Analysis and Design Principles of Microwave Antennas
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Lecture – 20
Endfire Linear Uniform Array

Welcome to today's lecture on Endfire Array.

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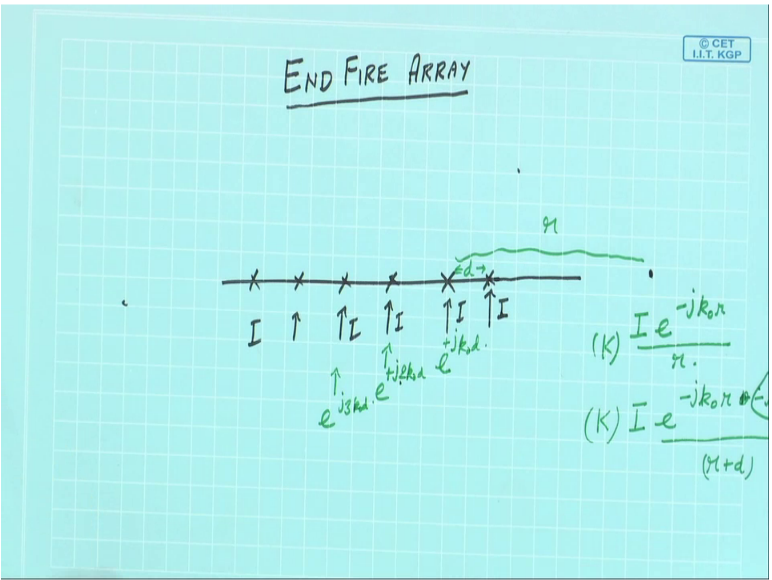

We were discussing in the last class, uniform linear array. Now, that has two varieties; one is broadside array that we have discussed. Today, we will discuss the End Fire Array. Now, physically what was broadside array, we were not giving any phase shift to each individual elements. So, that is why in the broadside direction, all were getting interfere that constructive interference and the maximum was coming to the broadside of the array axis. Now, look at an Endfire. Suppose, this is a array axis and I have elements here, now here suppose, the this is fed. So, everyone is getting fed. So, let us say this is I, this is I, this is I.

Now, at any point in space, this I radiation that will give me we know that this current in to e to the power minus j k naught r by r. This also will there. Now, you see if I want that the radii maximum radiation should be along this axis. So, I want let us say, here it should peak either here or this side. So, this one when it goes here, it has certain phase space depending on these distance, let us say this distance is r. So, due to this first one what will be the field here? Per field will be I e to the power minus j k naught r by r in to some constants where this 4 pi etcetera everything will be observed. Now, what will be the next one? Next one will be these.

So, next one will be this in K, I e to the power minus j k naught r plus sorry another distance minus j k naught if this distance is d minus j k naught d by that r plus d etcetera, etcetera ok. Similarly, the other one there will be minus j k naught sorry minus j 2 k naught d minus j 3 k naught d, etcetera. So, you see that between this one and this one, the difference is e to the power minus j k naught d.

Now, if while exciting compared to these, I give if extra phase in the current of e to the power plus j k naught d; here I give e to the power plus j 2 k naught d, here I give e to the power relatively; that means, compared to this I am giving e to the power j k naught d, relative to this I am giving j 2 k naught d etcetera, j 3 k naught d etcetera in the excitation current phase, then this part is getting cancelled. So, each one will be now constructively adding. This is the idea of Endfire array.

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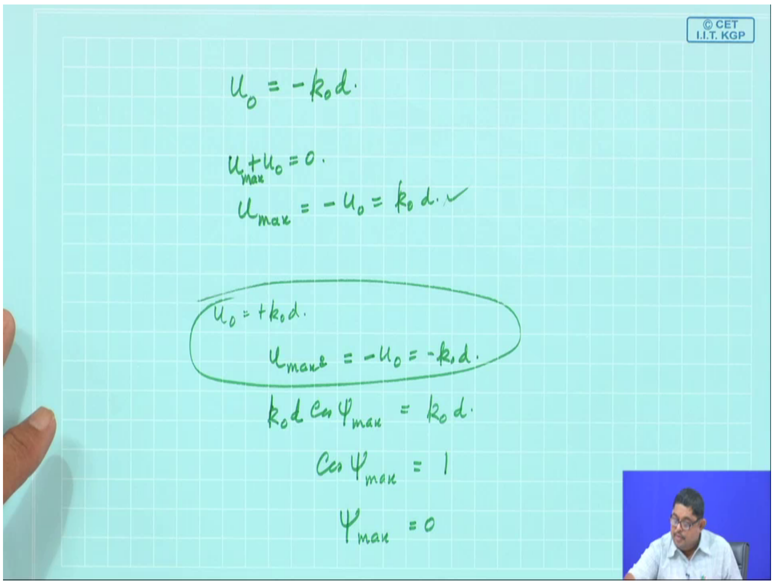

