Antennas
Prof. Girish Kumar
Department of Electrical Engineering
India Institute of Technology, Bombay

Module - 1
Lecture - 1
Antennas Introduction-I

Hello everyone, welcome to the exciting world of antennas. I am going to conduct 30 hours lecture series on antennas. Antennas are required everywhere, any wireless communication requires antennas. Look at your mobile phone. It has multiple bands. It may be having a GSM900, 1800, 3G, 4G, Wi-Fi, GPS, so it requires multiple antennas to receive the signal. Similarly, let's say a radio transmitter has to transmit the signal and your radio has to receive the signal, we need to send signal to satellite or receive the signal from satellite so we need antennas. Any defense communication is almost you know incomplete without the use of antennas. So, welcome to the exciting world.

So, we are going to talk about antennas, I am the course coordinator, my name is Girish Kumar, I am professor at IIT Bombay and I joined IIT Bombay in 1991. Just to tell little bit about myself; I did PhD from IIT Kanpur in 1983; From 83 to 85, I was at University of Manitoba Winnipeg Canada, where I worked in the area of antennas and from 85 to 91, I was assistant professor at University of North Dakota USA, Canada and in 91, we decided to come back to India, and since then I am here. I have been working in the area of antennas since 1979, so it is been long time, my PhD was on broadband microstrip antenna.

And in the last 30 plus years, I have published more than 200 papers in the area of antennas, I have also written a book on broadband microstrip antenna. So, let us see what this exciting world of antenna is in store for us, and what I am going to cover in this course.

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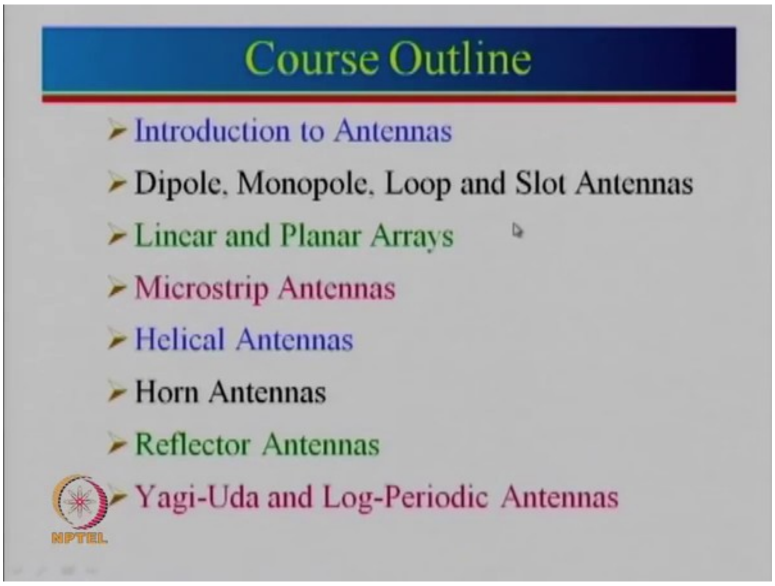

So, the course outline, I will start with the introduction to antennas, so what are the basic fundamentals of antennas. Then, we will look at very simple configurations like dipole, monopole, loop and slot antennas. Many of you might have studied these things in your under graduate course, but in this particular course we are going to emphasize on design, design and design. Our Prime Minister is saying currently make in India. Now, make in India will only happen if we do design in India.

Now, today we are importing more than 1 lakh Crore worth of antennas in our country and there are very few manufacturers who are manufacturing these antennas. So, what is the reason? The reason is very simple we do not have enough design available in our country which can be manufactured. In fact, after antenna design is done, manufacturing is relatively simple. So, let us see, we will start with the simple dipole, monopole, loop and slot antennas. We will see what these antennas are, after that we will go to linear and planar arrays so that means, arrays in form in the just in one linear fashion that is known as linear and arrays which are in the planar area which can be rectangular, circular, triangular, hexagonal circular, those are planar array.

