Lecture 30
Near field and Far-field
Antenna and Properties of Antennas

Hello and welcome, to NPTEL's MOOC on Electromagnetic Waves in Guided and Wireless Media. This is module 34 and we so, for what we have done, is that we have used this equations for a.

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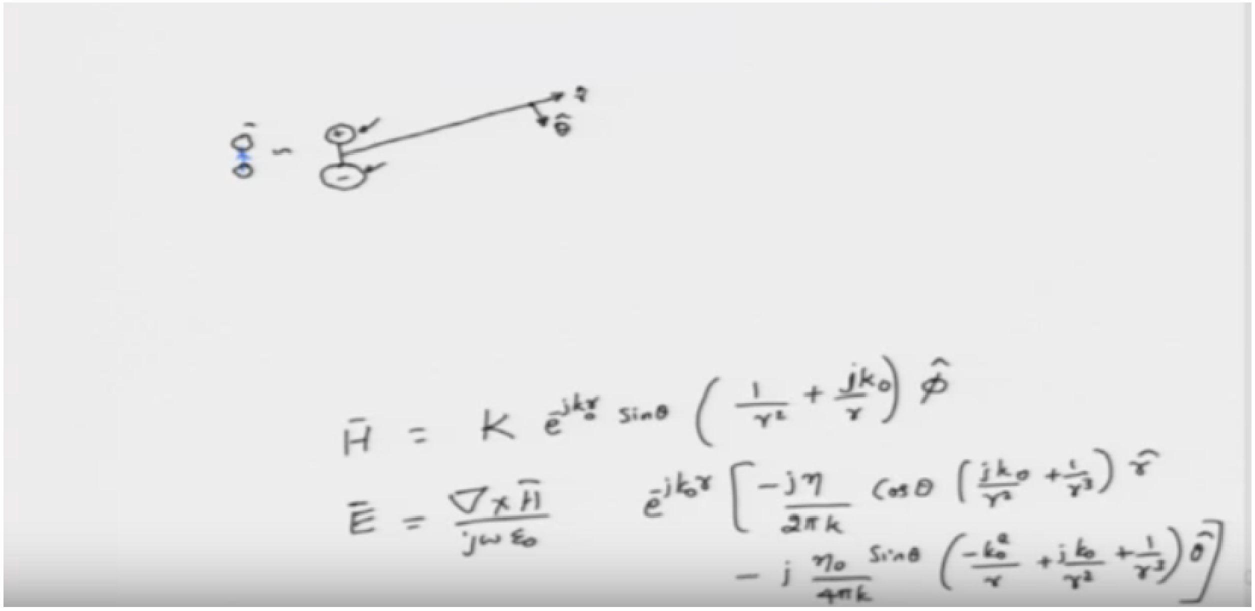

And find out what would be the electric field sorry, magnetic field component H, of an elementary dipole and then using the Maxwell's equations, which have written down here, we have obtained what is the electric field of that particular dipole. Now, you can see that there are lot of terms. But, we do understand that magnetic field is directed along the PHI axis, which is perfectly fine, as we have no told you in the last few last minute of the last module and with respect to electric field, you would see that there is an R N theta component which again, would also be fine, because you have this current, in the short dipole. Right? That is going from whatever the direction along you said and you know that, current cannot just disappear at the edges, because there is a continuity condition at the edge that one has to place although the edge in this case is just a point very short point, you still if you were to enclose this edge, this current being pumped into, must result in charge accumulation and current being drawn from the bottom surface, closed surface means that, there has to be creation of a negative charge. So, equivalently, what you would see is a spherical charge. Okay? Which is positive and negative? Okay? So, that the current or maybe it is minus and plus the other way around, because of the continuity condition, doesn't really matter whether it is positive or negative in the current condition, what is important is that there is a charge distribution which are of two types, which have to be created at the edges: that is where the charges have to be accumulated or be drawn from it. Right? Without that, the continuity condition won't hold and of course this is strictly speaking not true, where will the charges go so, so strictly speaking this type of an elementary dipole, does not exist in practice, it is a very, very, very good approximation, to those antennas whose length is electrically very, small that is whose length dz, it is much, much smaller compared to the wavelength. Okay? So, that you can treat them as a point particle. Al right? So, coming back to this, the effective dialect I mean, the dialect dipole that we considered, effectively would have some charge distribution at the edges, in this manner and if you were to look at what is the fields of this dipole, you would see that the field will actually, be one component will be the R component and the other component will be the theta component. Okay? So, the electric field of this one, would have an R and theta component, as you can think of two charges which are separated in space, by a certain distance dz, it would constitute a dipole and if you go back to electrostatic courses or other modules of NPTEL, where we discuss these electrostatics, then you can see that, the field would essentially be that of a dipole. Okay? R and theta component.

