Analysis and Design Principles of Microwave Antennas
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Lecture - 05
Farfield and Radiation Pattern of an Antenna

Welcome in the last class, we have raised the question that, what is the far field. What is the criteria for deciding, what is the far field. Now, today we will first start with answering that question. Actually this criteria far field is very interesting and general it is not only for a current element type of simple antenna.

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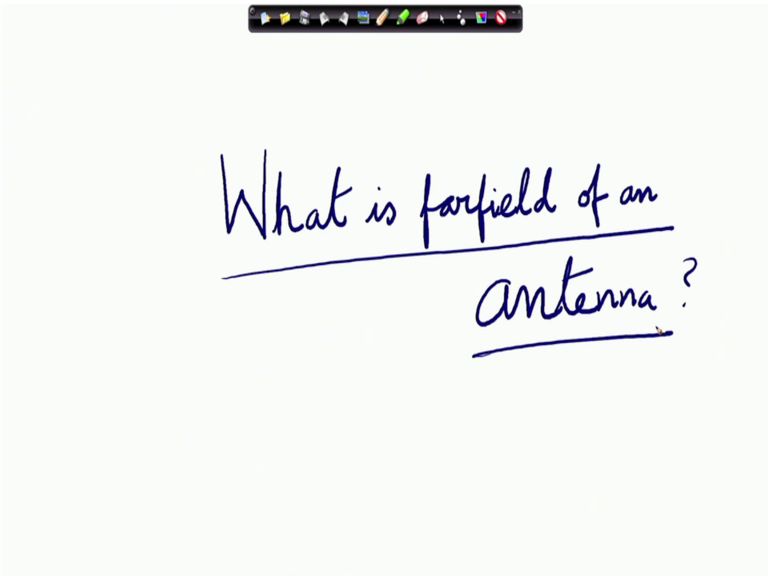

For any antenna actually far field represent the place from where actually the beam radiated beam is formed, the power is transported etcetera. So, it is very important to decide a quantitative measure of far field. Now, the criteria that is used actually three criteria's are there for determining far field and that should be satisfied simultaneously. So; that means, unless and until any of these criteria is not satisfied the far field does not start, that is why we will have to take the most stringent far field from these criteria. Now, what are those criteria's? First, I raise the question that, what is far field of an antenna? To answer that there are three criteria's.

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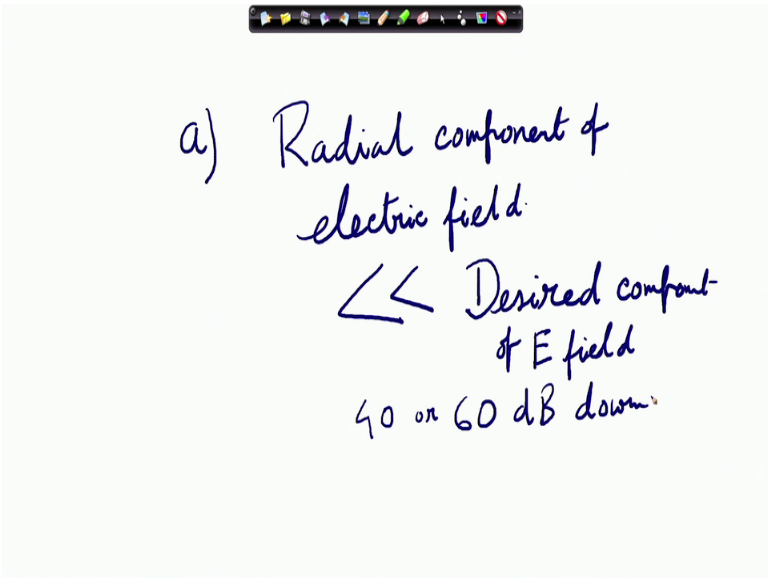

The first criteria is that the radial component of the electric field radial component of electric field should be insignificant or much much less than the desired component desired component of E field. Now, what do we mean by desired? We know that radiation takes is if for example, for the current element the desired component of E field is E theta component which has that 1 by r type of variation and radial component of electric field is E r.

