Antennas
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Module – 2
Lecture – 09
Dipole Antennas–II

Hello, and welcome to today's lecture on Dipole Antenna. In the last lecture we had started talking about dipole antenna, we took an example of infinitesimal dipole antenna, which I had actually said that instead of considering that as infinitesimal dipole let us assume that to be a uniform current because no matter how small the dipole is current will never ever be uniform it will be always 0 at the end. So, we did the derivation assuming just an imaginary current carrying conductor which has a uniform current along the length.

Then from that we had actually calculated various far field expression and we also looked at the criteria for far field distance. So, one of the criteria is r should be greater than 2 d^2/λ where d is the maximum dimension, but please do not use that only, there is another condition that r must be much larger than $\lambda/2\pi$. So, I generally say the criteria should be r greater than $2d^2/\lambda$ or r should be greater than λ whichever has a higher value. So, that should be far field criteria.

And then we saw that the radiation pattern of the dipole antenna is nothing but very similar to the way we look at a pen. So, maximum radiation or maximum intensity we see a perpendicular to this here. So, just like a pen we see a maximum and then if we go on the top we see 0. So, the radiation pattern of the dipole antenna is nothing but 0 here maximum. So, it makes a figure of 8 like this here and it has a uniform pattern which is known as the azimuth pattern, this is known as elevation pattern.

Then from infinitesimal dipole antenna we looked at the finite dipole antenna or a still small dipole antenna whose length should be less than λ/10 we found out how to calculate the radiation resistance, and then we also looked at how we can use a transmission line concept to find out the reactive part.

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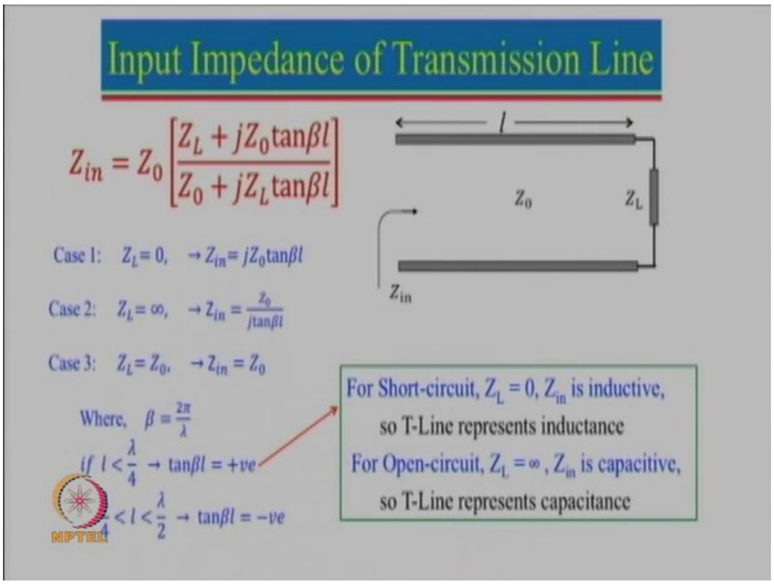

So, let us continue from here we look into the concept where we left in the last lecture. So, here is a transmission line which is terminated in load impedance for this we can calculate what is the input impedance. We look at the 3 different cases, but now let us focus on this particular case here which is Z_L equal to infinity for this is the case where we will have an open circuit here. So, that is what it would be dipole element which is open circuited at the end.

So, for this case input impedance is given by this expression and we saw that for open circuit then Z_{in} is capacitive provided length is less than λ/4, but let us see what happens if length becomes more than λ/4 and please recall this is the half wavelength we are talking about half of the dipole, full length will be double of that. So, less than λ/4 means l will be or the total length of the dipole will be λ/2.

If suppose if it is more than that then what really happens - in that particular case we substitute the value and this is the half-length is between λ/4 to λ/2 then in that case $\tan\beta l$ will be substitute the $\tan\beta l$ is nothing but $2\pi/\lambda$ into l which is here than $\tan\beta$ will be negative. So, in this particular situation for open circuit it will become a inductive impedance. So, please remember now for a small dipole antenna Z input will be capacitive along with the radiation resistance for larger dipole antenna this term become negative it may become inductive.

