Analysis and Design Principles of Microwave Antennas
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Lecture – 21
Parasitic Array and Log Periodic Antenna

Welcome to this lecture on Parasitic Array, actually arrays in which, not all of the elements are driven is called parasitic array.

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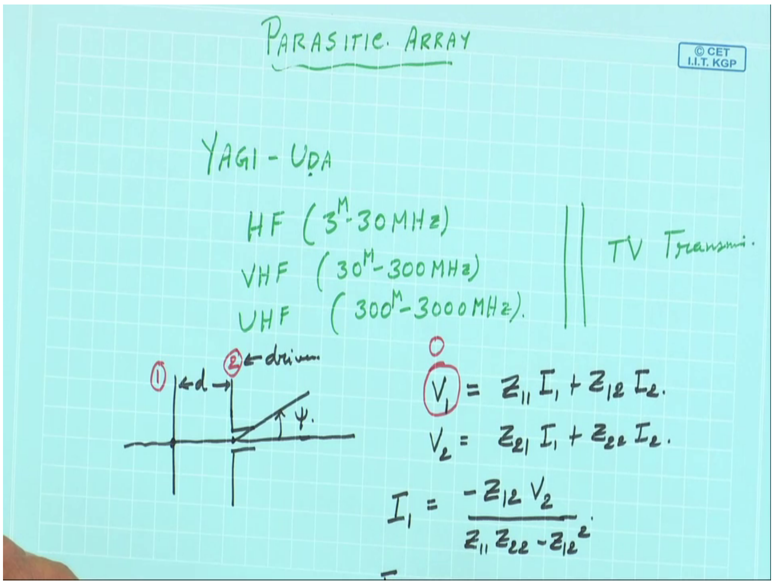

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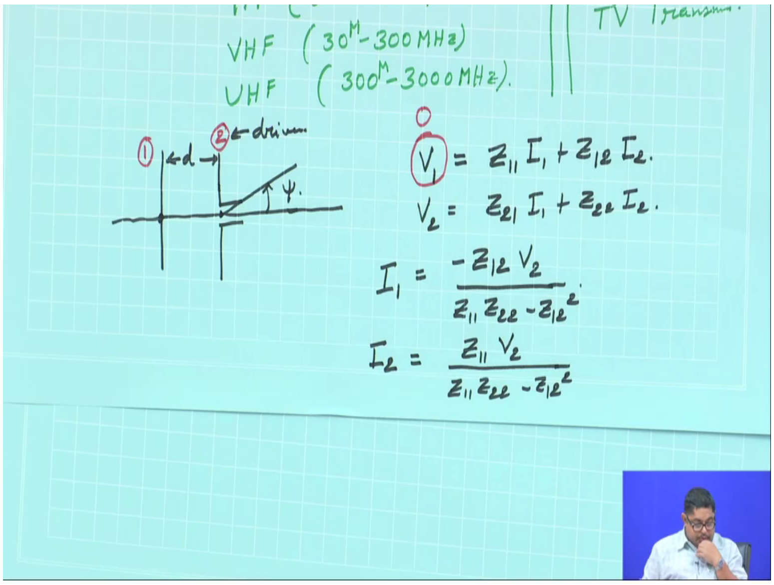

An uniform array, if I want to excide that I need to have a proper feeding arrangement, for every element with different phase and amplitude excitations as required. Now, instead of that, instead of driving all the elements, a parasitic array is fed by only one radiator and there we can put some other parasitic radiators, to give it a good directivity.

Now, this may work, may not work. So, some of the people have found out some of the very good designs, where the simple structure can work, one of that is a very famous Yagi Uda array. Actually, Yagi and Uda there are two scientists, Japanese scientists, they found out one such parasitic array, which is almost,everywhere used for HF. HF means 3 to 30 megahertz, then VHF 30 to 300 megahertz and UHF that is 300 to 3000 megahertz, 300 megahertz, it, TV transmissions. TV transmissions initially was in these zone then it became here. So, in all these cases the application is TV transmission.