So, for current element these criteria means the E r component should be much much less than E theta component. So, the distance at which this happens that is start of the boundary, according to these criteria. Now, how much what is mean by small usually, we can say that for a good analysis this radial component of electric field should be 40 or 60 dB down than the desired component. So that means, 40 dB down in field terms means actually 1 by 100th 40 dB; means 1 by 100 times it has become radial component and this means 1 by 1000 times.

So, any of these so, it becomes more and more stringent if we add this. Now, why these? Because, radial component does not contribute to the power flow, we have seen that those ultimately power flow pointing vector in which the direction the current is flowing, if we want that it should flow in the radial direction then both electric field and magnetic field they should be transverse to these direction.

So, that is why radial direction will not give any power flow, radial component of electric field; that is why each should be curtailed as much as possible and then only we can say far field has been there. So, this is the first criteria, actually this turns out to be the most stringent criteria. Many times we do not have such stringency, but still this criteria is important.

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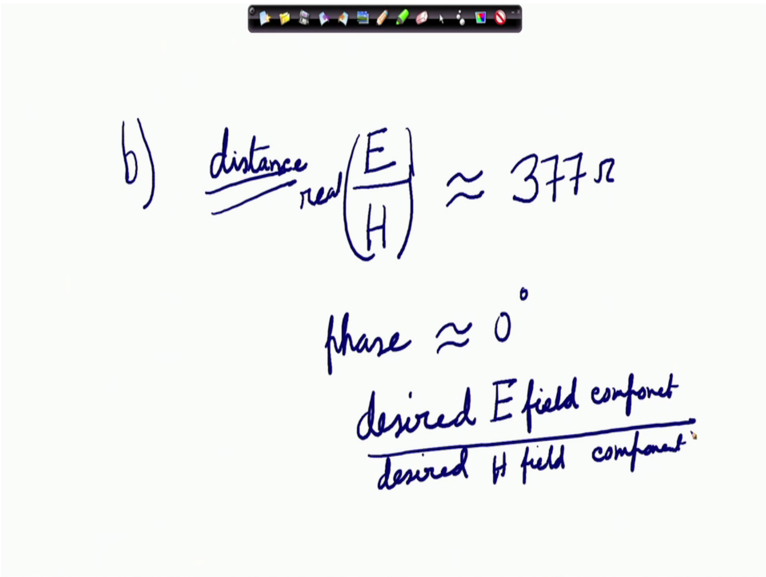

The second criteria is that the distance from the antenna, where the wave impedance of the radiated wave; wave impedance means the E field by H field. Now, E field is a complex quantity, H field is a complex quantity. So, this ratio is also a complex quantity. So, we say that real part of this real part of this impedance quantity, real part of that when that approaches the wave impedance or intrinsic impedance of free space; that means, 377 ohm and the phase of this quantity.

So, phase of this complex impedance term that is almost 0 degree. So, at that distance we can say that the far field has been started. So, I can say that the distance where the real part of wave impedance approaches the free space wave impedance and phase of wave impedance approaches 0 that is the start of a far field.

Now; obviously, what do we mean by this E and H? Now, here this E means that desired E field component; again for current element this will be theta, for other antennas we will have to see by desired H field component. So that means, this criteria says that when really the radiation far field radiation or radiation from the antenna that is approaching the plane wave structure.

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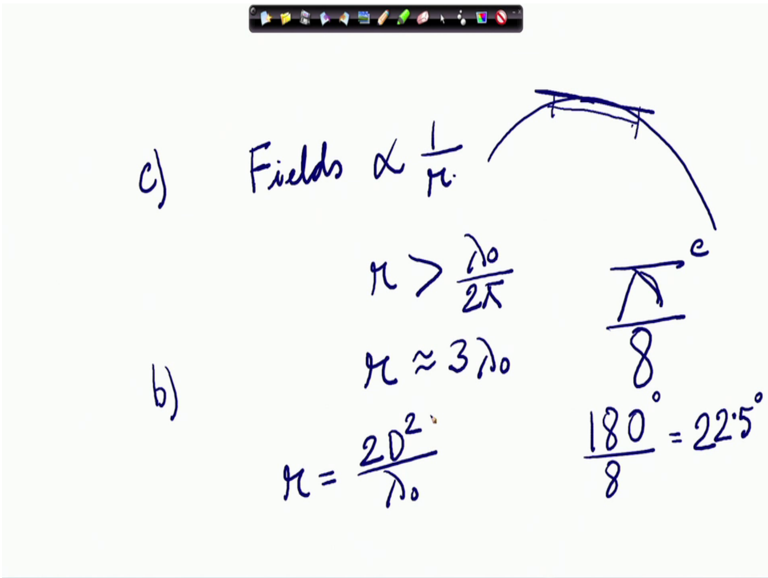