So, in the Endfire array, the progressive phase shift which was our it was base convention u naught that will have to choose as minus k naught d; that means, the to travel an inter element distance, the phase space acquired by a plane wave that we are, negative of that we are giving as the progressive phase shift. So, always we know that major lobe maxima that occur at u plus u naught by 0, this is from array factor we get.

So, where will be the new or I can say u max. So, u max will be now at minus u 0 and what is minus u 0, that is k naught d; that means, look at the diagram.

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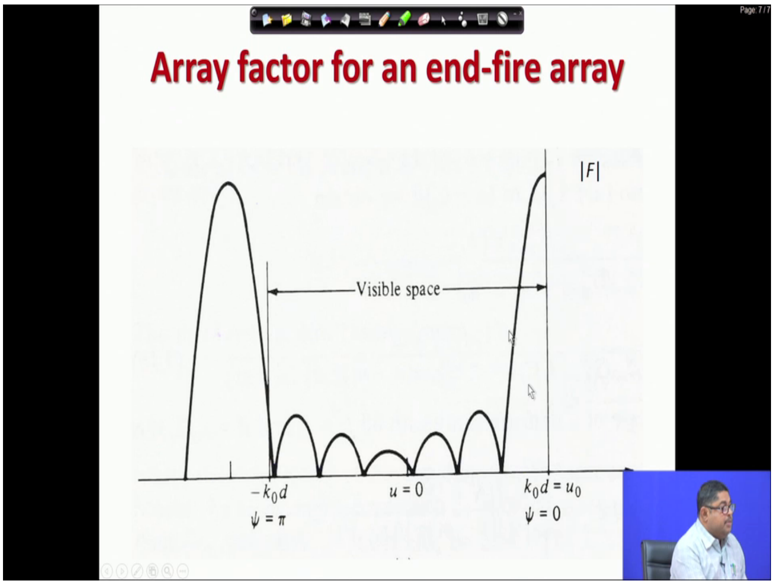

So, now the main lobe is at k naught d u naught k naught d; that means, just at the end of the visible space vector, you see half of the lobe is in the invisible spectrum ok. So, minus this is the End Fire Array. Now, if I want it instead of these, I want it in the opposite direction. So, I will have to just change it if I give it this u naught if I give as plus k naught d, then this u max or you can say u max 2, the second one that will be at minus u naught and that is minus k naught d.

So that means, instead of this diagram, the main peak that will be half of this main lobe peak will be here at that end. This is the End fire Array concept. So, and we can now find out the moment we have got these u max is k naught d, what was our u max it is nothing but k naught d cos psi max, that is I am taking this first one. So, k naught d so, then I can say that from here it is apparent that cos phi psi max that is 1; that means, psi max is 0.

So, what is psi? This is the array axis. So, psi is 0; that means, with these, this was psi. So, psi is 0 means it is having the peak at this direction. So, major lobe occurs along the array axis. So, this thing, we can see the array factor. Now, you see that the main lobe if you look here, the main lobe is at the extreme of the visible space. So, there is a high chance, you see that these next one this is the grating lobe. This grating lobe can enter here because this is already at the end. In earlier case in for the broadside array, it was at in between.