For TV transmission, this is an excellent a antenna and it gives good amount of directivity, which was not possible for a single dipole. So, the structure is to understand this structurelet us look like this suppose, I have a dipole antenna and this is a parasitic one. So, let me point out that this is, 1 is a parasite, I am not driving it, the 2 is a given element this is driven seen that I am having a feed here driven and this spacing is let us take d now. So, this is a two element array. What is the array axis? This is the array axis, this is one element, this is another element.

And my thing is I take the, this driven 1 as a reference and this angle is my psi angle ok. So, this is the array axis two element array this is my observation thing. Now, this whole thing you see I can view as a two port network; this is one port, this is another port. So, I can write that there is; obviously, I am exciting it; so, there is current here. Now, since this is nearby this radiator 1, because this is a conductor. So, sum of this radiated field that will induce here, because the mutual coupling between them and that will also induce some current here. So, I can write that, that, what will be the voltage at port 1. This is my port 1, this is my port 2.

So, V 1 will be z 1 1 I 1 plus z 1 2 I 2 and V 2 will be z 2 1 I 1 plus z 2 2 I 2. Can I write this for a two port network and, and this element 1, it is not driven. So, I can make that the voltage, this voltage will be 0. So, now, I can solve for this I 1 and I 2. So, what will be I 1 I 1 will be minus z 1 2 V 2 by z 1 1 z 2 2 minus z 1 2 square and I 2 is equal to z 1 1 V 2 by z 1 1 z 2 2 minus z 1 2 square ok.

So, there will be radiation from both of them. It shows that, even if I do not excide this, but mutual coupling between them, which is nothing, but this z 1 2 and z 2 1, if we were not earlier considering this, but in practical cases this is there. So, I 1 and I 2 both having currentsso, both will now radiate. So, my any far field radiation will be some of them

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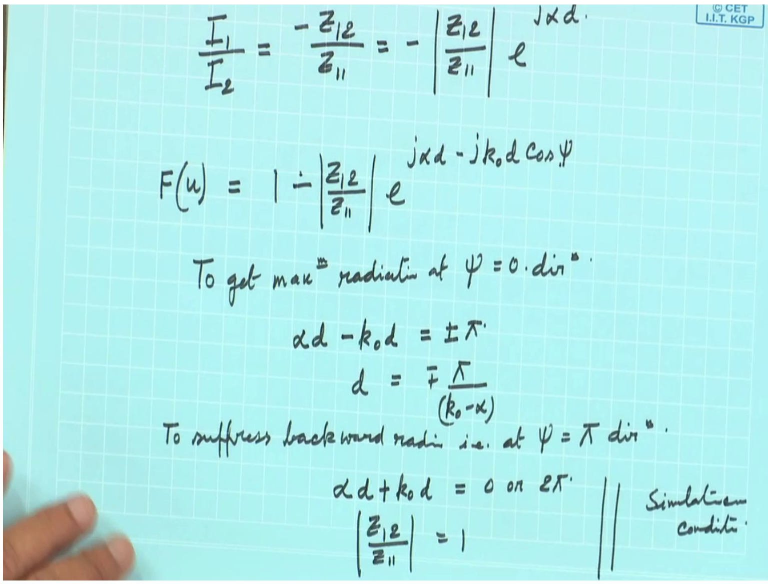

Now, from that I 1 I 2 I can write that I 1 by I 2 is minus z 1 2 by z 1 1 ok. Now, these two are complex impedances, because these are self impedance of the first antenna as the um, first radiator by the mutual impedance of the this radiator when it is driven by 2, z 1 2 with the minus. Now, this I can write as minus magnitude part and some case part, because this is basically the mutual by these; obviously, this will depend on the separation of the two, because this mutual thing is dependent on what is the separation, that is why I have taken with some proportional d constant alpha ok.

So, this is the phase of this ratio um. Now, can I say that the field array pattern will be what? Can I say that, this is, this is my reference. The 2 is my reference you see. So, 1 plus this I 1s radiation; that means, 1 minus z 1 2 by z 1 1 e to the power j alpha d minus j k naught d cos psi. Can I write this, because there will be space, space between the two ok. So, this is the array pattern, of this two element array.