And the third criteria is that the fields, the distance at where the field should vary as 1 by r, predominantly not by 1 by r square or 1 by r cube etcetera. So, we have seen for our current element etcetera, that the first 1 by r that starts dominating when r is greater than lambda naught by 2 pi. But this is from this criteria, but from criteria b; that means, that impedance wave impedance is 377 ohm generally, that gives r as 3 lambda naught.

And another criteria is that this far field the field structure that can be approximated as a plane wave. So, but actually we have already said that the actual structure is spherical wave. So, a spherical wave; that means, the spherical surface at a very large distance I can approximated as plane wave. Now at which distance, at which distance from the antenna I can see it is a plane wave like thing. So, that that means, if I have a sphere, but suppose I am telling no this is not a spherical surface, this is a plane.

So, I am definitely committing some errors at this ends or if I say that I will approximate it by this one. So, at the ends I am committing error that permissible error there is a criteria that that permissible error, if we restrict it to let us say pi by 8 pi by 8 radian; that means, 180 by 8 degree 180 by 8 degree means 22.5 degree. So, up to this if we commit the error then at what distance this happen that depends on actually that r is 2 D square by lambda, where D is the maximum dimension of the antenna.

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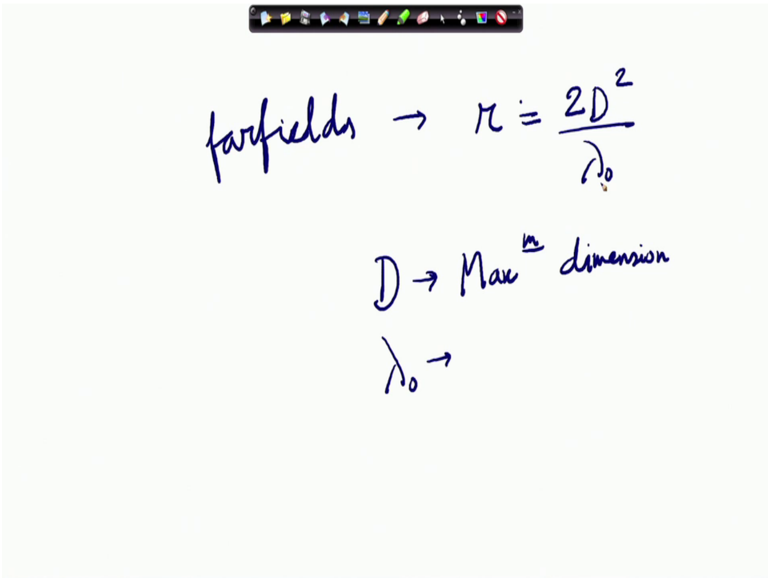

So, it generally out of all these criteria finally we can say that the far field starts at a distance when r is equal to 2 D square by lambda naught; this D is the maximum dimension. So, suppose an antenna is a rectangle. So, the length which is the largest dimension, for wire antennas this is the total length, for other any other type the maximum dimension of the antenna; whether it is length or breadth or sometimes maybe the rectangle I the diagonal you can take. So, maximum dimension is D and lambda naught; obviously, is the wavelength of the source excitation, this is the wave length. So, based on these generally we say far field.