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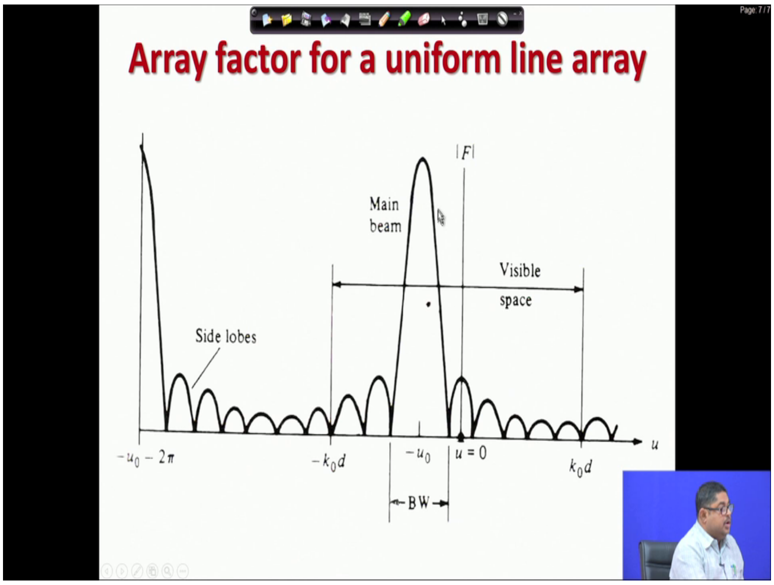

You see that it was in between, the main beam was in between. Here, it has gone through one extreme. So, there is high chance that the next one can put to for a array end-fire array. So, we will have to find out that to avoid grating lobes what we can do? We know that the array factor is a periodic function that we have said that array factor is periodic with a period 2 pi.

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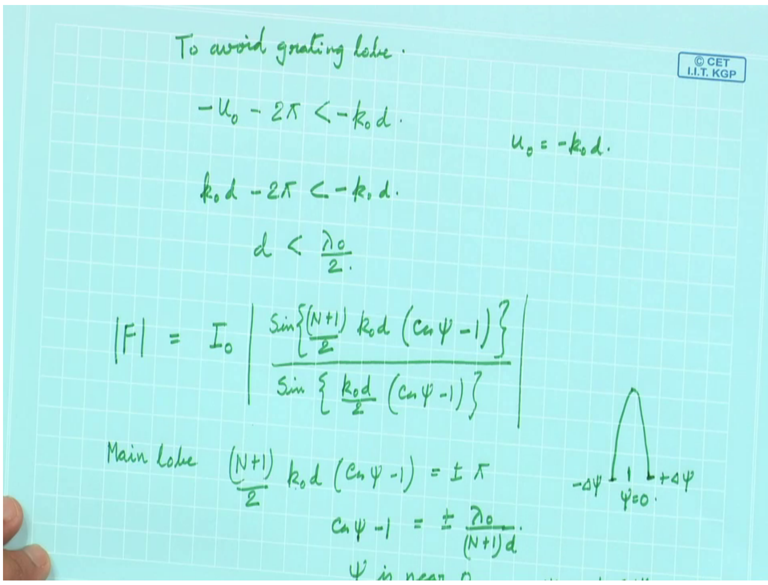

So, we can say that minus u 0 minus 2 pi should be less than minus k naught d. What is the meaning? This is my minus u 0 and minus 2 pi, it will go here. So, these should be beyond minus k naught d; that means, less than minus k naught d, that is the condition. So, to avoid grating lobe, I require these. So, for End fire we have seen that u naught is how much, u naught is minus k naught d. So that means, putting it here that k naught d minus 2 pi less than minus k naught d. So, if you solve these, this says that d should be less than lambda naught by 2; so, you cannot take d more than lambda naught by 2 for End-fire array.

So, to avoid getting the lobe, u should be always less than half of the operating wavelength. So that means, the length of the End fire array generally smaller than the length of the broadside array because for broadside array for avoiding grating lobe, you can go up to d, slightly less than d generally we take. But here, you are am sorry d means lambda naught here it is half of that.