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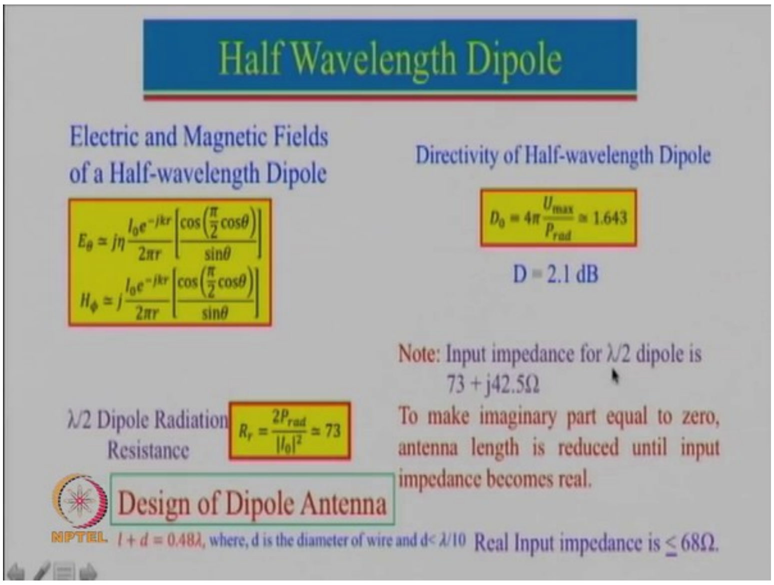

So, from this now, let us talk about half wavelength dipole. So, for a half wave dipole again we can do the same process find the vector magnetic potential; integrate over the length from that find out the far field pattern. So, I have just given here the expression for far field pattern E_θ and H_Φ; will see how the pattern varies for different lengths. But now the directivity of the dipole antenna, for half wavelength the numeric value is about 1.643 which is equal to 2.1 dB and for a very small dipole antenna this value is nothing but d_0 equal to 1.5. So, for small dipole it is 1.5 as the dipole length increases to λ/2 then it becomes 1.6 or which is 2.1 dB.

Now as far as the input impedance is concerned, the dipole radiation resistance is nothing but 73 ohm. Now if you have read several books they actually say that input impedance for λ/2 dipole antenna is 73 + j42.5 and they still call it a resonant length λ/2, well that is not really correct. If the dipole is a resonant configuration then the impedance should be real that is how we define a resonance condition. Resonance condition is where reactive part becomes equal to 0 so, but for λ/2 dipole antenna this impedance is 73+j45.5.

So, where is the problem? where are the issues? The issue is that when the length is equal to λ/2 dipole antenna. So, what will be the half length? Half length will be λ/4. So, let just go back and see that dipole antenna configuration first.

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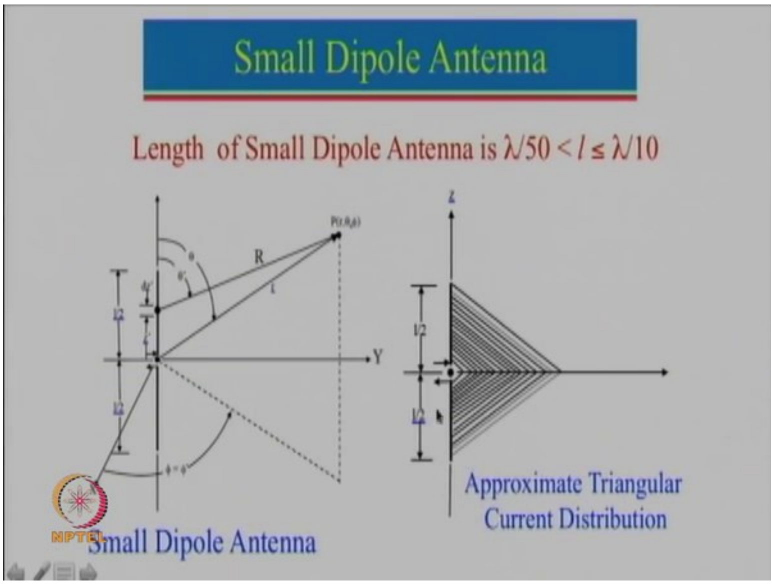

So, what is really happening? So, we can see that over here when there is a dipole there are fringing fields associated with this, now because of the fringing field effective length of the dipole antenna is slightly more than the physical length of the dipole antennas and that is the reason when the physical length is slightly less than the effective length. So, what happens then? Half the length is λ/4. So, effectively because of the fringing field that length becomes greater than λ/4, effective length, and if the effective length is greater than λ/4 which I was talking about here then the transmission line represents basically the capacitive will become inductive because it is now negative. So, that is why input impedance of a λ/2 dipole antenna is inductive.

