

Microwave Theory and Techniques
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Module - 10

Lecture - 47

Dipole, Monopole, loop and Slot Antennas

Hello, in the last lecture, we talked about fundamentals of antennas; we talked about radiation pattern of the antenna, polarization of the antenna, directivity of the antenna and also bandwidth of the antenna. For VSW less than 2 or for reflection coefficient less than minus 10 dB. We also took some practical examples of microstrip antennas and arrays just to show you how gain can be increased. Today, we are going to talk about dipole antenna, monopole antenna, loop antenna and slot antenna. So, let us start with the infinitesimal dipole antenna. So, basically what is the definition of infinitesimal dipole, where the length of the dipole is less than lambda by 50? I just want to tell you this is not a practical antenna at all this is just to explain the concept of the dipole antenna.

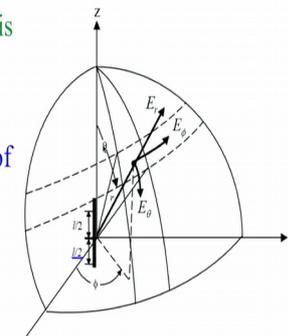
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Infinitesimal Dipole

An infinitesimally small current element is called the Hertz Dipole (Length $L < \lambda/50$)

Assume an infinitesimal current element of length l carrying an alternating current I_0 .
The instantaneous current is:

$$i(t) = I_0 e^{j\omega t} \hat{t}_z$$



Dipole and its field components
in polar co-ordinate

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So, here we are assuming that there is a element of length L , current is uniform along this particular element. I just want to tell you this is an approximation again at the open end current will be equal to 0, it will not remain uniform. So, right now you can just think

about it is a uniform current carrying conductor, and then will do the derivation after that we will talk about the practical cases. So, let us see if you have a current carrying conductor here, there will be magnetic field like this here, and there will be several electric field components. Let us first define the polar component. So, here you can see axis x, y and z.

So, angle phi is measured from x-axis in this particular plane, angle theta is measured from z-axis in this particular direction and r is given in this particular direction, where we want to find out the electric field. So, that is how x, y, z components can be defined in terms of r, theta and phi component.

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Infinitesimal Dipole – E and H Fields

$$E_r = \eta \frac{I_0 \ell}{2\pi r^2} \cos \theta \left[1 + \frac{1}{jkr} \right] e^{-jkr}$$

$$E_\theta = j\eta \frac{kI_0 \ell}{4\pi r} \sin \theta \left[1 + \frac{1}{jkr} - \frac{1}{(kr)^2} \right] e^{-jkr}$$

$$E_\phi = H_r = H_\theta = 0$$

$$H_\phi = j \frac{kI_0 \ell}{4\pi r} \left[1 + \frac{1}{jkr} \right] \sin \theta e^{-jkr}$$

where,
 $k = \frac{2\pi}{\lambda}$



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So, for the uniform current carrying conductor, we can find out these components of E and H fields. So, let us see these are the expressions for E r, E theta, E phi and other H components. You can see that these components are equal to 0, and we have these three other components. In this particular expression, I just want to tell you a few things. So, k is defined as 2 pi by lambda, some books mention beta, so beta is same as k, so you can say beta is equal to k equal to 2 pi by lambda. You can see over here this term here correspond to free space impedance, which is 120 multiplied by pi or equivalent to 377 ohm.

Now, most of the time antennas are defined in terms of near field and far field. So, let just look at here also, if k r is very large for a given value of frequency k will be fixed

which is 2π by λ . So, if r increases; that means, as we are going further away from the antenna, so this term will become 0, this term will also be equal to 0. So, we will be left with only this term for far field.

Now, let just look at this expression here r square is coming in the denominator, whereas there is a only one r over here. So, r much larger distance this component will also be equivalent to 0. And then we have a $H\phi$, so you can see that this component will be also very small. So, we will have only this particular term for $H\phi$.

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The slide is titled "Infinitesimal Dipole – Near and Far Fields". It defines three regions based on distance r from the antenna:

- Near Field Region** (indicated by a green box):
 - Near Reactive Field Region** (indicated by green text): $r < \frac{\lambda}{6}$
 - Near Radiative Field Region** (indicated by green text): $\frac{\lambda}{6} < r < \frac{2d^2}{\lambda}$
- Far Field Region** (indicated by a green box): $r > \frac{2d^2}{\lambda}$

where d is the maximum dimension of the antenna.

Additional conditions for the Near Field Region are shown in red boxes: $r \ll \frac{\lambda}{2\pi}$ and $r \gg \frac{\lambda}{2\pi}$.