Now, I want that in this direction, I should have maximum radiation, in this direction; that means, that psi is equal to 0, because wave will come from here, I will get it. So, I want this as an (Refer Time: 09:12) thing. So, to get maximum radiation at psi is equal to

0 direction. What we require? We require that this part should be how much alpha d minus k naught d should be equal to plus minus pi. Can I say this, because then this part will go alpha d minus k naught d. So, that gives me d is equal to minus plus pi by k naught minus alpha.

So, if we choose d like this, we can get maximum radiation in direction. Also if we now, impose that we want that, it should have maximum here and in this direction it should have null, in this direction, in the back direction it should have null. So, what is the condition; that means, we want to suppress the radiation in the backward direction. So, to suppress backward radiation, I e at psi is equal to pi direction. We require alpha d minus k naught we require alpha d plus k naught d, because that direction, so cos pi is minus 1.

So, plus cannot be, should be either 0 or 2 pi and also I want z 1 2 by z 1 1 magnitude should be 1, both should be simultaneously satisfied, simultaneous condition, if I want to produce that. But this second condition is not possible, because the self impedance and the mutual impedance. Mutual impedance is always much-much lower than self impedance, that is why we were earlier neglecting it and this condition we cannot meet. So, there will be some radiation, but we want minimum radiation, we cannot get a null. So, complete null is not possible in the backward direction. So, now this is as I said that ideal.

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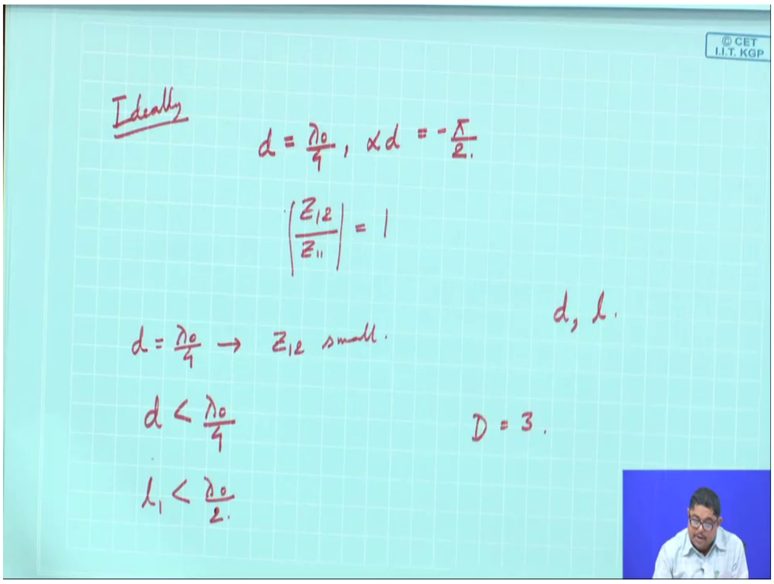

So, for ideal here (Refer Time: 12:46). We should have d should be, this people have found from experiment alpha d is equal to minus pi by 2 and z 1 2 z 1 1 is equal to 1, but this is not made. Now if we take d is equal to lambda naught by 4, this results in very small z 1 2 become small. And if z 1 2 is small; that means, the current in, the parasitic radiator is quite small, and so people, also people took that the this smaller than, generally the d is taken a bit smaller then the naught by 4.

Now with proper, so what are the design parameters? Design parameters are this d and also the length of the dipole; that is also another parameter, with that in a these two element array you can get a directivity of 3 can be achieved. Now, if the parasitic element is shorter than this resonant length; that means, I can say l 1 is less than lambda naught by 2, then it acts as a director and maximum variation occurs in the director; that means, people have made the structure like this that.