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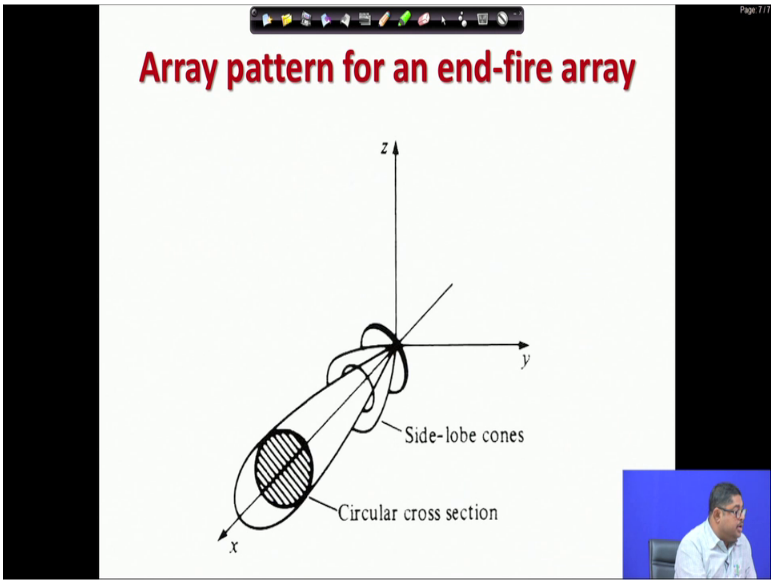

And so, we can see how the thing looks like; array pattern for an end-fire array is looks like this. These are the side lobes. So, you see x axis is the array axis and the main beam is along the array ok. It is a figure of revolution about the array axis and we now need to find out the other parameters of this, the array factor we can write. What is the array factor of end-fire array? That is I naught sin n plus 1 by 2 k naught d. You see that u naught I will put this thing.

So, it will come as cos psi minus 1 by this is the array factor. So, where is the main lobe, we have already seen; where is the main lobe, maxima occurs. Now, where is the main lobe null occurs? So, main lobe null obviously, when these thing will be plus minus by this argument; that means, n plus 1 by 2 k naught d cos psi minus 1 will be plus minus main lobe, other lobes you can find out, but main lobes is this. Now, for large n, what is the value of this cos psi minus 1 is plus minus you put here k naught value 2 pi by lambda naught. So, we will get lambda naught by n plus 1 d.

Now, you see for large n, this right hand side is quietly small number, so that means, cos cos psi that value is 1 plus minus something. So, we can say that psi is near 0 and what is the value we can say that the null at nulls, the value of psi is plus minus delta psi whether it is very small value. So, now what is that value now we will have to solve, now what is the value of this delta psi? So, so I can draw these that this is the main beam. So, this is at psi is equal to 0 we have seen the peak occurs and the this one is at plus delta psi. This one is at minus delta psi ok.

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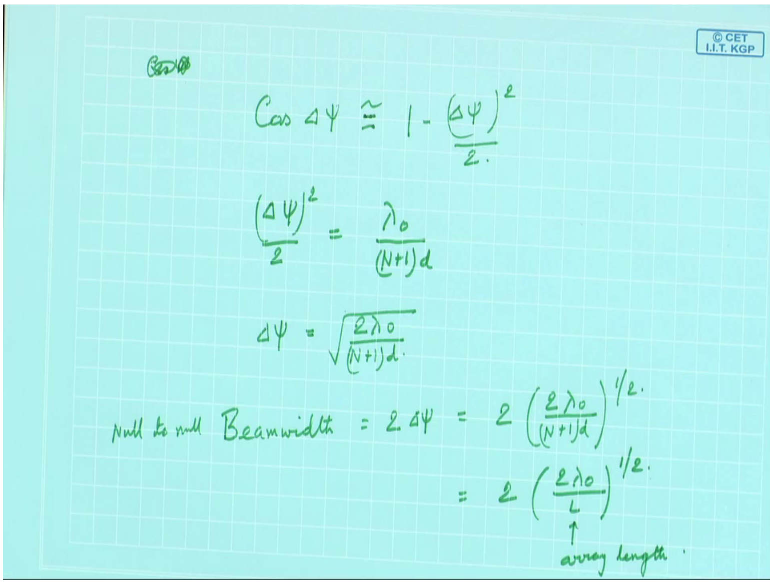

Now, for small delta psi, we can write cos cos delta psi that can be approximately written by series expansion as 1 minus delta psi square by 2; cos x is equal to 1 minus x square by 2. So, we can put that delta psi square by 2 is equal to lambda naught by n plus 1 in to d, is not it? Because already we have found this cos psi minus 1 is this. So, equating this, we get this. So, what is delta psi? Delta psi is 2 lambda naught n plus 1 into d. So, what is our beam width? Beam width is if we look at here, beam width null to null beam width I should say null to null beam width is 2 delta psi and that is 2 into 2 lambda naught n plus 1 into d. Now n plus 1 into d is nothing but the array length L. So, you can write 2, 2 lambda naught by l power half. This L is nothing but the End fire length array length.