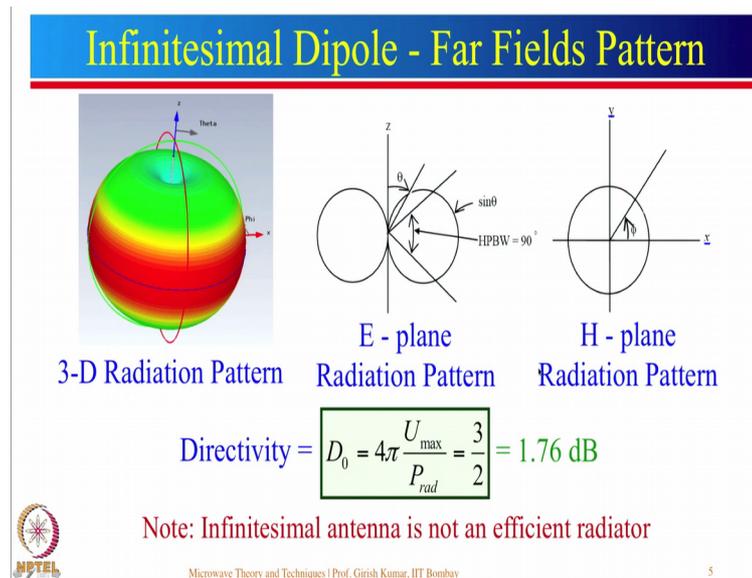
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So, there are two regions we define near field region and far field region. So, near field region is defined in terms of actually speaking you can think about this thing as kr much lesser than 1. So, what is the value of k , k is 2π by λ , so that goes over here. So, r is much, much less than λ by 2π that is a near field region. This region again is divided into two different components. One is for r less than λ by 6 that is known as near reactive field region, and for this particular range of r that is known as near radiative field region. Far field region criteria is that r should be much greater than λ by 2π there is another condition, which is r should be greater than $2d^2$ by λ where d is the maximum dimension of the antenna.

You can see that same term is coming over here. So, just to tell you if the dimension of the antenna is very large, then r becomes very large also. Just take a simple example, if d is equal to λ by 2 then what will be the value, if d is λ by 2 this will become

lambda square by 4. So, this term becomes equal to lambda by 2. But if suppose d is equal to 10 lambda, so if d is 10 lambda, then this will become 2 into 100 lambda square, so that will be 200 lambda. So, you can say that r will be very large when the dimension d is very large.

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So, let us just look at now the radiation pattern I had discussed about this 3-D pattern in the previous lecture. So, just think about same current carrying conductor. So, this is the current carrying conductor, field will be maximum along this particular direction, minimum along this particular direction, so that is how this pattern comes into picture. And this 3-D pattern is shown in E plane and H plane. So, you can see that in H plane, it is uniform pattern, whereas in E plane it forms figure of a. Now, for this particular case directivity is equal to 1.76 dB. Please remember this directivity is for very small dipole antenna and not for lambda by 2 dipole antenna. I also want to mention that infinitesimal dipole antenna is not an efficient radiator. So, generally it is not used. So, far it was only for the derivation purposes only.

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Half Wavelength ($\lambda/2$) Dipole

E and H Fields of $\lambda/2$ Dipole

$$E_{\theta} \approx j\eta \frac{I_0 e^{-jkr}}{2\pi r} \left[\frac{\cos\left(\frac{\pi}{2} \cos\theta\right)}{\sin\theta} \right]$$
$$H_{\phi} \approx j \frac{I_0 e^{-jkr}}{2\pi r} \left[\frac{\cos\left(\frac{\pi}{2} \cos\theta\right)}{\sin\theta} \right]$$

$\lambda/2$ Dipole Radiation Resistance

$$R_r = \frac{2P_{rad}}{|I_0|^2} \approx 73$$

Note: Input impedance for $\lambda/2$ dipole is $73 + j42.5\Omega$

Directivity of $\lambda/2$ Dipole

$$D_0 = 4\pi \frac{U_{max}}{P_{rad}} \approx 1.643 = 2.1 \text{ dB}$$

Design of Dipole Antenna: \Rightarrow Real Input impedance is $\leq 68\Omega$

$l + d = 0.48\lambda$, where, d is the diameter of wire and $d < \lambda/10$



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So, now let us just look at half wavelength $\lambda/2$ dipole antenna. So, for this particular dipole antenna, E field and H fields are given by this particular expression. Please again note down that these are far field radiation pattern, and not near field radiation pattern ok. Now, the directivity of $\lambda/2$ dipole antenna is equal to 2.1 dB. Now, that radiation resistance of a $\lambda/2$ dipole is given by this value here. I just to tell you, how to obtain the radiation resistance. So, we know what is E field you know what is a H field, so from that we calculate what is the power radiated. And from the power radiated, we find out what is the radiation resistance.

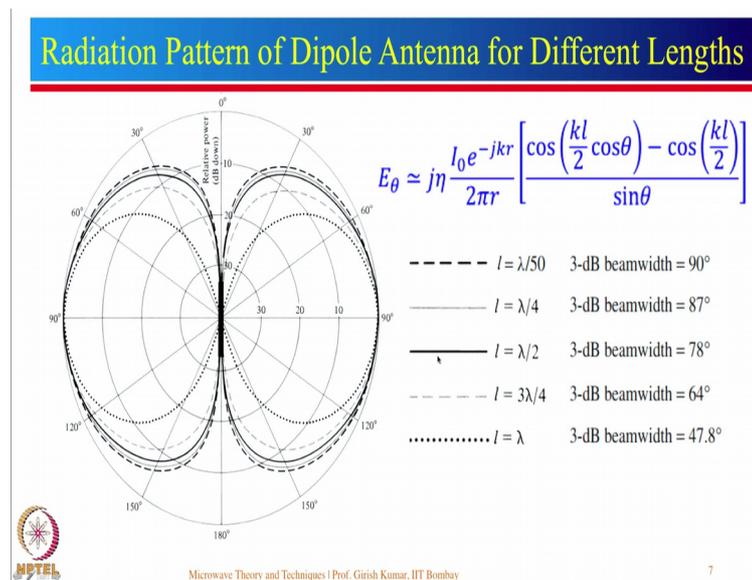
Now, this is the radiation resistance value, but for a $\lambda/2$ dipole antenna input impedance is actually equal to $73 + j42.5$. So, you can see that there is an imaginary term which is coming into picture. And this represents the inductive component; not this is not really at perfect resonance. See at resonance we know that the input impedance of antenna should be a real quantity. So, to make imaginary part equal to 0, so what do we do we reduce the antenna length slightly, so that input impedance becomes real.