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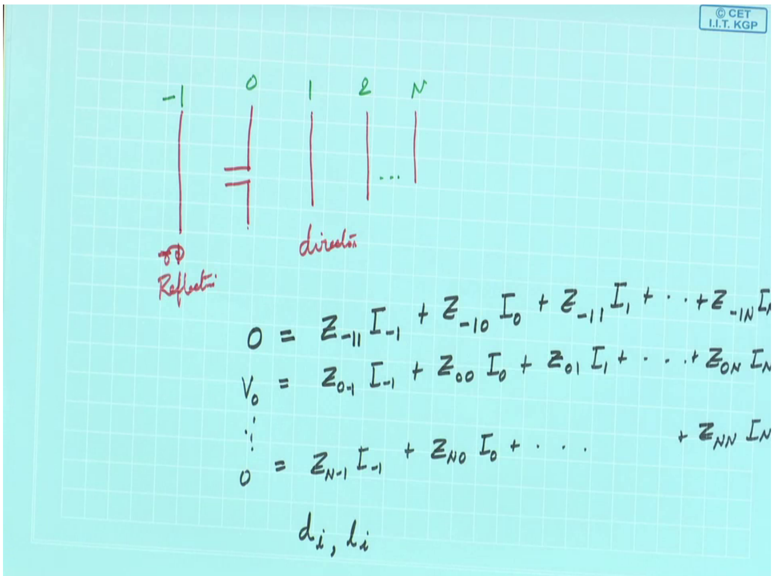

Suppose I have a, this is the driven element, this is a, this direction I do not want radiation, this is a parasitic element. And here I have a shorter element, shorter than lambda naught by 2, so this one will improve the radiation, these are called directors. People take may take several of this elements, even their sizes are may vary that people arrive at. This one is the given element, this is a lambda by 2 dipole and this is a, this is called reflector

So, this reflector suppresses the radiation in the backside and these directors improve these. So, actually if I call that, let us say this is called minus 1 element, this is called 0 element, this is called 1 2. So, let us in general I can have n number of directors, so then we can write the. This now becomes an n plus 1 port, so you can see that, we can write the n port z matrix like this

So, the design problem is, choose the space in d i and element length l i; such that the currents I will have the proper phase to provide in phase addition to the radiated field in the forward direction, but since all this adjustable parameters are inter related, it is difficult to solve, but people have write some um empirical programming thing, so these programs are available in some books these are given. So, also these are available in done at this problem, so by that you can have this.

Now, the serious problem of a this parasitic array is, that the radiation resistance if we look at this um dipoles um terminals, the driven dipoles terminal that becomes quite lace, it is not the 73 ohm that we get for a dipole; that is because some of this energies they are not radiated, they are getting abstracted by this directors and reflectors etcetera. So, the, with this it has been found that the reduction of radiation resistance with a spacing of 0.1 lambda naught for a single parasitic element, this by a factor of 0.15.

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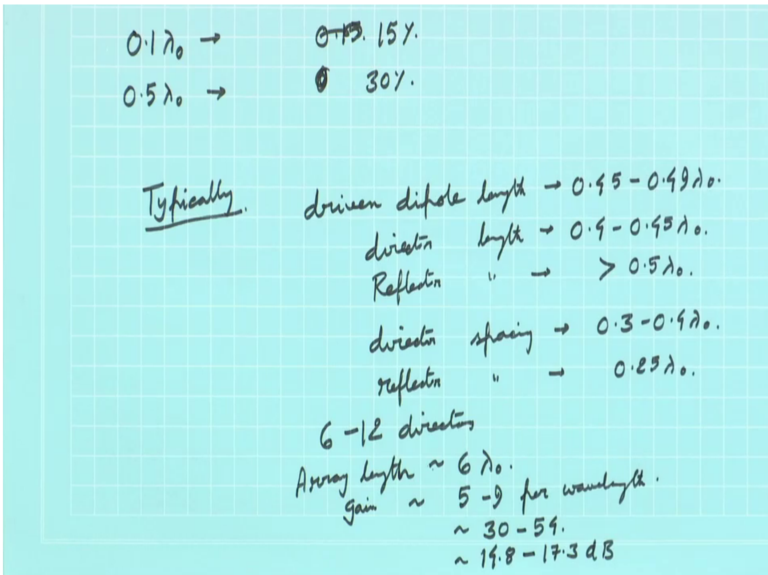

