Antennas
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Module - 01
Lecture - 02
Antenna Introduction-II

Welcome, in the last lecture, we discussed about basics of antennas. So, we looked into a different types of antennas, however, we will see more detail today. We also looked at the fundamentals of antennas for example, radiation pattern, half power beam width, first null beam width, side lobe levels and so on and then we also looked at simple expressions for directivity, gain as well as how to calculate reflection coefficient from the input impedance of the antenna and then how to calculate VSWR.

Today, we will look at a very important parameter what is a link budget, how do we really decide, what should be the gain of the antenna or what should be the power transmitted, what should be the receiver sensitivity and so on and then we will start looking all these antennas one by one.

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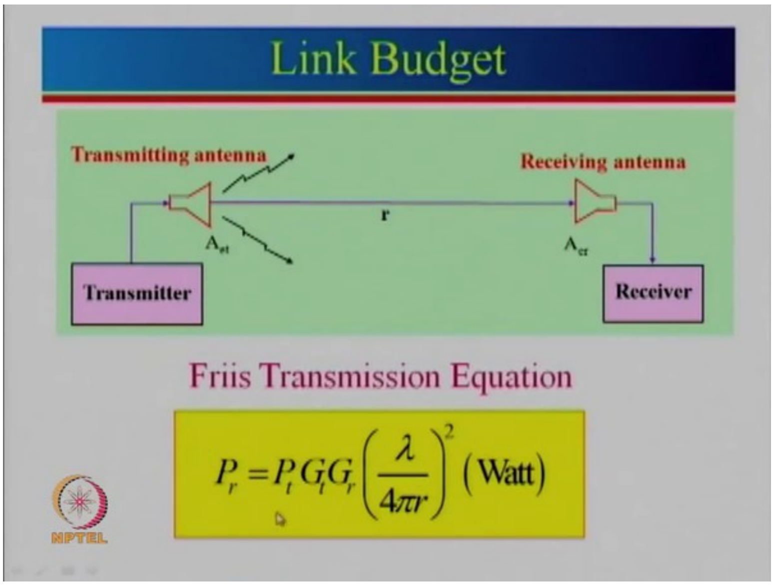

So, let us start with the link budget. A link requires a transmitting antenna, let us say we have a transmitter that transmitter is connected to the transmitting antenna, and then there is a receiver with the receiving antenna, and in between the transmitter and receiver the distance is r and what we need to do it is? We need to find out if there is a certain power transmitted and what is the gain of the antenna; then what will be the received power. So, received power is given by this particular expression.

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi r}\right)^2 \ (Watt)$$

When we start looking into more detail of antenna fundamental, we will see how this expression is derived. But, just to tell you the received power depends upon what is the transmitted power. So higher the transmitted power higher will be the received power, and if the gain of the transmit antenna or gain of the receive antenna if they are large then power received will be large.

Now, one can see that it is proportional to λ^2; where, $\lambda = c / f$, so that means it is inversely proportional to f^2. Also, it is inversely proportional to r^2; that means if the distance is let us say increase by ten times then the power received will be reduced by hundred times or if the distance is doubled then the power received will reduce by four times. So, this is a very very important equation to design any given system, in fact all the satellite communication, they start looking at that how much power should be transmitted, what will be the attenuation through the path and also many a times, when we design for a link budget, we always plan for minimum 10 dB gain margin.

So, just think about when you are listening to the radio station and these days we have these dish antennas, and if you are watching the TV if it is raining, suddenly you see that the signal actually gets lost and a cable signal comes there- ‘there may be a some problem in the connection and so on’. Basically, what happens, because of the heavy rain, the satellite signal which is coming down to the earth is getting absorbed by these water particles or getting diffracted by water molecules, so that is why the power received by the our receiver is reduced and hence, signal is not good. So, minimum general criteria are 10 dB gain margin.