So, real input impedance becomes around 68 ohm, if you follow this particular design criteria. So, the design of dipole antenna actually is very simple, all you need to do it is use this particular simple equation. So, what is this equation, this is length of the dipole antenna, this is diameter of the antenna and this is equivalent to 0.48λ ; whereas, if you see over here this is l is equal to 0.5λ , but here l is smaller than 0.5λ .

And generally speaking diameter of the dipole antenna should always be taken less than lambda by 10 ok.

So, just take a simple example. Suppose, if I say that a diameter of the dipole is suppose 0.01 lambda. In that case l will become 0.48 minus 0.01 that will be 0.47 lambda. If you take diameter as suppose 0.04 lambda, then l will become 0.44 lambda. So, let me just give you simple example how to design a dipole antenna. So, let us say if the desired frequency is 1 gigahertz then lambda will be 30 centimeter. So, from that value of lambda, you can calculate what is this value, then choose the value of diameter which can be let say lambda by 10 to lambda by 100, and you can find the value of l that will be your starting point of designing a dipole antenna.

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So, let us see how the radiation pattern of the dipole antenna varies for different length. So, this is the case when it is a very, very small dipole antenna for that 3 dB beamwidth is about 90 degree, as the length increases as you can see from lambda by 50 to lambda by 4 lambda by 2 length increases, you can see that half power beamwidth decreases, so that means, gain increases.

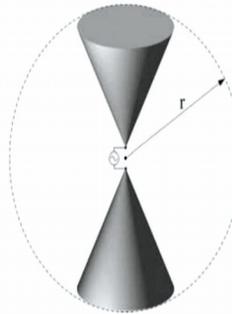
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Broadband Dipole Antenna

Bandwidth of dipole antenna is directly proportional to its diameter



Cylindrical Dipole Antenna
(can use hollow pipe also)

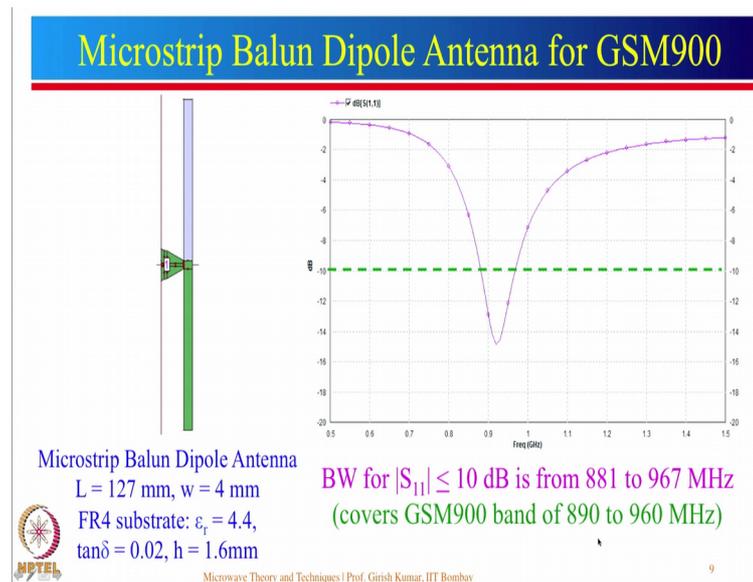


Bi-conical Dipole Antenna
(can use wire grid also)

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So, now let us talk about broadband dipole antenna. So, bandwidth of the dipole antenna is directly proportional to its diameter, so that means, if you increase the diameter of the dipole, bandwidth will increase. However, there is a restriction that you cannot use diameter of the antenna greater than $\lambda/10$. So, this kind of limits the bandwidth of the dipole antenna. So, if you want to very large bandwidth, then Bi-conical dipole antenna can be used. And this particular antenna can give very large bandwidth; however, these dipole antennas require input, which is plus over here minus over here. However, majority of the sources may have a single ended output other terminal being a ground plane, but to feed the dipole antenna we need plus over here minus over here which is known as balanced feed.

