Antennas
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Module - 08
Lecture - 38
MSA Arrays – II

Hello and welcome to today's lecture on micro strip antenna array. In fact, we started discussing about micro strip antenna in the last lecture. And where we actually noticed there are 3 different types of feed techniques, one is series feed, another one is corporate feed also known as parallel feed or hybrid feed which consist of both series and parallel feed. In the last lecture we did see of one configuration where we had used the series feed antenna array. So, let us continue from there and let us look at other options of series feed antenna array.

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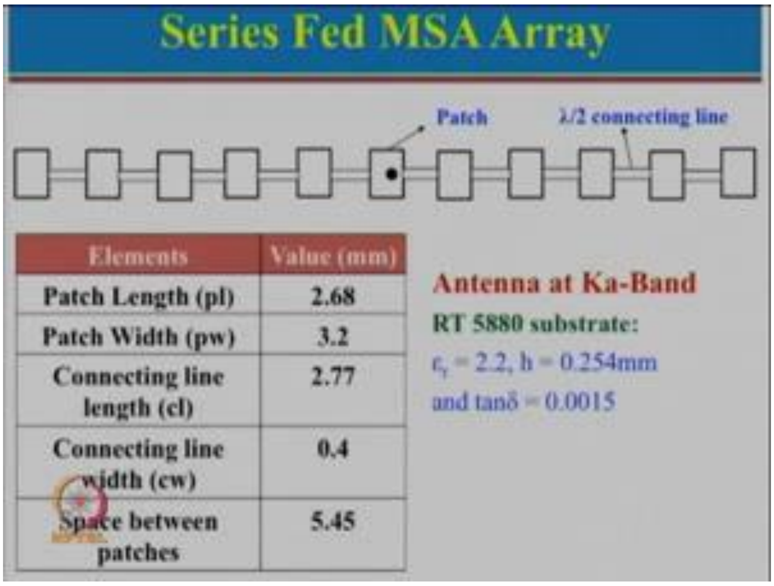

So, in the last lecture, we had seen the series feed micro strip antenna array. Where we had noticed that there are number of patches are there which are connected with the lambda by 2 connecting length. And the idea of this lambda by 2 connecting length is so that minus plus.

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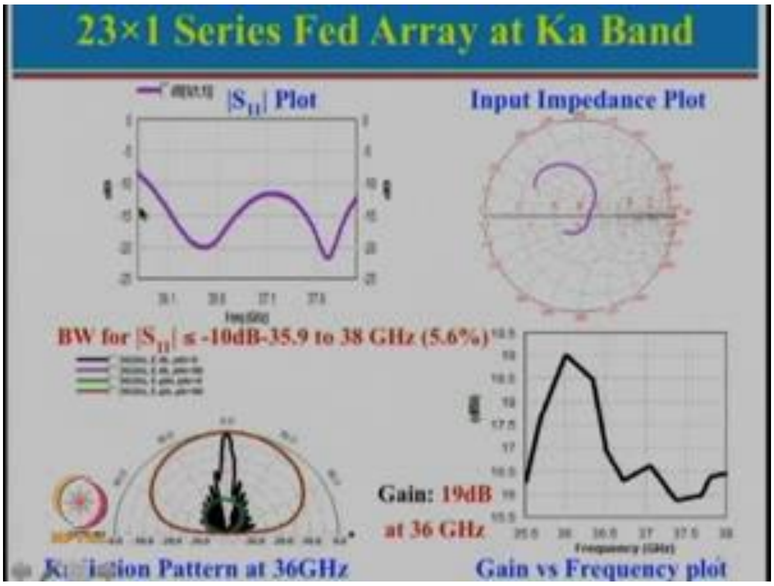

Here which is the voltage distribution for a patch then this plus here going through this a lambda by 2 which is 180-degree phase shift will give minus then this will become plus then this minus plus. So; that means, that all the patches will have a similar phase and they will radiate in the broad side direction. Then as an example we looked at a Ka-Band micro strip antenna array. So, let us just look at the results of that. So, these are the results for 23 elements series fed array at Ka-Band. One can actually see this is the reflection coefficient plot and that is a minus 10 dB. So, if you look at along this line here we get bandwidth for s 11 less than minus 10 dB which is almost close to gigahertz, which is about 5.6 percent this is the input impedance plot and this is the radiation pattern at 36 gigahertzes and at this particular thing shows over here gain variation with frequency. And one can see that the maximum gain is around 19 dB at 36 gigahertzes, but the gain falls off rapidly.

So; that means, gain bandwidth is not very good as compared to the VSWR bandwidth. And the reason for that is that if we look at the micro strip antenna array. So, what happens as frequency changes this length will be not lambda by 2 anymore, it will be slightly different. So, that phase change progresses significantly from here to here to here. So, this one tries to shift the beam in the right hand side direction and this side tries to shift the beam in the left hand side direction. So, with the result beam is in the broad side direction, but that happens only for limited frequency range. For larger frequency range what happen this one shifts to the right side this one shifts to the left side. So, for narrow bandwidth the radiation is in the broad side direction, but for larger bandwidth what really happens this phase delay is very significant. And this phase delay is also very significant and what we notice is there is a beam split in the broad side direction.