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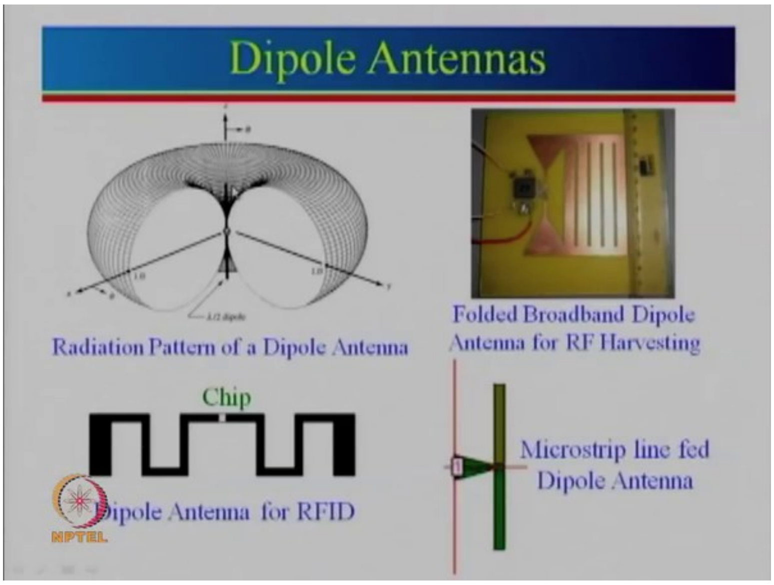

So, now let just look at these basic antennas one by one. So, the simplest most antenna which we look at, is a dipole antenna; a dipole antenna is right over here. Now, typically you know people start with the theory. Also it starts with the very small dipole antenna, then we talk about a $\lambda/2$ antenna, and of course one can increase the length of the dipole antenna also. But, this one here, the radiation pattern if you see it is actually radiating uniformly in all the direction, but if you start looking here, the maximum radiation is in this direction and then as we go up, we actually see the very little of that.

In fact, the dipole radiation pattern can be very simply realized by just thinking of this pen in my hand is like a dipole antenna, but please do not apply this to all different types of antenna. For example if we look at a pen, if I look from the pen this side, I see the full length, if you see from your side, the pen is looking full size, somebody is looking from this direction it will also see the full length. But now, if someone moves from here, starts moving from here, goes to the top what you really see now is just the tip of the antenna or the tip of the pen over here.

So, when we go from here maximum visibility or maximum radiation, as we move up we only see the projection; that means we will see lesser radiation or lesser intensity and as we go up we will see 0 here. So, now maximum then it is going to 0, and then same thing happens here. So, it actually makes a figure of 8. Now this figure of 8 is getting rotated all around, so it almost looks like a donut, but donut with a hole not a continuous donut. So, a donut with the hole is; what is the radiation pattern of a dipole antenna.

Now, what are the different applications of dipole antenna? In fact, it is used in so many different things but currently there is a one application where it is used very extensively and these are RFID; that is radio frequency identification. And that RFID there is a this chip is sitting there and then what it has? It has roughly about λ/4 distance on this side and roughly about λ/4 distance on this side; so why we do the bending because the size is small. You might have seen that many of these RFIDs are fitted in the visiting card. So, in the visiting card you can see that the size is a big limitation, so if we try to use a straight λ/2 dipole, it will be very long; so what we do instead of having this long dipole antenna, we bend it so that we can fit in the given credit card size.

Now, the dipole antenna actually requires a differential feed over here. So, it requires a one '+' here and then '-' here which should feed these two element. Now there is another application which we have used. This is actually a very important application in a sense that we have used multiple things over here. So, this triangular shape has been used to obtain broad bandwidth and these numbers of folds are used to increase the input impedance of the dipole antenna and that is connected to a RF harvesting chip. So, it can actually harvest the signal. So, if you put a mobile phone next to it, it can generate a voltage; or if you take it next to the cell tower or Wi-Fi, it will actually generate the voltage.

Now, instead of using a '+' '-' feed which is known as a balanced feed. Here is an example where a coaxial feed is used. So, coaxial feed is known as unbalanced feed. Why? It has only a center pin and the outer periphery is grounded, whereas in the case of the dipole antenna it requires '+' and '-', so this '+' is connected to this branch and the '-' is connected to the other branch. So, this is known as a balanced feed.