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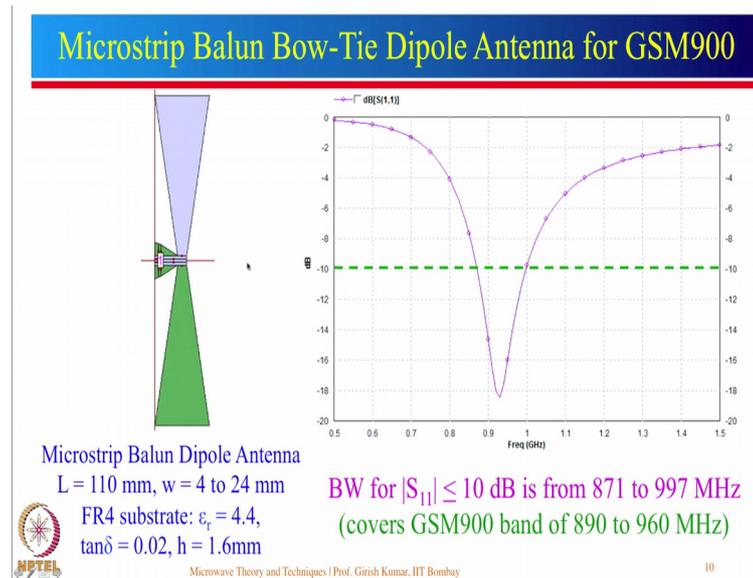
So, let us see how we can design this Balun in a very, very simple manner. So, Balun is not what we used to make chapatis at home, this Balun stands for balance to unbalance ok. So, here is a dipole antenna which is printed on a low cost FR 4 substrate which has substrate parameters given by these values. So, green portion is printed at the bottom side of the substrate, and this particular portion is printed on the top site of the substrate. Here a coaxial feed is used. So, let us see how we have converted this unbalance to balance. So, this one here green portion represents the ground plane from where a coaxial pin is coming here on the top there is a line like this here.

So, a tapered portion is used at the bottom side and on the top side a straight line is used, so that straight line connects over here and the bottom taper portion is connected to this. So, basically this simple configuration acts as a Balun, it converts the unbalanced feed to the balanced feed. So, let us see what is the result for this particular antenna? We had designed this particular antenna for GSM 900 application. GSM 900 band is from 890 to 960 megahertz. So, again to design the antenna you take the centre frequency use that concept of l plus d equal to 0.48λ , but I just want to mention here.

Here there is a not a wire diameter, but we have used a printed antenna over here. So, you have to use width of this particular dipole antenna. Also since this particular dipole antenna is printed on a substrate. So, think about the field, so field mostly it is in the air, but part of the field is within the dielectric region. So, effective dielectric constant of this

particular antenna is around 1.1 to 1.2. So, use that particular value to find the value of lambda, lambda will be equal to lambda 0 divided by square root epsilon E. So, by using that you can see the parameters here l is 127 mm w is 4 mm. So, let us see what is the result? So, we get bandwidth for S 11 less than minus 10 db from 881 to 967 megahertz. So, you can see that this particular bandwidth covers 890 to 960 megahertz.

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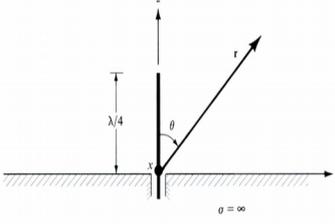
Now, in this particular case instead of using a straight line actually speaking we have used bow tie dipole antenna, bow tie dipole antenna gives relatively larger bandwidth compared to a simple rectangular dipole antenna. Also in this particular case, it is this slant length which is important instead of a vertical length, if you see the total length in this particular case is 101 mm which is smaller than the previous case here small w varies from 4 mm at this particular point to 24 mm. Let us see the result of this particular antenna. So, in this particular case, we get a larger bandwidth compared to the previous case, now the bandwidth is increased from 871 to 997 megahertz.

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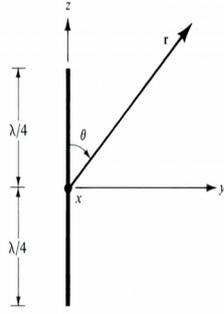
Monopole Antenna on Infinite Ground Plane

Quarter-wavelength Monopole Antenna on Infinite Ground Plane

Note: $\lambda/4$ length is only valid when ground plane size is infinite



$\lambda/4$ monopole on infinite electric conductor



Equivalent $\lambda/2$ dipole

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Now, let us talk about monopole antenna, now majority of the time various books would talk about a monopole antenna on infinite ground plane and they would mention that use this particular length as lambda by 4. So, let us see what most of the books write. So, basically what they show this is a lambda by 4 antenna which is fed using a coaxial connector. So, this is good for infinite ground plane; however, in reality we never ever have a infinite ground plane. So, I just want to mention 4 finite ground plane this length will always be greater than lambda by 4. So, this lambda by four monopole on infinite ground plane is equivalent to lambda by 2 dipole, because there is a mirror image of this particular lambda by 4 antenna

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Monopole Antenna on Infinite Ground Plane

Electric and Magnetic (E and H) Far Fields

E and H Fields for $\lambda/4$ monopole on infinite ground plane
are same as that of dipole antenna in upper half

Input Impedance

$$Z_{in}(\text{monopole}) = \frac{Z_{in}(\text{dipole})}{2} = \frac{73 + j42.5}{2} = 36.5 + j21.25$$

Directivity = $2 * D(\text{dipole}) = 2 * 1.643 = 3.286 = 5 \text{ dB}$

Design of Monopole for Real Input Impedance

$$h + r \approx 0.24\lambda, \text{ where } r \text{ is the radius of wire and } r \leq \lambda/20$$


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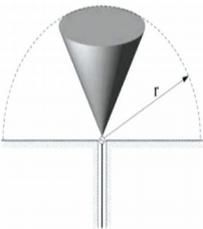
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So, let us see what are the different parameters for monopole antenna on infinite ground plane. So, E and H fields for a monopole antenna are exactly same as dipole antenna, but only in the upper half. Please remember this discussion is only for infinite ground plane. Input impedance of a monopole antenna will be half of the input impedance of dipole antenna, which comes out to be this particular value. Directivity of the monopole antenna in this case will be two times the directivity of dipole antenna. Why, in case of a dipole antenna, it is radiating in this particular fashion. However, a monopole antenna on infinite ground plate will radiate only in the upper hemisphere. And since power is now radiated in half portion compared to a dipole antenna that is why directivity is double of dipole antenna, which is approximately equal to 5 db.