So, what has actually happened in the process? As we were increasing the length of the dipole antenna, so it was initially capacitive then it became real and then it became inductive. So, from capacitance to the real value to the inductive values, so really speaking what is happening that this effective length is slightly more than the λ/2 and; that means, effective half length is more than λ/4 which is giving rise to this imaginary term. So, if you want the imaginary part to be 0; that means, antenna length should be reduced in such a way that effective length becomes λ/2; that means, physical length should be slightly less than λ/2, so that the total length including the fringing field will become λ/2 and if that is the case then input impedance becomes real.

So, let us see now how we can design a dipole antenna. So, please remember now what was this here *l* equal to λ/2 which is equal to 0.5 λ. Now in all these derivation we had ignored the diameter of the dipole antenna, all the dipole antenna will have a finite diameter. So, here is a very very simple thing to design. So, l+d which is the length of the dipole plus d which is the diameter of the dipole should be equal to 0.48 λ, you can see that this term is slightly less than 0.5 λ and this is because we have fringing field. So, account for the fringing field. So, if you take this particular expression then that will give us length equal to approximately the effective length will be approximately equal to λ/2 and that particular point then for this value the real input impedance will be there and approximately that value will be about 68 ohm which is slightly less than 73. So, we will now see the different configurations now.

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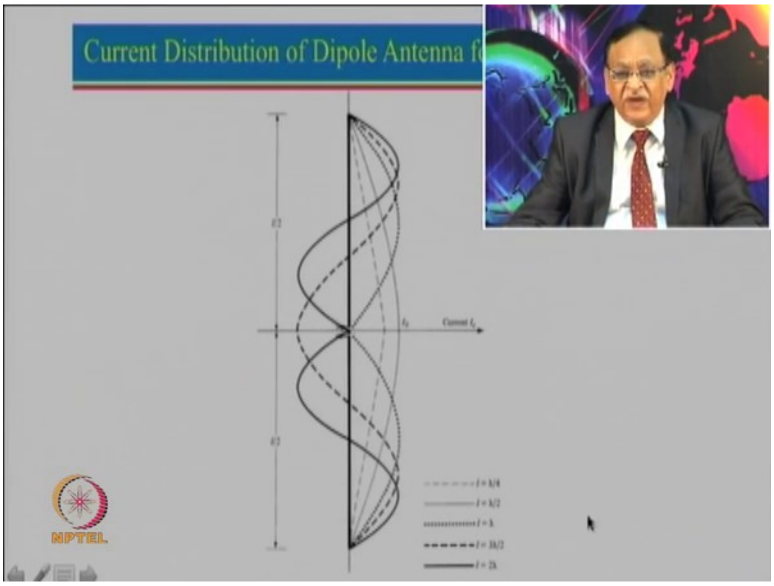

So, let see current distribution for different dipole length. So, here is a dipole length which is equal to λ/4 and λ/4 total dipole length means half length will be λ/8. So, that is still approximated as a triangular distribution. When the length is λ/2 then half will be λ/4, so will have a sine wave going from here 0 to maximum and coming back to 0.

When the length is equal to λ, for λ the plot will is given by, so this is the λ here will be means this will be λ/2 this will be λ/2. So, there is a half wavelength variation here and another half wavelength variation here and if the length increases so will be the more number of current variations along this. But just to tell you practically we do not use dipole antennas which are much larger than the wavelength here.

