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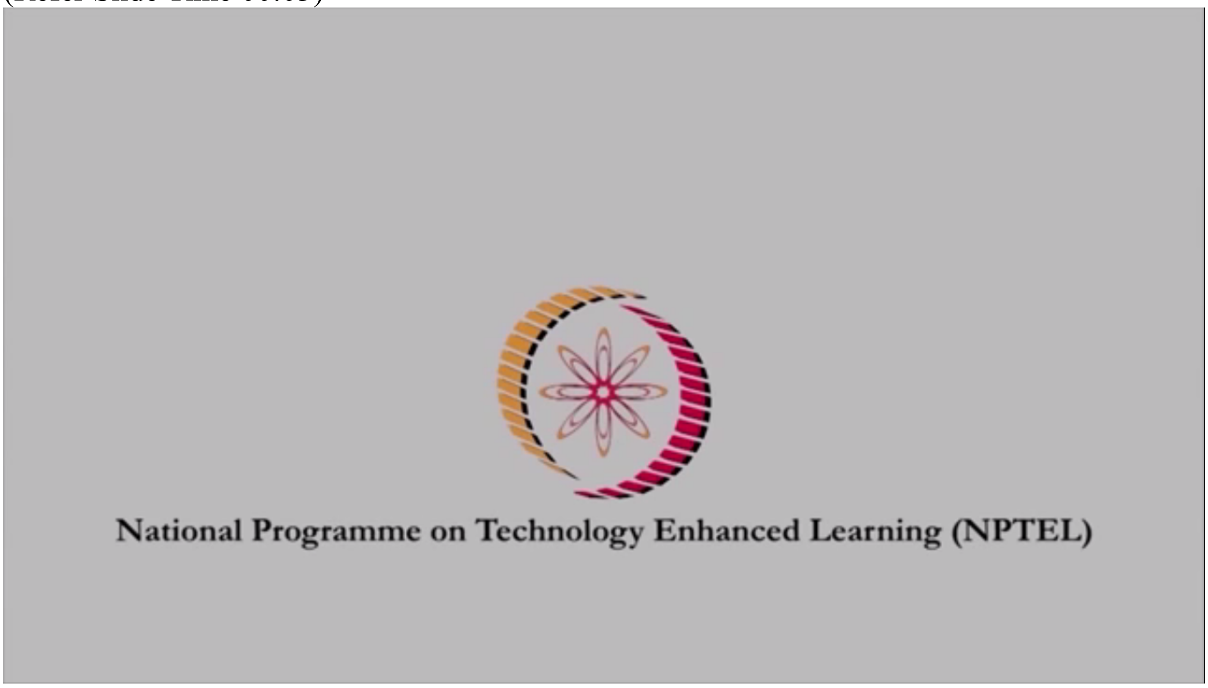

National Programme on Technology Enhanced Learning (NPTEL)

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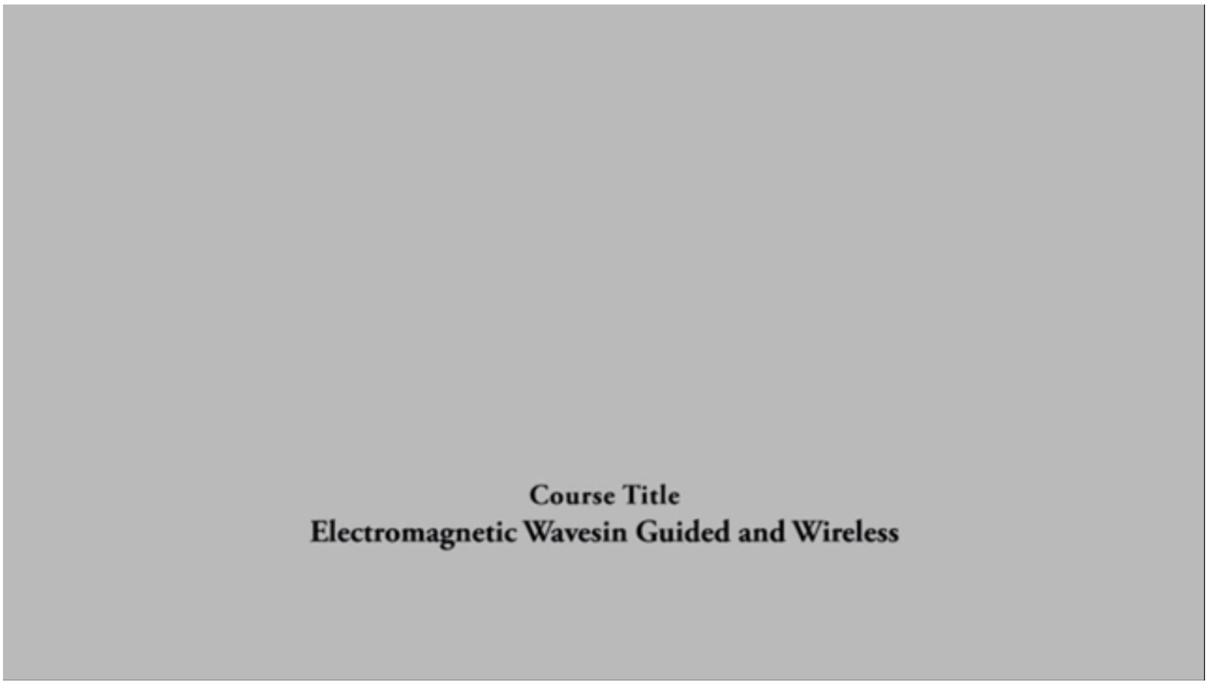

Course Title
Electromagnetic Waves in Guided and Wireless

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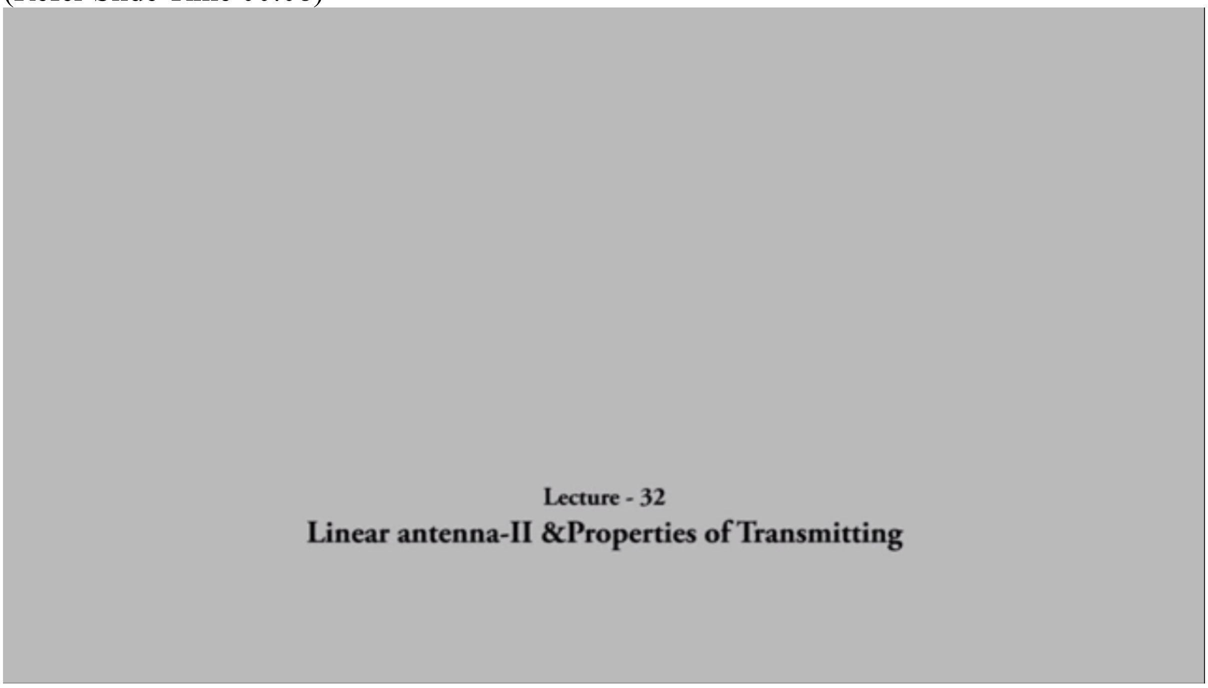

Lecture - 32
Linear antenna-II & Properties of Transmitting

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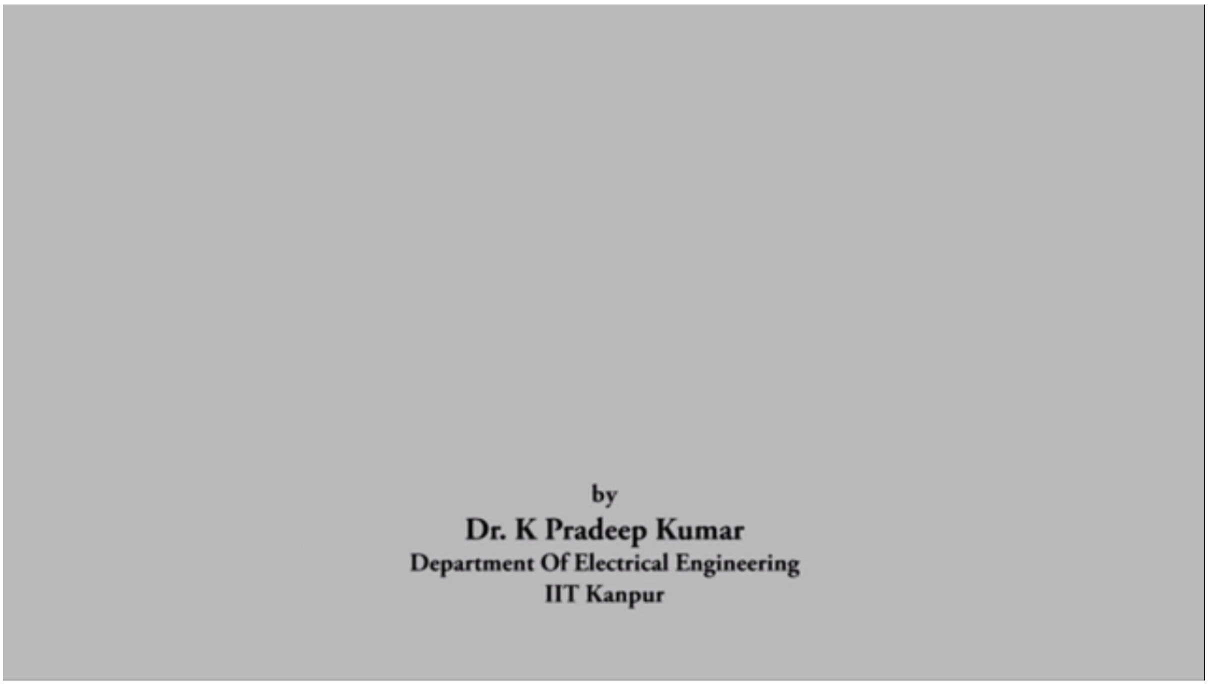

by
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Hello and welcome to NPTEL MOOC on Electromagnetic Waves in Guided and Wireless Media. We will continue and finish our discussion of linear antenna and then we consider some additional properties of transmitting and receiving antennas which I promised to tell you the relationship between these two is very crucial for all communication applications. Okay.

So in the last module, we derived expressions for the vector potential as well as electric field and magnetic field of a linear antenna whose length is comparable to that of the wavelength. Okay. So if you recall that these fields were actually dependent on θ in a manner that we can write it as a radiation pattern $F(\theta)$ as $\cos (kl \cos \theta) - \cos kl$ divided by $\sin \theta$. Okay.