So, you see that beam width of an End fire array is inversely proportional to the square root of the array length, array length, electrical array length or array length measured in wavelength. Now, this was the for broadside, this was inversely proportional, this is inversely proportional to the square root of the length. So that means, the beam is not as narrow as the case was for broadside. So, here the End fire it is not as narrow, but the point is this narrowing occurs in two planes; the grater beam width compensated by an narrowing of the pattern in both e plane and h plane.

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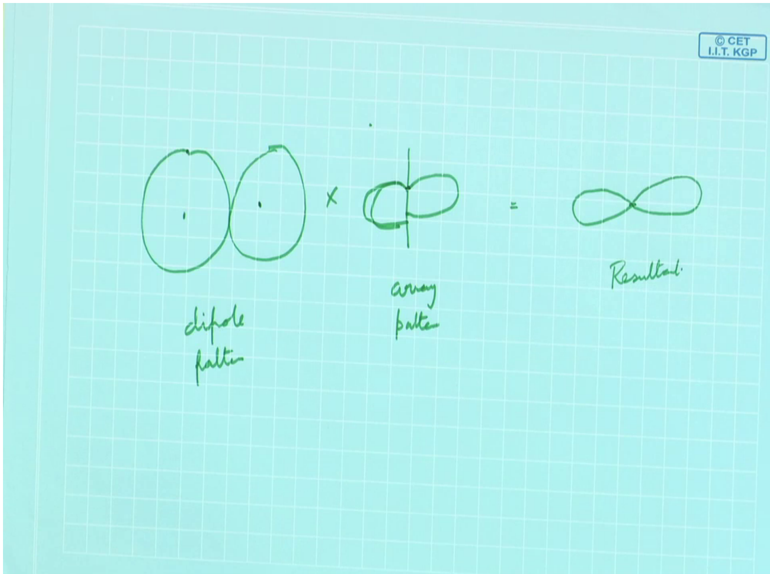

So, here you can say that the suppose this is the dipole pattern and here this is not very narrow, sorry this is array pattern, this is dipole pattern. So, pattern multiplication will give that I will have the resultant pattern like this. So, here both e and h plate patterns are governed by array pattern and if n is large; the element pattern of half wave dipole has little effect here. So, mainly for End fire arrays, the resultant pattern is both governed by the End fire things. Now, we can come to the directivity. Now for directivity, you see that let us estimate the directivity.

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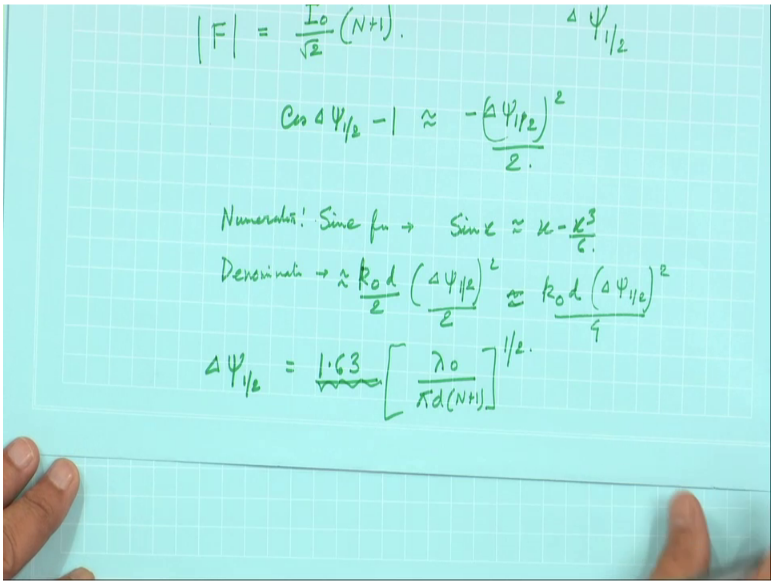

So, for directivity we take the array factor will be root 2 n plus 1 because there we take 3 db things. Now here, we can put that where is the previously written array factor huh, here all these we will have to put as cos psi half if we call that, suppose the angle at which the half power beam width, let us call that psi delta psi half. Earlier from null to null, we are calling delta psi.