Whereas, simple feed which we had shown over here; here it is a coaxial feed. In fact majority of the generators will just give us a single feed and then we need to design a concept which is known as a Balun- b a l u n that is known as balanced to unbalanced. So, here, we have tried to achieve balanced to unbalanced using a micro strip version and that is what is a microstrip line fed dipole antenna. So, as we go along in the course, we will see how to design all these antennas.

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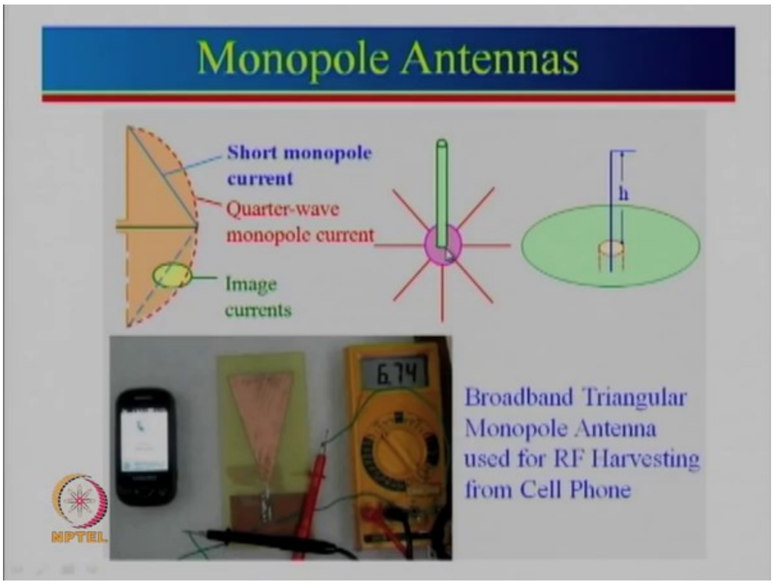

Then let us just look at monopole antenna; monopole antenna is nothing but half of the dipole antenna. So, one can see here this is the complete dipole antenna, but if we just draw the line in between here if we make that plane grounded and then this one is acting as an image, so most of the derivation in the beginning, we will see for infinite ground plane that is for derivation point of view and for infinite ground plane, we can see the image current which is directly there.

So if the monopole is a quarter wave; that means the current will be 0 here and current will go to maximum, and this is the image here which you will not be seeing it as such it is just imaginary thing. But, if it is a short monopole then the current variation will be from 0 to triangular variation. The reason for that is what a wavelength actually satisfies the complete boundary condition. This is an open circuit set; open circuit current will be 0 we are feeding it over here. So, this is the half wavelength and it says sinusoidal waveform.

Now, in practice, there will never ever be an infinite ground plane. So majority of the time we use finite ground plane. So, here is a monopole antenna and this is a circular ground plane which is used over here and this is the coaxial feed which is feeding the monopole antenna. Now, many a times, this is also not possible, then what we do, we use an approximation of that, so we actually use practically wires over here. In fact for medium wave transmission which I mentioned in the last lecture medium wave transmitter at 1 megahertz would require an antenna of the height of 75 meter and there we need to provide a ground plane. Now, earth may not be always a perfect ground plane, so, lot of these radial lines are put on the ground and these are long radial lines which have to be put. So, they will actually simulate the real ground plane.

We have actually shown here one practical example also. Here, we have designed a broadband monopole antenna and this one here is a RF harvesting circuit. So, what you can see here that when this mobile phone makes a call, you can see that the antenna is placed at a certain distance, and the DC voltage which is generated over here is connected to the multi meter. You will be shocked to see that it actually generates about 6.7 volt. So, imagine what a mobile phone can do: it can actually generate such a high voltage. In fact, this voltage can be used even to charge a battery. So, it is a perfect example for RF harvesting application.