So, radiation resistance gets reduced by 15 percent if we have a spacing of 0.1 lambda naught um. If we have a spacing of 0.5 lambda, this reduction becomes say 15 percent reduction, 30 percent reduction etcetera. So, typically for a, give the array, the radiation resistance of the dipole is something like 20 ohm, so quite small ah. Another problem is the frequency band of operation. Usually the frequency band of operation does not exceed 2 to 3 percent, because of the required critical tuning of the parasitic elements for optimum results

Typically, we can say some values which are used by designers, so driven dipole length is 0.45 to 0.49 lambda naught, directors length is 0.4 to 0.45 lambda naught, you say typically less than 0.5 lambda naught, reflector length is greater than 0.5 lambda naught, so that is why ny, if you see an Yagi array, you can easily identify the reflector and the directors by this, reflector is the um maximum of the log, the driven dipole you can always identify what the feed is given and director. So, by that you can find out in which direction radiation is taking place. Radiation is in the direction of the directors and suppressed in the reflector direction.

Then director spacing; that is typically 0.3 to 0.4 lambda naught and reflector spacing; that is 0.25 lambda naught now the directors are not necessarily of the same length and dia various designers use different a thing and it has been found that more than one reflector does not change the radiation characteriatics So, usually in most of the design there is only one reflector. And for directors, it has been found that you can increase that um number of directors that increases the radiation performance, but beyond a certain point or beyond a certain number of directors, induce current in the director is so small; that is contribution to radiation becomes negligible

Usually the designers have 6 to 12 directors, so array length is typically 6 lambda naught and gain is typically 5 to 9 per wavelength. So, typically that comes to 30 to 54 or in dB terms 14.8 to 17.3 dB which is quite good. Actually, that is why if you in many TV applications it becomes that, you put a single dipole you are not getting the reception, but the moment you get, because it is making your gain quite large compared to a dipole and that gives you this.

Now, important radiation characteristic of this Yagi antenna is forward and backward gain. So, gain in the backward direction also how much reduce you can get; input impedance, bandwidth, front to back ratio, minor lobe level etcetera ok. So, this is a good example of an empirical design, and then finally, we will see another array that is called log periodic array.

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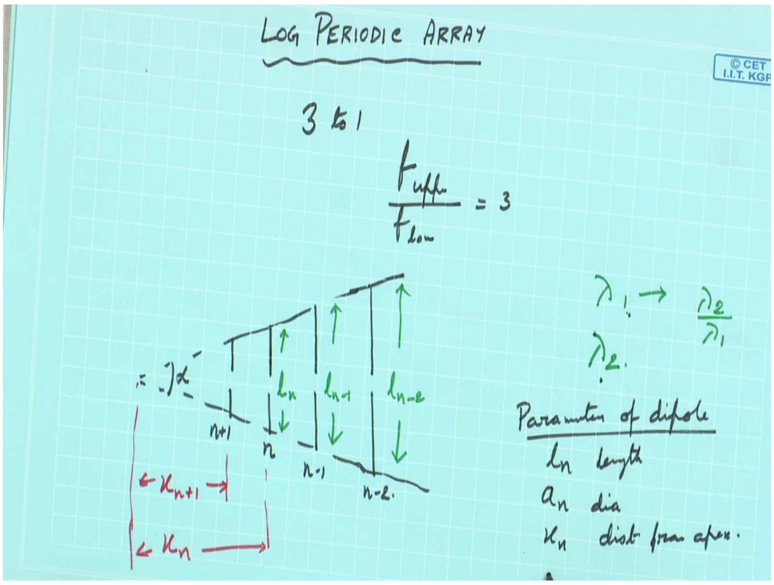