Now, it is delta psi half. So, here will take several approximations; one is this is already, we have taken that since for null to null delta psi that was small. So, delta psi by half will be further small. So, cos this minus 1 that we can write as minus delta psi half square by 2 and in the numerator, these sin function can be approximated by numerator sin function, expand in a series expansion, take only two terms.

So, what is sin x? Sin x is x minus x cube by 6 ok. And in denominator, you have the sin k naught d by 2 cos psi minus 1. Now, cos psi minus 1, this is small this multiplied by this overall thing is small. Here, that overall was not small that is why because n plus 1 is there that is why we actually is expanded here, we can directly write denominator will be that, the whole sign thing will be k naught d approximately the denominator will be k naught d by 2, then delta psi half square by 2; that means, equal to this is k naught d delta psi half square by 4. So, if you put it there will be a bit manipulation and also there is a quadratic expression will come, not quadratic cubic expression will come.

So, finally, we get that this thing will be 1.63, sorry 1.63 lambda naught by pi d n plus 1 to the power half ok. So, this will be delta psi. Now, we know that what is the, at which point half power things come. So, solid angle occupied by the main beam. So, I can write solid angle occupied by the main beam of the End fire array will be these.

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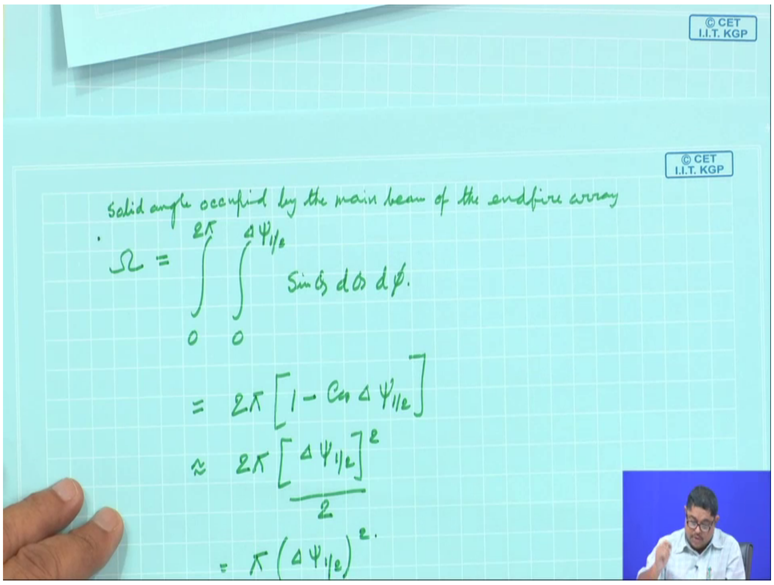

And what is that, 0 to 2 pi, then 0 to delta psi half sin theta d theta d phi. Please remember these, this is not minus to these because look at the End fire pattern. So, we have only this; suppose somewhere here will be delta psi half to 0 because other half is not there for e prime in the visible space. So, these, if you do this is simple because you now have the expression for this thing. So, that will be this expression you know. So, 2 pi 1 minus cos delta psi half and that can be approximated 2 pi delta psi half square by 2. So, it is pi delta half square, this is the solid angle occupied by the main beam

