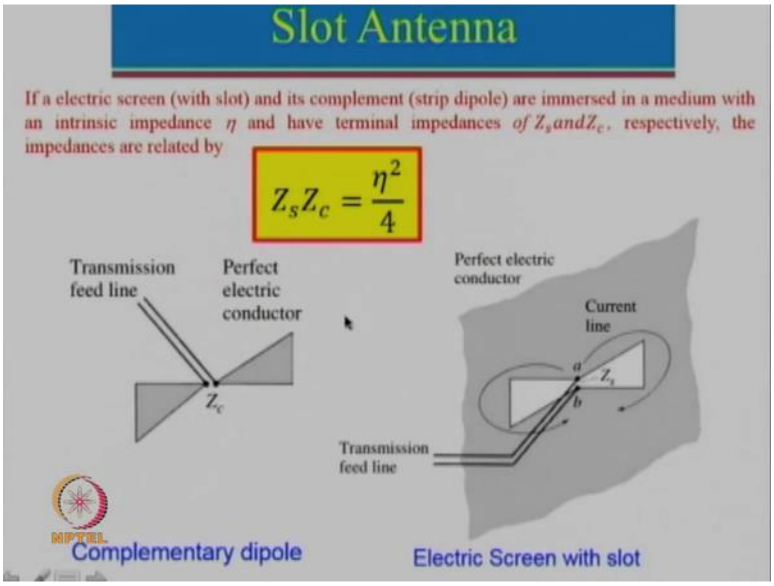

So, let us start our discussion on slot antenna. So, let just see here slot antenna is nothing but it is a complement of a dipole antenna. Here instead of showing a normal dipole we have shown a conical dipole antenna. For conical dipole antenna we need to feed it by a balanced transmission line. Now, just the opposite of that will be that what? See here it is all air and we have a metal. A slot antenna is nothing but all metal and then in between we cut this particular thing. So, you can just see it is exactly opposite of that, metal is replaced by the slot and air is replaced by the metal. Of course, now practically realizing this kind of a slot is impossible, because you need to have a infinite ground plane and then you cut a slot in that. So, practically we always have a finite ground plane and in that we cut a slot and we need to feed here the transmission feed line. So, one point will be connected here another point will be connected over here.

Now, there is a one very interesting relationship between dipole antenna and this here and the relationship is nothing but you can actually see that Z s multiplied by Z c that is the impedance of the dipole and slot antenna is nothing but equivalent to this here and that should not come as a surprise because see free space impedance is nothing but eta which is equal to 120 pi. So, we can actually see that if we use this concept here. So, that is one which is the dipole, this is the slot antenna.

The product of this will be related to the free space E field becomes H field H field becomes E field the ratio of E and H field is nothing but eta. So, that is how this is a constant thing. In fact, lot of research these days is being done. Where people are trying to combine dipole antenna and slot antenna. So, if you combine these two antennas, then the product will be constant and if the product is constant; that means, it will give us a very large bandwidth over the frequency range. In fact, theoretically or ideally this actually there is no frequency term coming you can say that the product will be having a infinite bandwidth. Of course, practically it never happens, because you will never have a infinite ground plane and all the conditions of ideal will never happen in the practical scenario.

But, nevertheless this expression is very useful to design very broadband antennas also, but right now let us just look at the slot antenna.

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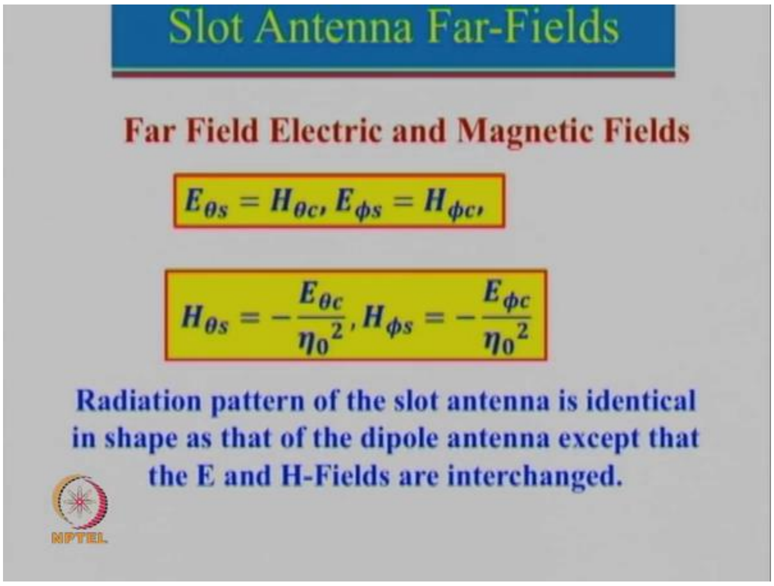

So, now for slot antenna far field electric and magnetic field will be exactly same as the dipole antenna with only one difference that, E field will be replaced by H field and H field will be replaced by E field. So, other than that everything remains same.