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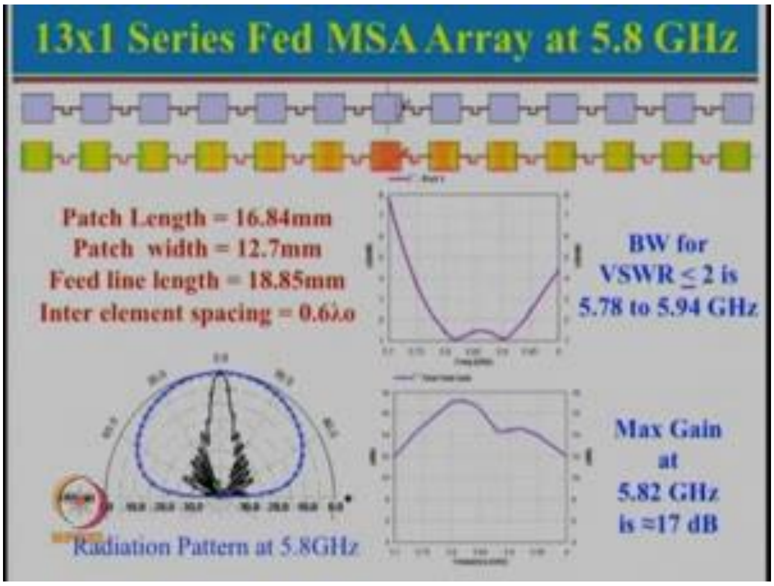

Let us look at another example of the series with micro strip antenna array, and this we have designed at 5.8 gigahertz. So, what we can see here we can see actually 13 elements over here, and instead of using the straight feed here what we have done we have used a u shaped bend. The reason for this bend is so that the spacing between the 2 patches can be reduced.

In fact, that spacing can be now control by changing the depth of this u, and suppose let us say we want to have a lesser spacing. Then this 2 will get closer and the shift here or the bend here down will be more. If you want the spacing to be increase then this will increase and the u shape the depth will actually reduce, and if you want a larger spacing then this length can become straight line. Now for this particular case here it is very important that the right hand side and the left hand side should be symmetrical, and if they are symmetrical that can be seen through the current distribution. So, let us see we are feeding the central patch you can see that it is much more reddish; that means, stronger current flow in this particular patch as we move away from here you can see that the strong reddish color is kind of reducing right. And if you also notice that this particular side is actually symmetrical to this particular side.

Now, the reason why this is happening, because we are feeding this particular patch from this patch, it is flowing in this direction as well as flowing in this direction. So, from here when the power comes here part of the power is radiating and then rest is flowing here, then part of the power is radiating rest is flowing here. And that is why you can see that the reddish portion is almost diminishing. In fact, this particular thing has an additional advantage that we have maximum amplitude here and that will be decreasing this side as well as decreasing in this side. So, this series feed antenna array provides a natural amplitude distribution, and if you recall array theory we had mentioned that if all the elements are fed with equal amplitude and phase then the side lobe level can be about minus 13 to minus 13.5 dB, but if we use taper amplitude distribution then side lobe level performance can be improving. So, one can see the radiation pattern at 5.8 gigahertz.

So, you can see that the side lobe levels are much lower in this particular case here. One additional thing I want to mention that the impedance matching could not be done for the larger array. So, that is just by feeding along the patch. In fact, up to about 7 by 1 element we could just feed the patch here. In fact, the feed point was just shifting towards the edge, but for larger array input impedance was relatively inductive. So, we have actually added a small stub over here, which provides the required capacitance for impedance matching. And because of this good matching one can see that the VSWR less than 2 is this particular line here corresponds to VSWR equal to 2, and this one here you can see that VSWR is less than to here. And the bandwidth for this particular configuration is from 5.78 to 5.94. And the maximum gain this is the gain plot verses frequency maximum gain is obtained at 5.82 gigahertz which is of the order of 17 dB.

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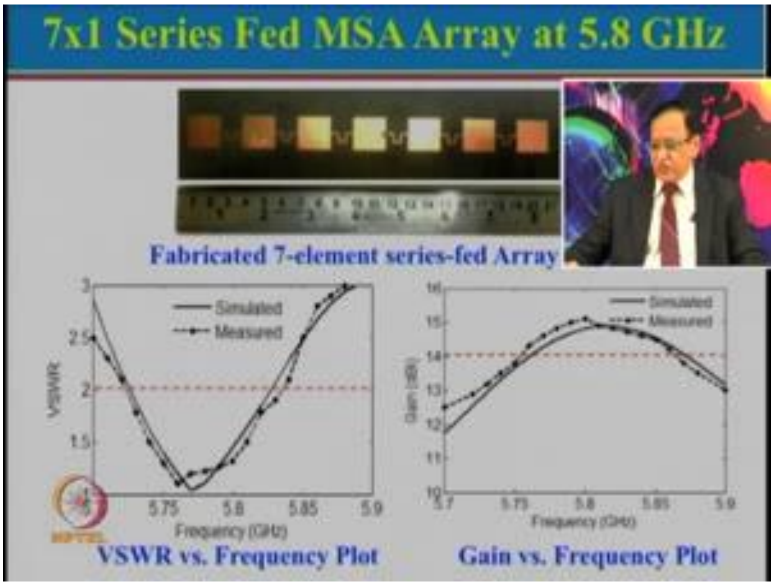