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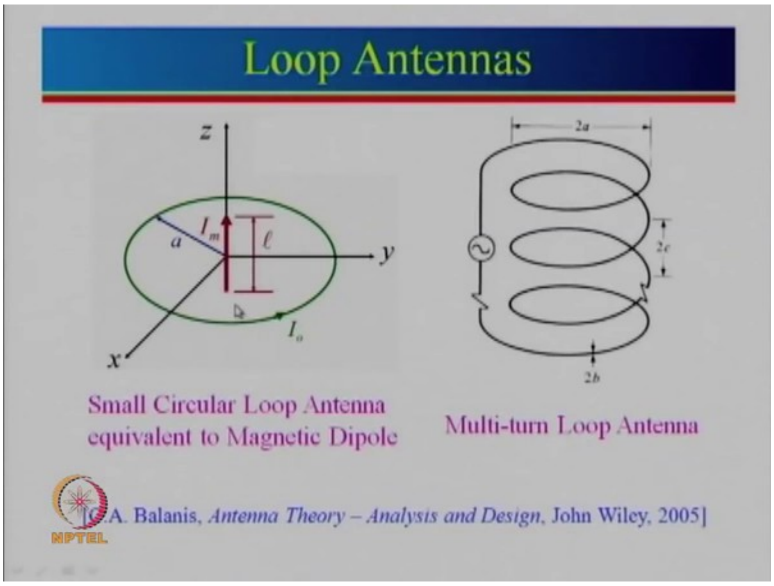

Then, we will look at loop antenna. So, loop antennas can have a very small loop diameter to a very large loop diameter. However, practically majority of the time loop antennas are used which have a small diameter. Now, this is shown here as a small circular loop. So, if we assume that the current is uniform over here then this can be thought in a slightly different way. See, when we were looking at a dipole antenna; so we had a vertical dipole antenna, and where was the magnetic field? Magnetic field is around the dipole. So, if this is the dipole antenna, magnetic field will be like this here, so that is what is known as omni directional and then the E-field is like this which was making a figure of 8. So, that is a directional antenna.

Now, for the loop antenna we can actually think reverse of that. So, loop antenna current is moving in a circular fashion. So, this can be thought about now that this is equivalent to instead of electric dipole; if it is a magnetic dipole then this will be the field around that. So, approximation actually is valid that instead of using an electric dipole all we need to do it is we think of this as a magnetic dipole, so, this one instead of becoming a magnetic field, now it is electric field.

In fact, we can actually use this particular simple assumption and that way we can find out the radiation pattern of dipole antennas and by using it interchangeability, so whatever is valid for dipole antenna, so E-field for loop antenna it will become H-field, and whatever is H-field for dipole antenna will become E-field. So, E- and H- fields are reversed.

Now, one of the another interesting thing with the loop antenna is that instead of using a circular, one can use even a triangular or square. If it is small, radiation pattern is still given by the simple magnetic dipole equivalent to the electric dipole. Now many a times multiple turn loop antennas are used also because since it is a small loop antenna it may have a very poor radiation characteristic as well as poor impedance which we will see when we talk about more in detail about loop antenna. So, multiple turn antennas are used for better impedance matching. And lot of these figures, I have taken from the Balanis book.

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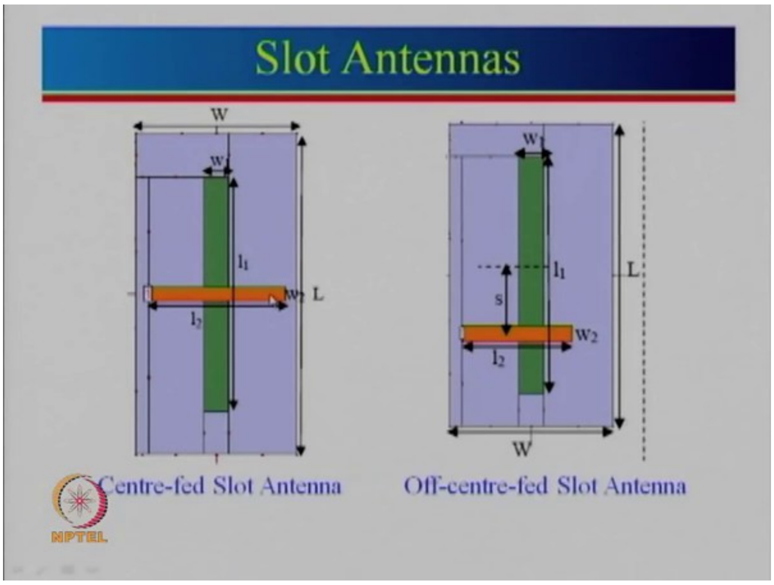

A slot antenna: slot antenna is nothing but a complement of a dipole antenna. We had seen that the dipole antenna is nothing but a metallic thing here; here I have shown a flat version; a dipole is normally we look at a dipole as a circular rod or a circular wire. However, in printed dipole antenna we just take a printed configuration. So, slot antenna is nothing but a complement of a dipole antenna. So in principle; what we actually do in principle is that a slot is cut in the infinite ground plane. So, what dipole sees- a metal and then there is an air all around, here what we have here is all the metal and you cut a slot in between.