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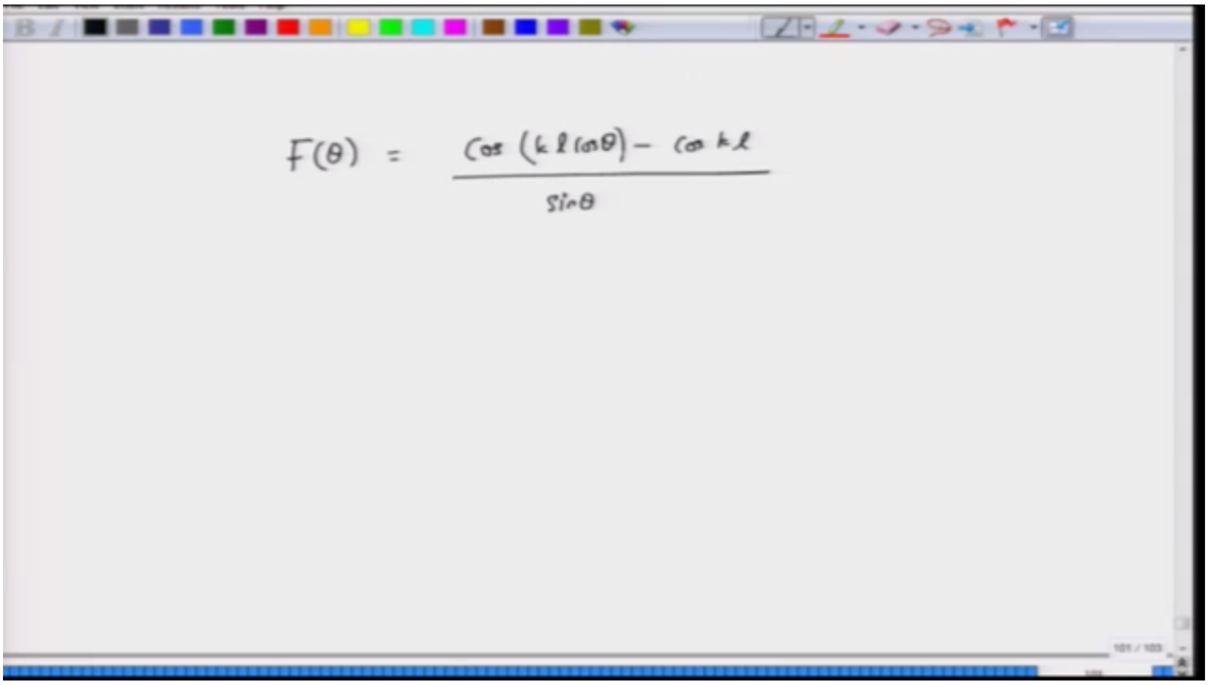

I am only writing the θ dependent part of the expressions for the electric field and the magnetic field here because variation with respect to θ at a constant r is what is going to give us the electric field pattern or the magnetic field pattern or the power pattern, which is what sometimes, which is what you are mostly interested in to know. Okay. The patterns are θ dependent and at a particular r is what we have been evaluating. Therefore, I have not written all the other terms that go with this like e^{-jkr}/R, some $\mu_0 I_0$, whatever those, you know, constants that were there, I have removed all of that to concentrate only on the θ dependence or the antenna pattern. Okay.

Of course, the average pointing vector can be obtained by writing this as by evaluating this half of E x H conjugate and because I know that, you know, this fellow is along θ and this H conjugate is along, I mean, H is along φ, so if you simply multiply these two and then recognise that, sorry, this has to be r, not z, so recognise that the radiation pattern or, sorry, the average power density or the pointing vector would be pointing in the radial direction. So this is, you know, this is a simple expression that you can find out.

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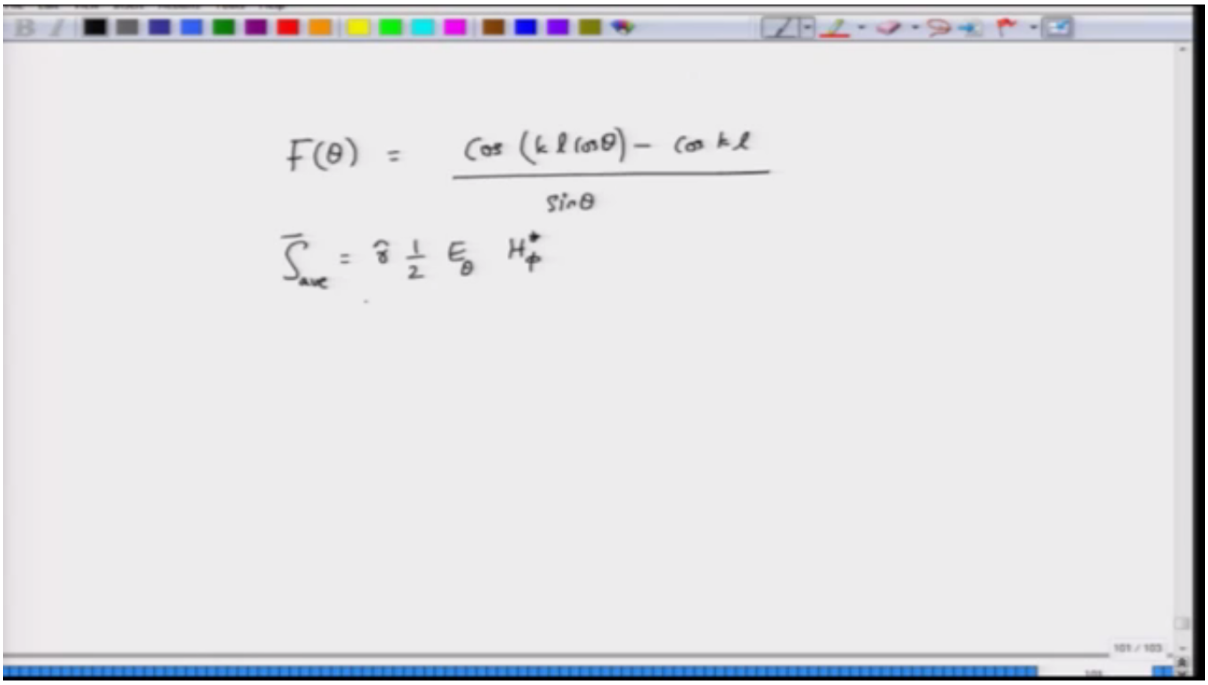

And because E_θ also contains $F(\theta)$ and H_φ also contains $F(\theta)$, this pattern is proportional to $|F(\theta)|^2$. Okay. Of course, $F(\theta)$ is really in our case, therefore, you could simply have written it as $F^2(\theta)$, but writing this as $|F(\theta)|^2$ will eliminate any, you know, misconceptions about the fact that this could be a negative number as well. No, because it is power, it will always be a positive number. Okay.

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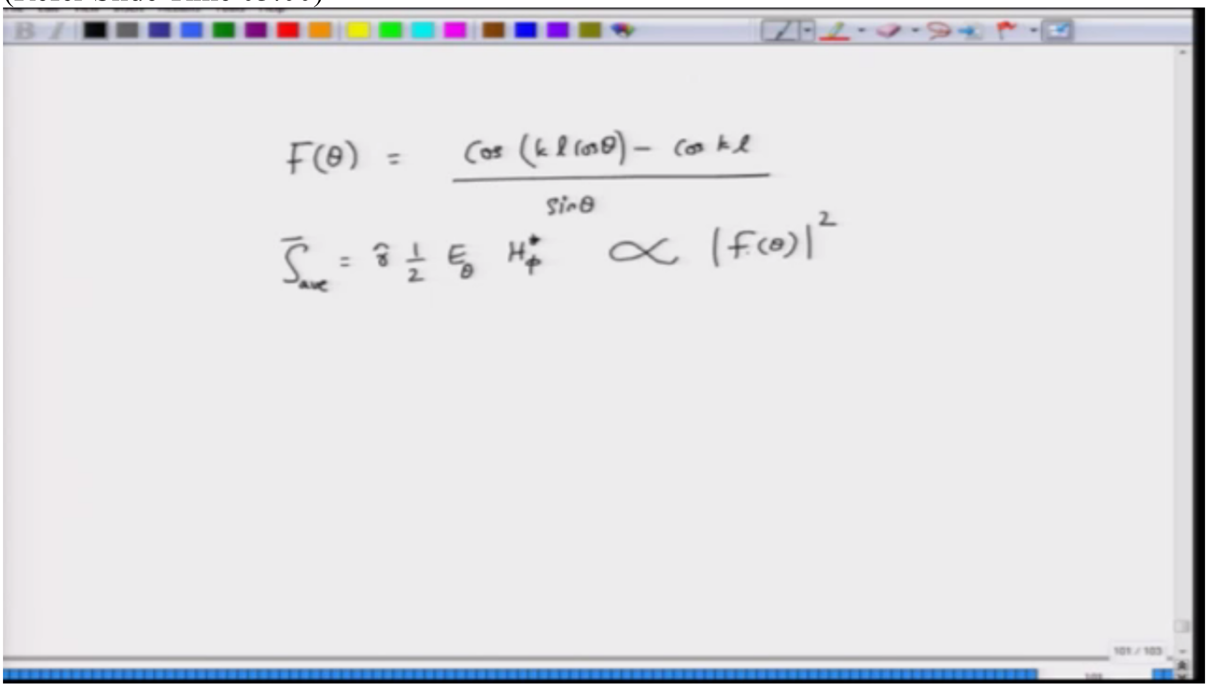

Of course, this $|F(\theta)|^2$ is also dependent on the length of the antenna, right? Why is it dependent on the length of the antenna? Look at the expressions here. Okay.

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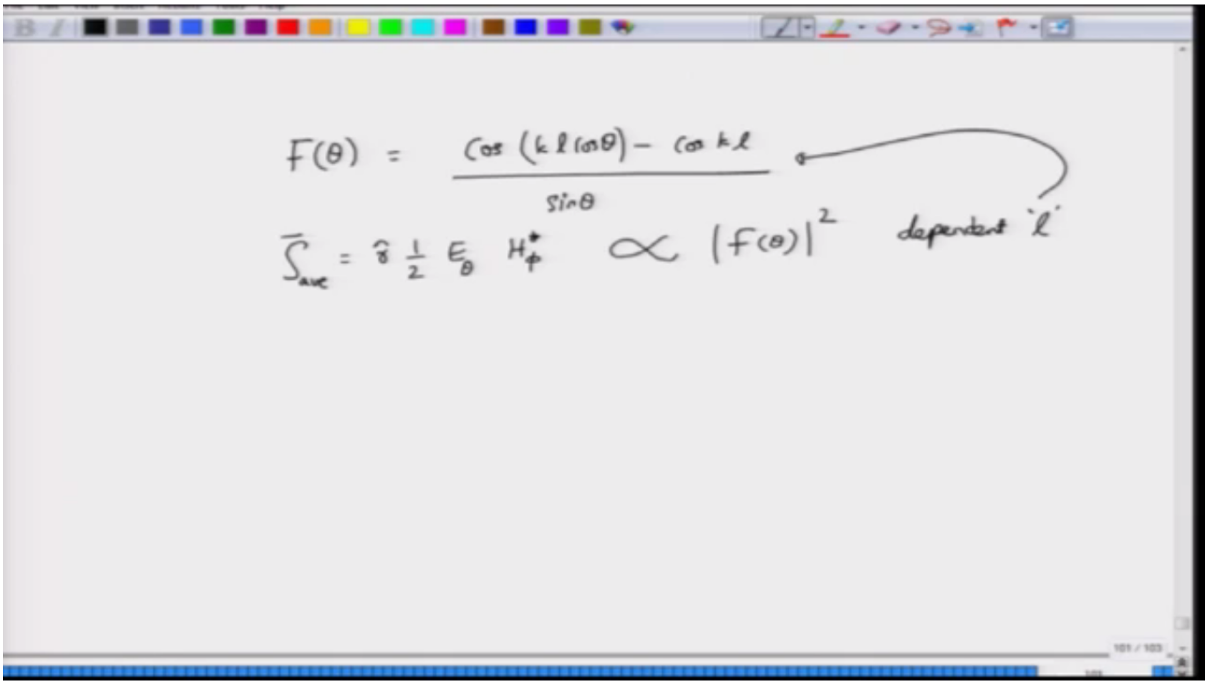

Because there is l here and l inside this cosine interval, so, I mean, cosine argument, the pattern that you get, the average power pattern or the electric field pattern of this linear antenna is dependent on the length of the antenna itself. Okay.

The general rule is that as the length increases, the number of lobes of the antenna would also increase. Okay. There is a particular case where the number of lobes is only one meaning that the main lobe is the one that you have to consider, but as you increase the length of the antenna, additional lobes start to appear. Okay.

So we will look at couple of patterns here for different lengths. The constants that we have neglected in writing the average power density will become important when you have to integrate this average power density over the spherical area at, you know, whatever the radial distance r that you consider and this particular radius or the spherical area will be integrated over θ and φ variables.

So when you do this, you are going to get the total power that is being radiated or the average power that is being radiated by the antenna and once we equate this average power to half, you know, I^2R rate, okay, with I_0 as the current that has been input to the antenna itself, then you can find out what would be the radiation resistance. Okay.