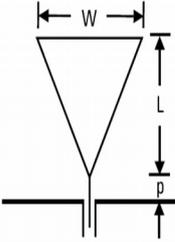
So, now design of monopole antenna for real input impedance is defined by $h + r$ equal to 0.24λ , I just want to mention this is straightway coming from the dipole antenna. In case of the dipole antenna, it was $l + d$ equal to 0.48λ you have divide everything by 2. So, h is half of l , r is half of d and this is half of 0.48 . So, where r is the radius of the wire and this should be always less than λ by 20.

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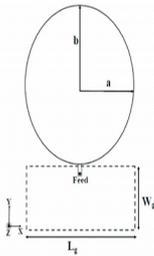
Broadband Monopole Antenna Configurations



Conical
Monopole
Antenna



Triangular
Monopole
Antenna



Printed Elliptical
Monopole
Antenna

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So, you can increase the bandwidth of the monopole antenna. As I mentioned earlier for the dipole antenna, but now we will take some practical cases. So, one can use conical monopole antenna instead of a conical monopole antenna, a triangular monopole antenna can also be used. And this is the example of a printed electrical monopole antenna which gives very large bandwidth.

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Conical Monopole Antenna

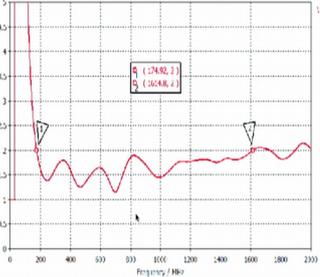


Slant length = $\lambda/4$ at lowest frequency of operation.

$$Z_{in} = 60 \ln \left[\cot \left(\frac{\alpha}{4} \right) \right]$$

where α is cone angle.
For $\alpha = 90^\circ$, $Z_{in} = 52.9 \Omega$

Physical Specifications	
Height of cone	300 mm
Maximum radius of cone	300 mm
Minimum radius of cone	5 mm
Distance from ground	2 mm
Cone angle	90°



BW for $VSWR \leq 2$ is from 175 to 1615 MHz

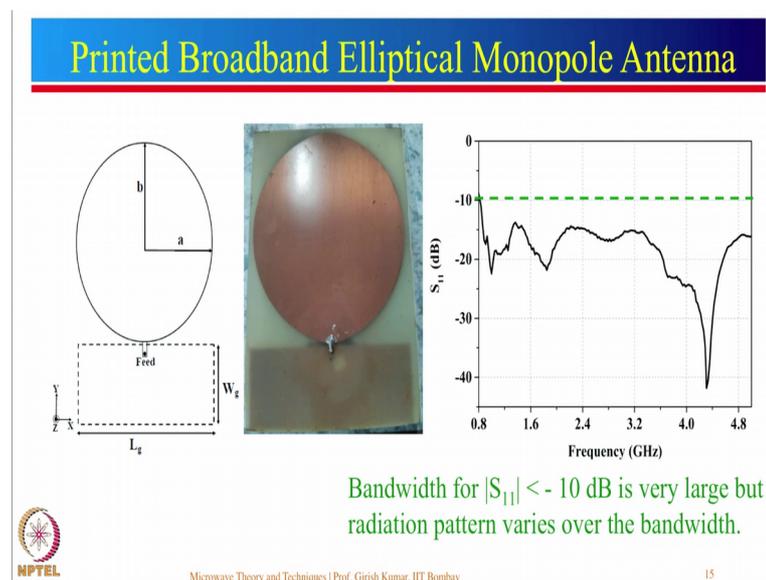
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So, let us take a few examples. So, this is a conical monopole antenna on the finite ground plane. So, here slant length should be about lambda by 4 at lowest frequency of

operation. So, I just want to tell you these are the physical specifications of the design antenna. You can see that height of the cone is 300 mm, so as about 30 centimeter. So, in the picture, it may look small, but this is about 1 foot height antenna and that is the radius of the cone, but just to tell you how we designed this particular antenna.

The angle of this particular thing is important. So, this is the equation which we have used to find out the input impedance. So, for the desired input impedance which is 50 ohm, we have actually found out the value of alpha. So, for alpha equal to 90 degree, you substitute the values Z in comes out to be 52.9 ohm, which is close to 50 ohm. So, let us see what is the result of this particular antenna. So, one can actually see that bandwidth for VSWR less than 2 is from 175 to 1615 megahertz. You can see that it is a very large bandwidth. Of course, the antenna size is large, because we have designed this antenna at low frequency antenna size is inversely proportional to the frequency. So, frequency increases, size will decrease.

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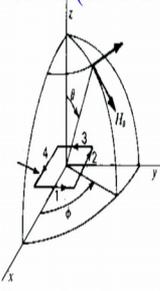
Let us see the result of a printed broadband elliptical monopole antenna. You can say that this is an elliptical antenna printed on top side of the substrate this is printed underneath of the substrate, which acts as a ground plane. And here equation feed has been used. So, let us see what bandwidth we have got in this particular case. So, here you can see that responses from 0.8 gigahertz to up to about 5 gigahertz here. So, in this entire bandwidth,

you can see that reflection coefficient is less than minus 10 dB. So, we can really realize very large bandwidth using these configurations.