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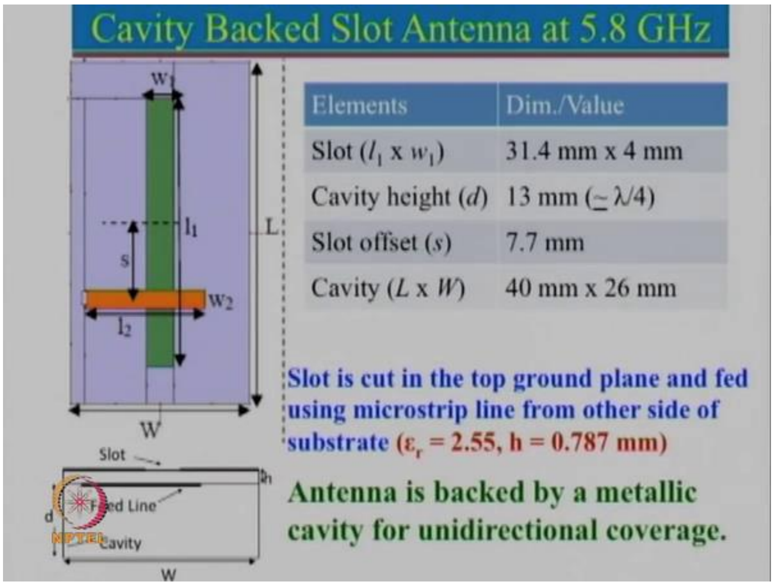

So, here now we have taken a practical example and I just wanted to tell you. See this project was actually given to us that we had to design an antenna, which is at 5.8 gigahertz and this should have a large beam width. We will tell you what are the beam widths and other things. So, gain was not that important for a single element, but of course, gain was important for larger arrays. So, we will look into that also one by one.

So, our objective was to design antenna at 5.8 gigahertz, but the requirement was also a unidirectional not Omni directional, but unidirectional. So, it should radiate in one direction. So, what we have done here let us look into this here. So, here we have taken a one substrate and on that substrate here let say on the top side of the substrate we have a metallic patch and on in the substrate we have actually removed this rectangular slot.

So, rectangular slot has been cut of length l 1 and width w 1 and then a feed line is put on the other side here. So, this is a microstrip line feed and this microstrip line feed here then is fed by a coaxial probe. So, the ground plane of the coaxial probe will be connected on the top side and then the center pin will be soldered to this here. So, this has lot of different different parameters which we will look into one by one and this is backed by a cavity.

So, that it gives us a unidirectional radii see slot will radiate like this here that is how the E field will be like this per remember for dipole antenna H field was like this, but for slot antenna E field will be like this here. So, we have put a cavity. So, that it goes here and reflects back. So, the cavity has been at a distance of approximately lambda by 4 because short circuit at lambda by four will act as an open circuit. So, loading of the cavity will be relatively less on this here now this is of course, the project, but in reality just to tell you what actually is done for the slot antenna let us just look into that here. So, let us say we have a metallic plate we cut a slot.

Now in case of a dipole antenna what we had seen if the length is lambda by 2 or approximately lambda by 2 for dipole antenna we actually take effective length as lambda by 2, but physical length is less than lambda by 2 and for the dipole antenna current is 0 here current is maximum and then current is 0. Now for slot antenna reverse of that happens why because here it is all metal. So, at this point now voltage is 0, but current is maxima. So, voltage is 0 here voltage is maxima and current is maxima here current is 0. So, at this particular point then along this impedance is very high the reason is that voltage is maximum current is zero which is reverse of the dipole antenna that is why we are feeding it off center. Since the voltage here is 0, impedance at this point will be 0 impedance is maximum at this point. So, in between we can find a point where we can feed it.

But, in a more simpler way if you just take a metallic plate, we need not always have a slot antenna printed on a dielectric substrate. We can just have a simple metallic plate we can cut a slot in this here and then if we need to feed that what simply we do we take a coaxial cable and for the coaxial cable the outer shield which is a ground, will be soldered over here and the center pin can be connected over here. Of course, we do not put in the center because impedance will be high.

So, generally coaxial connector can be put over here the outer cable will be put somewhere here and the center pin can be connected to this other side here and that way one can feed a simple slot antenna. But here it is a slot antenna printed on a dielectric substrate and also backed by a cavity. So, here we have taken a substrate which has a epsilon r equal to 2.55 and thickness is approximately equal to 0.8 mm. So, let us see what are the things we have taken the cavity dimensions are taken as this one here, but before we come to this here what we need to do now we need to choose the slot length. Now, slot length should be approximately lambda by 2. But now recall again for dipole antenna physical length was less than lambda by 2 because, fringing fields were outside here it is reverse the case.