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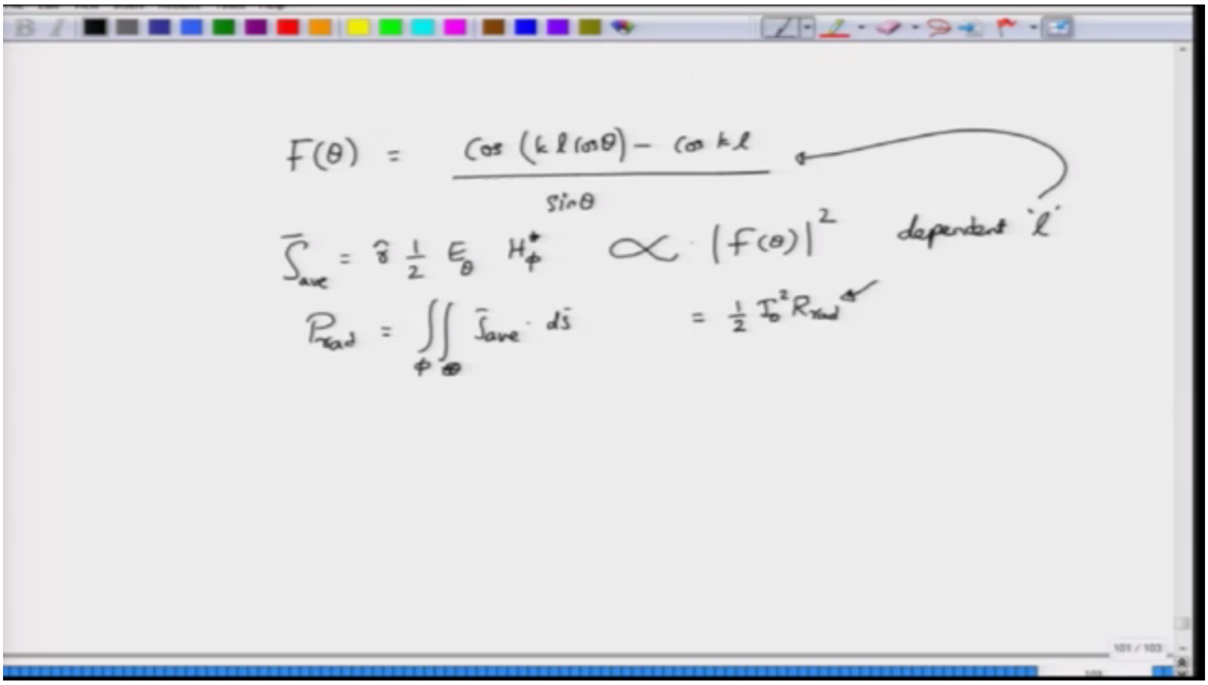

I will leave as an exercise for you to find out the constants. Okay. They are very simple to find out. You just have to multiply the two equations and identify any, any factors or any terms that would not be there in terms of this magnitude square. So those rest of the constants you find out. Once you find those constants, you can integrate this expression.

Luckily, for us, the integration is only over θ and not over φ because the expression for the average pointing vector is not or the pointing power density vector is not dependent on φ. It is dependent only on θ.

So you can instead of a double integral, you will get a single integral. You do all of that and then find out an expression for the radiation resistance, and I will tell you what that expression will be later on. Okay. But for now we want to sketch this power pattern, which is $|F(\theta)|^2$ for couple of cases. Okay.

The first case that we consider is $2l = \lambda/2$, okay, for the $2l = \lambda/2$ meaning that antenna length, which is two times l will be equal to $\lambda/2$. Okay. As before, we consider the polar angle. So this angle will be equal to 0°. This angle will be equal to 90°. θ be rotating in this manner. θ would also rotate in this particular manner going from 90° to -90°, right?

So you have to imagine that this is the antenna that I am considering and I am actually going at a very, very large distance and then, you know, considering a sphere around it, okay. And then look straight up from the antenna, that would be θ = 0 and then as you move along that particular radial, you know, line or the sphere surface, you reach θ = 90°.

Of course, you can move this way also and you can move from the bottom case as well. So you will have a complete pattern. So if you are not interested to know the complete pattern, you can only know the pattern in the half plane or the half hemisphere. The pattern would be symmetrical in the other half. Okay. So that is essentially the power pattern that we have already seen for the short dipole.

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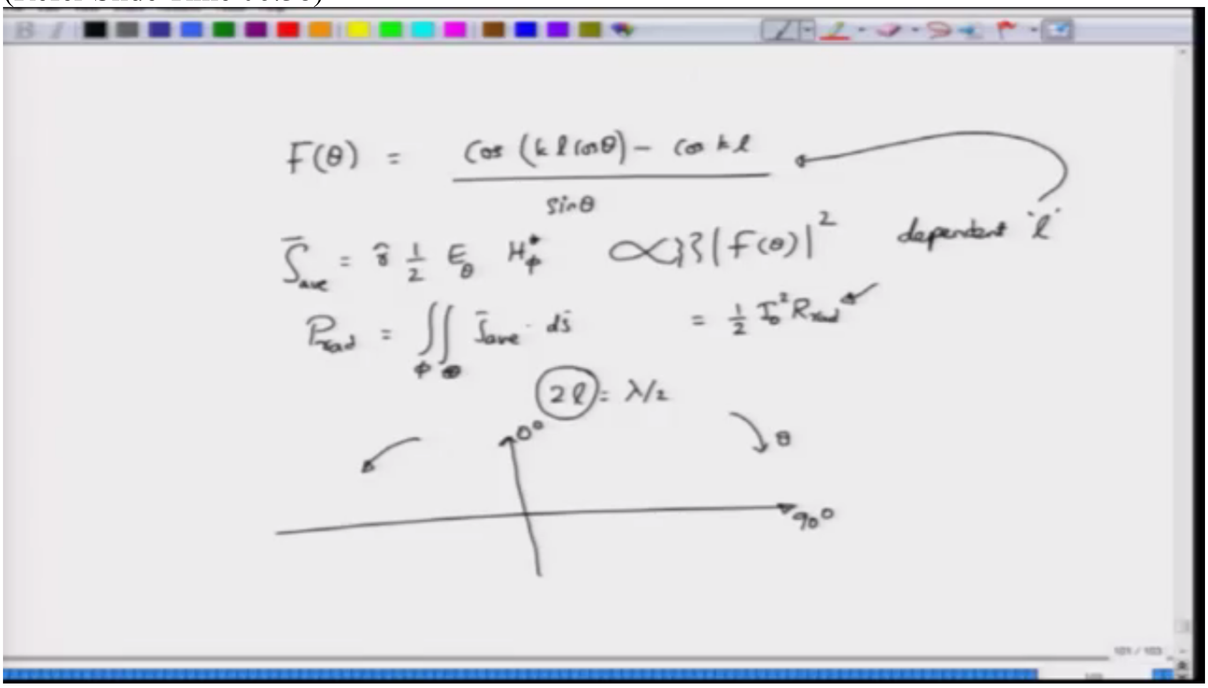

Now we are going to write it for the linear antenna as well, and for the case that we have taken $2l = \lambda/2$, which means k times l will be $(2\pi/\lambda)(\lambda/2)$, λ cancels and 2 and 2 is gone. So you will have cos π here. So $|F(\theta)|^2$ in this case will be cos π cos θ. How did we get this as cos, sorry, l is λ/4, so you will actually have 2 here. So you have (cos π/2) cos θ minus what is cos π/2? Cos π/2 is 0. So, luckily, cos kl will be equal to 0. So this is not there, divided by sin θ magnitude square. So this is the expression that you have.

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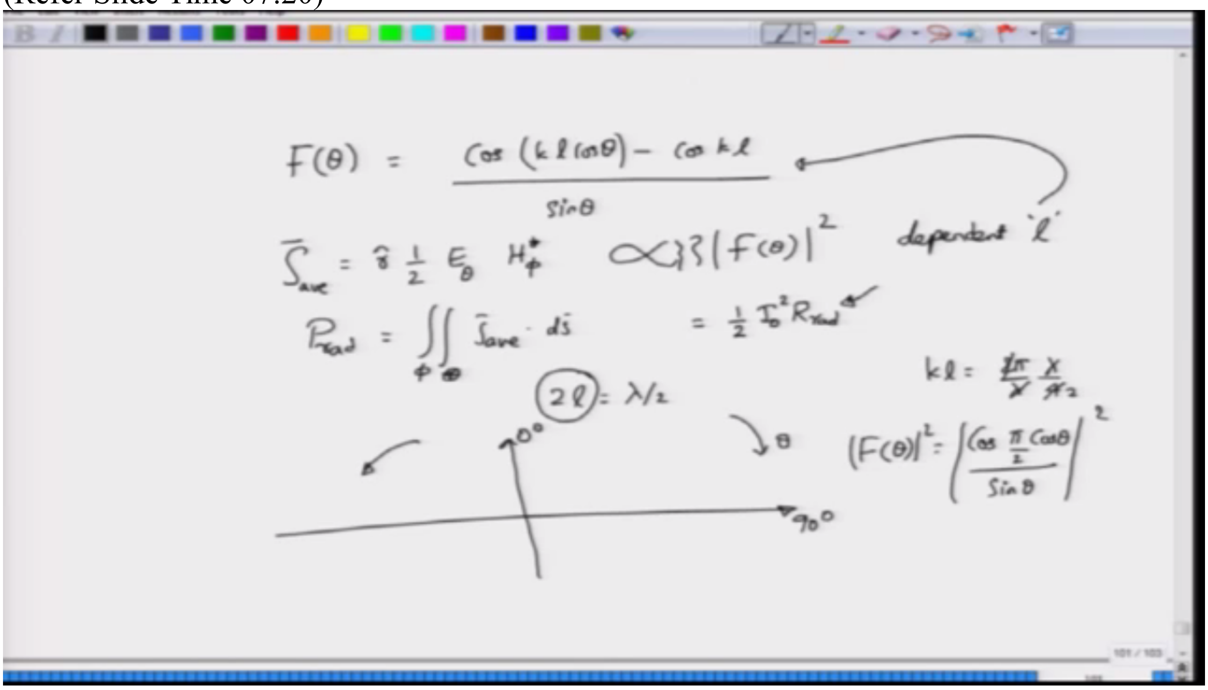

What will be the value at θ = 0? Look at this expression carefully. At θ = 0, sin is 0, right? And in the numerator what you have? Cos 0, which would be 1, multiplied by π/2 and then the cosine of that, that would also be equal to 0.

So you are having a situation where the numerator is also going to 0, and the denominator is also going to 0, and then you are taking the magnitude square of that. Of course, you know that you cannot evaluate such expressions. The way to do this one would be to differentiate both numerator and denominator with respect to θ. That differentiated value and then find out what would be the value for θ = 0, and you can show that the value at θ = 0 will still be equal to 0 and it would reach its maximum when θ = π/2, right, because see when sin θ = π/2, that would be 1 and cosine π/2 is equal to 0 at which point cos 0 will again be equal to maximum.

So, therefore, this pattern would reach its maxima at 90 equal to 0 and it would be a pattern at this point as well. Sorry. I did not close that correctly, but this is the pattern that you are going to get. Okay.

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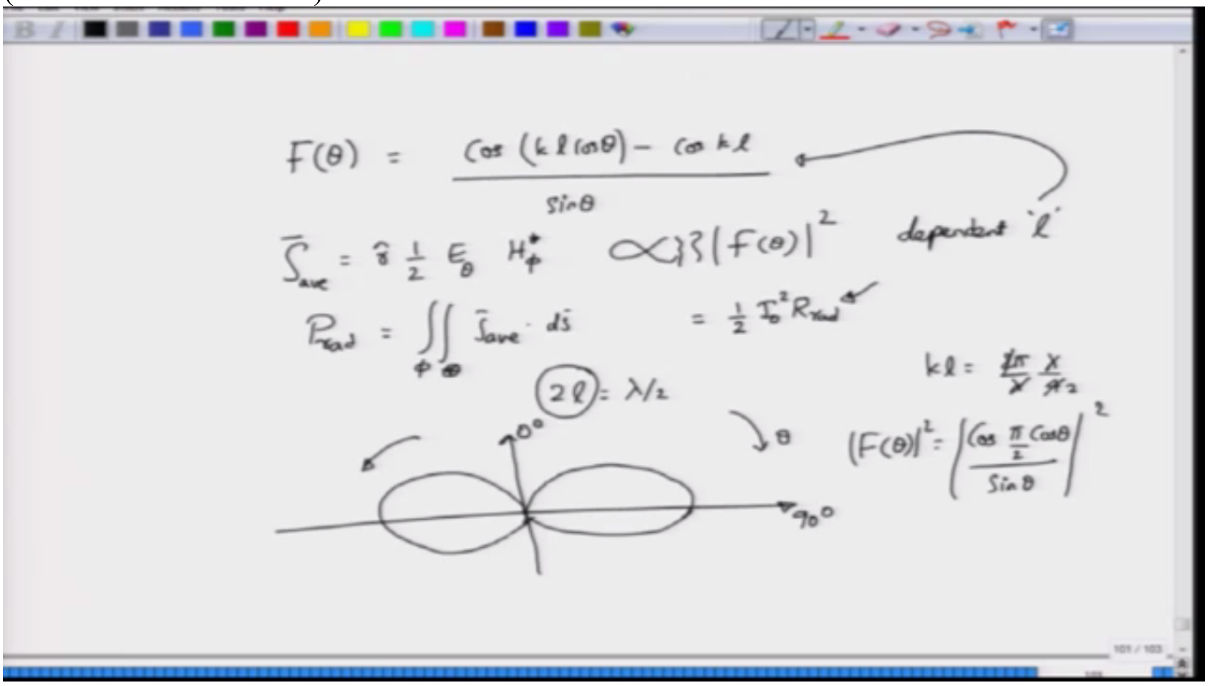

You can, of course, find out what would be the half power beam width of this antenna meaning that if you look at a particular θ, right, at some point, so if this maximum power is normalised to 1, then at the power at this point will be let's say half. Okay. The power at this point will also be half and this distance or this width can be called as θ_{HPBW} that is θ_{HPBW} meaning that it's the beam width of the antenna, the values of θ wherein the power is actually greater than half. Okay.