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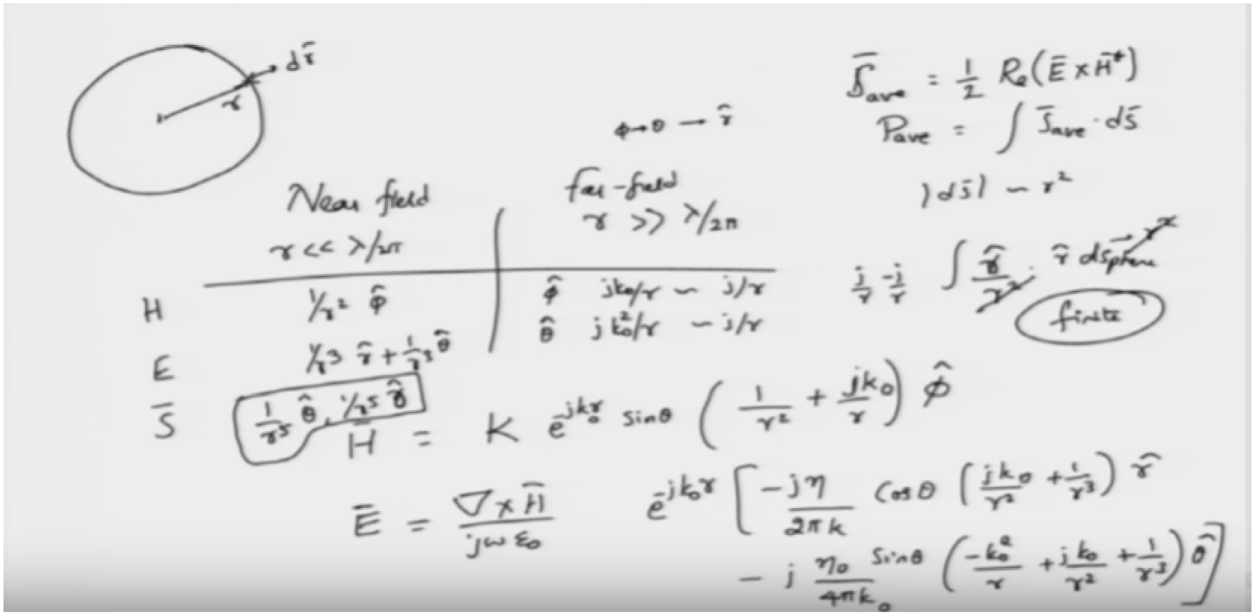

So, at this point, we are at least in agreement, about what the directions of the magnetic field should be and what the directions of the electric field should be that is, what components should the electric field have and what component should the magnetic field have, there is some, constant here K, which you can don't have to worry too much about it and E bar minus JK zero R is essentially the phase factor, which simply gives you the time delay or the phase shift that we have already spoken of, but, what we did not expect, to see the field components itself, if you just take the magnetic field H here, this 1 by r component is what you want? 1 by r square component is what you would expect? If you were dealing with the static condition. Okay? Now, if your antenna is, at this point and your distance R is in such a way that, this R is much, much larger than lambda that is longer than lambda: that is you're far away from the antenna. So, R is much, higher than lambda, then in that case, you see that 1 by R, is a term that would grow more slowly, compared to the 1by r square. Right? So, if you actually plot, the magnitude of 1 by r square term and k0 by term. Okay? So, if you plot them, for short distances one by r square term will be higher, whereas one by r square term will be lower, but, for longer distances that is, when r becomes much, much larger than lambda, in fact lambda by 2 PHI, then 1 by r term will be higher, than the 1 by r square term which would have gradually gone down to 0 or rather rapidly gone down to 0. So, if you're there at a distance which is lambda by 2 PI, less than that distance approximately of course: that is observation points are less than lambda by 2 PI, then the term 1over R Square will dominate over, JK 0 by r and when it does, so let's put down, this has two numbers. Right? So, when R is much less than lambda or lambda by 2 PI, then the dependence in terms of R, will be 1 over R square for H and for the electric field again, looking at this 1 so, this is 1 over R square along PI hat, of course here between 1 over R square and 1 over R cube, it is obvious that, 1over R cube will be dominating over 1over R square. So, you will have 1 over R cube, in the r direction, plus again 1over r cube, in the theta direction, of course I have neglected all the other sine theta, cosine theta, all those terms I am only interested in showing, how the fields are changing with respect to r and this is what you actually get. Okay? Now, what does paintings' theorem tell us? Pointing’s theorem tells us and we have already seen that 1 that, the average power density, which we will call it as, ‘S’ or maybe s average power density is given by, half of real part of e cross, H conjugate when e NH are expressed in terms of phasor. Right? And the power that is, carried away, by this wave, is given by integrating this average power density, over the surface that you are considering and this surface, happens to be that of a spear. Right? Because you have this antenna somewhere and you enclose the antenna in terms of a spear of a certain radius R. Right? Which is where you are also observing the fields so, this integration should be carried over the surface area of the spear and surface area magnitude of a spear goes as, R square. Okay? Now, if you look at this H and E phasors that you have and you take a cross, H conjugate. So, in this case don't worry about too much, about the conjugate because that anyway will be taken care of now, what you see is? There is an R hat and a PI hat and theta hat and a PI hat. Right? So, you have R theta and PI, so when you look at R cross PI, the resultant will be a theta direction, so if you write this as S, then there will be a component with the theta direction, which is going as 1over R bar 5. So, you have theta