Now where will be the fringing fields? So fringing field will be actually inside. So, for the slot antenna fringing field will be inside. So, effective length will be now smaller than the physical length. So, this is the major difference compared to a dipole antenna in dipole antenna the physical length is slightly less than lambda by 2 in slot antenna physical length is slightly more than lambda by 2.

So, let us just look at 5.8 gigahertz wavelength is approximately equal to 52 mm. So, 52 divided by 4 is 13 mm which is the cavity here, but 52 divided by 2 will be about 26. But you can see that we have taken slot length which is larger than 26. So, physical length is now more than the effective length, effective length should have been close to 26 mm as lambda by 2. So, you can see that there will be fringing field; however, now there are too many additional parameters are there.

So, what is the effect of the length? We know that in general, if the length is increased frequency will change. We need to know what is the effect of the width, we also need to see; what is the effect of this offset, we need to know what is the effect of this length over here, we also need to know what is the effect of this width here. Now generally this width is chosen as a 50 ohm line which is for a microstrip line corresponding to the epsilon r and thickness. Now this length here determines the coupling from this line to the slot. So, just to tell you here, current is 0 here and current will keep on increasing. So, at a distance of lambda by 4 current will be maximum and at maximum current there will be a magnetic field which will be maximum and that will get coupled to the this particular slot here.

So, if we choose lambda by 4 length here that will give rise to maximum coupling. But we can control the coupling from here to this slot here and why we need to control the coupling, because we would like to have a impedance matching with a 50 ohm line. So, let just see quickly; what is the effect of the various parameters.

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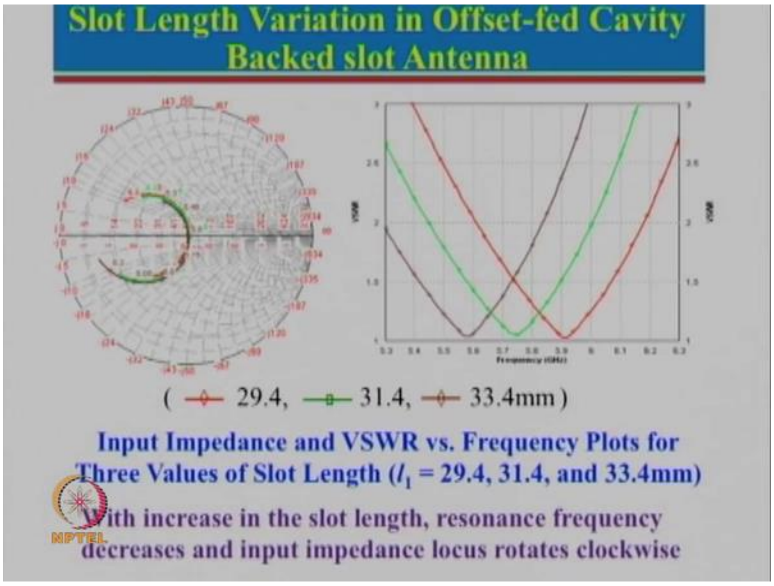

So, remember whenever you are doing any design, it is always good to start with a good starting point what should be my starting point and then to refine your design you should use some software to do the refinement. But what we generally do we also do a parametric study. So, that we know what are the effect of different parameter.

So, let us see here we have the plots for 3 different slot length. So, this is 33.4, 31.4, and 29.4. So, we know that if the slot length is increased, what will happen if the slot length is increased from here to here frequency should decrease. So, you can see that from here frequency is decreasing. So, that is a straightforward thing here we can also look at the smith chart plot here one can actually see that the starting point has shifted slightly. So, we can actually see that with increase in slot length resonance frequency decreases which is obvious and input impedance locus also rotates clockwise recall that for an antenna as you change the frequency the position on the smith chart also changes.

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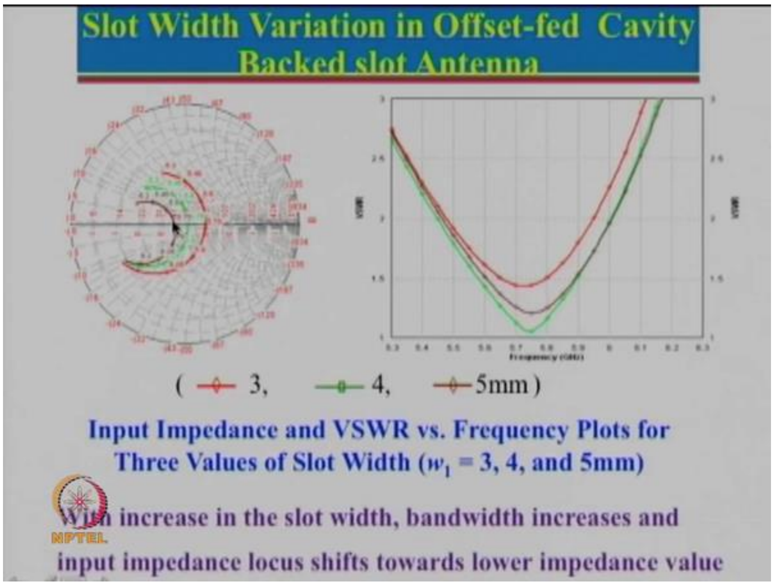