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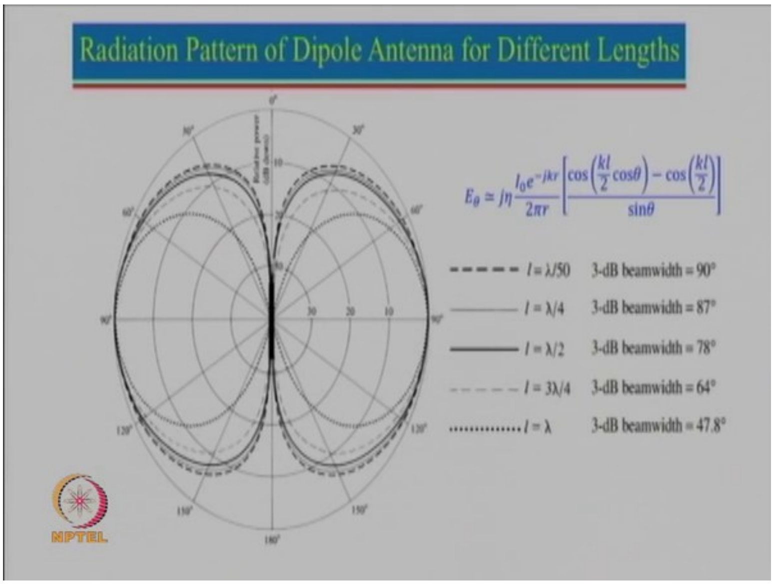

So, this is how the radiation pattern varies of a dipole antenna for different lengths. Here I have shown the radiation pattern and by the way these curves have been taken from the Balanis book. So, I just want to mention here that this length is, let say the total length is λ/50 that is shown as dotted line. So, that is the current variation for that will be along this here this is the radiation field in E plat pattern and that is how it looks like and for this case half power beam width is about 90 °.

So, let us look why that is the case - see we saw that the radiation pattern variation for E field was given by the term sinθ was there. So, if you look at sinθ, θ is measured from here. So, sign 0 will be equal to 0 so that is the 0 radiation, θ term then θ equal to 90 sin90 will be equal to 1, so that is the maximum radiation here.Now sin45 ° will be equal to $\frac{1}{\sqrt{2}}$ so that is the sin45 °. So, that is where on a 45 ° means also implying $\frac{1}{\sqrt{2}}$ implies half power.

So, half power means half power beam width is not defined between this and on the other side the same thing. So, 45 and 45 will become 90 °. So, that is why 3 dB beam width is 90 ° for small dipole antennas.

Now as the dipole length increases one can see that now the pattern is slightly narrower. So, narrower pattern would mean beam width is now slightly reduced 87 °. So, for λ/2 half power beam width is 78 ° and as we keep on increasing this is for λ half power beam width is about 47.8 you can actually see that this is a much narrower beam here.

So, one can actually see that from here to here to here to here if we are increasing the length beam width is becoming smaller that would mean gain is increasing and we know that gain is directly proportional to the aperture. So, if the length is increasing gain should increase correspondingly half power beam width should reduce. Now in all these cases we actually notice that the there is only one beam over here.

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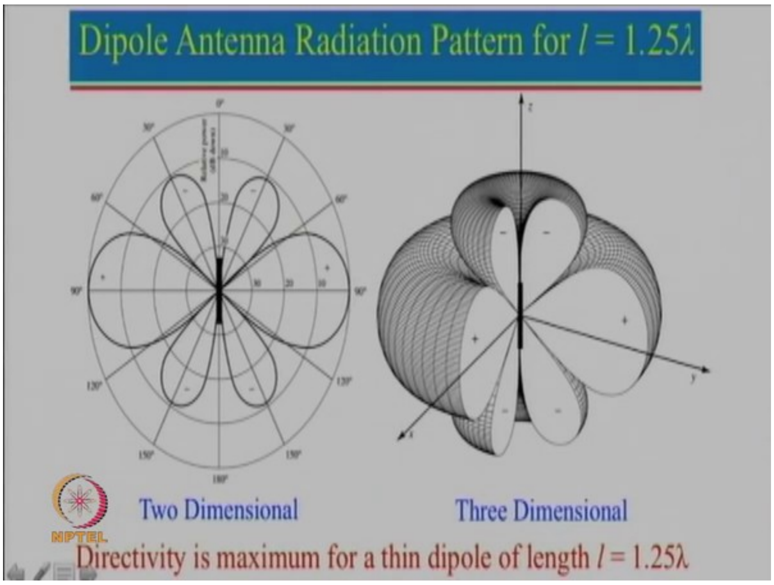

Whereas for the next case we will show you that is when the dipole length is equal to 1.25 λ in this case there is another minor lobe which has come in between. So, just recall up to l equal to λ this pattern was from here maxima it was going to 0, but now for this here there is a side lobe is also coming and since everything is symmetrical with respect to this here, if you just look at this pattern here, you can actually repeat that on this side and repeat on this side and this side.