at 5, which would be going as R. But that would also be 1 over R bar PI, in the r direction. Right? And when you integrate, since d s on a sphere, would actually point in the direction of the increasing R. So, what you would actually see is that, integration with respect to theta will give you 0 and integration with respect to R will still give you 0, why because? The integration or the average power would now be, dependent on, R PI is in the denominator, R square in this integral in the numerator and you'll get 1 by r cube. Okay. 4 are much less than lambda by 2 PI, there seems to be that s is actually you know, going as 1 over R cube. But, you can actually show that, this fellow will be imaginary and when you take the real part of it: that would actually be equal to 0. Okay. So, although it seems that because we neglected some of those constant, it seems that there is power carried in the field here or power dissipated or power delivered, there’s really no power and what you actually see is that, in the near field, most of the power is actually, in the field itself it's not radiating away. So, it's, it's Dade's as a stored energy, the real part of that will be equal to 0. So, it's mostly the reactive, energy that you are going to have, the situation which we are mostly interested. Right? Is in the far field case, in the far field case R is much larger than lambda, meaning that you’re far away many, many wavelengths away from the point of the source or from the wavelength that you have considered and at that point, as we have seen, it is the 1 by R term, which would be larger, than 1 by r square and 1 by r cube term. Right? So, in that case H field, will be mostly like jk0 by r. Okay? And the e field, will have no R component, because it's 1 by r square and1 by r cube component. So, they will go to 0 and in the theta component I will have, minus and minus becomes a plus. So, I will have a plus j, k0 square by r. Okay. So, of course, there will also be a k 0 here that may cancel out. So, if I reduce this one further I will have j by r and j by r. Now, this is interesting and this is important because, now when you take this j by r and then in tick you know, take the dot product or the cross product of that one with say minus j by r, the result, because this fellow is in the PI direction and this fellow is in the theta direction, the result in terms of PI and theta, will actually be along the r direction. Okay? So, when you look at this one, the denominator is going as 1 over R square and it is directed along the r direction. So, when you integrate, this fellow with the spear, surface area, which also goes as R square, this R square in the denominator and R square in the numerator cancels and the integral of this fellow will give you a finite, value in fact this would be the value or this would be the power: that the electromagnetic fields that are emanating from the her elementary dipole, will be carrying. Okay? And if you have another antenna, which can successfully absorb all of the power, then essentially what this dipole has done, is to deliver power, without any guiding structure, it has delivered some power, onto the antenna which is located in a remote place. Okay? Of course in practice no antenna is perfect in the sense that it cannot capture all of the electromagnetic energy, we define the capturing of the electromagnetic energy, by what is called as, 'Effective Aperture' or sometimes called as the, 'Vector Effective Area'. So, we will see all those terms later on. But, you essentially understand that, the antenna can radiate certain amount of power and the receiving antenna, can capture most of the power or some part of the power depending on how the antenna is, designed. Okay? The fields that you are going to get the antenna will be mostly, either capacitive or inductive meaning that, they are like capacitors or inductors, they