Now, here is the slot width variation. So, what we have done we have taken 3 different slots here 3, 4, 5 by changing the slot width the change in the resonance frequency is very small, but what we really see here is the change in the impedance plot is very very significant. So, for thin slot the bandwidth is actually less or we can say other way impedance is high. So, impedance variation will be more. So, which is given by this curve here and then the slot width is increased.

So, this is the curve over here and this is the slot width increased further and that is over here now we know that, for the dipole if we have a thicker dipole; that means, if the width of the dipole is increasing then its impedance bandwidth will increase and since we know that impedance of the dipole multiplied by impedance of the slot is a constant quantity. So, if the dipole antenna is bandwidth is increasing then slot bandwidth will also increase.

But; however, if you see this curve here let just see here. So, this is 3 mm this is 4. So, compared to this 3, you see that this is the VSWR 2 line here compared to this here we can see that the green has a wider bandwidth. However, for this here you actually see that the band width has not increased significantly. So, you might start wondering what is that why bandwidth has not increased well the reason for that is impedance for that is not matched properly. So, we need to do something. So, that we can do better matching for this particular width if it is properly matched then this curve will shift on this side and then this is the VSWR equal to 2 circle. So, you will have a larger frequency inside the VSWR 2 circle.

So, remember bandwidth for w equal to 5 mm will be larger than bandwidth for width equal to 4 mm it is not. So, obvious over here the reason for that is impedance matching is not done properly. So, impedance matching if that is done properly you will see a much larger bandwidth for 5 mm.

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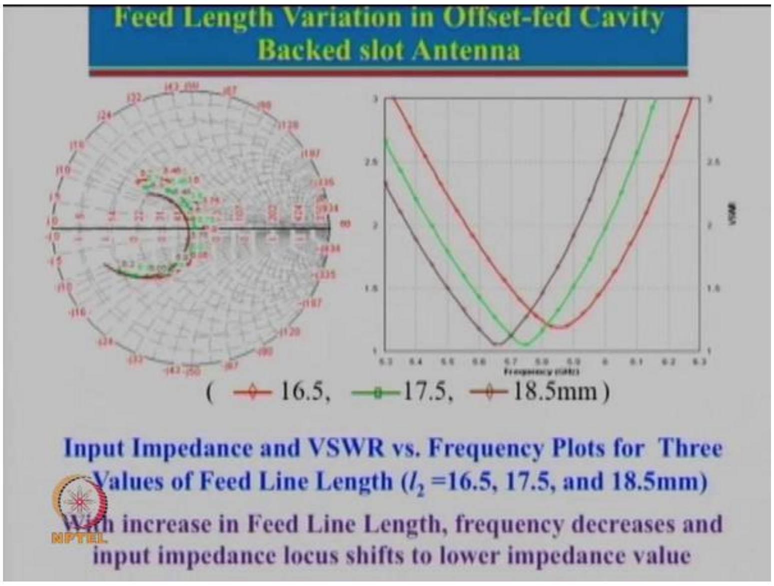

So, here is the effect of the feed length variation. So, what is feed length? Let us just look into here. So, this is the feed length variation. So, if we increase the feed here we know the current will be 0 here and the current will be maximum at this point and also if the feed length changes my feed point is over here. So, the effective length is increasing. So, one can actually see that, if the feed length is changing from 16.5 to 18.5. So, as the length is increasing frequency is also changing slightly. So, one can use this parameter also to do the optimization for the slot length.

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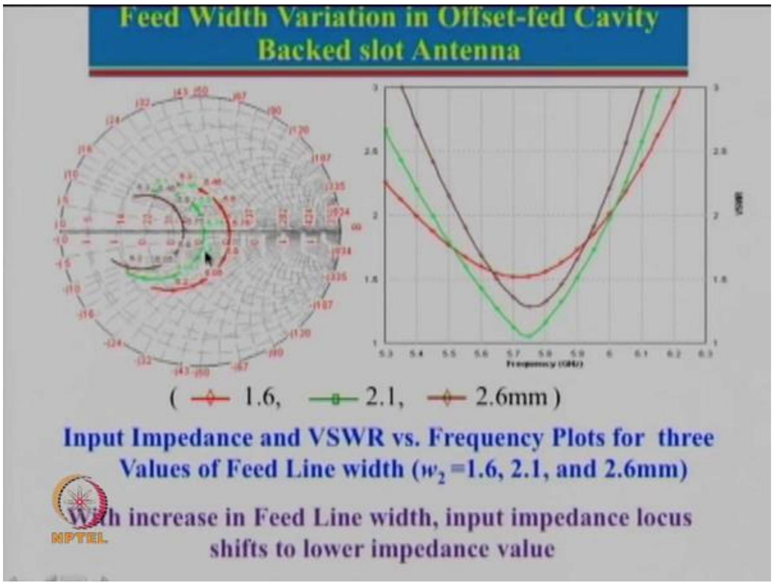