But, now of course, we also know, you cannot have infinite ground plane, so majority of the time, we have a finite ground plane and we cut a slot over here. Now, this slot can be fed through this microstrip line over here. So, what is a microstrip line actually speaking? It is a line which is printed on a let us say a PCB, printed circuit board. So, on one side we have a ground plane with this particular slot and on the other side, we put this feed and here we are feeding the antenna. So, this current flows through over here, it actually sees an open circuit here. So, current will be maximum here if this length is approximately $\lambda/2$. So, the current is maximum here; that means the magnetic field will be around that and that magnetic field gets coupled to the slot antenna.

Now, for slot antenna the voltage currents are slightly different or opposite of the dipole antenna. See, in case of a dipole antenna, current is 0 here, current is 0 over here, current is maximum. Whereas, for the slot antenna, voltage is 0 here, because it is short circuit voltage is maximum and then voltage goes to 0 here. So, current will be maximum here, current will be 0. Now, you can see that if current is 0, impedance is given by voltage divided by current. So, voltage has a finite value, current is tending towards 0, this impedance becomes very large.

So that is why, instead of using a centre-fed slot antenna, many a times, offset-fed slot antenna is used. So, that a proper impedance matching with let us say 50 ohm coaxial feed can be obtained.

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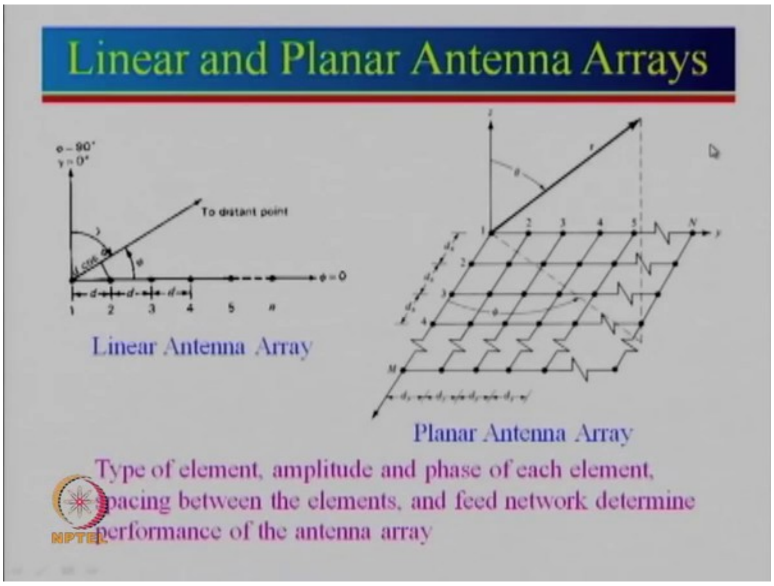

Then, we will talk about linear and planar arrays, and why we need arrays. So, just to tell you, we have discussed about dipole antenna, monopole antenna, slot antenna and loop antenna. Majority of the time, the gain of these antennas is just about 2 dB or if you take a very large dipole antenna it can be up to 3 to 4 to 5 dB. But, what if we want a very large gain and large gain is also associated with let us say, I want to send a signal from point a to point b. So, what we need is we need a directional antenna, so we should radiate in this direction and I need a directional antenna to receive the signal.

Or this signal can be radiating in all the direction for example, let us say for FM radio which is transmitting in all the direction. But however, if I use a directional FM radio I can get a much better signal. However, majority of the time we do not use directional FM radio there also. We still use a Omni directional thing. But however, if we use a directional antenna, one can get a much better quality, because you know that where is FM transmitter.