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Loop Antenna

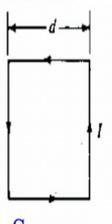
Loop antennas can have circular, rectangular, triangular or any other shape. It can have number of turns and can be wrapped in the air or around dielectric (solid or hollow) or ferrite material.



Circular Loop



Circular Loop



Square Loop

A small electric loop is equivalent to a small linear magnetic dipole of constant current amplitude I_m .

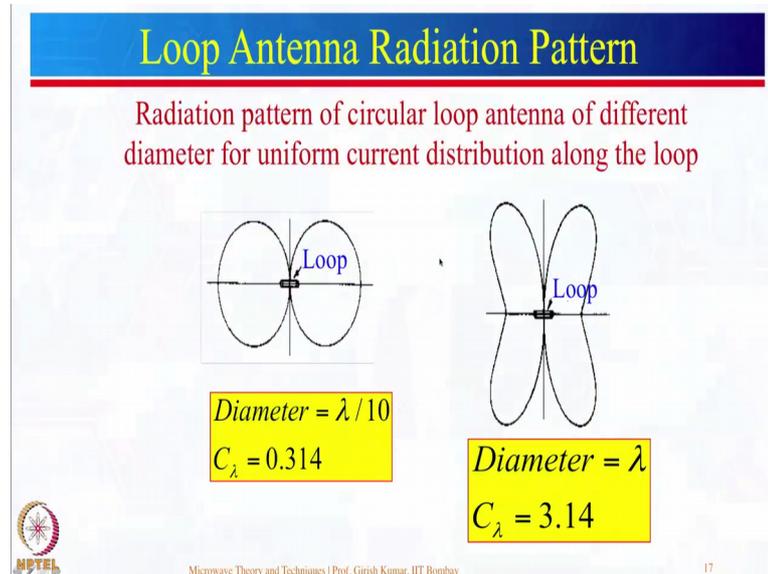
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Now, let us shift to the next antenna which is loop antenna. So, loop antenna can have various shapes, it can have circular shape, rectangular shape or triangular shape or any other shape. Of course, most of the time, we take regular geometries, which become easier to analyze. Now, one it is a loop antenna can have number of turns. So, basically you can rap at the same place number of turns, it can be wrapped in the air or it can be on the dielectric material or it can be on a ferrite material also. So, let us see this is the loop antenna which is placed at the origin. So, we are going to first look at a uniform current which is flowing through this particular thing.

And in the beginning I will focus on only a small loop antenna. And if it is small it does not matter, whether you take a circular shape or you take a square shape. So, when we talk about a let us say uniform current flowing through this here. Now, recall the discussion of a dipole antenna. So, in the case of dipole antenna, we had seen that, if we have a uniform current like this then this is the magnetic field. Now, you can think about that this is the current in the case of a circular loop antenna and we can now visualize that this is a magnetic dipole antenna. So, for magnetic dipole, then this will be the current which is going to flow over here. So, a current carrying loop antenna can be thought of as a magnetic dipole antenna. So, the all the analysis, which we have done for

dipole antenna will be valid for loop antenna, all you have to think about is that E field, now becomes H field, and H field now becomes E field.

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So, here radiation pattern of loop antenna is shown for two different diameters. So, this is for diameter equal to lambda by 10, then what will be the circumference, circumference is equal to 5 times d. And what is the C lambda actually C lambda is C divided by lambda or in other terms you can say it is normalize C with respect to lambda. So, C lambda is equal to pi d, so that will be pi divided by 10 equivalent to 0.314. Since, it is a small loop antenna, you can see that the radiation pattern is similar to that of a dipole antenna except for the difference that whatever was the H field for the dipole antenna, now it is E field for the loop antenna. Now, this is the radiation pattern for large loop antenna.

So, for diameter equal to lambda C lambda becomes 3.14, you can see that this pattern is not similar to this particular pattern. So, I just want to tell you majority of the applications do not use large diameter loop antenna the invariably use small diameter loop antenna. So, I will focus mainly on loop antennas having small diameter.

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Loop Antenna Radiation Resistance

For Single Turn Small Loop Antenna: $R_r = 20\pi^2 \left(\frac{C}{\lambda}\right)^4$

where $C = 2\pi a$ is Circumference of the Loop Antenna

For N turns: $R_r = 20\pi^2 N^2 \left(\frac{C}{\lambda}\right)^4$

Example: If $\frac{C}{\lambda} = 0.1 \rightarrow R_r = 20\pi^2 \left(\frac{C}{\lambda}\right)^4 = 20\pi^2 \times (0.1)^4 = 0.02\Omega$ (very small)

For N = 50

$R_r = 20\pi^2 N^2 \left(\frac{C}{\lambda}\right)^4 = 20\pi^2 \times (50)^2 \times (0.1)^4 = 50\Omega$

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So, for single turn small loop antenna radiation resistance is given by this particular expression where C is nothing but 2 pi a or you can say 2 pi r which is circumference of the loop antenna. I just to tell you this particular expression is valid for circular loop antenna; however, if it is a rectangular loop antenna, in that particular case circumference will be equal to 2 times l plus w. Now, this radiation resistance increases by a factor of N square, if we use n turn, so for N turn loop antenna R r becomes N square times this particular expression.