So, here is the effect of the feed width variation now. As I mentioned generally you should choose the width of the feed line as 50 ohm which is what is the coaxial feed which you are using, but this is just for the seeing what is the effect. So, if we choose the feed width smaller, smaller feed width would imply larger impedance. So, that is why the curve is here now as the feed width is increasing its characteristic impedance will reduce. So, the curve will shift towards this particular direction here sometimes this different width can be taken to do the proper impedance matching.

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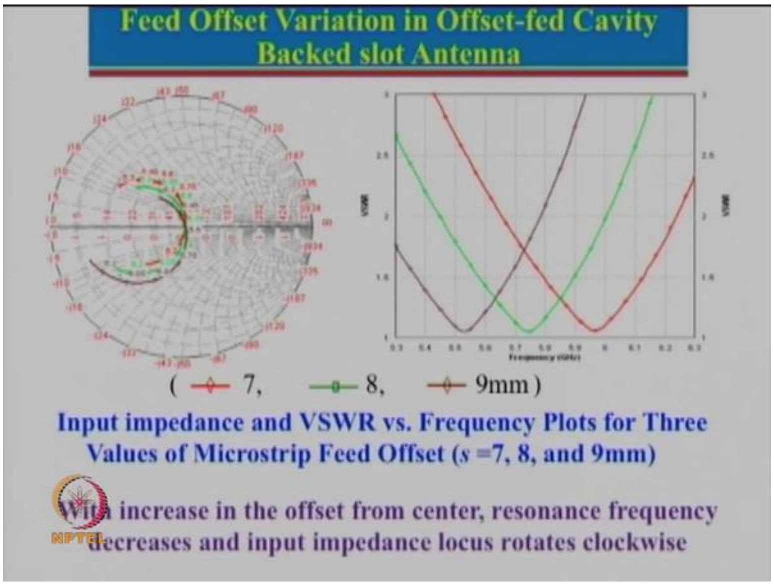

Here is the effect of the offset. So, if you change the offset now one actually wonders why if the offset is changed or the resonance frequency changes? The reason why resonance frequency is changing that this offset feed is placed on the slot. So, what is happening here now this is getting coupled along with this here. So, current distribution variation varies because of this loading.

So, the loading effect is there and because of the loading effect, the effective length of this one changes and that is why there is a change in the resonance frequency now this effect may not be very obvious as such. So, that is why we need to study all these things to do a proper design. So, once the design has been optimized for the case values, which I had shown in the table. So, after studying all the parameter these were the things chosen and then fabrication was done.

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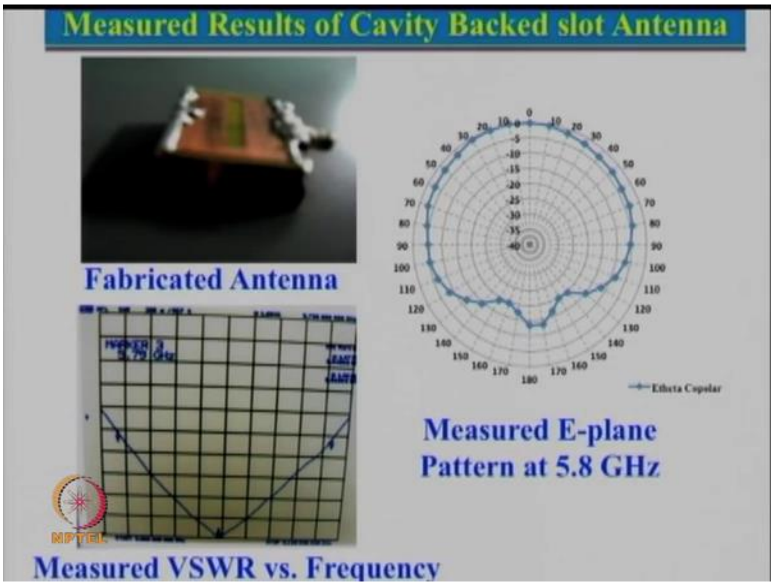

And now let us see; what are the measured results, so this is what is the slot which one can see over here. And here is the cavity which is not. So, visible and that cavity has been soldered to the slot and here is the feedpoint and that is where a microstrip line is going over here. So, one can see that the impedance matching is fairly decent and this is the measured E plane pattern at 5.8 gigahertz. And one can see that the maximum radiation is in 1 direction and the back radiation is relatively less because we have provided a cavity in the backside.