And this is the 2-D pattern this is the three dimensional pattern. So, you can see that the beam is maxima then it is going to 0 then in between a side lobe comes and then comes back over here. So, this is the pattern.

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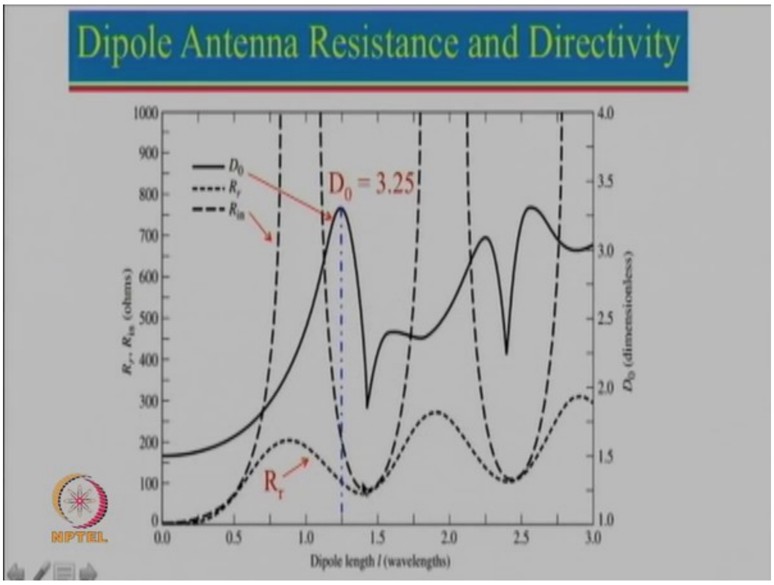

Now why did I show this pattern? There is a reason for that because for this particular pattern we actually get maximum directivity. So, what is this curve here? Well you can see multiple curves here I will go one by one. So, what we have here along the x axis that is a dipole length in terms of wavelength. So, that is a normalized dipole length so; that means, 0.5 here means length will be λ/2, here length will be λ, here length will be 1.5 λ and so on. Now why did I show the case of the case which is a 1.25 λ? So, when length is equal to 1.25 λ you can see that directivity is maximum. So, this is the curve for the directivity.

Now the values of directivity are shown over here this is the dimensionless. So, 1.5 or 2 here you have to actually take in terms of dB we have to take 10 $\log_{10}(1.5)$ or 10 $\log_{10}$ (2). So, corresponding to this here you can see that this value is approximately equal to 1.5 so; that means, for very small dipole antenna directivity is equal to 1.5 as this one is increasing. Now, corresponding to λ/2 length you can see that this is slightly more than 1.5 which is somewhere coming here and we saw that the directivity of a dipole antenna is approximately equal to 1.64 of course, in terms of dB it will be 10 $\log_{10}(1.64)$ which is equal to 2.1 dB.

Now corresponding to this here you can see that the directivity is increasing. So, maximum directivity is obtain which is equal to 3.25 you can say that that is more than double than a small dipole antenna, but after that the directivity keeps on decreasing and then increasing it varies because mainly what is happening that many other side lobes are coming in between.

So, in reality even though we are increasing the length of the dipole antenna considerably directivity is not at all increasing. So, that is why higher order modes of dipole antennas are almost never used.

Now what are the other curves here? So, another curve let us just look at is a radiation resistance curve. So, here is a radiation resistance curve and you can see that it is very very small, just recall for a small dipole antenna I had given the expression which is 20 π^2 multiplied by l/λ whole^2 , 20 π^2 can be approximated as 200. So, 200 times l/λ^2. So, you can see that when l/λ is approximately equal to 1 you can see that this value is getting closer to 200 ohm. So, you can see here of course, it is not perfect because that l/λ^2 assumed that it is a triangular distribution, but in reality there will be a sinusoidal variation. So, do not use that formula all the time. So, this is the variation for R_r you can see that these values are also changing and as I mentioned very rarely we use these modes. So, we really need to look into this here.