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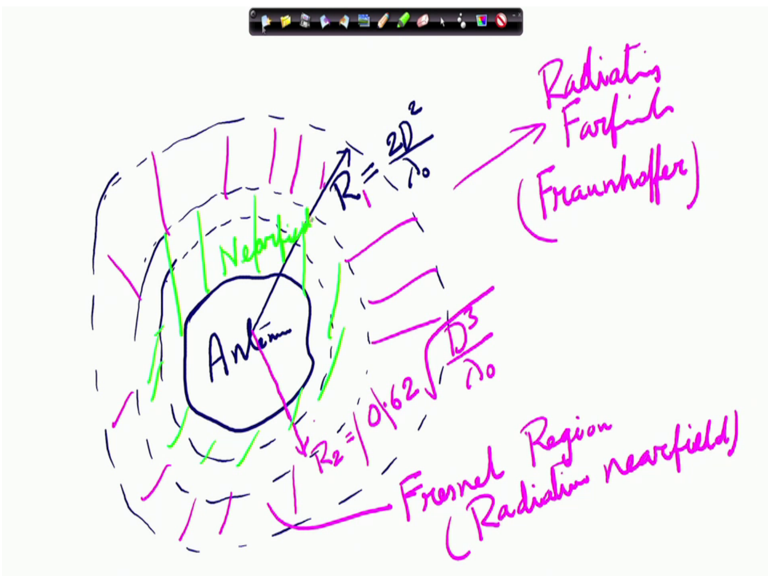

So, actually the region suppose this is the region of the antenna, suppose this is antenna. So, we can draw that from this a at a distance of we can call R, this R is 2 D square by lambda naught roughly, this is an nowadays acceptable criteria that far field starts. But what happens in between? In between also there is another region, another actually two regions. So, I will draw like this let me choose another colour. So, there is another distance let me call this there are two regions.

So, another region this one, this if I call R 1, let me call R 2 is another region which is generally given by 0.62 root over D cube by lambda naught. So, what happen? So, beyond this is the far field and this region in this region this is called Fresnel region or also it is called radiative near field region.

So, this region I will say Fresnel region Fresnel region or sometimes called radiative near field. Like far field this is also called Fraunhofer region, against the scientist Fraunhofer or radiating far field. You see this is radiating near field, this is Fraunhofer region and very near to the antenna the rest region, sorry this another all this region this is actually the near field region. So, what is the difference between this? So, you see near the antenna there is near field, after that there is region which is Fresnel region or radiative near field and further away is the Fraunhofer region or radiating far field.

So, what is the point why we are saying that this three regions are a so, near field near field region is actually reactive near field. So, they are immediately surrounding the antenna the energy is getting stored, but not radiated. So, in efficient antennas they mainly store the energy in the near field they cannot radiate. So, you are giving power, but if ready antenna is not properly designed, if it is in efficient the antenna it will store that energy in the near field. It would not be able to pump that energy to the far field. So, those antennas we call it is a very bad antenna. So, that is why that is a reactive near field. So, that shows as the impedance of the antenna is has a large reactive part.

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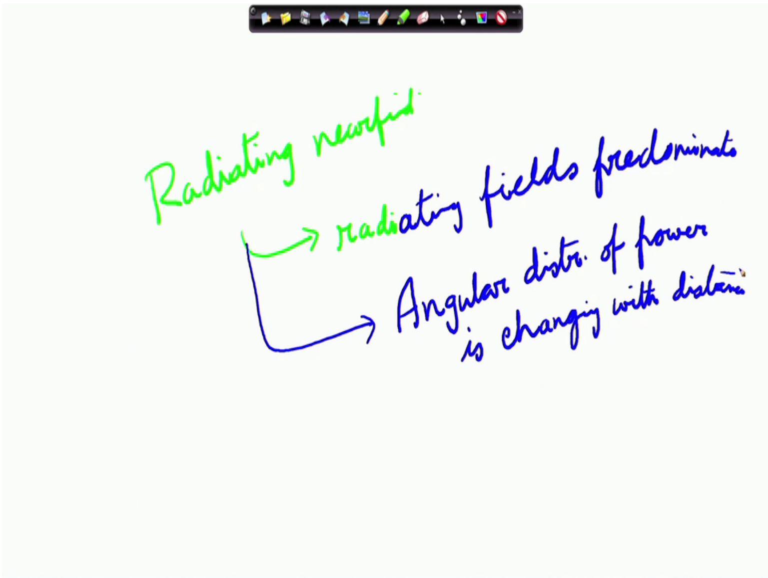

Now, what is radiating near field? Radiating near field is there radiation is taking place so, there the pointing vector is having substantial power. So, more than the near field 1 so, radiating near field so, here radiating fields predominate. Radiating near field means, radiating fields predominate that in far fields also they predominant. But one important point is here still the power that is flows in different direction; that means angular distribution of power that is still dependent on the distance.