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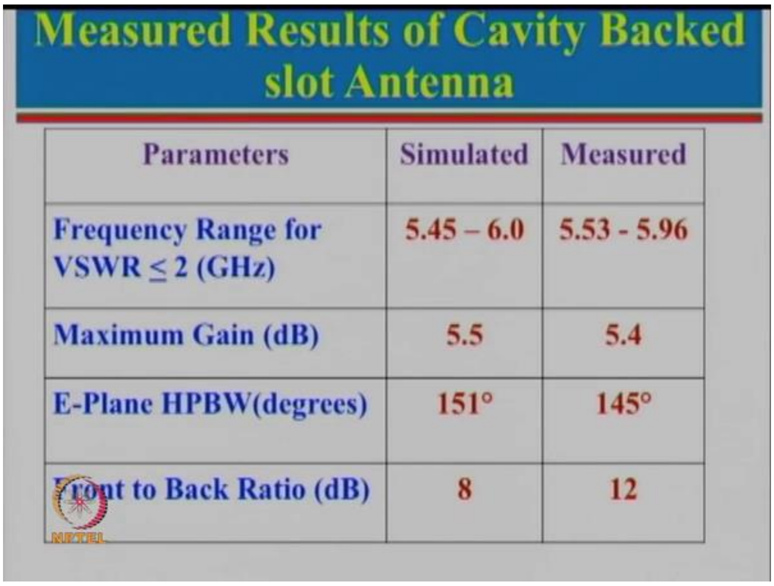

Measured Results of Cavity Backed slot Antenna

Parameters	Simulated	Measured
Frequency Range for VSWR ≤ 2 (GHz)	5.45 – 6.0	5.53 - 5.96
Maximum Gain (dB)	5.5	5.4
E-Plane HPBW(degrees)	151°	145°
Front to Back Ratio (dB)	8	12

So, here is a comparison of simulated and measured results. So, simulated results we got a bandwidth of you can say that fairly large bandwidth of more than five hundred mega hertz and these are the measured results. You can see that they are relatively close to each other gain measured and simulated are fairly close and these are the half power beam width. So, this half power beam width can be actually seen from here, that one can see that this was much larger thing here.

Now, had it been just a slot antenna only slot antenna. Then it would have been full coverage like this here which will be omnidirectional. But, because of the cavity here back radiation has reduced, but we can see that half power beam width is still within 3 dB over a large angle which is given by about, measured is about 145 degree. Now just to tell you when we got this project the requirement was minimum half power beam width of 120 degree larger beam width was acceptable so we achieved that. Now there was another requirement and that was the beam width in this plane is fine, but the requirement was also a narrow beam width or a higher gain by using a array of this one here. So, what we have showing you here.

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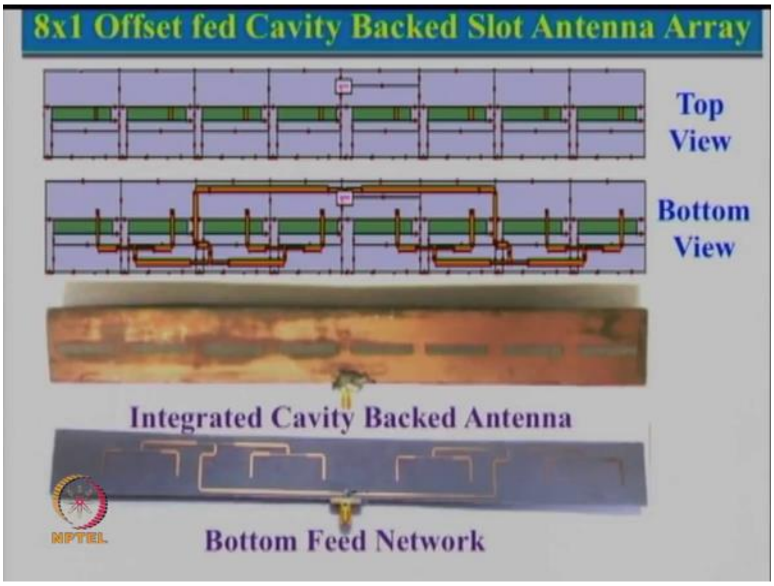

We have used arrays of these elements. In the next lecture I am going to talk about antenna arrays, but today you can think about a preview of things which are going to come in time to come. So, what we have here let just have a quick look here. So, one can actually see that there is a top view and a bottom view I will show you one by one here. So, there is a this whole thing is a metal and in the metal, one can see that a slot has been cut over here a slot has been cut over here, a slot has been cut over here do not worry this metal is same as this metal here this just shows the way modeling is done.