Now then what is this third curve here? That is R_{input} (R_{in}). So, R_{input} curve you can see that R_{input} curve is almost similar to R_r as long as the dipole length is small, but then R_{input} changes here and when the dipole length is approximately 1.5 λ, R_{in} is equal to R_r. So, what is the reason for that? Actually for that you have to see the current distribution, so let me just show you the current distribution first. So, one can actually see again I will go back. So, this is the λ/4, so you can see that the current is maximum, how do we find radiation resistance?

In general we can say resistance is nothing but voltage divided by current. So, that is the current here. So, here also current is maximum, but at this point what is the current here current is going close to 0. So, voltage divided by 0 current here will give rise to very high impedance, and this current distribution is for λ length and this will be λ/2 this will be. So, for *l* equal to λ, current is approximately equal to 0 and that is why input impedance is going to be very large.

Now, again for let us say the length when it is equal to 1.5 λ then the current is maxima hear. So, since the current is maxima R_{in} is similar to R_r. So, one can see that when we are feeding a dipole antenna let us say if it is a λ/2 dipole antenna we can see R_{in} will be very similar to R_r, but the imaginary part that, but at close to this one here length equal to 1 you can see that the input impedance becomes very very high here and then it changes here, now this is about the real part, what about the imaginary part.

So, for imaginary part you have to think about that transmission line concept which I had mentioned to you. So, up to here to here, the whole impedance will be capacitive then it will become inductive then again becomes capacitive and so on and so forth. I will give you the plot which we have simulated for different dipole antenna will explain you this part again.

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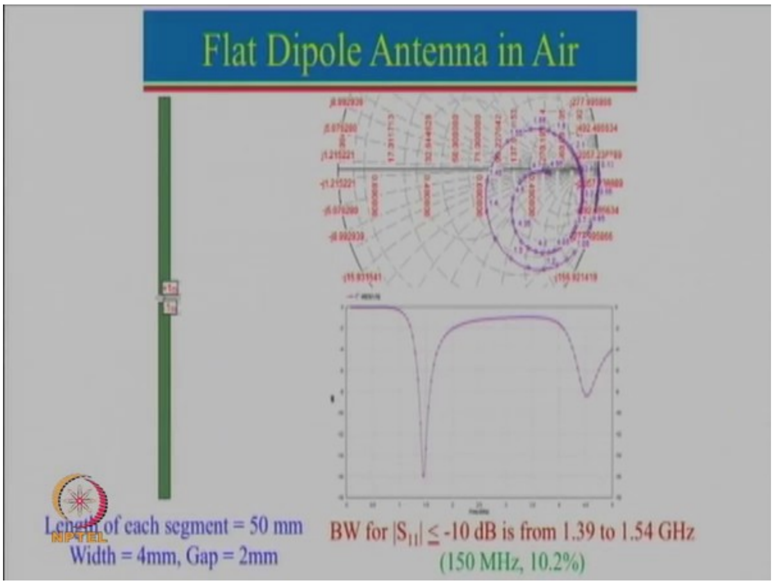

So, here is the case here, we have taken just a simulation of plot dipole antenna. So, instead of taking a wire which will have a diameter here we have taken a plot dipole antenna and that is in air. So, we have a one strip here, one strip here, this simulation has been done using IE3D software which is available from mentor graphics. So, here for simulation there are 2 segments are there - one segment here, one segment here. It is being fed with +1 and -1 which basically is giving me a balanced current here. So, from this side if I feed things like this is plus and this will be minus. So, we have taken length as 50 mm, 50 mm total length will be about 100 mm; width of this trip has been taken as 4 mm and gap is taken as 2 mm.

Now, for this one here one can see that there is a, this is the resonance curve here. So, we can actually see that there is a resonance over here and that is what is showing as the reflection coefficient plot here and generally we define bandwidth for S_{11} less than -10 dB. Now this is approximately equal to corresponds to VSWR equal to 2 to a -10 dB reflected power basically implied reflected power will be equal to 10%. So, one can see that the bandwidth for this antenna is from 1.39 to 1.54 GHz. So, what you need to do it is you just look at the S_{11} less than -10 dB draw the horizontal line and then read the lines from here and that will give us the bandwidth. So, this is the bandwidth is about 150 MHz which is about 10%bandwidth.