This is a interesting array, actually it is called broadband array, but in modern times we do not call it broadband, earlier people use to call it broadband. Actually broadband has a conation that if an antenna is broadband then I can, I will be able to pass a pulse through it, but there is another way of calling broadband, which earlier people use to call that, suppose I am having a narrow band signal, I am sending that with the same antenna another narrow band signal at some other frequency I am sending. So, the lowest narrow band frequency signal and the highest narrow band frequency signal, if this is sizable, people use to call it broadband

But the problem is um this type of broadband antenna, where I have several narrow band signals can be sent, they are dispersive in nature. If I send a pulse to them, it needs that simultaneously all the frequencies need to be passed, that cannot be passed by this log periodic array. So, it is a dispersive array; that means, there are dispersion if it, if I try to send a pulse, but if I try to send narrow band signals, then over a very large bandwidth it can pass that signals. So, with this a thing I can say that these arrays are called, in that sense broadband antenna, they can be made to operate over a 3 to 1 frequency band. This means that highest operating frequency and lowest operating frequency; that means, f upper by f lower is 3

Now, what is the concept? The concept was, actually this was professor Ramsay used to work on this and most of the concepts are for him. His concept was that build a structure that can scales itself up periodically, as the frequency gets changed. Suppose his point was that this angle is alpha, I have two salutes and now there you see, his point was suppose an antenna is operates satisfactorily at a wavelength lambda naught. So, the point is, it will also perform um, it will also perform at a wavelength lambda 2, if the dimension of this first one is changed by a factor of lambda 2 by lambda 1.

Suppose um 1 antenna is operates over a frequency means immerse of that la wavelength, over a certain wavelength, let us say 3 meter it can do. Now the same antenna can do at 2 meter wavelength, if I scale its dimension by a factor of 2 by 3 that was the idea. So, what you suggested that, suppose I have a structure like this; that means, it is a angle alpha, and here suppose I take a element.

Now you see if I take an element here; that is getting scaled suppose I call it n plus oneth element, I call it n element, then this is n minus 1, this is n minus 2 and let us say that this length is l n, this length is l n minus 1 and this distance is x n plus 1 this distance is x n etcetera

Now, so, you see a continuous, I mean infinite array of dipoles. Now what are the parameters of the dipole? Parameters of dipole are length l n, diameter a n, distance, this is diameter, this is length, distance from apex and d n is the inter element spacing, so that means, this is d n, this is d n minus 1 etcetera etcetera.

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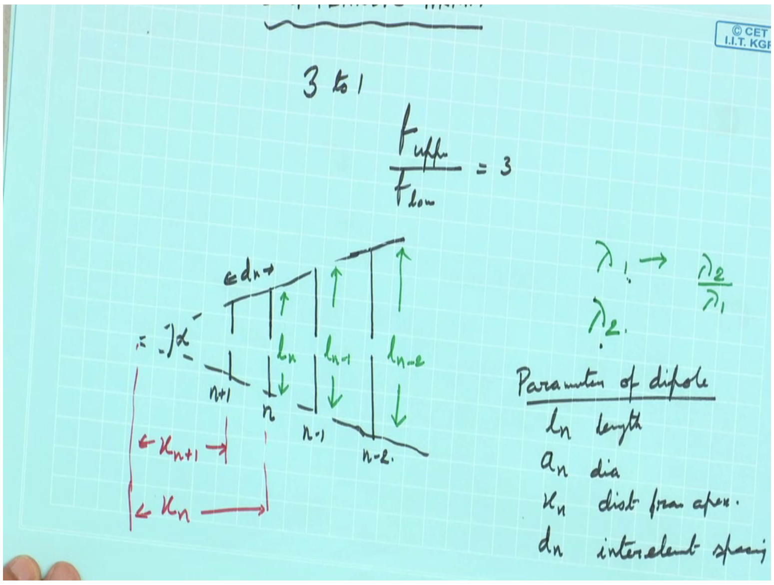

Now, if we relate that x n plus 1 by x n is equal to l n plus 1 by l n is equal to d n plus 1 by d n is equal to an plus 1 by an is equal to a parameter tau.