But otherwise you can see a 1 slot, 2 slot, 3, 4, 5, 6, 7, 8. So, there are total 8 slots are there you can actually say it is an array of slot antenna, this is known as also linear array why we say linear array, because all the slot elements are arranged in the linear fashion. Now we have 8 slots we need to feed these slots also. So, how do we feed? Generally there is only 1 feed point and then we design a power divider network. So, let us see one by one.

So, here we actually saw there is a one slot antenna and for this slot we need one microstrip line feed here. So, this is fed over here, now this we had seen that it was matched with 50 ohm line now this 50 ohm we have used a quarter wave transformer. So, quarter wave transformer of characteristic impedance approximately 70.4 and we had seen that if you use a transmission line concept, this acts as a quarter wave transformer. So, impedance at this point will be Z 0 square divided by the load impedance.

Now, Z 0 square is 70.7 square which is actually 50 into square root to whole square of that divided by fifty that gives us hundred ohm now we can see another slot here that slot is again a quarter wave transformer is used. So, we get 100 ohm. So, 100 in parallel with 100 we get 50 ohm then that 50 ohm again a quarter wave transformers is used, again a quarter wave transformer is used. So now, these are 2 slot these are another 2 slot. So, the same for the other two slot is done and then this is combined and feed over here.

Now this combination of 4 slots is right over here and then from here we took the point on this direction here. Now I just want to tell you normally, when we design an array generally feed is actually this 2 into 1 then 2 into 1 4 element. So, this is the feed for 4 generally what is done we take the point from here, we take a point from here we do the combination from here and then feed this kind of a feed is actually known as a corporate feed. You know how the corporate structure is? That let us say corporate structure will be let us say there will be 1 president, then there can be 2 vice presidents then there will be people working under them. Let us start let us say 1 then 1 by 2 then each of them let us say 2. So, this is what is done normally. So, 1, but here we took it on the other side, the reason was when we were taking this thing on this side over here.

Remember, now these are slot antenna and here there is a feed network. So, these were kind of acting like a reflector for these slot antennas. So, radiation pattern was not coming symmetrical. So, that is why. So, partly this acts as a reflector, partly this as a reflector. So, they kind of evened it out. So, this one had a more symmetrical radiation pattern. So, now, what is really happening? Now in this plane we have not added any slots. So, beam width remains broad in this plane, but we added number of slots in this direction here. So, beam width is reduced in this particular direction.

So, when we talk about linear array in the next lecture we will look into that how the number of elements are fed. So, whether they are fed with equal amplitude or equal phase and what is the amplitude between them and how we can design? But this is just a preview of that. So, here, but conceptually what you can think about that if there is a one element which is let us say giving a gain of say, in this particular case we saw let us say 5 dB. So, suppose now if you use 2 element now naturally one would expect if I use 2 element gain should double which in terms of dB it will increase by 3 dB. Now instead of 2 element if you use double of that which is from 2 if you go to 4.

So, what do we expect? That gain will increase by further 3 dB. So, 4 element gain approximately be increased another 6 dB if you use 8 element then what do we expect the gain will increase 8 times which will in terms of the dB that will be equal to 9 dB. So, let us just see now how we did the fabrication part. So, here is the design part here is the fabricated part. So, if you see the top view that is what you see here on the top you only see the slots and nothing else and that is the integrated cavity back antenna you can see that the shadow is basically nothing but it is cavity has been connected over here and then you can see there is a bottom feed network which is actually shown over here.

So, only the feed network is coming on the backside of this here. So, you can see that these are the microstrip line and then you integrate. So, this is the complete antenna assembly you can see that basically one thin substrate. On the top side we have just etched the slot on the other, other side we have etched this one, just one substrate and one metallic thing, so it is relatively low cost also.

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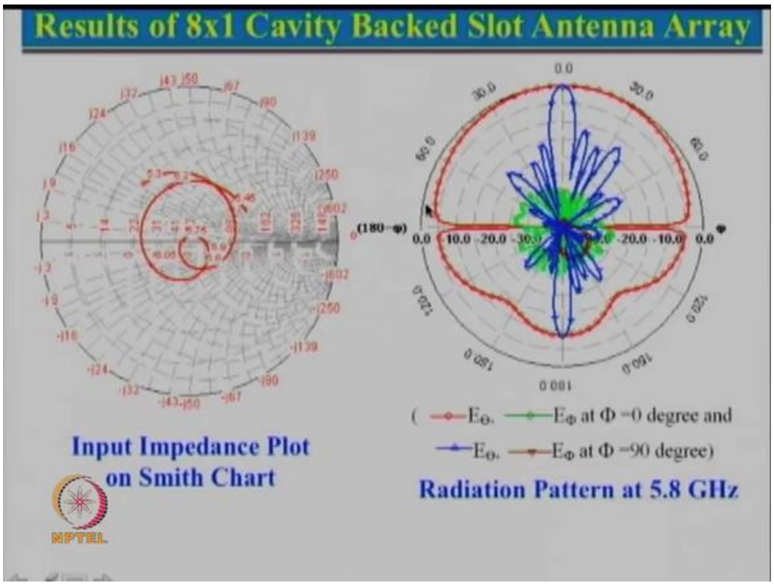