However, if we need a very high gain then we can use arrays of these antennas. So, for example, it shows here 1, 2, 3, 4…. n element array now this is known as a linear antenna array because all the elements are placed in the linear fashion. Here is an example of a planar antenna array. I have shown an example of a rectangular planar array where m elements are placed in this axis and then n elements are placed in this axis and that is getting replicated in this particular plane which is x-y plane. So, the total number of elements will be m multiplied by n. So, these are the number of element.

Now, I have shown here just the planar or rectangular array, but it can be square, it can be triangular, hexagonal, and circular and so on and so forth. So, the array performance depends upon so many factors and what kind of an element we have used. So, in the beginning when we start the array theory we will use an isotropic element and then we will take specific elements, then it depends upon amplitude and phase of each element.

So, at what amplitude these elements are being fed? And what is the phase difference between all these elements? Just to tell you when all these elements are fed with the same phase it will radiate in the broadside direction i.e. in this particular direction, and if the phase of each element changes then the beam maxima which is in this direction that can be scanned in the different direction. So, phase array concept comes from here if we change the phases between different elements.

It also depends upon the spacing between the elements; so smaller the spacing for the same number of elements total aperture will be small so gain will be small, but larger spacing would mean that aperture area increases the gain will increase. However, there is a limit we cannot keep on increasing the spacing beyond certain limit. So, for now I can just say spacing has to be always less than λ.

Then it also depends upon the feed network. How these elements are being fed? Because there may be a one common source so that source may be dividing the power into different things. So, how we design the feed network; so all these things govern performance of the antenna array.

One more thing I want to mention here that this linear antenna array can be generalized for continuous line source also. So, just think about if the spacing between the element is reduced; let's say this shows here d if the spacing is reduced to say by 10 times and number of elements are increased by 10 times. So, the total aperture size may still remain same, but now the elements are very close to each other. So, here we can generalize if $d \rightarrow 0$ we can say that there is a continuous source. In fact, linear and planar antenna array concept will be used to explain all the different types of antennas.

For example, microstrip antennas, they can be modeled as two slot antenna array, or we can think about a helical antenna which is an axial mode helical antenna. We will see that it is a typical example of increased directivity end fire array. So, another example- let us say horn antenna. See if I look at a simple pyramidal horn antenna of this shape, so what actually happens E-field is uniform in this direction and it varies sinusoidally in this particular direction. So, we have a uniform field in this direction and we have a cosine field distribution in this particular direction. So, array factor theory can be modified to find out the overall radiation pattern of horn antenna.

Same thing can be applied even for a parabolic dish antenna. So, where the shape is parabolic but the outer here is circular, so over here again we can apply the array theory concept in this E- plane as well as in H- plane and then we can find out what is the aperture distribution. So, array theory is very very important to actually define most of the other aperture antennas.

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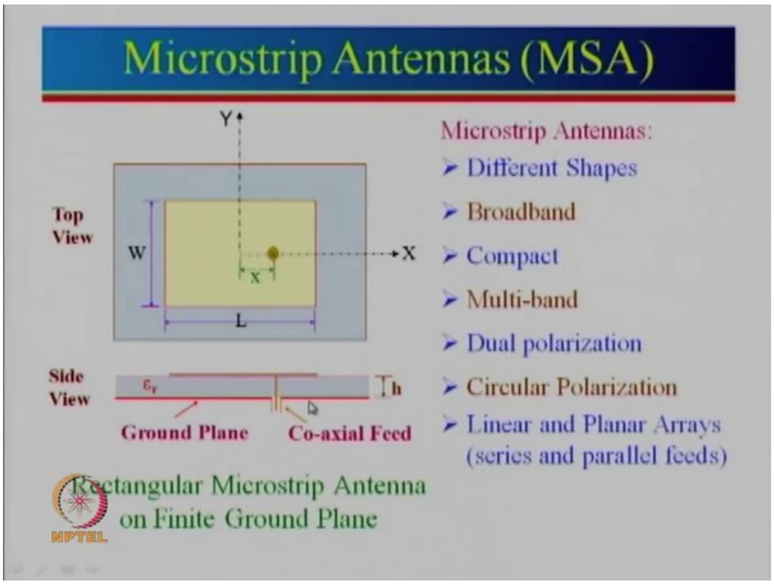