can only store energy, they cannot dissipate any energy. So, unless there is a dissipative factor, which is present only in the far field, there is no energy transfer that usually happens. Of course there are a lot of applications where you are looking at near field communication, where some of these concepts have to be revised, later on depending on the application. But, as far as, most traditional antennas are concerned, most traditional antennas are designed, to operate in the far field region, for various other reasons, which we will go into the detail here. So, they will be usually operating in the far field region and in the far field region you want H to be, going as one by r and usually directed along the PI axis and electric field should be directed along the theta axis, so that theta cross PI, can give you the direction along r and if H is going as one over R and E is going as one over R, then that product essentially, will go as 1 by R square, which then cancels out, the R square term in the numerator and so that you, essentially get a finite energy being carried by the electromagnetic wave. So, that is all about the R dependence that we have seen. So, you can for future reference, call this as, 'Near Field' and call this as, 'Far Field'. Okay? After having discussed that,

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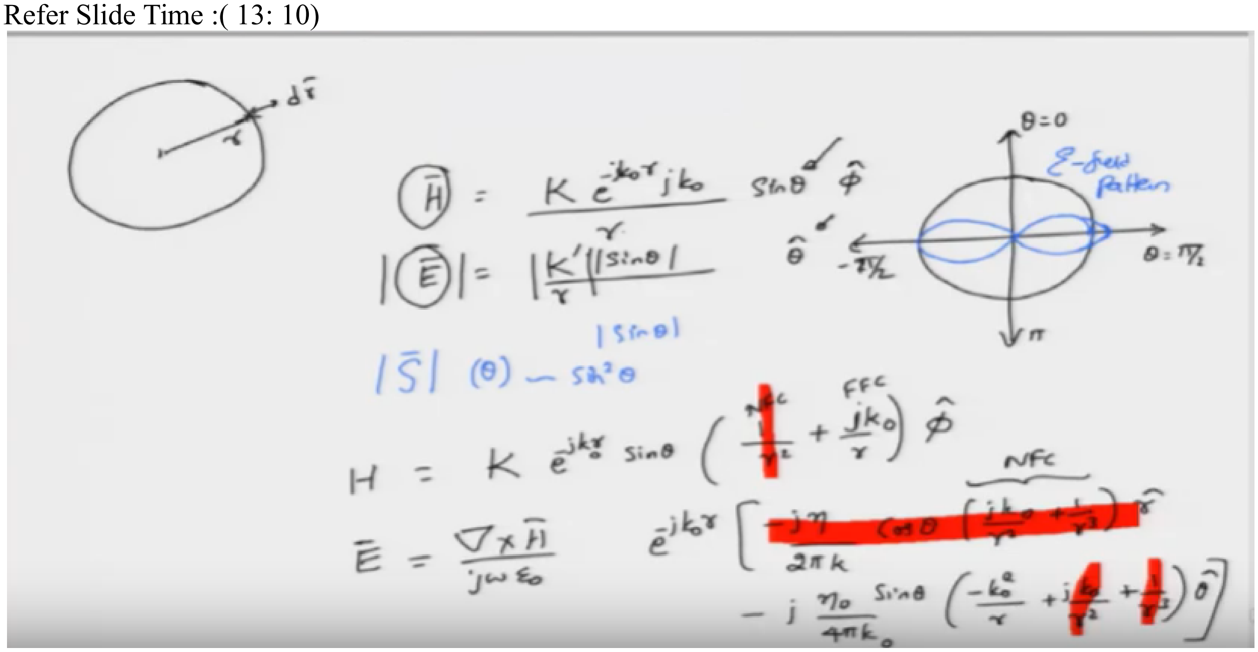

let us now, go back to the terms that are actually, present which we haven't discussed here, I am NOT writing these terms again in the new, sheet I amusing the same sheet, so please, forgive this, the reason being I do not want to write the terms again and again. Okay? And we have these fields return here, so they are feasible all the time, so please, keep looking at the electric and magnetic field expressions, as we now make various approximations. Okay? Now we have this H fill and e field. Right? So, and we have said that, this is a near field component, this is the far field component and this is both our near field components. So, I can actually, no cancel out, this entire term. Okay? And retain only the term that is present here, again I can cancel out, this term here and this term and this term, because I'm interested in only the far field component. Right? So, what is the H you know, in the far field component, it will have some constants, don't worry about that and you have E bar minus JK zero R and then you have some JK zero divided by R. Okay? And most importantly, there is a theta dependence, on to the H PI component. Okay? So, if you again write down what will be the electric field? Electric field would also be in a very similar manner, it would also have some constant, which we will call as, ‘K Prime’. Okay? And then you have, sine theta, you have E bar minus JK 0 r, divided by r you will have some k0 square as well to work with, so you don't worry about that, all of that has been put into the K prime thing. Okay? And this of course will be along the theta direction. Now observe that, H is not only a function of R, but it’s also a function of theta and what is Theta? I'll tell you in a minute, similarly electric field is also a function of theta, again what is Theta? I'll tell you in a minute, but now, both electric field and magnetic fields are functions of theta, in fact they’re functions of theta in the form of a sinusoidal function, they are actually equal to sine theta in that sense. Now, if you were to take the magnitude of the electric field, then taking the magnitude and fixing our to be a constant means that I can remove this E bar minus JK zero term. Okay? And then I'm, simply looking at some constant K prime, by R and in terms of theta dependence, it is actually going as sine theta and the same thing will happen for or other magnitude sine theta and the same thing will happen for the magnetic field as well. Now, what is this theta? Now, imagine