So, now let us what are the results. So, one actually got here for this particular array we got a decent matching you can see that it is centered around 50 ohm line over here we will see the measured and simulated VSWR here is the radiation pattern. So, we can see that in one plane there is a no change because we have not added array, but in the other plane you can see that this is the one main lobe and then there are lots of side lobe. One can also see that the back radiation is less compared to this (Refer Time: 26:05), because we have added a cavity. So, the back radiation is relatively less ok.

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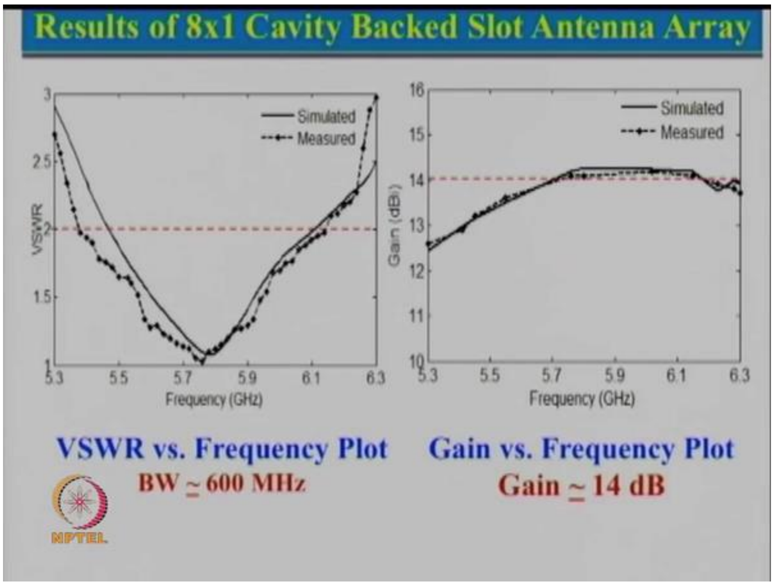

In fact, this met the requirement which was there and let us see; what are the measured and simulated results. So, one can actually see this is the simulated result here measured results are reasonably close to the simulated result. So, we got an approximately a bandwidth of about 600 mega hertz center frequency desired was close to 5.8 gigahertz there is a small shift, but still it is meeting the requirement of the bandwidth now here is the gain plot, which I mentioned to you for a single element gain was roughly 5 dB. So, if we use a larger number of elements which is in this case.

So, we got a larger gain which is approximately 4 dB and one can see that the gain is relatively constant, but yes at lower frequency gain is reducing and that is also one can also apply the concept of the aperture area concept what is the aperture area which says that directivity is equal to 4 pi a by lambda square. So, 4 pi is a constant a is area of the array now area remains fixed, but 4 pi a by lambda square where as at lower frequency lambda will increase. So, if lambda increases directivity or gain will reduce, but we can see that reduction is not very significant over the desired bandwidth here. So, it meets the requirement of the antenna.

So, now we have discussed different type of slot antenna we actually saw parametric study. So, we noticed that and it is very very important whenever you are designing an antenna it is important that you do parametric study see what are the effects of various parameter because that helps you to design an optimum antenna where you can do proper impedance matching you can do a proper requirement matching of the gain or the radiation pattern. So, we also looked into today how to use a cavity, to convert a antenna which is a bidirectional or omnidirectional antenna to a unidirectional. In fact, the same concept can also be applied for a dipole antenna.

You can have a dipole antenna put a metallic plate behind it. So, it will radiate only in this direction or we also saw that by cutting a slot on a substrate then we fed it using a microstrip line from the other side and then the location of the feed point or the microstrip offset is very important for proper impedance matching and again remember one another thing that the total effective slot length will be slightly greater than lambda by 2. So, physical length will be greater than lambda by 2. So, that effective length will be approximately equal to lambda by 2 then we applied the concept of the array to realize a larger gain antenna with a narrower beam in 1 plane in the next lecture we will talk about arrays, arrays and arrays.

So, we will start with the linear array we will see different cases of amplitude different cases of phases how we can change the beam how we can change the pattern how we can increase the gain of the antenna. So, first we will talk about linear array and then we will look into planar arrays.

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