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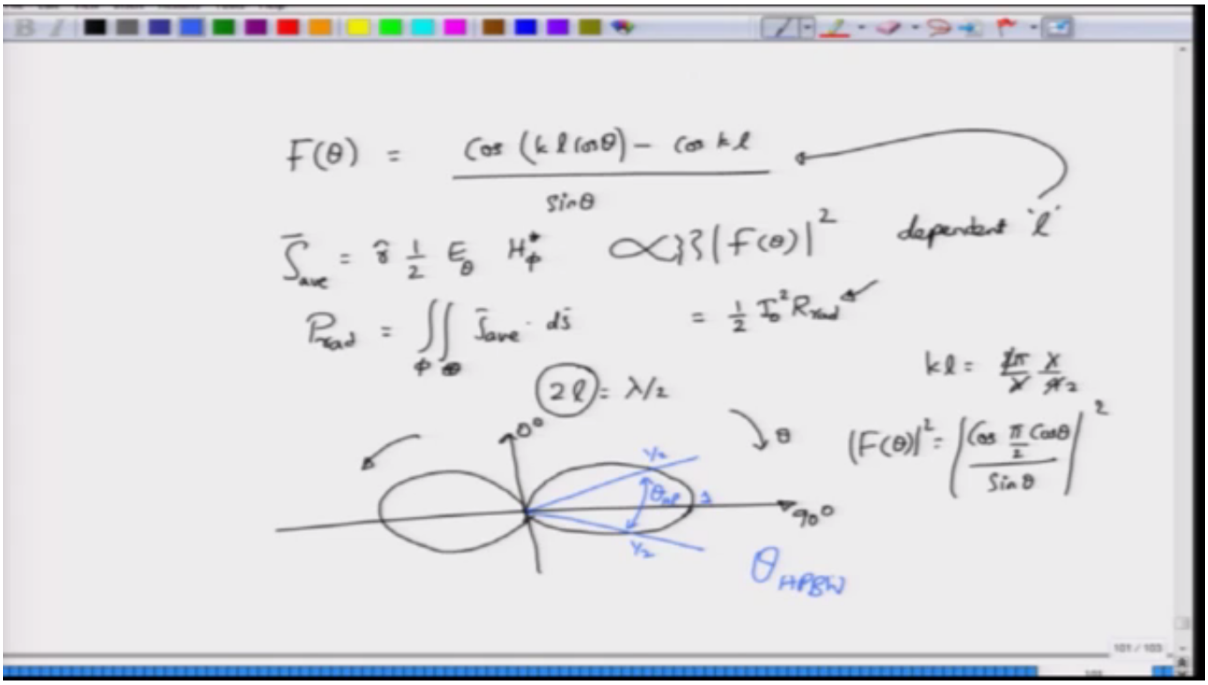

So this is like the 3dB bandwidth that you, that you find and this is exactly what we have found out. Okay. This is the bandwidth in terms of half maxima that you have found out. Half power bandwidth or half power beam width is what we call this because we are dealing with antennas and we deal with beam widths, not really with bandwidth.

Of course, we also have an antenna bandwidth, but that's a separate thing because bandwidth is usually with respect to frequency. Beam width is with respect to the θ value. Okay.

So look at this antenna. It seems that there is directivity of this antenna. It turns out that if you calculate the directivity by the expressions that we have already given earlier, you can show that this would be 1.64 times $|F(\theta)|^2$. So what would be the maximum directivity of this antenna? This would be 1.64 in the linear scale. Okay.

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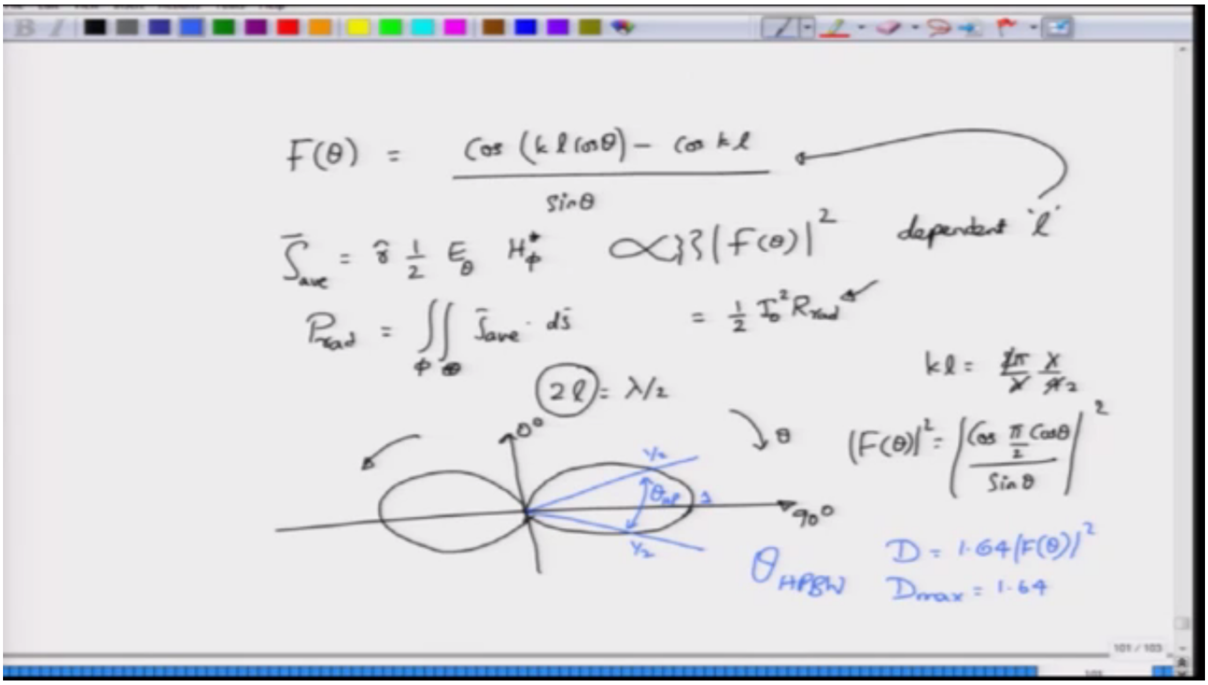

So if you compare the maximum directivity of a short dipole, the maximum directivity of the short dipole was 1.5 whereas the maximum directivity of this linear antenna is 1.64. So there is not much of an improvement in terms of the directivity, but what we will see is that there is a large improvement in the radiation resistance. Okay.

So I trust that you would have calculated this radiated power. You can use those expressions to calculate the radiated power and you can show that for the case of $2l = \lambda/2$ that is for the half dipole, half wavelength dipole or half wave dipole as sometimes we call it, half wave because you know it's half of wavelength out there.

So for this half wave dipole, the radiated power is actually given by 36.56 times I_0^2. I_0 is assumed to be real. Of course, this constant that is multiplied, that is multiplying this I_0^2 is actually half times radiation resistance, so which implies that radiation resistance of this half wave dipole is about 73 ohms.

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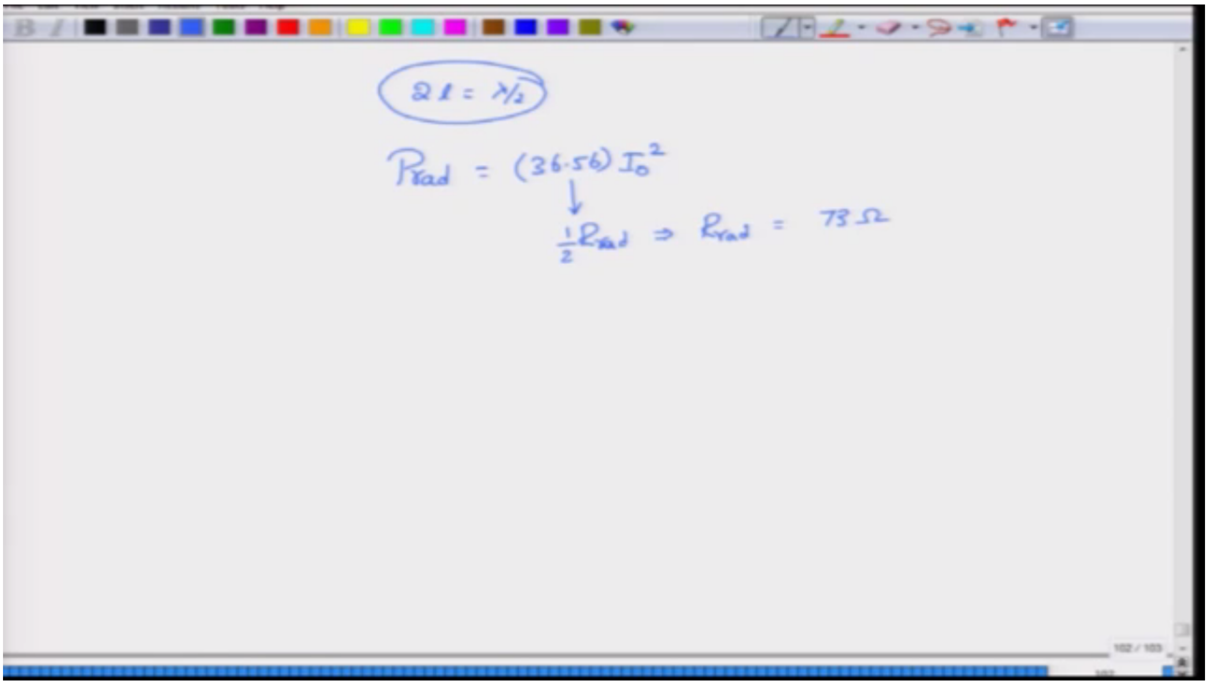

Now I don't know whether you know this one, but there are cables which have a 75 ohm impedance. Okay. Earlier TV cables used to have this 75 ohm impedance and the 75 impedance was actually to match the antennas there. Okay. So most antennas were this half wavelength antenna and their radiation resistance is 73 ohm, but because you don't get 73 ohm, you round it off to 75 ohm. So that 75 ohm standard which you can find in many microwave and RF areas comes because of this half wave dipole matching. Okay.

But there is also another matching or another impedance which is 50 ohm impedance, which is another standard. The origins of that 50 ohm is actually to do more with the transmission line thing, not with the antennas. Okay. So the two standards in RF that are 50 ohm impedance standard and 75 ohm impedance standard are actually because of, one because of the transmission line, the other one because of the antennas and these two are essentially the kind of, you know, common impedances that we actually try to match all our RF devices to all our microwave devices to. Okay.

So this was for the case of a half wave dipole. Now as I told you, as I increase the length, so let’s say I take this length greater than λ. Okay. So, in fact, I will take this one to be equal to 3λ. Okay. The overall antenna length has now increased to say 3λ. Then what you find as a pattern, you know, you can actually use nice Matlab function to plot all this or you can just write a small script to find out what would be the pattern by varying the angle θ and you will find an interesting antenna pattern. So you will find something like this. Okay.

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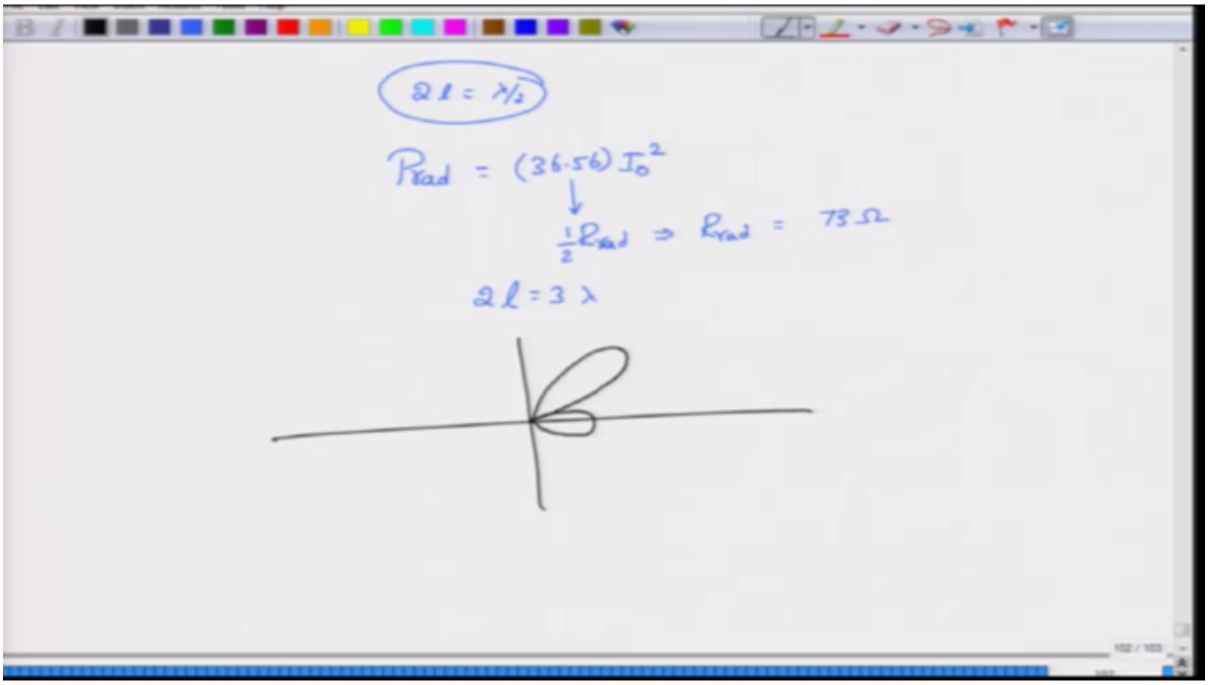

So you will find an antenna pattern. I have only written for one third here and on this side again you will find an antenna pattern that would look like this.