You can actually see that this is a 13 by 1 element and the previous array was 23 by 1 element. So, since the size is relatively close to half of that that is why the gain is also reduced by approximately 3 dB also. So, let us just look at the practical result. So, instead of fabricating a large 13 by 1 array, we actually fabricated a 7 by 1 series fed micro strip antenna array. And these are the simulated and measured result. So, one can actually see that the results are fairly in good agreement with each other, and these are the results for simulated and measured. So, one can again see that this is the line corresponding to about 14 dB gain, and one can actually see that because now the elements are 7 by 1 the previous result which I had shown over was for 13 by 1.

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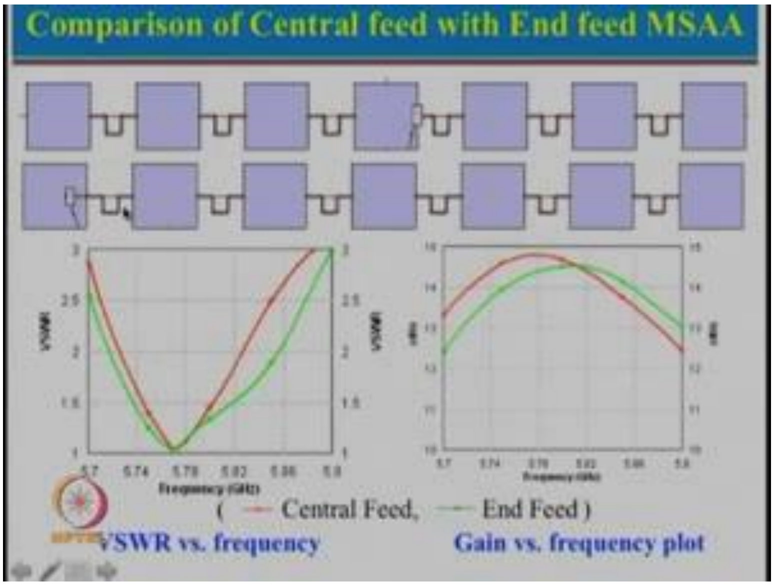

So, again number of elements have reduced by an approximately half. So, hence gain is reduced correspondingly. So, now, let us just do a comparison that if we instead of feeding the center feed over here, what if we had fed over here. In fact, this kind of an array is known as end feed array and this one here this known as central feed array. In fact, if you notice we have actually taken everything symmetrical with respect to this. So we have let us say 3 elements here we have 3 elements on this side. Whereas, for end feed there is a no restriction we can have any in even number or odd number; however, the problem with the end feed is that this length which can be lambda by 2 at the central frequency, but as frequency changes the phase delay increases so; that means, the beam shift takes place and this time now beam shift is taking place only in one side whereas over here these elements try to shift in the right side these try to shift in the left side and the maximum radiation still remains in the broad side.

But over here because of this delay in one side only we will see that the pattern shifts, but over here let us just see. So, if you look at the comparison, the red line is mainly for this here and the green line is for this. One can actually see that for end feed VSWR less than 2 bandwidths is slightly larger, but this is not really a useful bandwidth. Also one can see that the gain is slightly smaller frequency slightly shifted the reason for that again is it is an end feed.

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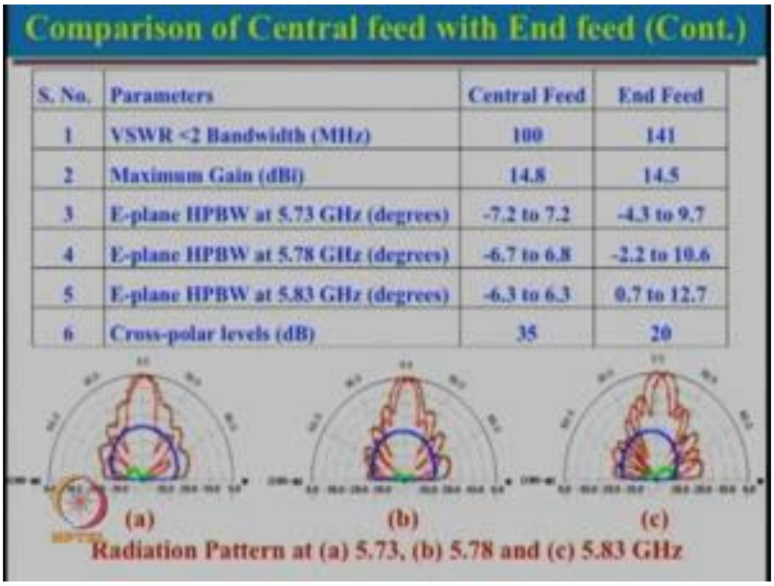