So now, let us just look at a microstrip antenna. It is one of the most promising antenna these days. Or why it is very promising, because the structure itself is so simple one actually looks at it. So, there is a ground plane and a patch is printed on the other side. So, just like you are familiar with a printed circuit board PCBs, I mean it is there inside your mobile phone or inside any of your electronic gadget you will see a PCB, if you have designed microcontrollers; so you know that there are multiple lines are going parallel to each other or perpendicular to each other. Whereas, a microstrip antenna is much much simpler.

So, all you do it is you take a PCB, we commonly call it a substrate a dielectric material is there, so on one side for a PCB it will be a copper and on the other side there is a copper. So, you do not etch out the copper underneath the thing, only we etch out the copper on the topside here. So, if this particular shape is a rectangular it is known as rectangular microstrip antenna, if it is circular it will be circular microstrip antenna, triangular microstrip antenna, or it can be hexagonal shape microstrip antenna, pentagon shape, sectoral, annular ring and so on and so forth.

Now this antenna, actually you can see that this is the length and I have shown this as a width so this length should be approximately equal to λ/2. And if this length is approximately equal to a λ/2, now you can see here this is an open circuit this is an open circuit so current will be 0 here current will be 0 there. So, the field will vary from here 0 current to the maximum current and goes to 0, because that is what is making half waveform.

What about the voltage? Voltage will be maximum here and then voltage will go to 0 and then voltage will go to the - maximum. So, it will start from ‘+’, it will go slowly to 0, and then it will go to ‘-‘ here. So, if the voltage is maximum, current is 0 so impedance will be V divided by I, so impedance will be very high. Over here along the centre line, voltage is 0 current is maximum. So, impedance will be 0 here. So, along this central one the impedance will be 0 here, impedance will be maximum here. So, then we can find a place where the impedance will be 50 ohm and then we can feed with a coaxial field.

It is just one of the types of the feed when we talk about microstrip antenna, we will talk about different types of feed there and by choosing a proper feed point then we will be able to match the impedance. So in fact, this particular configuration does not require any external impedance matching network, it does not require any Balun which is balanced to unbalance and it is such a simple configuration, all you have is as just very thin printed circuit and this printed circuit will have a very less weight, less volume it can be bent around. In fact, there are printed lines are there, in fact there are flexible PCBs are available which can be wrapped around a missile, it can be put underneath the aero plane, it can be put inside a pager or a mobile phone.

So, microstrip antennas are gaining lot of advantages and in fact in this particular course, we will talk about so many different types of microstrip antenna. We will start with the rectangle but we will look at different shapes of the antenna. Then, we will look at several configurations how to increase the bandwidth of the antenna, we will also see how to make this antenna compact antenna, then multiband can be realized. We will also see how dual polarization can be achieved that is horizontal or vertical. We will also see how circular polarization can be obtained and then we will look at linear and planar array. We will look at different types of feed also; series feed, parallel feed and even we will see how to use combination of these feeds.

Today in general, we talked about simple principle of the link budget which is very very important to design an antenna system along with transmitter and receiver. It actually helps and determines what should be the transmitter power, what should be the receiver sensitivity, what will be the coverage, what are the gain requirements for transmit and receive antenna.

And then we talked about a very basic antenna which is, we started with the dipole antenna, then we went to the monopole antenna, then we talked about a circular loop antenna which is nothing but a small circular loop antenna looks like a magnetic dipole antenna, then we looked into slot antenna which is nothing but the compliment of the dipole antenna. So, you cut a slot in the infinite ground plane which is theoretically OK. Practically, we cut it in a finite ground plane.

We also just quickly looked into how to feed for proper impedance matching and then we looked into microstrip antenna and why they are so popular because of the reason they are very easy to fabricate and their weight is very small, volume is small and the cost is also relatively small, they can be mass produced without any problem and we will see what are the different things, we can do for microstrip antenna, how to realize broadband, circularly polarized, arrays and so on and so forth.

Thank you very much.