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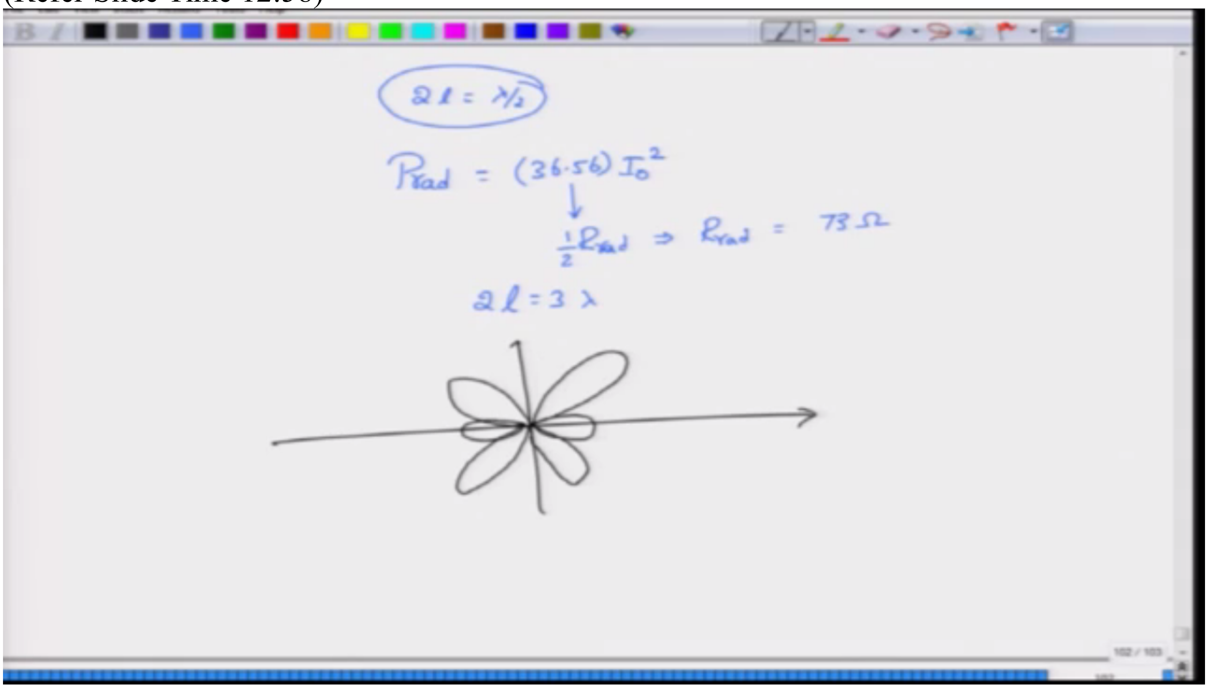

So this looks very colourful or rather very beautiful like a butterfly pattern, but consider the drawbacks of this antenna. Okay. The main drawback of this antenna is that you don't get only a single lobe. Now you get three different lobes. Okay. Well, the energy is now being redirected or redistributed into multiple lobes. Okay.

If your antenna is not, you know, if your antenna is fixed along the max line that is the θ = 90° line, then you don't get that much of a power as you would get with a say 45° line, which is where you're getting the maximum. Okay.

So in some sense the antenna has many lobes, but if all the lobes are not being completely utilised at all the times, then the energy transmitted into those lobes will be useless. But on the other hand, if you have multiple antennas, as people are now talking about MIMO antenna thing, so, I mean, of course, this is not exactly MIMO that we are talking about, but if you imagine simply that in space you have six different antennas, right, so you keep six different antennas in the orientation of this particular antenna pattern, max orientation of this pattern.

So you will, and if you transmit the same information on all six, then you have captured all of the six radiated powers, that is powers in all the six directions and you can presumably use that to increase your information detection capabilities. Okay. So this, of course, is not exactly what a MIMO does, but this is the basic idea.

So you place multiple transmit and multiple receive antennas and try to extract power from all parts of the antenna that is radiating. Okay. So that is one advantage. The disadvantage is that if you don't want to go to a MIMO case, well, you are wasting your power by increasing the length.

Now there is another reason why you don't normally want to increase the length a lot because all our derivations that we have done and all our theory that we have developed, all our theory that we have developed in finding the antenna properties were all done on the assumption that these antenna elements were all lossless. Introduce laws and introduce scatters. Then many of the properties will change drastically and we have, we don’t really have, you know, time nor the space to do justice to all those changes, but that is an active area of interest in antennas and right from the beginning, okay, what is the effect of scatterers which are present outside? What is the effect of ground, for example? You know, these are all very important problems.

I would like to mention one final thing about this practical antennas that we were considering. Of course, we haven't considered lot of different antennas. There are many varieties of antennas that we could have considered, but time constraints forces us not to do that, but you can actually instead of, you know, using two lengths, which we are, you know, you remember this antenna that we have. We had l in the positive direction and m in the negative direction where $z'=0$ was the centre fed part.

You can actually eliminate all the negative, you know, or the bottom portion of the antenna if you just put a conducting patch here. Okay. The reason why you can do this is because a ground will act like an image. Okay. A ground will induce an image charge or an image current which will then complete the circuit. So you can just have one feed line and then, you know, connecting to a voltage generator one feed line and then one line or one wire that would correspond to say $\lambda/4$ of the antenna and the remaining part is taken care by the property of the ground itself.

So such antennas, which do not have two poles, rather they have only a single pole are called as monopole antennas and you have, of course, horizontal monopole antenna, vertical antenna and because your length is only half of the half wave dipole, these are called as quarter wavelength antennas. Okay.

And these quarter wavelength monopole antennas are very widely used. Many early police cars actually used to have this quarter, you know, monopole antennas because you don't need to get the other half. The ground itself will act like, you know, an image. I mean, ground itself will create an image of that antenna about the ground plane and you know it will give you the same radiation pattern as the other one, but the radiation resistance unfortunately would remain the same. So luckily, not unfortunately, it would remain the same. The details of which we don't really want to go into this course.

Okay. So we have looked at couple of antennas and I have, of course, given you the general procedure as to how to follow. Please do remain, I mean, remember that or please do keep in mind that this procedure is not, you know, in concrete. That is to say this is not the only way to understand antenna problems. Several different antenna problems would have to be approached in different manner, but this general procedure even if it is tedious will always work, okay, provided that you start with the assumption on current distribution. There are a lot of theories as to how you can arrive at the current distribution, but that is something that we will not be looking at.

Okay. Now we are on to the last part of this antenna thing, okay, and this is very crucial because this is what will directly lead us to the next of problem that of the wireless channel model. Okay. The basic idea here is this. I have my transmitter, okay, and then I fix an antenna on to this transmitter. Okay. I have a receiver, okay, and I fix an antenna at the receiver. Okay.

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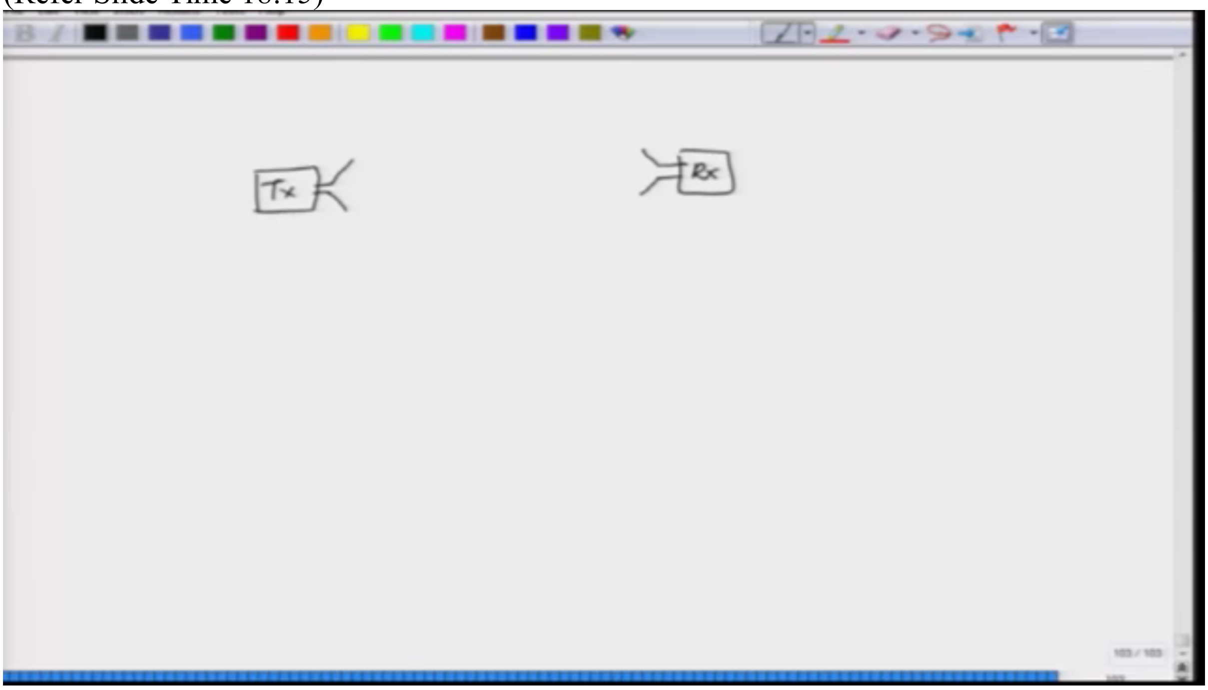

What I have not told you is that an antenna can actually work as a transmitting antenna and the same antenna can actually work as a receiving antenna. That is the antenna as such will have no change in the pattern whether it is being fed a current or whether an electromagnetic wave is impinging to produce the same current. Okay. That is the reason why you can use an antenna for both transmission as well as the same antenna for the reception. Okay.

The idea here is that what is the distance between these two that we should, you know, like fix or we have this distance that will tell us, okay, what would be the power that the receiving antenna would receive as we move the receiving antenna or what is the maximum distance R that I can keep between the transmit and the receiving antennas such that I will still be able to receive some power? Okay.

Now I can't approach that problem directly because I have to introduce an additional, you know, two parameters of the antenna that we need to deal. So I am going to do that one. Okay. First imagine that I have some electromagnetic waves incident, which we will call as E^i in, you know, with a electric field indicator on top of that. So these EM waves are incident on the antenna.

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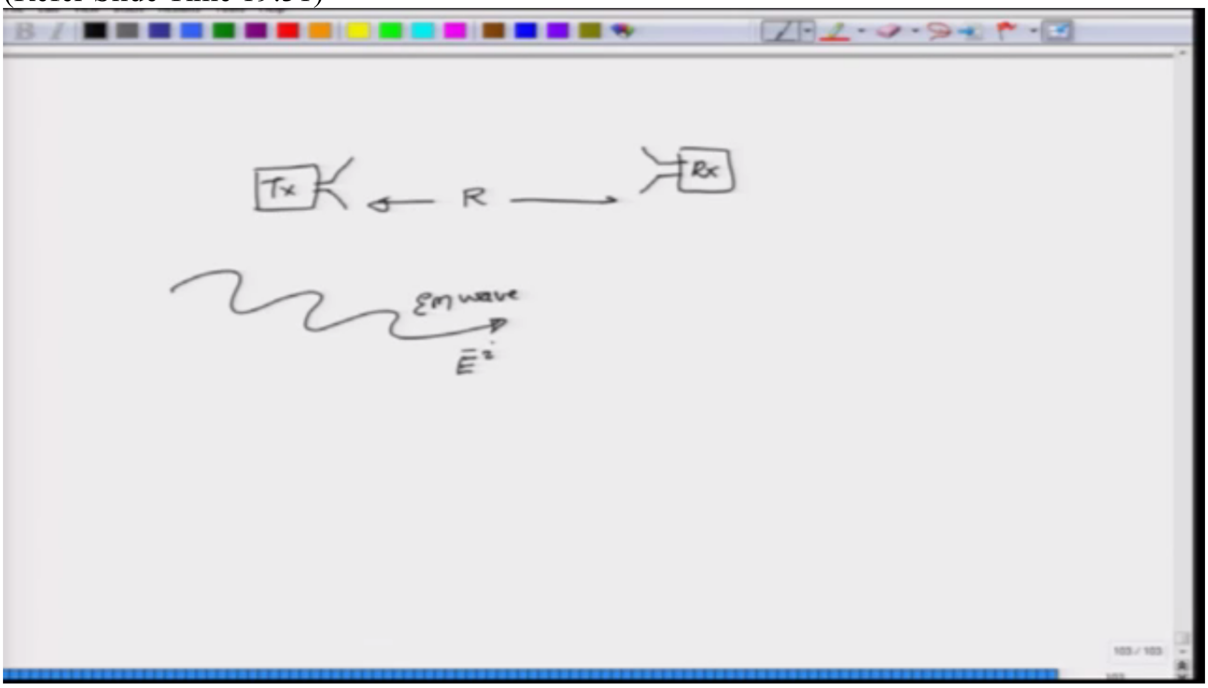

So you can, of course, think of these EM waves as being, you know, transmitted from the transmitter antenna and then falling on the receiving antenna. So now when you put the receiving antenna, it will induce some current onto this. Okay. So there will be some current that is induced on the antenna terminals and this current would then also induce a voltage across the antenna terminals. Okay. And this voltage that is induced can be written as the incident electric field times what is called as vector effective length of an antenna.