So, as you change the distance the angular distribution is getting changed. So, angular distribution of power is changing with distance. So that means that the still the beam has not been formed. The radiation beam that has not been formed, it is still forming that is why if you measure there a pattern that how the power is there and in that zone in another distance if you measure you will see a different pattern. So, there is no standard pattern in that plane. So, that is called Fresnel zone that is why it is important.

So, if you want to put your antennas in Fresnel zone you need to be very careful, that what is the distance from the antenna. Actually, in modern day communication particularly this 4G, 5G they required this because they cannot have that I will put the receiver only in the far field, but they want to correct for that the antennas characterization is necessary in the Fresnel zone. So, there are first Fresnel zone, second Fresnel zone etcetera that needs to be carried out if you want to have an antenna for that 5G etcetera.

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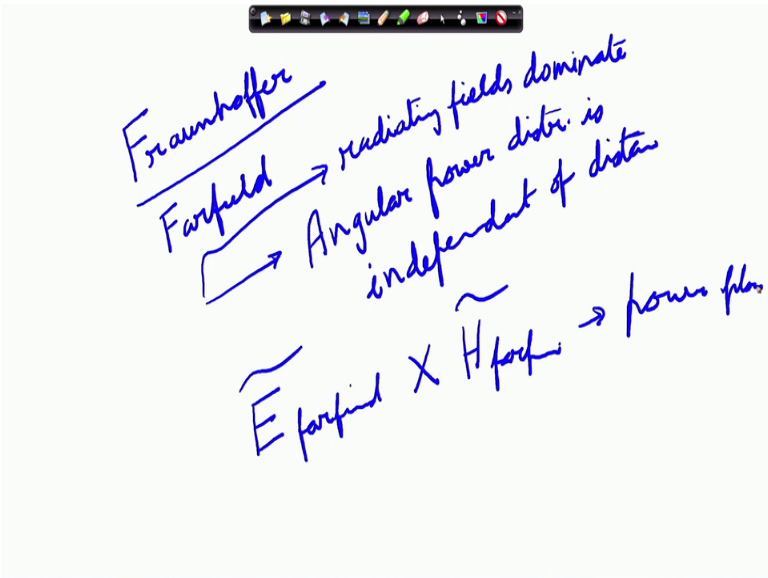

So, this is the radiating near field, we have already said that at what distance this happens and then far field. So, far field already we said that in the radiating far field or Fraunhofer zone which is our main interest for any antenna characterization. So, Fraunhofer or far field there already we have said that; obviously, the radiating the radial component has diminished, then 1 by r term dominates. Then impedance; that means, E far field by H far field is equal to the free space impedance that is 120 pi. Then angular power distribution is not dependent on so, one thing is; obviously, it is radiating fields dominate.

But angular distribution of power angular power distribution is independent of distance. Angular power distribution obviously, if I measure at a further away distance the power will be reduced. But angular distribution that means, at that distance at different angles how it is distributed that distribution does not change in the far field. That is an important criteria, because it will lead us to characterize the directional nature of the antenna, which we will discuss when we discuss the radiation pattern etcetera.

And another criteria is that in this case this E far field cross H far field they represent the power flow etcetera. So, this is about the far field of the antenna. So, now we know if you get a antenna you always can calculate that, at what distance it will have a far field. So, you will characterize the antenna only in the far field generally, we do not do it in the near field except when finding the impedance of the antenna ok. So, this was one important concept we have seen.

Next, we will see the sum of the antenna parameters because always we said that we would not be able to find out the analytical expressions of the antenna. Because more complicated antennas there we cannot always find the j current density distribution on the antenna surface.

So, we always cannot find the power electric and magnetic fields, but we can have some measurements etcetera, by which we can always characterize that how the antenna is behaving. So, we will discuss those parameters here; the first one that we discuss is called radiation pattern of the antenna.