S. No.	Parameters	Central Feed	End Feed
1	VSWR <2 Bandwidth (MHz)	100	141
2	Maximum Gain (dBi)	14.8	14.5
3	E-plane HPBW at 5.73 GHz (degrees)	-7.2 to 7.2	-4.3 to 9.7
4	E-plane HPBW at 5.78 GHz (degrees)	-6.7 to 6.8	-2.2 to 10.6
5	E-plane HPBW at 5.83 GHz (degrees)	-6.3 to 6.3	0.7 to 12.7
6	Cross-polar levels (dB)	35	20

Radiation Pattern at (a) 5.73, (b) 5.78 and (c) 5.83 GHz

So, now let us just see the comparison. So, here is a comparison of central feed with end feed. First let us just look at the radiation pattern at 3 different frequencies 5.73 5.78 and 5.83. Now these are the frequencies which are within VSWR less than 2, but now let us see here one can see that this is the pattern for the central feed you can see for central feed the pattern is relatively symmetrical.

But for the end feed one can see there is a small shift here, then there is a little larger shift in the b maxima, and here there is an even more larger shift here. In fact, that can be seen from here. So, let us just see for central feed VSWR less than 2 bandwidths is about 100, which increase to 141 gain is approximately same, but now let us just see the half power beam width if you look at these numbers here it is actually symmetrical with respect to the broad side direction, but if you look into this here the beam is shifted which is from minus 4 to 9 then you can see there is an even more shift and over here you can see that the beam is really shifted away from the broad side direction. And also it has a higher cross polar level compare to the central feed in this particular thing. So, now, from series feed let just see corporate feed. Now this is the one example of a corporate feed or this we have designed at X-band.

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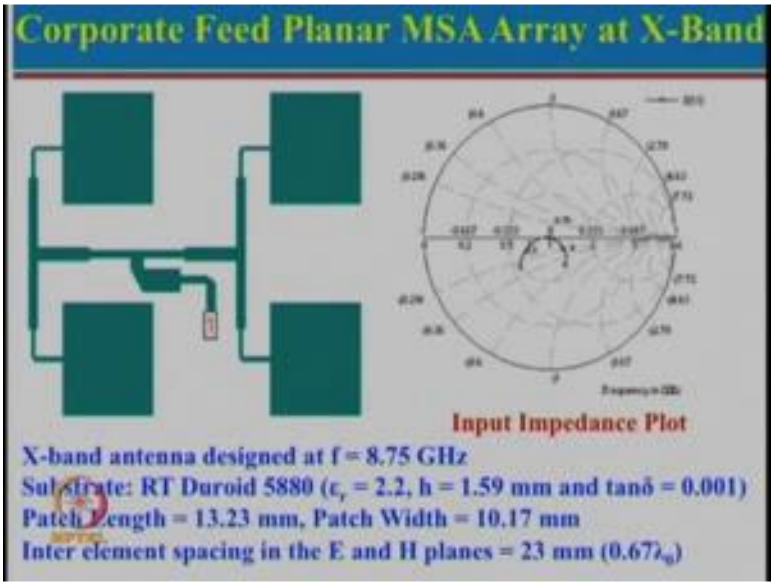

In fact, I have given you different flavors. So, the first example we give at millimeter wave that another example we gave at c band which is 5.8 gigahertz let us just look at another example which is at X-band. So, here we designed antenna around 8.75 gigahertz. So, let us see what we have here. So, we can actually see it is a 2 by 2 micro strip antenna array and now we need to feed these elements. So, now, what should do in general first you do the simulation of a single patch and these are the substrate parameter. So, for these substrate parameter first what you need to do for this particular frequency find the length and width. So, these are the length and width which we have taken and then inter element spacing has been taken close to 0.67 lambda 0. In fact, you can take inter element spacing between 0.5 lambda 0 to maybe even up to 0.8 lambda 0.

So, we took in between value. So, here now what we did you calculate the input impedance at this particular patch. And since this is relatively narrow band antenna impedance will be high. In fact, this impedance maybe of the order of 200 ohm or. So, what we have done we are used a quarter wave transformer to transform this impedance to 100 ohm. Again the same thing it is symmetrical. So, this impedance is transformed to 100 ohm at this micro strip line has a characteristic impedance of 100 ohm, this one transform to 100, 100 remains 100 here, 100 remains here 100. Now 100 in parallel with 100 will become 50 ohms, now then from 50 ohms in fact, if we just use 2 by 1 element that design would be over you just use this much portion and we can feed at this particular point, but now this example is 2 by 2. So, now, this 50 ohm has been now again transformed to 100 ohms here by using a quarter wave transformer of impedance 70.7 ohm. So, that transforms the impedance 200.