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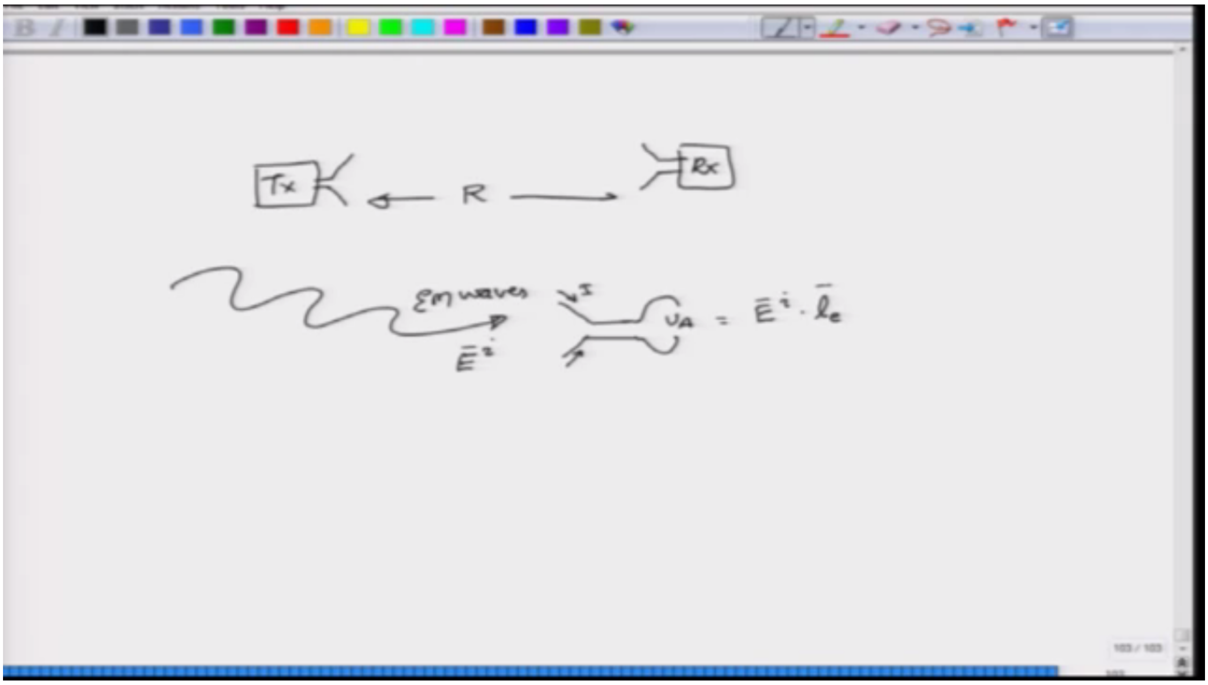

Okay. The determination of vector effective length requires you to actually do many times to do experiments, okay, in which you take the electromagnetic waves and then you make it fall on the antenna and then you start changing the orientation, okay, meaning the polarisation of the antenna keeps changing, and then you keep noting down what is the voltage VA that is developed across the antenna terminals and from these measurements find out what is the effective length. Of course, I have told you very simply, but it's rather more complicated than that, but you don't need to know that complication.

You just need to understand that the electric field that may be oriented in some manner, the antenna terminals may be oriented in some manner and the effective length of this antenna will simply tell you the mismatch in the orientation. Okay. When these two are oriented perfectly parallel to each other, then you get maximum power, sorry, maximum voltage across the antenna terminals. If not, the amount of voltage will be reduced by that and that is what is captured by the dot product of the EM waves with the effective length. Okay.

So this is the voltage that you are going to develop across the antenna terminals, and we have already seen that if you have the antenna equivalent circuit, then you should also have its internal impedance Z_A or the antenna impedance of that one and presumably, this is going to go to some load Z_L. Okay. I should not have written as resistance, but I am going to be slightly, you know, more general and then write this as Z_L.

Now many times what you are interested is to find out what would be the voltage across the load and what would be the current through the load. Why are you interested in these two? Because if you know what is the voltage and the current, the value of these two will give you the power that is being delivered into this one, right? Of course, you are interested in the real part of this. So the power that is being delivered is half of real part of voltage times the current conjugate and you can, by using simple circuit theory, you can show that this would actually be equal to $|VA|^2/2$ times real part of Z_L/Z_A+Z_L. Okay. Or rather there is a magnitude square in the denominator. Okay. So this is what you are going to get.

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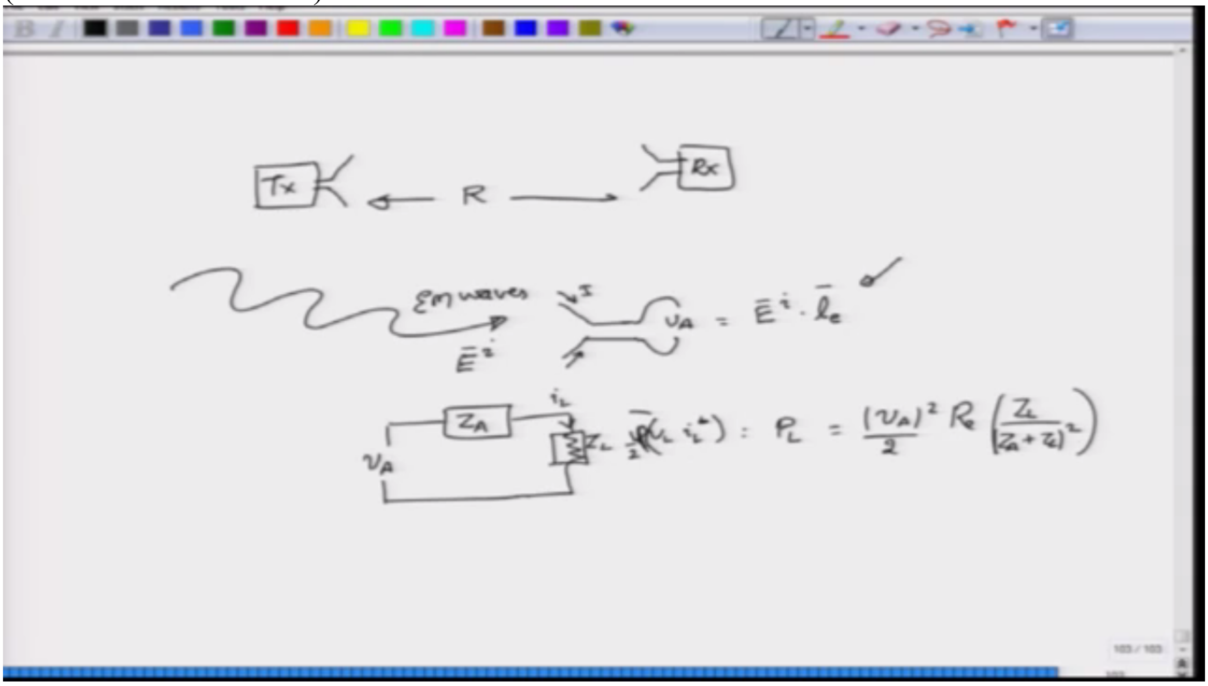

Of course, you also know from your, you know, theory of circuits that you will get maximum power across the load for a fixed internal impedance provided you make Z_L to be equal to Z_A conjugate, right? So this is what is called as conjugate match and in fact we have done this conjugate matching even in Smith chart transmission line scenarios where we were trying to match the load to its conjugate value and this is the same thing.

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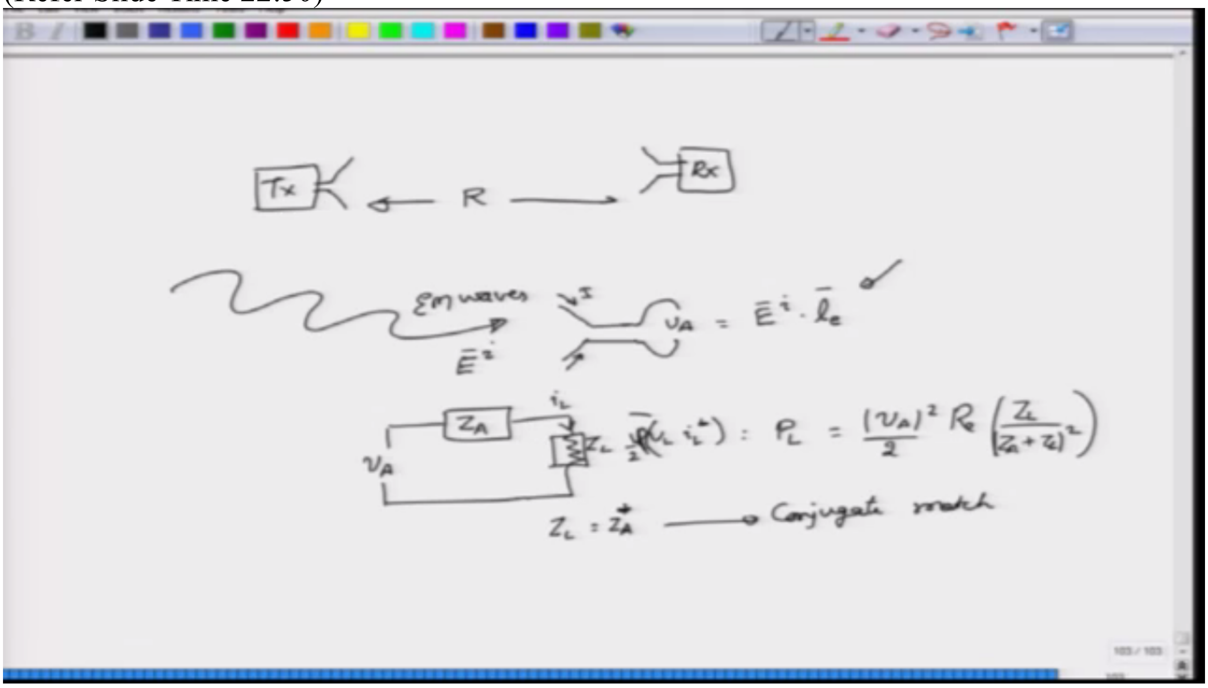

So you have to match conjugately the antenna to obtain the maximum power across the load. Okay.

So if you are interested in the maximum power transmission, you do this conjugate match with the antenna and once you have done that one, you can show that the power max that you are going to get under the conjugate matching condition will be equal to $|V_A|^2/2$ and the real part, so remember Z_A actually contained both the radiation resistance which was the, you know, Z_A actually had the radiation resistance as the real part and some, you know, reactance of the antenna.

Now because you are conjugate matching, the reactance part is gone and the real part of Z_L will also be equal to the radiation resistance.

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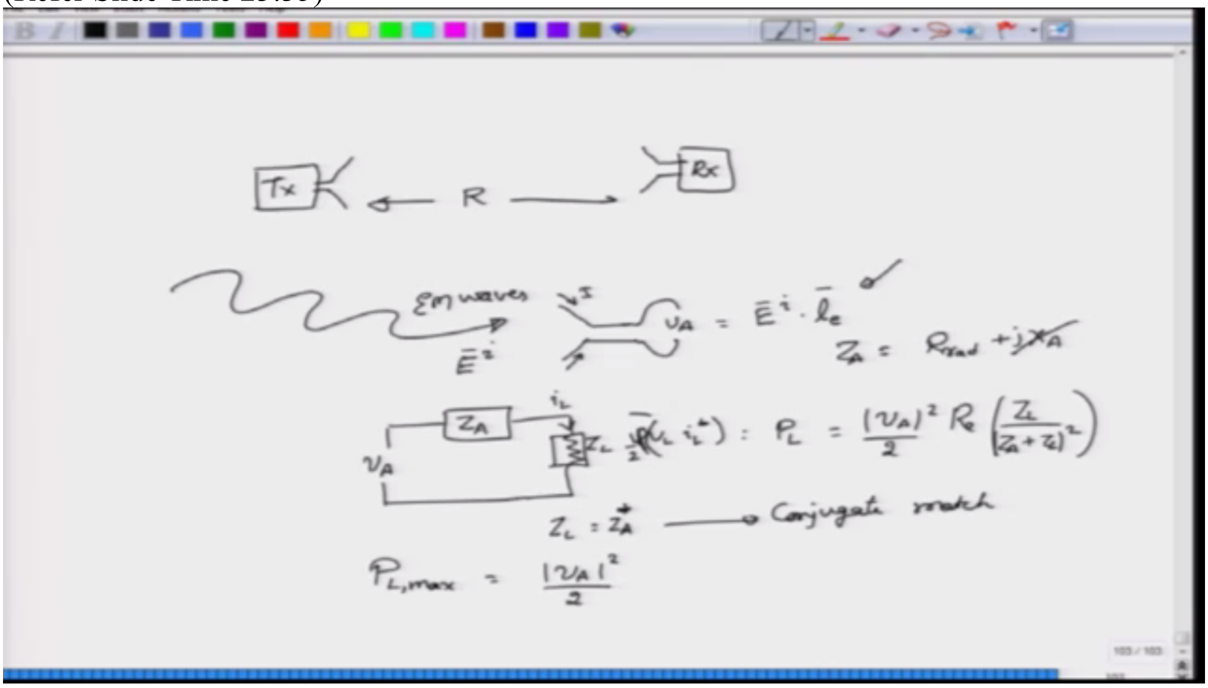

Okay. And because of that the expression becomes rather simple. So you have R radiation resistance divided by $|Z_A+Z_L|^2$ will be four times R radiation resistance square. So you can cancel one radiation resistance on the top and then look at the V_A. $|V_{A|}$ is basically the magnitude of this incident electric field times l_e. So I can rewrite this expression as $|E^i.l_e|^2$, okay, divided by eight times radiation resistance. Okay. And I can split this itself into $|E^i|^2$ times l_e^2 assuming that these two are oriented in the same polarisation.