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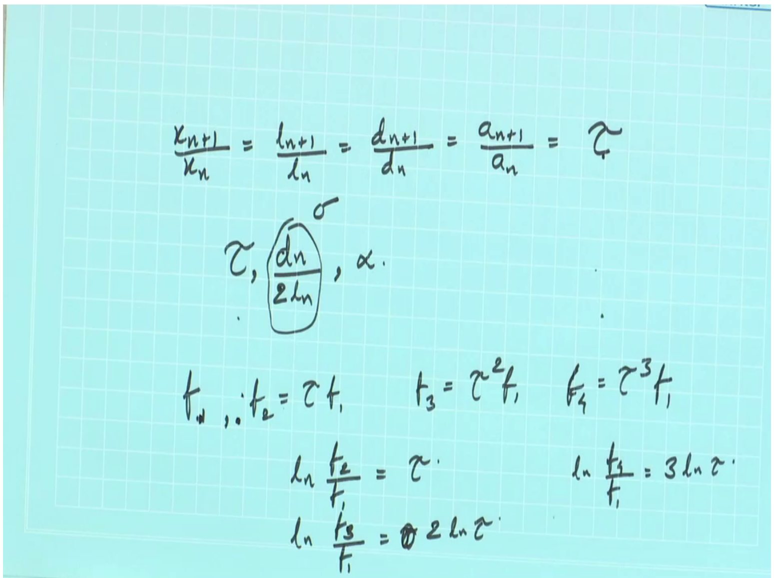

So, you see, the array is completely defined by this parameter tau and one of these or I can say tau d n by 2 l n or alpha, alpha also can define, any two of them, so this parameter is called sigma. So, tau sigma or alpha, any two of them can completely define this array

So, if we multiply all dimensions of the array by tau, it scales itself with element n becoming element n plus 1. So, the array will have the same radiating properties at all frequencies that are related by a factor tau; that means, suppose the first one he or. So, this side suppose, suppose this one is f 1, so this one will be tau into f 1. So, if this array operates satisfactorily at f 1, then it will also operate at f 2 is equal to tau f 1, f 3 is equal to tau square f 1, f 4 is equal to tau q f 1 etcetera

So, actually we can know that what is ln f 2 by f 1; that is tau, ln f 3 by f 1 that is tau ln tau square; that means, 2 ln tau, ln f 4 by f 1 that will be 3 ln tau. So, tau is called the log period you will see this. So, in order to obtain radiation from the array, it must be excited by a fed system. So, generally you people feed it that this. So, there will be, so um there will be feed here, now the same feed is given here and this one is given 180 degree feed.

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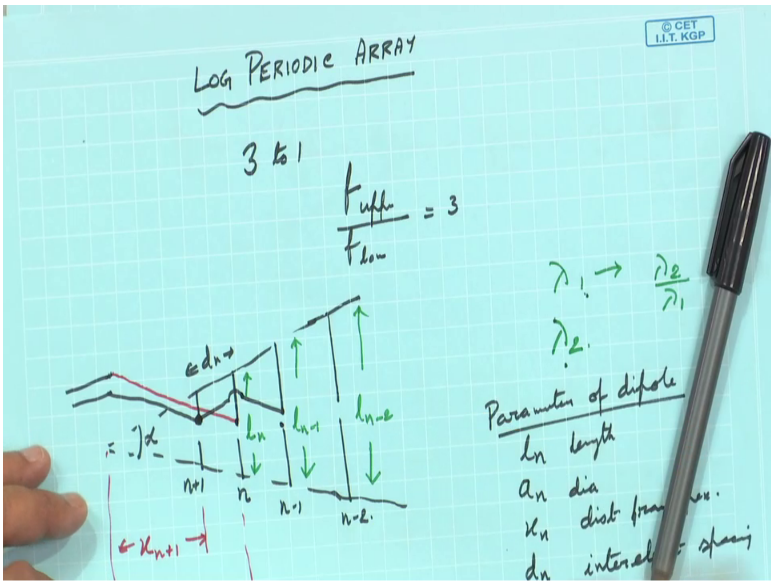

That means if there is a transmission line here, so one end is connected here, the same end now goes and the other one is transmission lines, other end connects here ok.