Let us just take an example. So, if you take C by lambda as 0.1 and we substitute the value of C by lambda equal to 0.1. Let us see what do we get, we get R r as 0.02 ohm, which is extremely small. If you try to feed this loop antenna with 50 ohm, most of the power will get reflected back and nothing will transmit. However, if we take N equal to 50; that means, you take 50 turns loop antenna, let us see now what happens. So, this R r is now increased by a factor of N square, so that comes out to be 50 ohm. So, that means, if you use 50 turn loop antenna of circumference equal to 0.1 lambda, then we can get radiation resistance which is equivalent to 50 ohm.

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Radiation Resistance of Loop Antenna on Ferrite

$$R_f = \mu_{cer}^2 R_r = \left(\frac{\mu_{ce}}{\mu_0}\right)^2 R_r$$
$$= 20\pi^2 \left(\frac{C}{\lambda}\right)^4 \left(\frac{\mu_{ce}}{\mu_0}\right)^2 N^2$$

Example: N-turn circular loop antenna has a diameter of 2 cm and the wire diameter is 0.2 mm. It is wound on the ferrite core, whose effective permeability is 10. How many turns are required to obtain $R_{in} = 50$ ohm at 3MHz.

$$N^2 = \frac{R_{in}}{\mu_{cer}^2 20\pi^2 \left(\frac{C}{\lambda}\right)^4} = \frac{50}{10^2 20\pi^2 \left(\frac{\pi \times 2}{10000}\right)^4}$$

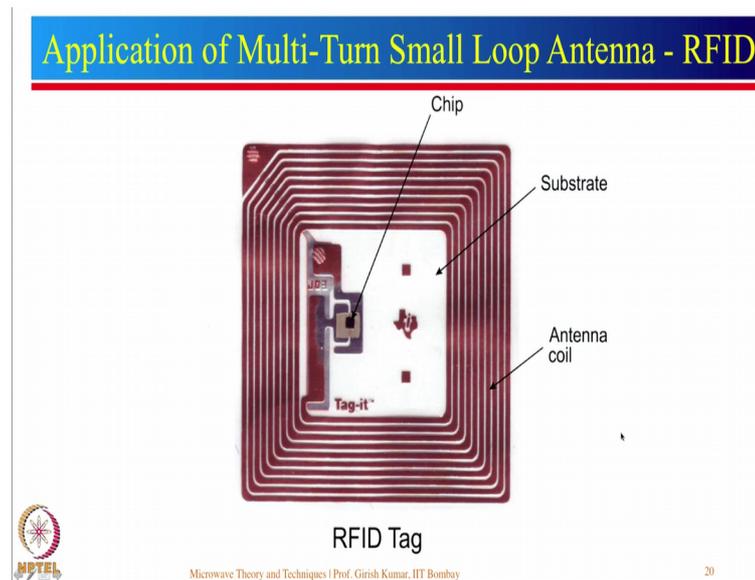
$$N = 127485$$



Now, the radiation resistance of loop antenna can be further increased, if it is rapped on a ferrite rod. So, you take a ferrite rod and you wrap the wire around this particular ferrite rod. Then R_r increases by a square of this particular factor over here which is actually effective permeability of the ferrite element.

So, let us just take an example here N turn circular loop antenna has a diameter of 2 centimeter, wire diameter is 0.2 mm. It is wound on the ferrite core whose effective permeability is 10. Now, the question is how many turns are required to obtain R_{in} equal to 50 ohm at 3 megahertz. And if you use now this particular expression, you get N equal to this, you can see that it is really a very, very large number. And now just imagine, if we had not wrapped it around of ferrite core, this number would have increased by a factor of 100. So, you can see the importance of using ferrite core. However, in practice we may take a larger diameter. And by taking a larger diameter we can reduce the number of turns significantly.

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This is one of the application of the loop antenna. So, you might have use RFID tag. RFID stands for radio frequency identification. I just want to show you here how loop antenna is connected to this particular chip over here. So, you can see that this is the pad where the chip is soldered. And then this one over here is making a kind of a loop antenna, you can also say that it looks like a spiral ok, but it is all right. You can still call it a multi turn loop antenna, if you wish you can also call it as spiral antenna, but now just follow this particular copper portion and you can see over here there is a pad.

Now, this particular thing you can see that there is a vth that made over here and a line is connected underneath. So, this is this line here is other side of the substrate. And majority of the time these tags are actually made on very thin substrates, it can be even a flexible PCB also on which you can fabricate these thing. And then this other terminal is coming over here, and the chip is sold at to these two output of the loop antenna.

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Slot Antenna

$Z_s Z_c = \frac{\eta^2}{4}$

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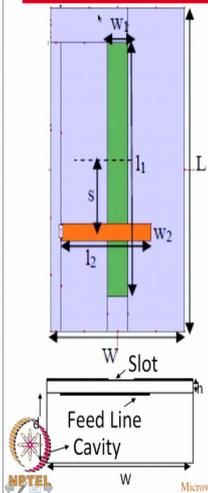
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Now, let us talk about another antenna which is slot antenna. Slot antenna is nothing but a complement of dipole antenna this one shows over here a bow tie type of a dipole antenna, and this is where it is being fed by balance line. So, complement of that would be is that you take a very large ground plane and cut a slot of this particular fashion and feed the slot like this. So, this is nothing but a complementary antenna of dipole antenna. So, there is a relation between the input impedance of the dipole antenna and slot antenna, which is given by this particular expression.