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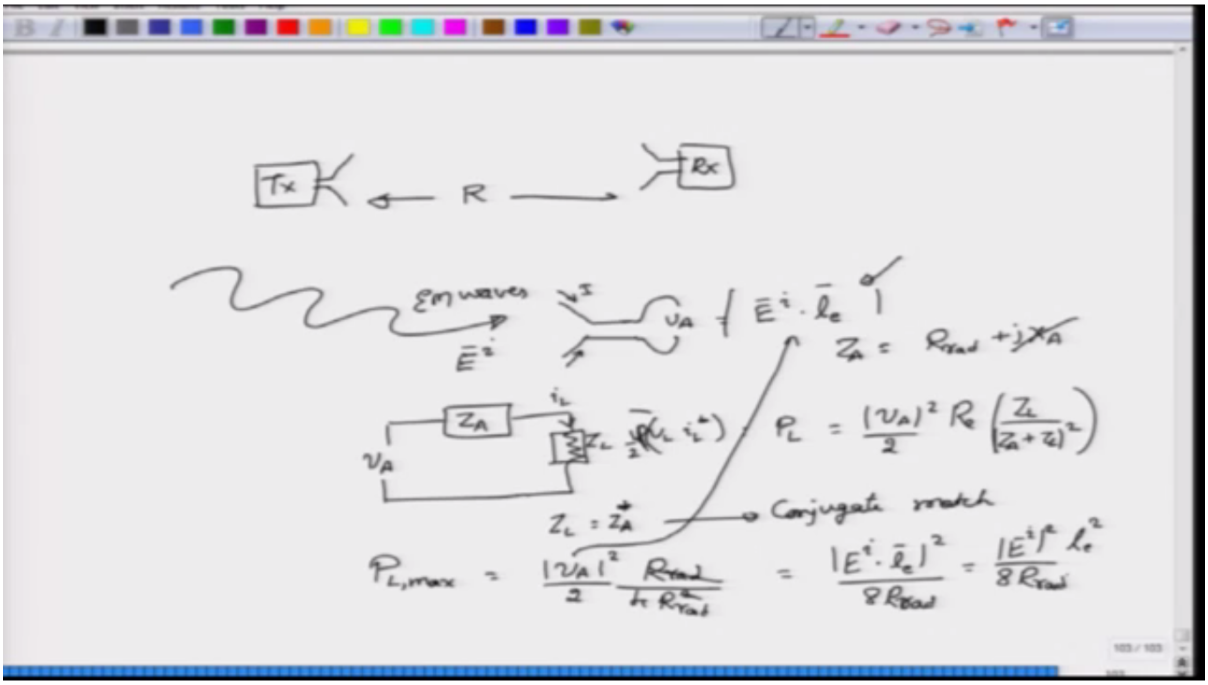

That is to say the incident electric field and the vector effective length are oriented in the same directio so that you get maximum power. Then you have this as the expression for the max power that can be delivered by the antenna. Okay. So that can be delivered by the antenna to the load terminals. Okay. So that is what you have.

But in practice, of course, you will have P_L to be less than P_{Lmax} and that, of course, will correspond to what is the efficiency with which you are trying to match. Okay. But let's say the maximum power that we found out as an expression was $|E^i|^2 l_e/8$ radiation resistance R_{rad} can also be reinterpreted in terms of what is the maximum incident, you know, pointing vector times the effective area of the antenna. Okay.

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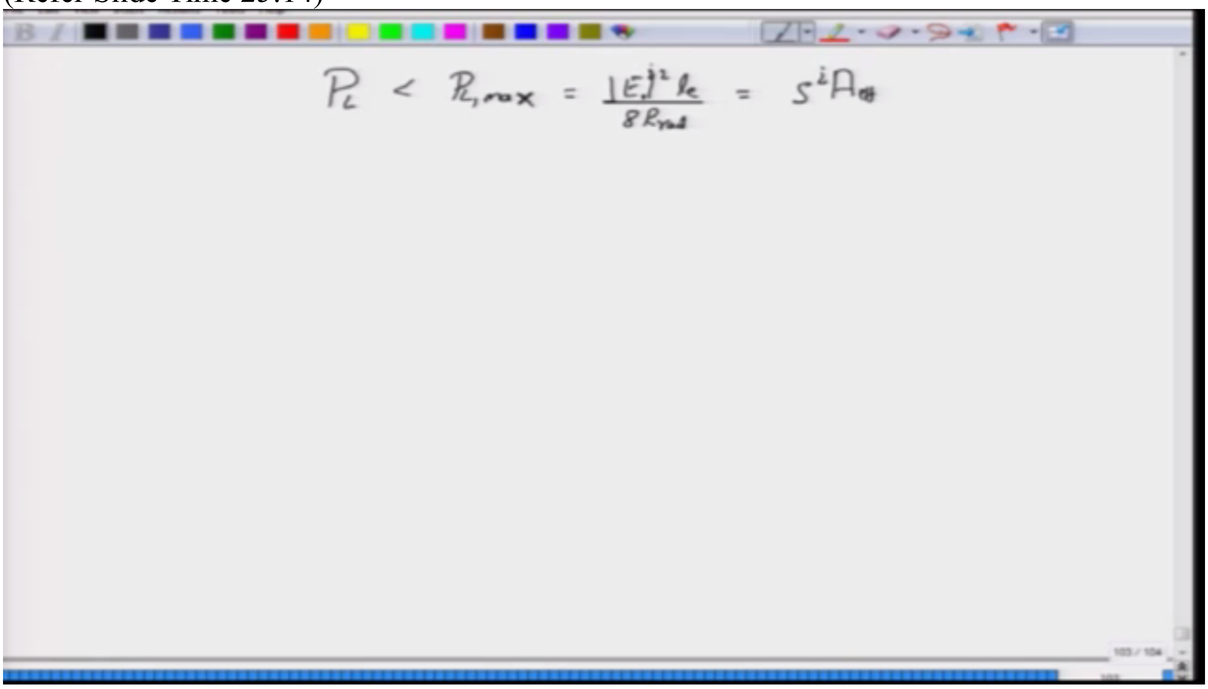

We haven't decided what the effect or defined what is the effective area of the area, but it kind of feels that if I have what is the maximum power density times the effective, you know, area of the antenna, that should essentially be the maximum power that I can extract from this EM wave, right? So the EM waves are propagating. You put a certain aperture, right? Aperture or the effective area and this is the area over which the electromagnetic field is interacting or rather the antenna is interacting with the electromagnetic field and the larger this effective area is, the larger is the amount of power that can be delivered. Okay.

And I know what is the incident energy or incident power on the, I mean, carried by the antenna fields. That would be $|E^i|^2/2\eta$ where η is the impedance of the media. Okay. So you can equate these two expressions to each other and then write $A_{effective}$ as $\eta l_e^2/4$ radiation resistance or rather $4R_{rad}$ and this is an expression, which, of course, depends on our knowledge of l_e.

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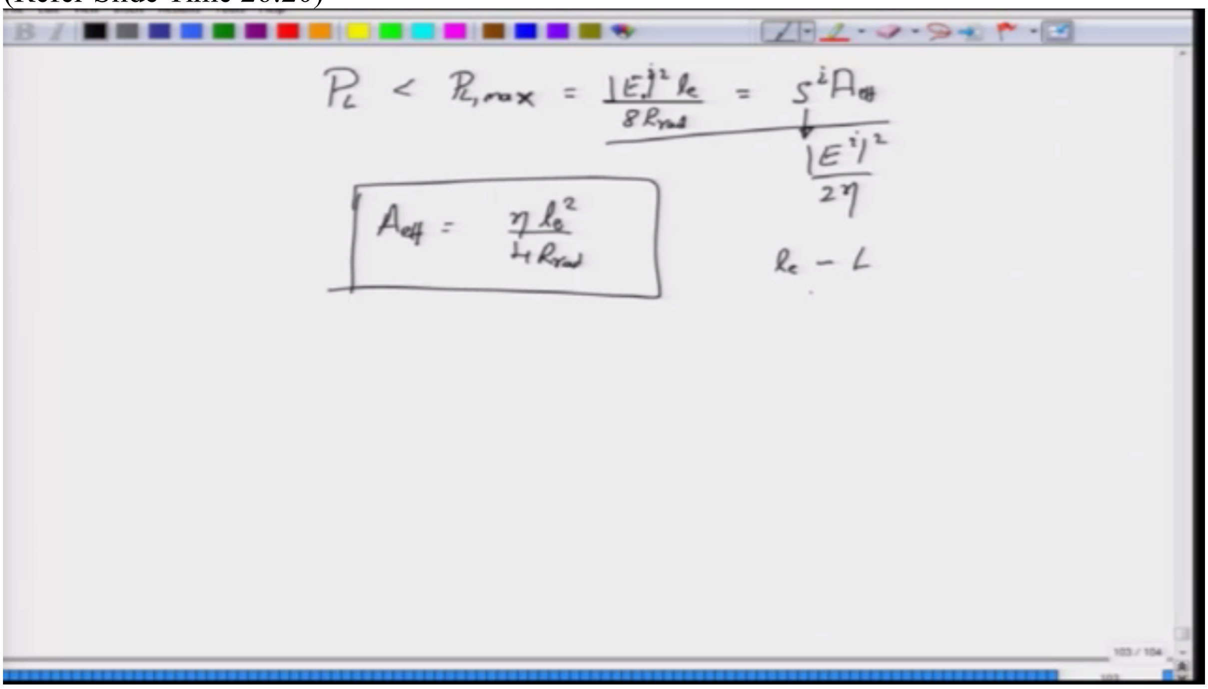

Most of the times we take l_e to be of the same order of the physical length of the antenna itself. Okay. For a short dipole, this length will be about Δz for the half wave dipole. This would be about $\lambda/4$ and for the short dipole you can also show that, I mean, you have also derived the equation for the radiation resistance as $\eta\ k^2(\Delta z)^2/6\pi$ and if you take l_e as Δz as I told you, you know, as in a first approximation, then you can show that this effective area of the antenna can be written as $.12\lambda^2$ after you substitute all the, you know, factors into that expression, you can show that this effective area will be about $.12\lambda^2$. This .12 is basically coming as $3/8\pi$. So if you get this one, turn your calculators on and then you can find out the effective area to be this.

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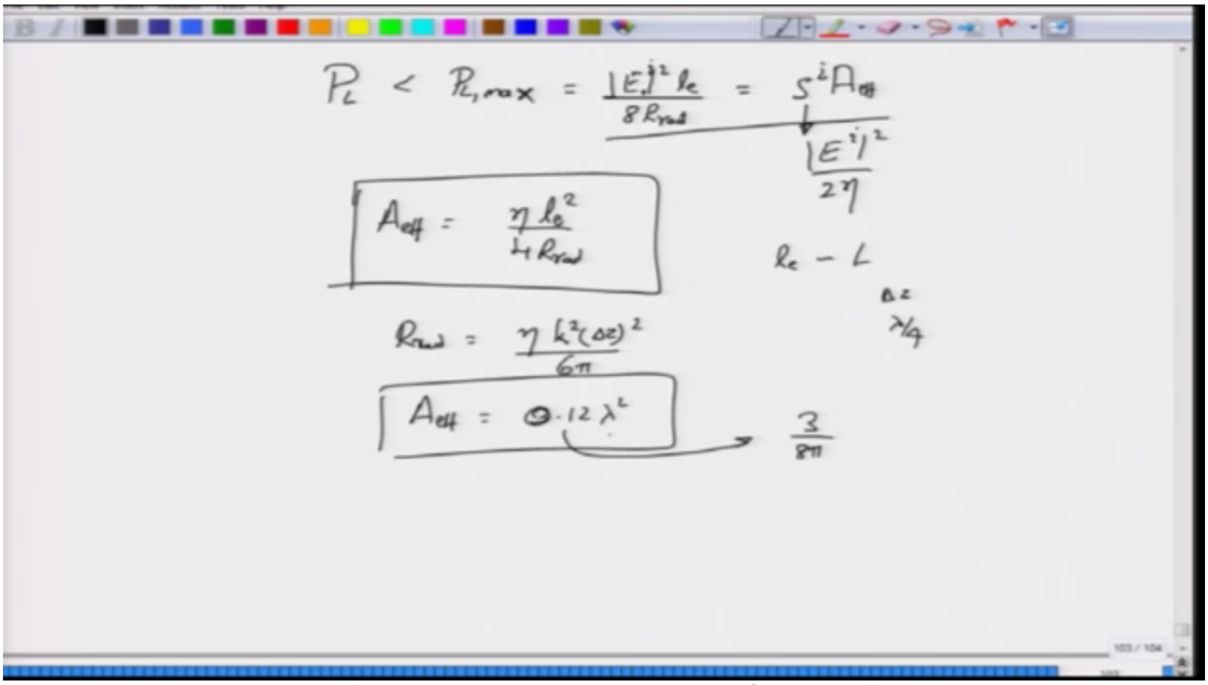

So the point here is that effective area is proportional to λ^2 at least for the short dipole case. I will leave the half wave dipole for you. The power that is delivered is proportional to the effective area. So, sorry, S^i times the effective area and the gain of the antenna is proportional to the efficiency of the antenna times D. Okay. And D and G are both proportional. In fact, you can show that D is related to $A_{effective}$ as $D = (4\pi/\lambda)A_{eff}$. Okay.