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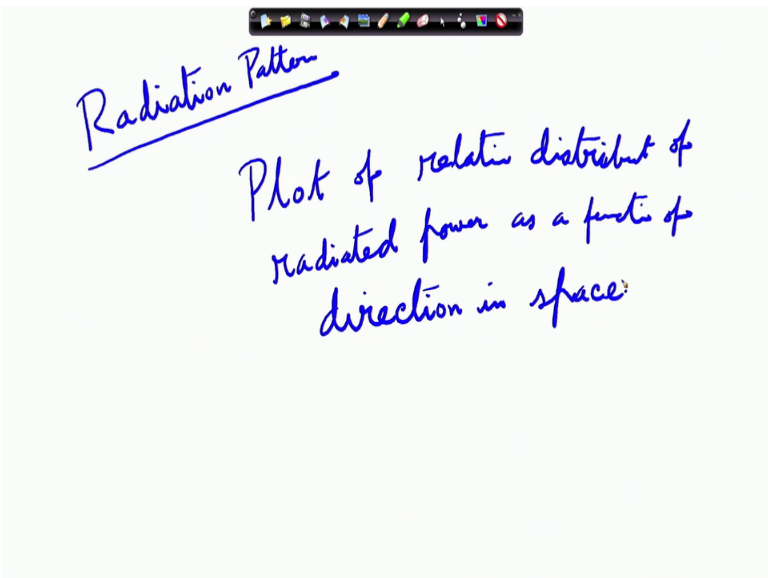

Already we have seen the radiation pattern for current element; that means, if I the it is the relative distribution of radiated power as a function of direction in space. This is called radiation pattern. So, radiation pattern is plot of plot of relative distribution of radiated power as a function of direction in space ok.

But we have already seen that this will be a 3D plot, because we have 3 that we have 3 in the three-dimensional space we will have to then put that at which all possible directions what is the radiated power. So, that will be a 3D plot now we can do, but a better we will for our understanding it is better to put the 2D plots because that is easy to visualize. So, for a that is why that sections various sections of this 3D plot that are generally put those are called 2D, two-dimensional radiation patterns.

So, which sections it is for that what we do, we define that if we have a linearly polarized antenna; that means, linearly polarized means the electric field vector is having a with time it is maintaining a along a line. Then in that case we can find that the, if we plot this radiation pattern in the plane where this E field vector and the direction of maximum radiation that makes a plane.

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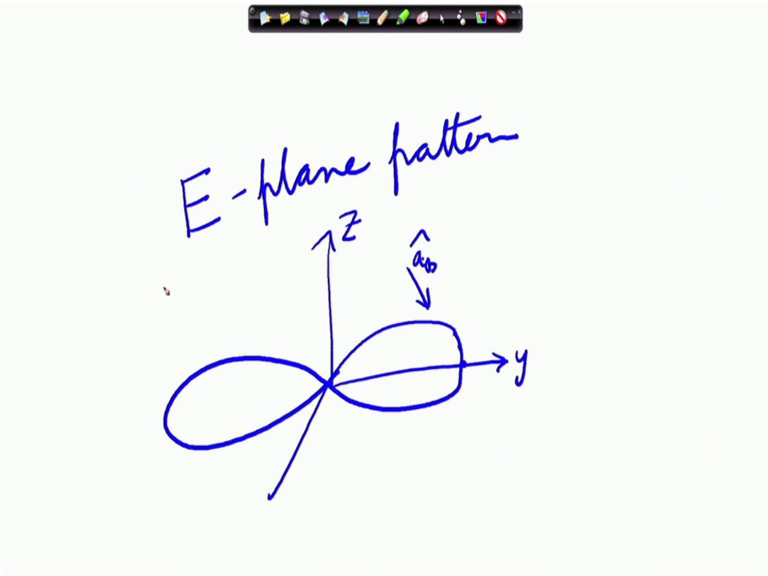

So, if we plot that that is called E-plane pattern. So, we are plotting that radiated power in the plane called E-plane. What is the E-plane? E-plane is the plane made by the electric field and the direction of maximum radiation. In case of current element, if you recall in case of current element the direction so, if we are here this is our z axis. So, the direction of maximum radiation was y axis in this direction and electric field that is in the theta direction.

So; obviously these; that means, this E theta and this y if we in that plane if we put, theta plane means you see that how it will be look like if I vary the angle theta. So, that pattern was we have already seen that pattern was like this so, this is the E plane pattern. The actual pattern was a revolution of these along this that in that we have seen. So, this is the E-plane pattern. Similarly, what is the H-plane pattern?