that this is my antenna. Okay? Or you can imagine that this is my antenna, I have this as the z axis and I'm actually looking at, the observation point on a spear. Okay? Which has a radius R? So, this is the spear that I am considering and the angle that is made between the z axis and the observation point that you have considered that is your theta. Okay? This is the spherical coordinate theta that we are talking about and the if you project the point down, onto the XY plane and then draw a line through that, that point would be the PI angle or the angle PI. But luckily, our components are not dependent on PI so, we don't have to worry about that, we only need to see how, they elect as you, you know move along the sphere, of some radius, as you keep moving. Right? What would be the effect of or what would be the dependence of the electric field magnitude and the magnetic field magnitude on to this and of course you can also, find out what would be the, dependence of the pointing vector also, in terms of this theta and you will see that, that would be essentially a sine square theta and electric and magnetic fields go as magnitude of sine theta. Now we will introduce, what is called as polar plot? In the polar plot Okay? Sorry, this was not very well written, you fix your angle theta equal to zero at this point. So, this is the angle theta equal to zero and this is equal to theta equals PI by2, this is theta equals PI and this is theta equals minus PI by 2 in some sense. Okay? But, because most of these radiation patterns can be specified only in the upper half, because most of them would be, essentially similar in the lower half, most of them not everything, then you can describe and this has a certain radius R. Okay. So, you fix R and then keep moving along theta equal to 0 and go all the way up to this circle. Okay? Usually you go up to theta equal to PI by 2 and theta equal to minus PI by 2 then, the patterns would essentially be symmetric and what you would actually get, is that, you are going to get, a magnitude sine theta dependence. Which will be equal to 0 at theta equal to 0 and it would be maximum, at theta equal to 1 or sorry, PI by 2. Right? So, this would be maximum, at theta equal to PI. Okay. I have really not drawn this correctly, but, this is what you are actually going to get and in fact, you are going to get a picture: that would look something like this. Okay. So, I mean it's, it's not exactly like that, so it should be slightly more on to this, because you want to show the maxima thing. Right? So, it's kind of a picture so, I will anyway refer you to textbooks where the patterns are plotted in three dimensions, which are very good. Okay. So, what you observe is, there is no radiation, along the z-axis or along the theta equal to zero or along this theta equal to PI by 2, direction. So, this is what you would actually observe and plot, such as these are called as, ‘E Field Pattern’ there is nothing specific about E field but, most of the people use e field to draw the patterns, you can also plot what is called as power pattern? In power pattern you are actually, plotting the magnitude of s, as a function of theta. Okay? And that would be essentially sine square of theta. So, the curve would be slightly different. Okay? But, it would be you know, in a sense of this one and sometime this is called as a, 'Donut Shape'. Okay? With a pinched off, donut at the center. Okay? So, this is, what you actually get as a power pattern or the electric field pattern and this is how, most antennas are actually described. Okay? However the best way to think of antenna patterns or the field patterns is to actually plot them in the three dimensions or at least refer to books, which show you the three-dimensional patterns for a better understanding. Okay? So, now what we want to do? Now, what we want to do is? I want to actually ask a question.