And now this one goes to the next one and this one goes to next one, by that each one is having an 180 degree fresh feed. It has also been found that at a given frequency the currents in all elements, except those that are close to lambda by two long are very small that is obvious, because actually what is happening at a particular frequency only one structure is resonating, so that one is having sizable current.

So, that is why and others are all having high impedance, high reactive impedance, so that is why currents are not um large there. So, that is why it is possible that though this structure is infinite, we can, depending on our lower and upper things, we can terminate it, suppose I want some frequency, so I take few smaller ones, suppose higher frequency, so extract few elements then I truncate it.

And this side the lower frequency, so extract 2 3 and truncate it. So, this is the finite structure, because it does not um matter, because others are not resonating, so that is why you can have a frequency then and over that there is antenna is radio resonating.

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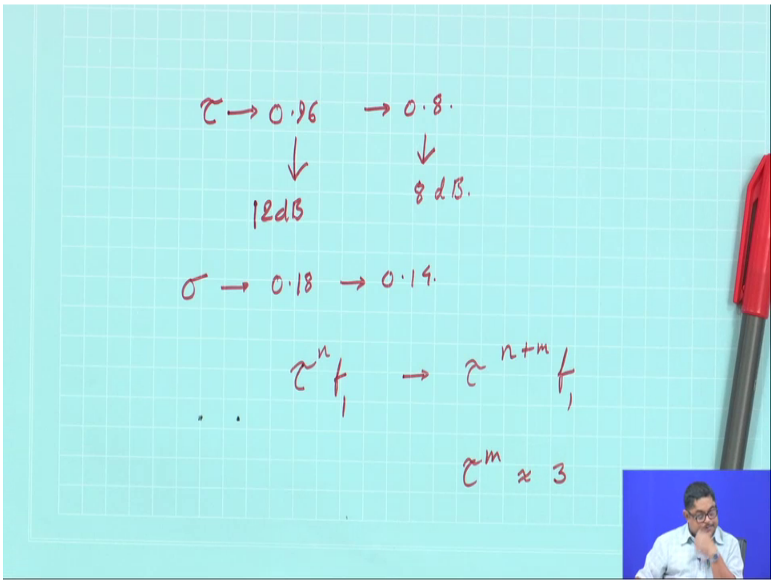

So, it shows that where, when tau is typically 0.96 to 0.8, we get. Suppose this one gives you the, this antenna gives you a gain of 12 dB and for this it gives a gain of 8 dB etcetera, and typical values of the other parameter sigma; that is 0.18 to 0.14. So, you can have that, as I said that after truncation you can have that from tau n f frequency to tau some other n plus m f. So, these are the highest and lowest frequency components you can say f 1 f 1 here

So, this ratio typically you can get 3 is to 1; that means, tau m is of the order of 3 ok. So, this log periodic structure is was an interesting concept and various thing. Actually if we remember the cornu spiral from our engineering mechanics days, that um that is also a log periodic structure. So, equiangular spiral antenna, actually that is a circular um antenna, but that also scales from this same principle; that means, where instead of length etcetera you define the structure by an angle, all those are can be used as a log periodic antenna, so this ends the array

So, how to make a array broadband in the dispersive sense that we have seen. Later when we will see the modern antennas we will see that the antenna that overcame this um problem of broadband and which make a truly non-dispersive broadband that is called impulse radiating antenna, which was invented in the first um decade of this century in 2005, around that time it was invented by D V Giri and (Refer Time: 37:58).

So, that actually was the first in the history of antenna that made this contribution that broadband, but really non dispersive broadband, so that you can send a pulse directly through that. Whereas, these broadband antennas you could not send a pulse, but if you have various narrow band signals over a long frequency band you can try to send all of them together through these antenna.

Thank you.