So, I just want to mention how this expression comes into picture. So, we know that for a dipole antenna this is magnetic field, but for a slot antenna, it will be electric field ok. So, E and H fields are related to each other with a factor of eta which is equal to 120 pi in the free space. So, we know that E by H is equal to 120 pi which is equal to 377 ohm.

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Cavity Backed Slot Antenna at 5.8 GHz



Elements	Value
Slot ($l_1 \times w_1$)	31.4 mm x 4 mm
Cavity height (d)	13 mm ($\approx \lambda/4$)
Slot offset (s)	7.7 mm
Cavity ($L \times W$)	40 mm x 26 mm

Slot is cut in the top ground plane and fed using microstrip line from other side of substrate ($\epsilon_r = 2.55, h = 0.787$ mm)

Antenna is backed by a metallic cavity for unidirectional coverage.

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Let us take an example of a slot antenna. Here we have designed a cavity backed slot antenna at 5.8 gigahertz. So, let me explain 1 by 1. So, let us first think of a printed slot antenna which is cut in a metallic conductor. So, this colour here shows metal this one over here shows that is slot has been cut. So, this is on one side of the substrate as you can see over here, other side of the substrate actually uses a microstrip feed line. So, this is where input is given and you can actually see that there is an open circuit just to tell you at open circuit current will be minimum.

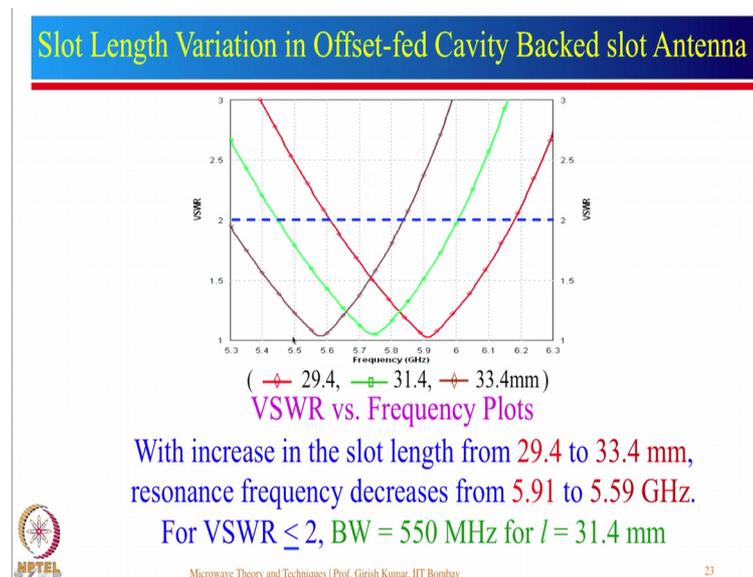
So, we generally speaking for maximum coupling from microstrip line to this slot line, we generally use this length to be approximately lambda by 4, because if current is zero here current will be maximum, so for maximum current magnetic field will be maximum, so there will be maximum coupling to the slot. So, why we have put this cavity at the back side, because we wanted a unidirectional radiation pattern, if we use only this particular portion, then slot will radiate in all the directions like this ok.

So, but by putting a metallic cavity in the backside, now slot will radiate only in one direction. So, at 5.8 gigahertz, again the length should be around lambda by 2 the cavity height has been taken as lambda by 4. The reason for that is that any short circuit over here will act as an open circuit. So, that there is a no loading of this metallic plate on this particular antenna over here, we have taken the width of the slot as 4 mm slot length is

31.4 mm. I am going to show you what is the effective the slot length in the next slide ok.

Now, we have use the offset feed the reason for that is at this particular point current is maximum so; that means, voltage will be equal to 0. So, if we feed at this point impedance will be actually 0; at the center current will be 0, voltage will be maximum. So, input impedance will be very high. So, somewhere between zero impedance and very high impedance we have actually found out where impedance matching is done with 50 ohm line.

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So, let us see the results. Here we have shown the results of three different slot lengths. You can see here 29.4, 31.4, 33.4. Now, as the slot length is increasing its resonance frequency decreases from 5.91 to 5.59 gigahertz. So, let us see what is the bandwidth for the design length of l equal to 31.4, we can see this is the response for this particular length corresponding to VSWR equal to 2 line bandwidth obtained is 550 megahertz. So, this 550 megahertz is approximately 9 percent bandwidth at the desired band of around 5.8 gigahertz.

So, just to summarize today we talked about dipole antenna. We started with very small dipole antenna, then we talked about lambda by 2 dipole antenna then we talked about monopole antenna on infinite ground plane. For infinite ground plane length of the monopole should be approximately lambda by 4. But for smaller ground plane length of

the monopole antenna should be taken as larger than 0.25λ . I recommend something like 0.3λ to even 0.4λ depending upon the ground plane size. Then we talked about small loop antenna I mention that the E field of the dipole antenna becomes H field of loop antenna, and H field of dipole antenna becomes E field of the loop antenna. Then we talked about slot antenna, slot antenna is complementary of the dipole antenna.

So, again e field of the dipole antenna becomes H field of the slot antenna, and H field of the dipole antenna becomes E field of the slot antenna. Then we talked about a cavity backed slot antenna slot antenna radiates in all the direction. So, we had placed a cavity on one side, so that the radiation of the slot antenna becomes unidirectional. In the next lecture, we will talk about linear and planar arrays to increase the gain of the antennas.

Thank you very much.