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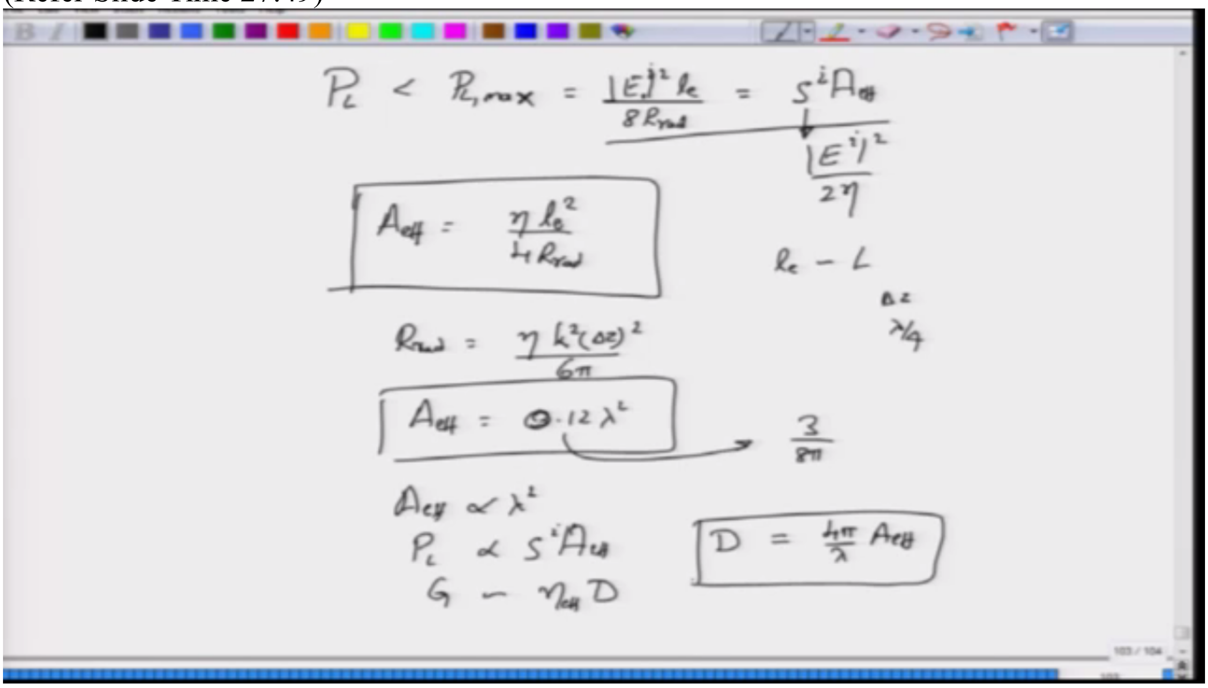

This equation is very important. Of course, I have not, sorry, this is $4\pi/\lambda^2$. Of course, I have not shown this relationship. The derivation is kind of complicated, but if you remember $A_{effective}$ scales as λ^2 at least for the short dipole many times it may not be the same, but it is a good approximation. The power that can be delivered is directly proportional to the effective aperture or the effective area of the antenna and gain is proportional to the efficiency of the antenna and it multiplies the directivity.

Of course, $A_{effective}$ is both θ and φ dependent in general. It's just not a number and because there is a relationship between D and $A_{effective}$, that relationship is going to be very crucial and D, of course, is related to G. So this relationship is going to be very crucial for us to answer the question as to what would be the power that the receiving antenna would receive if it is distant, if it is at a distance of R from the transmit antenna. Okay.

We will come to this question and answer the question in the affirmative in the sense that we derive a formula called as Friis Formula and from there we take off onto the wireless channel propagation.

Thank you very much.

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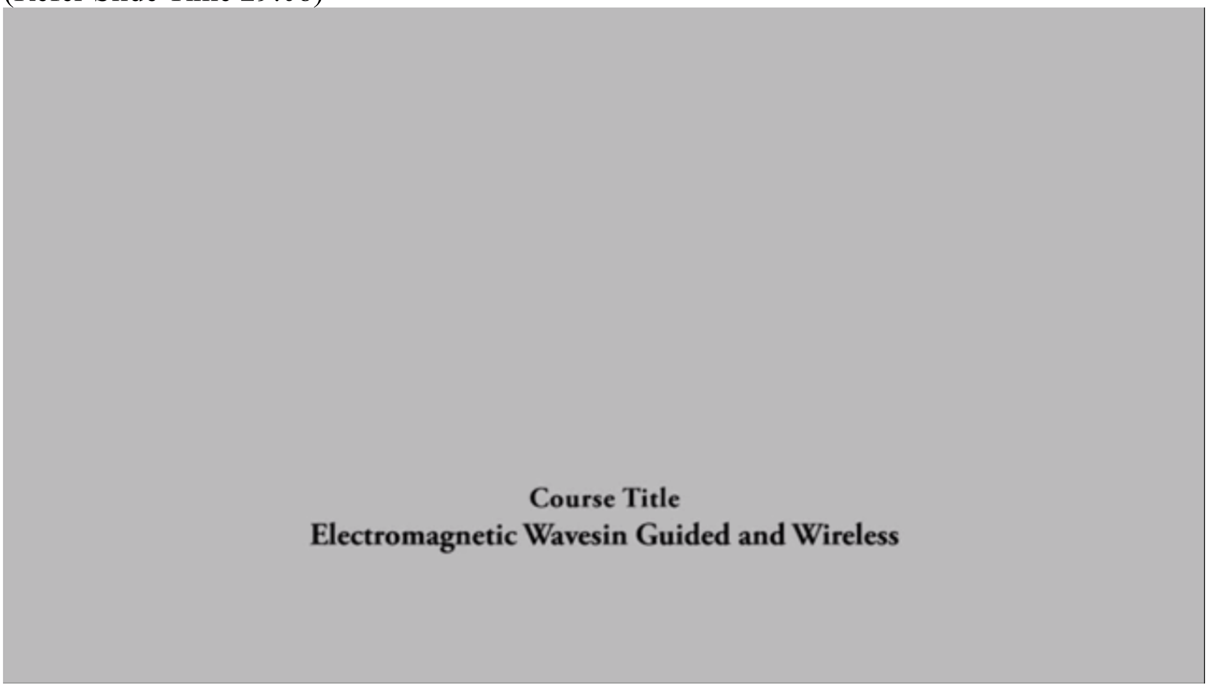

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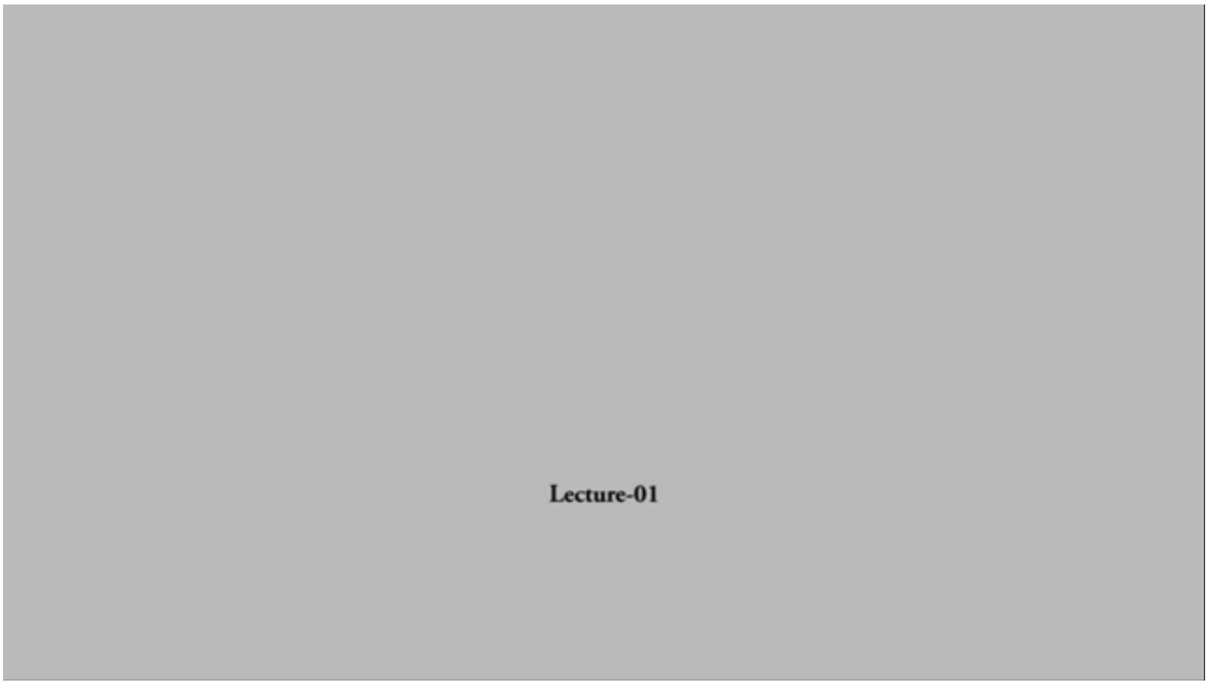

Lecture-01

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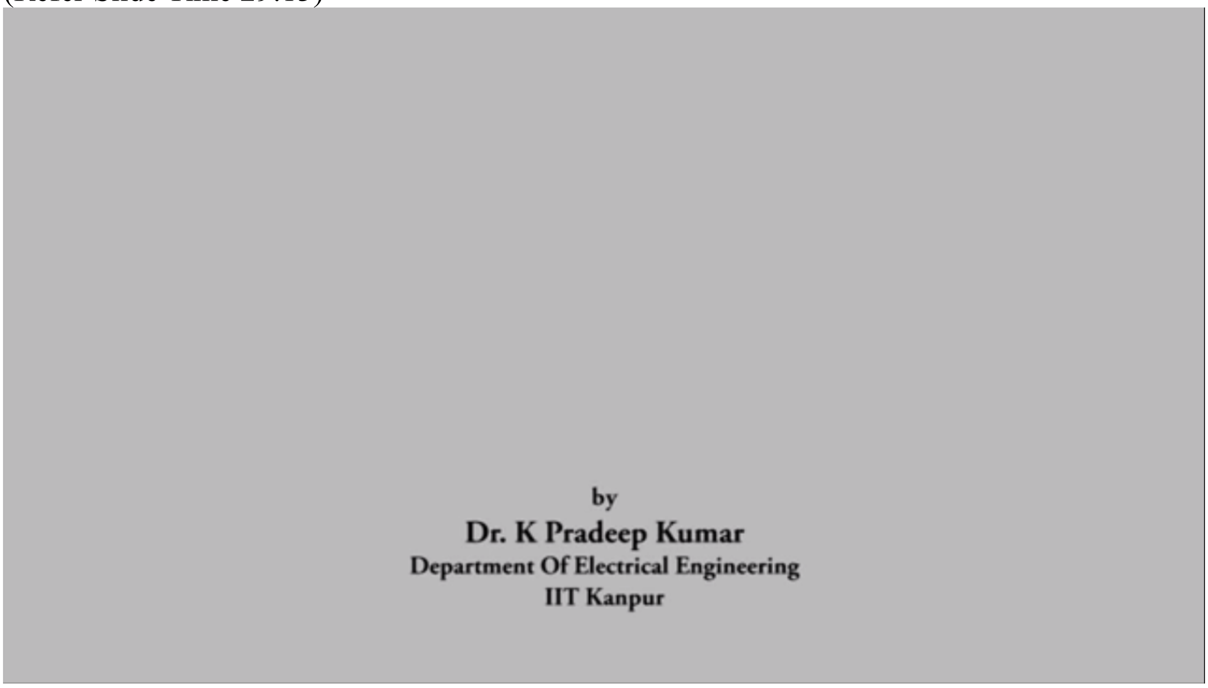

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