But now let us just see how the curve is varying with frequency. So, this is the lowest frequency and frequency is increasing. So, now, if you are familiar with the smith chart I will just repeat one more time. So, this is the 0 impedance then impedance increases along this line it is a real impedance was 0 ohm, 10 ohm, 20, at the center it becomes 50 and then it becomes infinity here; the upper portion represents inductive part, the lower portion represents capacitive part.

So, now, one can see that as frequency increases at very low frequency this dimension will become much lesser than λ. So, this is equivalent to something like λ/50 or more at a lower frequency. So, that is how the variation is. So, you can see that the impedance here corresponding to this point is very low if you look at this point also here impedance is relatively low. So, as the frequency increases impedance is increasing, but it is still capacitive.

So, this is the point where it is crossing the real axis and then the impedance becomes inductive. At this point here which is actually the second order mode theoretically it should have been infinity, but it is actually very large and that point corresponds to over here. Now this is where the third order mode is coming into picture, so you can see that this is the frequency which is let us say approximately 1.5 and the third order mode is coming approximately at 4.5. So, that is the third order mode second order mode impedance is very high. So now let us see; what are the radiation patterns at different frequencies.

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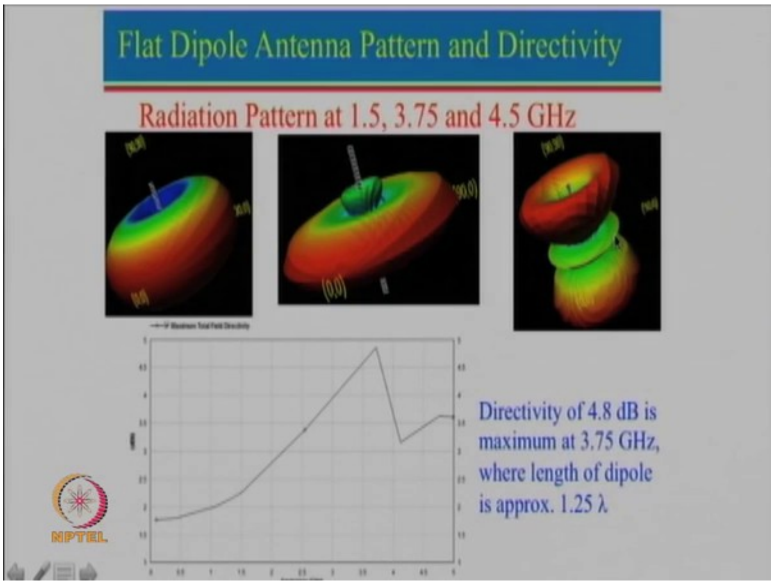

So, now I have shown the radiation pattern at 3 different frequencies and I will tell you why also. So, this is the radiation pattern at 1.5 GHz and that is the pattern which is of a λ/2 dipole antenna at this frequency it is acting like a λ/2. So, you can see that this is the position of the dipole maximum radiation is perpendicular to this side here and minimum radiation which is represented by a blue color is in this direction. So, as we move from here to this side here which is maxima then you can see that the color is changing from blue to green to yellow to orange and red - red representing the maximum power.

Here we have actually shown the simulated plot here. So, one can see that this is the simulated plot going on. I just want to highlight here this is the plot directivity and not the gain, so it is a directivity plot. I had mentioned to you the gain plot will be directivity multiplied by efficiency and gain also includes the VSWR reflection also.

So, here it is simply directivity and one can actually see that the directivity is increasing this is very similar to the directivity curve I have shown and we can see that the directivity is approximately 4.8 dB and that is at 3.75 GHz where dipole length becomes 1.25 λ and let us see the plot over here. So, we had seen that for 1.25 λ maximize here then it comes to 0 value, then there is a side lobe and then it comes here. So, you can see that it is following the similar thing maxima, then reducing the color changes to 0 which is bluish, then greenish and then coming back over here you can see a little blue dot over there so it is coming down to 0 value here.

Now, this is the pattern for third order mode. We saw that 1.5 is λ/4, half wavelength, λ/2 is the full length and this is the 3 λ/2 lengths at triple the frequency. Remember length we have kept fixed we are only changing the frequency, so by changing the frequency λ is changing and hence l/λ is changing. So, you can see that for this particular frequency the radiation pattern is not even maximum at perpendicular to the dipole axis it is actually a more like a conical pattern over here. So, so you can see that a cone is being formed.