Now, this side it is exactly the same thing here. So, this impedance is transformed to 100, 100, 100 in parallel with 150, 50 transform to 100 and now 100 in parallel with 100 will give us 50 ohms. So, if we did not want anything is we could have actually just fed over here with a coaxial feed and we could have got the impedance matching. Now this extension we have shown over here mainly to extend this array to the larger size. In fact, this approach one of the advantage of this particular approach is it is a very modular in nature; that means, one should design let us say 2 by 2 array you can then make it 4 by 4 or 8 by 8 or 16 by 16 array or even larger. So, now, for larger array this is the 50-ohm line. So, again what that has been done it has been transformed the impedance here. So, let us just first see the results of this and then will look at the larger array.

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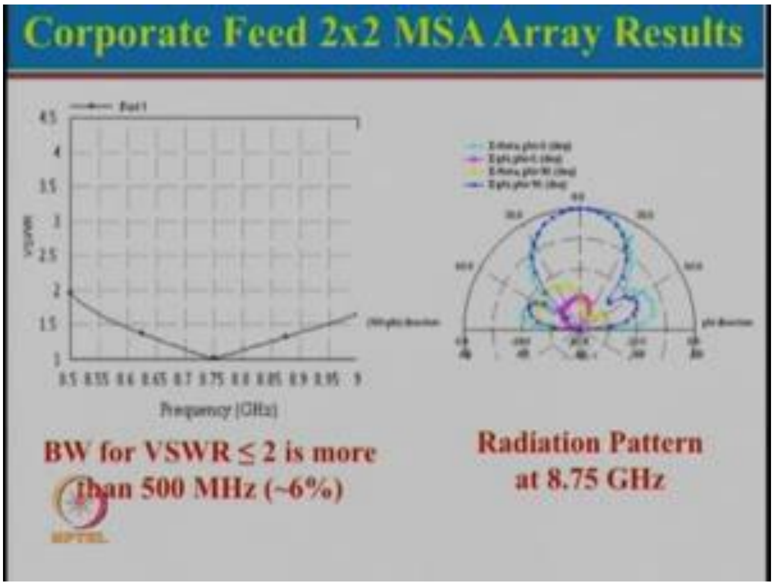

So, one can see here this is the VSWR equal to 2 line. And one can actually see this is the plot here we can say bandwidth for VSWR less than 2 is more than 500 megahertz this is 8.5 this is 9 VSWR is still less than 2. And this bandwidth is about 6 percent. We will also take some example where we get much larger bandwidth also, but for now let us see these results here. So, this is the radiation pattern at 8.75 gigahertz. So, you can see that the radiation is in the broad side direction.

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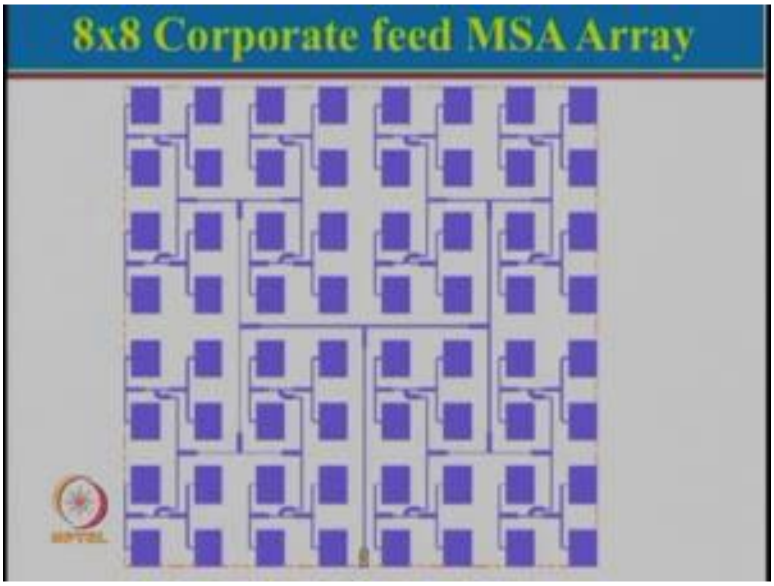

Now, let us just look at the another example, which is now an 8 by 8 corporate feed micro strip antenna array. So, just to tell you now suppose we have this 2 by 2 array which I discussed earlier. So, this 2 by 2 array and then let us look at this 2 by 2 array. So, for these 2 by 2 array here one set here and one set here you can see that this 50 ohm is now impedance transfer to 100 ohms. So, that is a quarter wave transformer used and this is the 100-ohm line. Now this set here is repeated over here exactly with the same thing.

So, here then again this impedance which is 50 ohm transfer to 100. So, 100 in parallel with 100 will be 50 ohms here. So; that means, if we now require only suppose 4 by 4 array our design would have been completed here we could have just use the coaxial feed at this particular point and that would have been a 4 by 4 array, but now this 4 by 4 array is now repeated 4 times. So, you can see first here this array and this array here first. So, this is 50-ohm quarter wave transformer is used to transfer this impedance to 100 same things here 100 in parallel with 100 will be 50 and then this 50 is transferred to 100 ohms which is over here, and then we could have used a coaxial feed at this particular point or this can be extended to the larger array.