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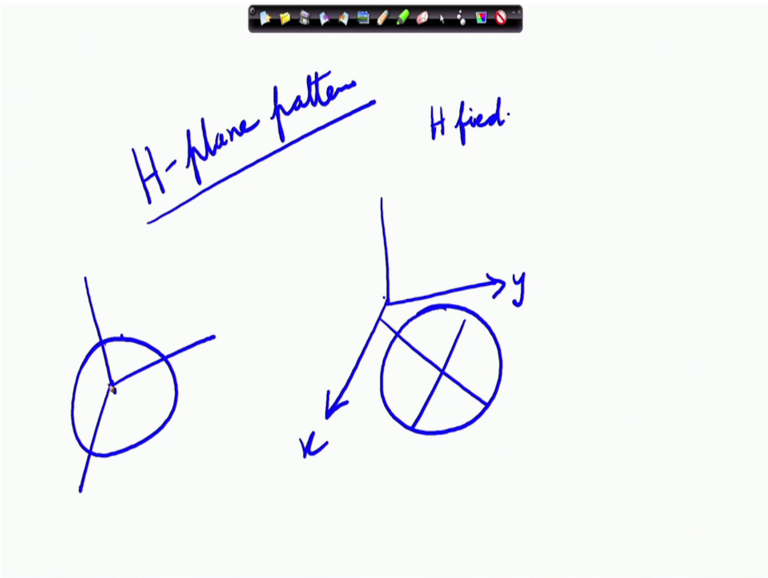

H-plane pattern means the direction of maximum radiation, again that y axis and the H field. So, what is the H field? That is the Azimuthal field and this direction of maximum radiation y so, the field is like this. So, in the x y direction if we plot we have seen that that will be a circle; sorry I will have to center it like this circle. So, everywhere this is same that we have already seen this way this is not correct, this will have to be centered. So, that is called H-plane pattern.

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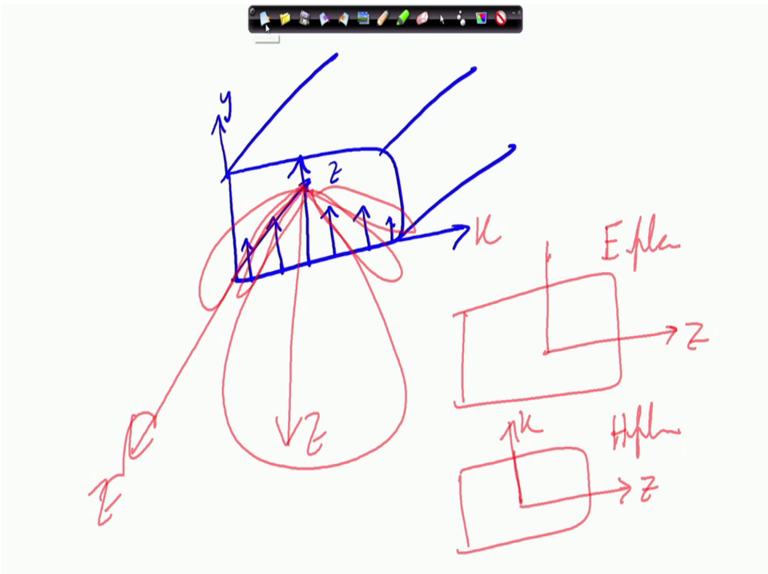

Similarly, if instead of this suppose I have a rectangular waveguide at the radiator many times this happens. In the rectangular wave guide in the dominant t 1 mode you know that electric field is like this, this goes to 0. So, electric field is in this direction; let us say that this is our y direction this is our x direction and this is our z direction that one. Now, so it is easy that maximum radiation is taking place in case of open handed wave guide the maximum sorry.

The maximum radiation takes place something like this and there are some small lobes, this is the radiation pattern of a rectangular waveguide. So that means, in the z direction this z direction the maximum radiation takes place. So, actually I will call this will be the z direction then so, I have this box then from here the radiation is coming. So, here the y z plane so that means, y and z plane this will be the radiation pattern I will have to plot here; this will be the E-plane.

So, here I will have to plot and x plane is in this case the magnetic field in the x direction; that means, this is x direction magnetic field here. So, x z plane will be the H-plane, H-plane is for rectangular wave guide it is x z plane. So, that will be the a plane. So, we will continue this discussion in the next class.