So, dipole is in this here. So, in this side here along the axis the radiation is still close to 0, but it is actually making a cone. So, if we require a conical pattern then only we should really be using third order mode you can also see that the gain is not very significant.

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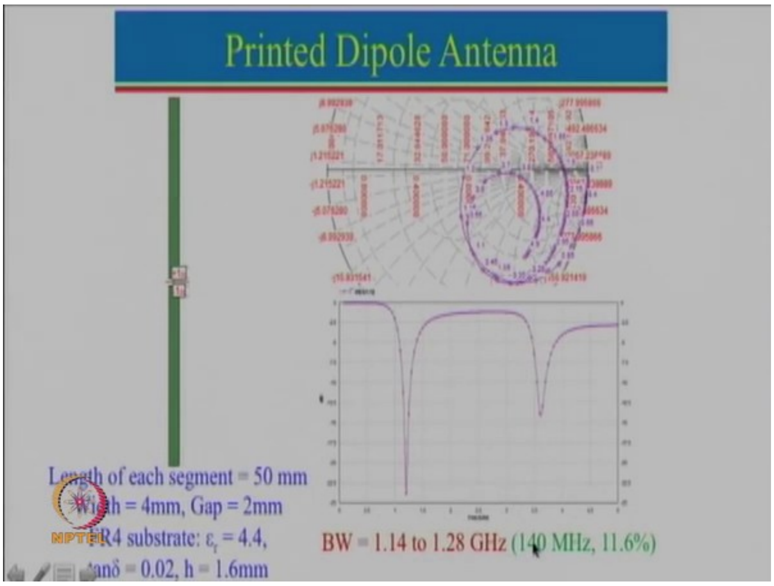

So, here is an example where I have taken an example of a printed dipole antenna, what we have done is we have printed this dipole antenna on a very low cost FR4 substrate this is actually known as also a glass epoxy substrate we use a dielectric constant of 4.4. Typically FR4 substrate dielectric constant may vary from 3.8 up to 4.6. So, this is the substrate which we have. So, 4.4 we took the thickness of the substrate as 1.6 mm.

Now since it is a low cost lossy substrate *tanδ* is high which is 0.02, but it is not affecting too much in this particular case because there is no backing here. So, this substrate when we print on the substrate it is only printed on the one side of the substrate other side is blank or there is a no metal on the other side. So, when you look at the magnetic field which will be around this here. So, most of the magnetic field will be in the air only the part of the magnetic will be confined within this substrate parameter.

So, effectively efficiency is still pretty good here and here I have taken exactly the same dimension as before, but because of the presence of the substrate part of the magnetic field and electric field will be confined within the substrate here. So, one can see that the resonance frequency has reduced slightly. So, basically length remains same, $\varepsilon_{effective}$ has changed earlier for air, $\varepsilon_{effective}$ was equal to 1. Now $\varepsilon_{effective}$ because of the presence, no, it is not $\varepsilon_{effective}$ here is not equal to 4.4, 4.4 substrate is there only for this thickness and the rest everything is air. So, hence $\varepsilon_{effective}$ is still close to about 1.1 to 1.2 and correspondingly then $\varepsilon_{effective}$ (ε_e) is reduced.

So, which actually changes the λ, λ becomes now $\lambda_0 / \sqrt{\varepsilon_e}$, λ_0 is nothing but c/f. So, that is why frequency is reduced slightly and here we are getting about a bandwidth of roughly 140 MHz.

Now in the next lecture we will see how we can increase the bandwidth of the dipole antenna. So, will take different examples, we will actually see that the bandwidth of the dipole antenna is proportional to its diameter or the strip thickness, will also see what are the other techniques for the dipole antenna, then we will also study a few other things like how to do the Balun design because most of the feed are coaxial feed for example, then from coaxial feed we have to get a balanced line which should feed plus and minus. So, that is where the concept of balun comes into picture. Balun – *b a l* is for balance, *u n* is for unbalanced.

So, balanced to unbalanced concept come. So, we will tell you how to even design very simple balun also so that you can realize it very efficiently. Then we will also look at how to design folded dipole antenna.

Thank you very much. Bye.