In fact, we have also done the simulation for 16 by 16 where then this point then is replicated this whole thing and take mirror image in this side bottom side and this side here and that was used to design 16 by 16 corporate feed MSA. I just want to tell here that as the number of elements increase simulation time increases significantly. So, one is to have good computer and with large memory so that you can do the simulation of these things.

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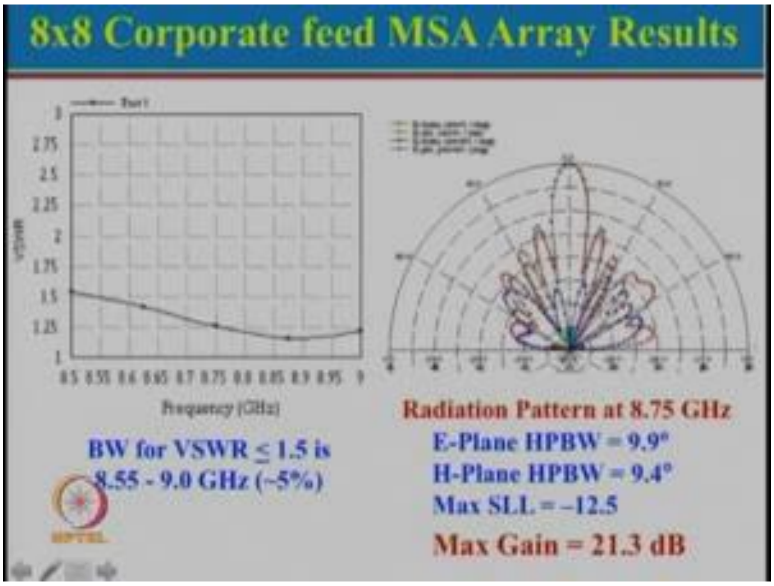

So, let us just look at the results. So, over here one can see that this is the line which is corresponding to VSWR 1.5. So, VSWR less than 1.5 we achieved the bandwidth from 8 .55 to 9 gigahertzes which is about 5 percent, but you can see that is bandwidth will be much larger, if we define for VSWR less than 2 and here is the radiation pattern at 8.75 gigahertz. So, the maximum gain obtained.

In this case is about 21.3 dB you can see that e plane half power bandwidth then H-plane half power bandwidth are approximately same because the array is symmetrical in the both the planes. A maximum side lobe level is about minus 12.5 which you can see over here and the reason the side lobe level is high because normally for an ideal array with an equal amplitude in phase it should have been about minus 13 to minus 13.5 slightly below there, but this is slightly higher that is because of the radiation taking place from the feed line, and that is why we use either amplitude distributed array or series fed antenna array.

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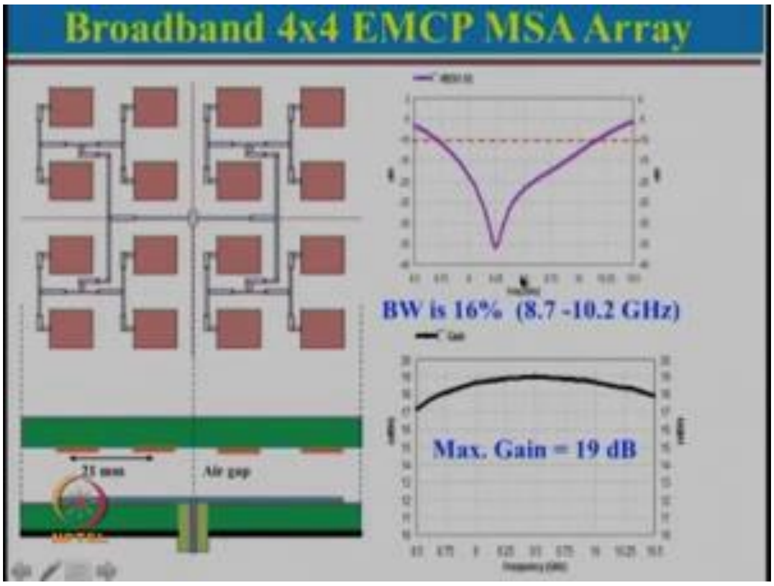

Now, let us just look at an example of a how to realize a larger bandwidth. This is an example of a 4 by 4 electro magnetically coupled micro strip antenna array.

So, just to mention here, here what you notice here there is a feed network which is shown in a green color here. And there is actually a patch here also which is of does say almost the same dimension, but that is on the lower layer. So, this is the side view. So, what you see over here this actually consist of the feed network as well as patches over here. So, which will be a 4 by 4 array, and we saw in the previous example if we just take 4 by 4 array bandwidth was not very large. So, here now all the patches which are down below here they are electro magnetically coupled with the top layer patches. So, what you see here these are total 4 by 4 micro strip antenna elements which are printed on the underside of the substrate.

So, this substrate also acts as a red home for this particular array. And if you now see the result here I have drawn the line for reflection coefficient minus 10 dB. And just to remind reflection coefficient of minus 10 dB is approximately equal to VSWR 2 and for this particular case we can see that for reflection coefficient less than minus 10 dB, bandwidth is about 16 percent and or you can say 8.7 to 10.2; that means, 1.5 gigahertz bandwidth. Now I will tell you this particular antenna array we had design for a very specific application. And that application requires the set of frequency to be 9.25 you can see that a very good matching has been obtained at 9.25. In fact, our requirement for this particular project was only from 9 to 9.5 which is about 500 megahertz, but if you see corresponding to this here.