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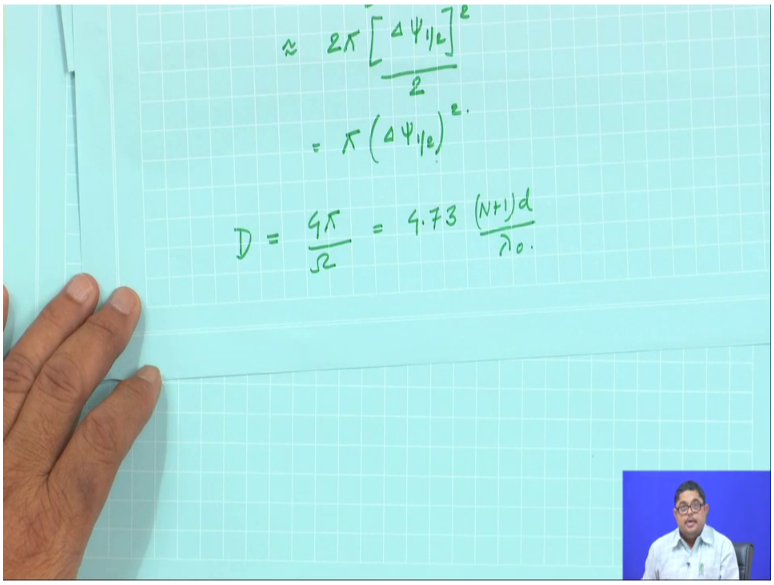

So, we know what is directivity, the isotropic radiators solid angle is 4 pi by this psi. So, that is 4.73 N plus 1 into d by lambda naught. This is the directivity of the End fire array. So, people have tabulated these.

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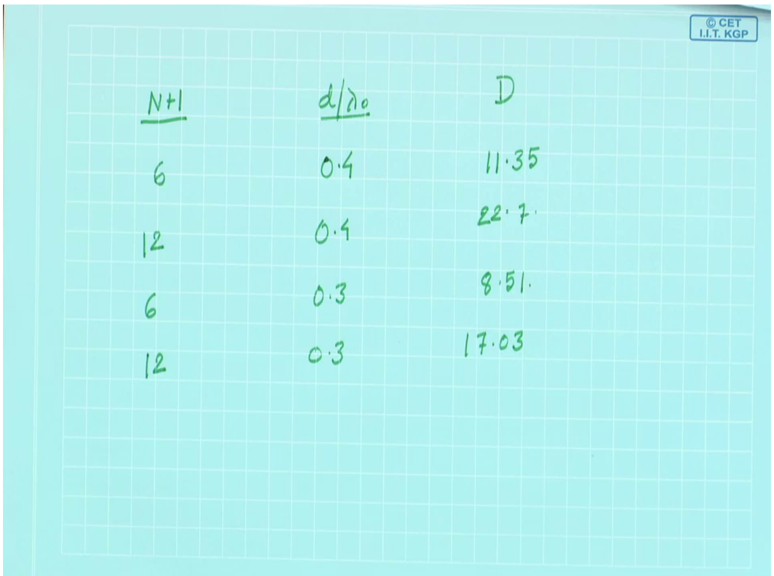

And suppose I take the number of elements, you have d by lambda naught and what is the absolute value of directivity; typically, let us take 6 d by lambda naught; obviously, to avoid getting lobe, this should be less than 0.5, let us take 0.4, this value turns out to be 11.35. If I make it 12, same 0.4, these will be 22.7. If I make it 6 but make it less, this becomes 8.51; if I make it 12, 0.3, 17.03. So, you see these are the typical values; some examples I have taken. Point is this table underscores the designer's problem that to get more directivity we will see from here that if I want to have more directivity, I need to increase d but I cannot do it, infinitely my end is less than 0.5.

So that means, to have more gain, you cannot do these but what people have found out actually that is a classical example Wood ward Henson thing that you do not put the main beam here, you actually this main beam, you try to protrude in to the invisible space and by that actually you are losing the main beam; that means, this energy you are losing but also the total energy. So, the loss you are making but the total radiated power if that also goes down because what is actually directivity? Directivity is the maximum radiation intensity divided by total radiated power.

So, if you protrude main beam here, the total radiated power also will go down and by that they are known that you can increase the directivity there. So, that is called Wood ward Henson technique for this but that is a advance technique. So, that is one way for proceeding for this End fire array. So, this we have seen how to design arrays, you can have either broadside array or End fire arrays etcetera and what is the directivity. So, required from required directivity you can find out what is d etcetera that you need to do. In the next, will see that some other arrays which are useful, some other very simple type of this arrays which are also useful in some particular applications and with that, we end this array antenna lecture.

Thank you.