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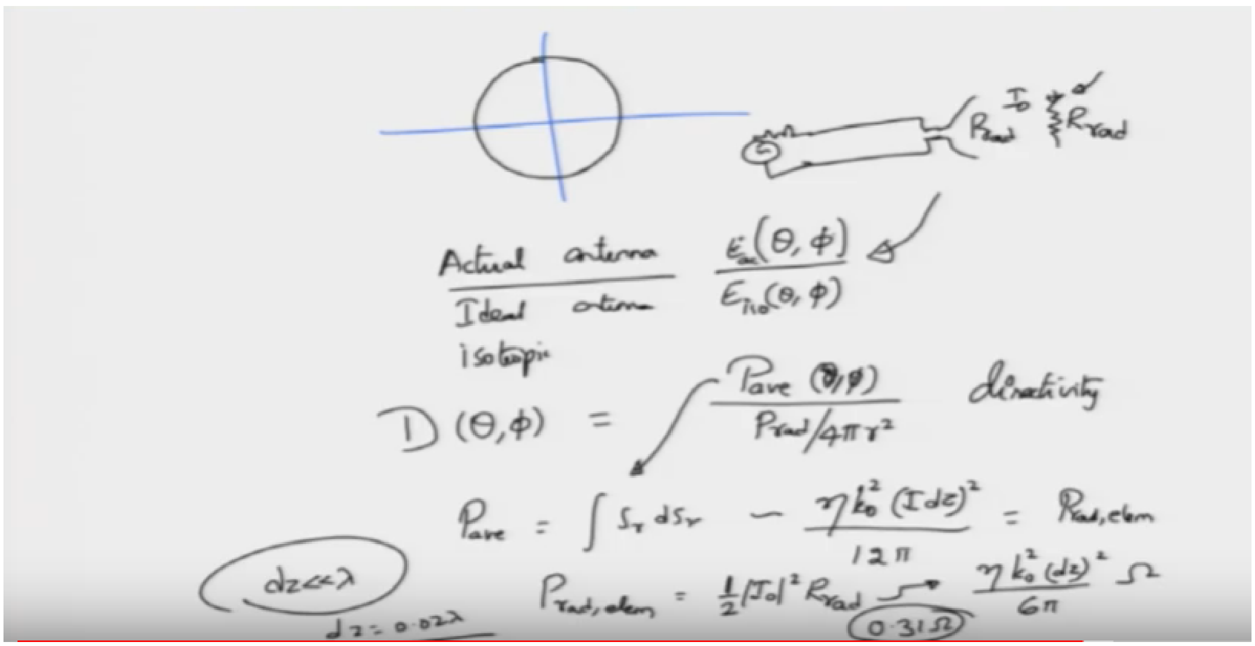

Is there something, like a perfect antenna, which would equally, radiate in all directions, would that antenna be useful, well in many cases this antenna would be useful, imagine that you have a base station. Okay? Which is a wireless you know, in the wireless scenario, base stations are the ones which you know, broadcast, messages to multiple users? Okay? And these pay station antennas are located usually on the true for on the tower and if this base station antenna, were to be uniform in radiating. Right? Then it would not matter where the, user the mobile user would be located, because each, user would receive, an equal amount of power. Okay? So, if you have a antenna, which is your actual antenna: that is the antenna under study. Right? So, this actual antenna may have a certain radiation pattern. Okay? As a function of theta and PHI, in general it will also be function of theta and PHI although, in the previous case we did not, so if you actually look for the power pattern or the field pattern in that one and then, divide then you actually look at, the ratio of or you normalize it, with the hypothetical ideal antenna, which is called as an, ‘Isotropic Antenna’. Okay? Isotropic antenna would be that antenna, which would radiate equally, in all direction, so it doesn't have any direction specificity. Right? So, isotropic antenna so, if you look at, either the field pattern or the field pattern so, this is isotropic is actual or the power pattern does not matter, this ratio, in some sense, will tell you the direction dependence, of the actual antenna. Right? So, most antennas can radiate efficiently in one direction, compared to another direction for example, in the dipole scenario, we saw that most of the antenna was radiating maximally, along the theta equal to PI by two, axis rather than at theta equal to zero. Right? Whereas in a isotropic antenna, theta equal to zero would equal it would receive equal, radiation compared to the theta equal to PI by two radiation. So, both will be essentially equal. Okay? So, you sometimes find antenna patterns being you know, reported by normalizing them with the isotropic antenna pattern and the ratio of these, would essentially tell you a quantity called as, ‘Directivity’. Okay? Directivity would tell you, the ratio of how much power, usually it’s the power thing or you can also make in the electric field doesn’t matter, it would tell you, in a given theta and a given five point, at a constant R, what is the average power being radiated by this antenna, to the power that would be radiated by the antenna if it were to be an isotropic antenna. Right? So, if you look at that, the average power that is being radiated at theta and PHI by this actual antenna, divided by the radiation that would be obtained. So, if you were to, give the same radiated power instead of an actual antenna and give it to an isotropic antenna, the isotropic antenna would radiate P radiation by 4 PI R square. Okay? So, if you take that as the reference, then what you get is what is called as directivity of the antenna? As I told you this is in some sense telling