You can actually see reflection coefficient is less than minus 20 dB. So, which really corresponds to about one percent reflected power 99 percent transmitted power and also VSWR equal to 1.22. So, you can see that it is a fairly broadband antenna, but just VSWR bandwidth is not sufficient we should also look at the gain. So, we can actually see here this is the gain plot and one can actually see that gain is fairly uniform over a large bandwidth. In fact, one can actually see that over one gigahertz bandwidth the variation is less than 1 dB. So, it is a fairly good array and the radiation pattern also variation over this band here is very small. So, when you are designing an antenna please do not just look at the VSWR bandwidth, just check each and everything see what is that radiation pattern is it stable over the bandwidth or not what is the gain is gain stable over bandwidth or not this particular array.

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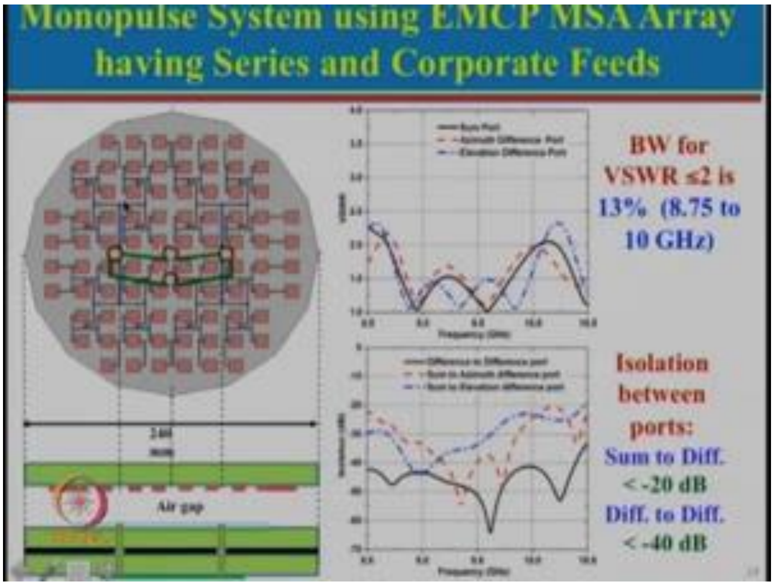

We would generally like that the gain should remain flat and the absolute maximum error which we can tolerate is about one dB, but over here you can see that whether the desired bandwidth the variation is less than 0.5 dB. Now this particular thing has been extended to a one interesting application which is monopulse system using electromagnetic coupled micro strip antenna array. So, now, let me just tell you this particular thing has been designed for one of the application where the specifications were that the entire array should fit within 240 mm diameter. So, that was our restriction. And I will also just tell what is this monopulse system as such what does this really mean. Now normally this particular thing is covered in the radar systems course here, but since we are designing antenna.

For this particular application, let me just tell you little bit more detail. So, generally speaking in monopulse system what is actually done, there generally 4 different antennas are used and in these 4 different antennas. So, let us say there is a one antenna second third fourth antenna. So, these 4 antennas are first fed with the equal amplitude and phase. So, that the radiation will be maximum in this particular direction and this is actually use for tracking the object which can be a flying object. So, then what it does it sends these signals together. So, that will have a narrow beam it will go there reflect back from the target. So, suppose now if the target is exactly in the center of these 4 elements then what will happen all of them will receive the same amount, and the same phase also and then what we do we take the sum pattern.

So, that we get the reflected beam which is sum of all these, and we also calculate what is the difference of this and this. So that case be azimuthally difference and then we also take the difference of this with respect to difference of this so that gives me elevation different. So, suppose now if the target is exactly in the center then what will happen? All these reflected wave will be exactly at the same phase and if we take the difference then the difference should give me 0 in the broad side direction we call it a null. But suppose if these 2 are not align and suppose it is shifted like this or there; that means, in the reflected these 2 will see a different phase and you can see that if it is aligned more with this so this will have a one phase this will have a little different phase. So, if the phase is different; that means, alignment is not proper and this will give me azimuth difference which has finite value.

Similarly, if the differences between this and this that will give us the elevation difference, so that would really mean that target is not exactly in the center it is either shifted in this side or this side which belongs to azimuthally difference. And if the target is shifted this way then that gives us the elevation difference. So, by looking at that then we can do the tracking of the object properly. So, let us just see what has been done over here to achieve that. So, think about this entire big array is to be divided in to 4 quadrate. So, this is the quadrate one then second then third and then fourth. So, this is the one antenna another, another one and another one. Now if you look carefully this particular thing here and just recall our 4 by 4 array which we talked about. So, just look at this portion here. So, 1 2 3 4 and if you see over here, this is nothing but the same 4 by 4 antenna array which we saw in the previous one.

But since we had some extra space available to us, we decided to add some more elements so that we can enhance the gain. So, what we have done over here. For this 4 by 4 element we took little bit power from here, and this whole portion is a corporate feed, but over here from this we have taken the power in the series manner. So, this length is now taken as lambda by 2. So, that this element is in the same phase. So, now, looking at these 3 element. So, they are fed with the equal amplitude, but this one here now even though it was fed with equal amplitude, but part of the power is taken to this one here. So, this actually gives us the amplitude distribution in this particular direction then the same amplitude distribution. We try to achieve in this direction because we had a room over here. So, what we did from the top elements. So, part of the power we took from here and fed it over here.

Now in this particular case actually this length is close to lambda. So, that this phase here remains same as this particular phase here. So, part of the power is given here part of the power is given here part of the power is given here.

So, what happens? Now if you look at the totality. So, it actually gives us the amplitude distribution complete as central elements are fed with equal amplitude. So, let us say we get a line like this and the end elements are fed with the lesser power. So, that will give a distribution. So, in a reality what we get a distribution something like this then uniform and then coming over here. So, that gives us the natural taper distribution. And also we could optimize the area available to us. So, now, these are the results given over here, but just to tell you the next part. So, the 4 feeds here they are actually fed to the 4 rat race things here. Now these rat race actually are nothing, but these are 3 dB hybrid coupler. So, the property of these rat race is that they give sum and difference pattern. So, we have taken sum and difference from here, then sum and difference from here, sum and difference from here, sum and difference from here.

So, one of the port then gives us sum port and the other 2 ports give difference and the forth port is actually terminated in a matched load. So, you can actually see that this is the VSWR 2 line here; bandwidth is almost from 8.75 to 10 gigahertz, which is more than one gigahertz bandwidth. So, over here now sum to difference is minus 20 dB, but what is more important is isolation between difference to difference which is minus 40 dB. So, you can actually see that the isolation between this is extremely good. Generally anything better than 20 dB is considered good and minus 30 dB is very good minus 40 dB is considered very good and because of this particular case here what we get is a very good null direction in the broad side direction.

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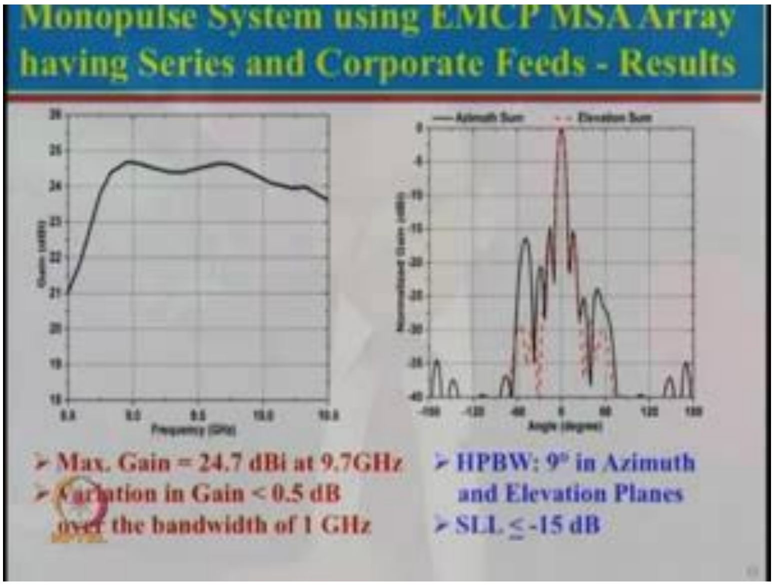

So, here is the gain you can actually see that in this particular region here gain is fairly uniform. The absolute maximum gain variation is about 0 point 5 dB over the bandwidth of 1 gigahertz. And we got a maximum gain of about 24.7 dB. Now this one over here shows sum of the azimuth and sum of the elevation.

So, one can see that sum of the azimuth and elevation they are fairly good. Only in this particular over here we see that the readings have slightly different, but that is not really too much of an importance because we are more interested in this particular region here. And the difference of these 2 actually gives us a null of better than minus 30 dB.

So, with that will conclude today’s lecture. So, today we looked at the series feed antenna array that will looked into corporate feed we noticed that corporate feed is very modular in nature, and you can start with 2 by 2 array and you can build array from that particular small module. So, that is also known as sub array. So, you can start with 2 by 2 sub array, make it 4 by 4, make it 8 by 8, make it 16 by 16, people have gone to 32 by 32 array also, but after that generally they do not make 64 by 64 using this feed network. Generally, for those kind of an array what they do they use.

Let us say one 32 by 32 another 32 by 32 and then use external 4-way power divider network. So, as the general rule, and then we also looked at the hybrid coupling which basically consisted of corporate feed as well as series feed. So, we could take power out of the corporate feed to also get better side lobe level performance as well as get slightly better gain.

So, in the next lecture will talk about more types of the antenna array and will see that in fact, will see something very interesting that an array which does not require any feed network. So, we will see something interesting in the next lecture till then bye, will see you next time, bye.