you the, specific directions or preferences of directions of your actual antenna. Of course I have not told you how to calculate this rage power, well the average power can be calculated by simply taking the integral of S r dsr, where s R is the field in the far field, direction it is actually not the field, I'm sorry, but this is the, pointing power density, in the r direction and then integrated over the spear. Okay? So, if you were to do this for a you know, short dipole, then this value, would essentially turn out to be, some ETA k 0 square, I DZ square divided by 12 pi. Okay? You can calculate it. Okay? By the use of expressions for electric field and magnetic field, you can calculate, what would be the radiation power, so we will call this as, ‘P Radiation of a hertzian dipole? So, that would be elementary dipole, this is what the power that would be radiated. In fact, if you think of this antenna, as a circuit element, which circuit element contributes or you know, kind of models, the radiating power. So, this is or I put this is an this is some antenna. Okay? Which is radiating, a power of P radiation you know, period and as far as the circuit is concerned, suppose you have this one connected to a transmission line, connected through some circuit here, as far as circuit is concerned this radiated power is something that would not be, recovered back. Right? Because this is the power that will actually be lost from the circuit point of view, lost in the sense it would be radiating away. So, from the circuit point of view, this is the amount of power that we have lost, so any power loss would essentially appear as a resistive, element and you can call this as radiation resistance and summarize the antennas performance in terms of telling how much, is the radiation resistance of this antenna. Okay? And the radiation resistance can of course be obtained, by equating this radiation radiated power, to half, I 0 square R rad, where I zero is the current: that would be flowing into this or the equivalent current that would be flowing into this, hypothetical radiation resistance. Okay? And using this expression you can show that, the radiation resistance of this elementary dipole, would be given by ETA K zero square, dz square, because I Square anyway will go away, divided by six pi. Okay? And this is in terms of ohms of course. Okay? And of course please remember dz is very, very small compared to lambda. Okay? So, if you satisfy this condition and if you take this dz equal to point zero two lambda, just for illustration purpose you will see that this radiation resistance will be around, point three one ohm. Meaning that, if this appears almost like a short circuit that is the amount of power, if you were to feed it through a transmission line and deliver it, to the antenna, only a miniscule, part of that antenna power will be radiated away. So, this is a poor, poor efficient antenna and there is a connection between directivity, gain and efficiency, meaning that, the gain is always, efficiency times, the directivity of the antenna. Okay? So, meaning that, antenna provides gain, but, the gain is not really intrinsic gain. It's again over an isotropic antenna. Right?

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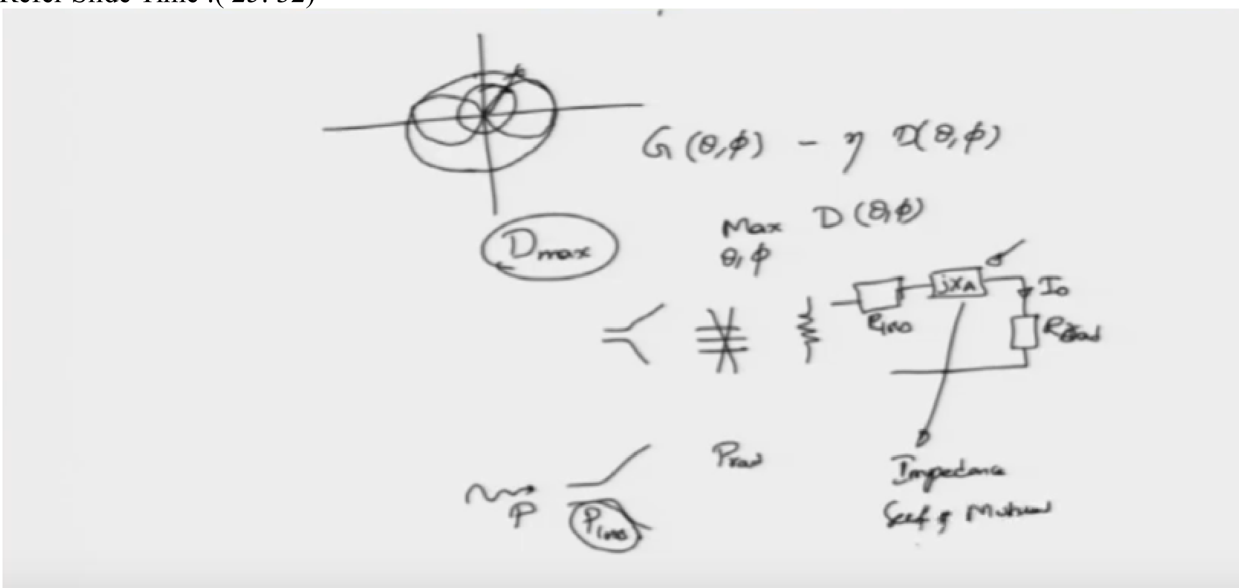

So, if you were to plot, the field pattern of this elementary dipole. Okay? And then compare it, with that of the isotropic antenna you would see that, I did not draw it correctly, but you would see that, in this direction for example. Right? The power radiated, again I did not draw it correctly, but there is a power radiated by the antenna, which would be higher, than the power that would be radiated, by the isotropic antenna. Of course I should have put it on a smaller circle, then things would have been correct, in comparison. But, that is what you get an idea. Right? So, this gain, which would also be a function of theta and PHI, can be expressed as ETA times D, where D is the directivity, sometimes you'll also be asked to find out what is the maximum directivity, at which point you find out, what is the max value of theta and PHI: that will maximize this expression of the directivity. Okay? And for short dipole, this directivity is actually quite small, this is about 1.5, not very high, meaning that, it does, have a directional preference. But, it is not so much, compared to that of the short I mean, the elementary dipole antenna. Okay? So, we have looked at a couple of and parameters, we have looked at directivity, we have looked at gain, we have looked at efficiency of an antenna, there is one part which we haven't looked at, is that antenna, doesn't really appear, only as a you know, antenna equivalent circuit is not just, as a resistor, in fir it appears as a some part of it has, what is called as the impedance or the reactance of it and the other part is R a which is r rad, which is the radiation resistance and there will also, be usually a lost term associated with the antenna. Meaning that, if you think of an antenna in this manner, you send in some amount of power P. Okay? Not all the power will be delivered or radiated away, the part that would be delivered will only be P radiation, there will be some intrinsic dissipation, which usually depends on the material characteristics of the antenna you know, something like skin depth: that we talked about. So, this P loss, corresponds to the power that is being lost in the antenna, not available for radiation and not available back to the source as well. Okay? Whatever the difference between the two, is the one that would be radiated, of course there active component or the reactive part of this antenna, would not, really dissipate anything it can only store and that J X a, is called as the, 'Impedance of an Antenna'. Okay? There are two things, one is called as, 'Self Impedance of an Antenna' and then there is another, thing called as a, 'Mutual Impedance of an Antenna' both are essentially reactive components, the self reactance or the mutual reactance would tell you whether you know, the antenna if it is in, isolation with respect to itself, you have a self interaction and a mutual is the one where it couples, to other antennas or even couples to the space itself. Okay? These concepts of impedance are quite involved and not something that we are going to pursue in the, remainder of the of the course. Okay? What is to summarize with respect to this dipole is that, you have your dipole, which is a very short element, which is directed along the z axis, as per our convention and the magnetic field and electric field components that you obtain, as well as the power, can be split into fields which are near field and far field, for those who are interested only in the far field, H and E both vary as one over R and luckily, they are mutually orthogonal, to each other. So that, the power will be finite over a spherical, of a sphere of surface, of radius R. Okay? We also, introduced the terms radiation resistance that effectively captures, how much of the power is actually being radiated by the antenna, we also talked about the antenna, intrinsic loss, as well as the reactance of it and most importantly the field patterns. So, if you draw the electric field pattern, magnitude of electric field pattern or you could draw the power pattern and you found out what is called as directivity, which would tell you how much power in a given theta and PHI, is being radiated by this specific antenna, over the other isotropic antenna. Thank you very much.