After that we are going to talk about microstrip antennas. In fact, a microstrip antennas are actually very very popular these days. It is replacing many other antennas. Whether it is your mobile phone, whether it is the antennas in the aeroplane or satellite or missile. Majority of the places, microstrip antennas are being used and I am going to spend a lot of time in the design of microstrip antennas. Then, we will talk about helical antennas. So, helical antenna is something very similar to what an inductor looks like. So, you take a wire wrap it around that makes helical antenna.

Horn antennas are again different types of horn antennas are there. Pyramidal horn antenna, sectoral horn antenna, conical horn antenna, so we look into all these things one by one. Then, we will look into reflector antennas - reflector antennas are nothing but a passive device which reflects a given antenna. So, the reflector antenna, there are different types. It can have a planar reflector, corner reflector or parabolic reflector and so on. After that, we will go to talk about Yagi-Uda antenna, Yagi-Uda name came from the scientists from Japan who invented this antenna and the log periodic antennas where all the dimensions vary in the logarithmic manner.

So, we are going to use many books for covering this particular course as there is a no single book which covers all the exciting things about antenna.

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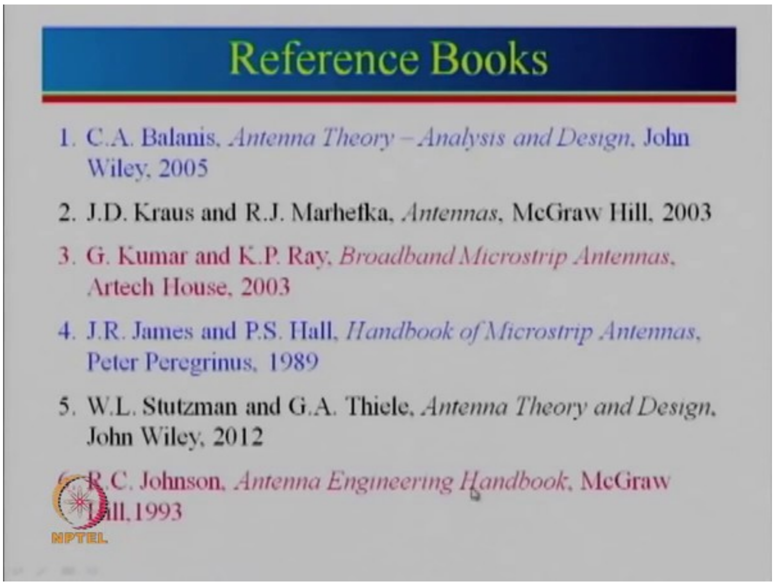

So, these are the texts or reference books. So, Balanis and Kraus book these are the very standard textbooks used all over the world. So, I recommend you can use any one of them. Kraus book is relatively more simple to read. Balanis is much more elaborate. So, you take a call, which one you want to procure. The next book is actually written by me and my student K. P. Ray.

So, broadband microstrip antennas where we have put about 20 years of our experience in that particular book and then we are also going to use handbook of microstrip antenna by James and Hall. Stutzman and Thiele book, is also gives lot of things. So, we will use some part of this particular book and then antenna engineering hand book by Johnson. We are going to use some material from this book, but; however, many other books are there and I am also going to use lot of journal papers and also lots of antennas which we have been designed and developed at IIT Bombay.

Just to tell you in the last 30 + years, we have designed probably 10000 different antennas and manufactured more than 1000 antennas. So, we will give you what are the practical aspects of designing the antenna and many a times, we will also tell you that whatever may be the best possible antenna it may not be the cheapest possible antenna also. So, for defense in space application we do need performance, performance and performance, but when it comes to commercial antenna their cost, cost and cost, so that is what is more important. So, when we look at the design and everything depends upon that design how you design an antenna that is what will determine what will be its cost.

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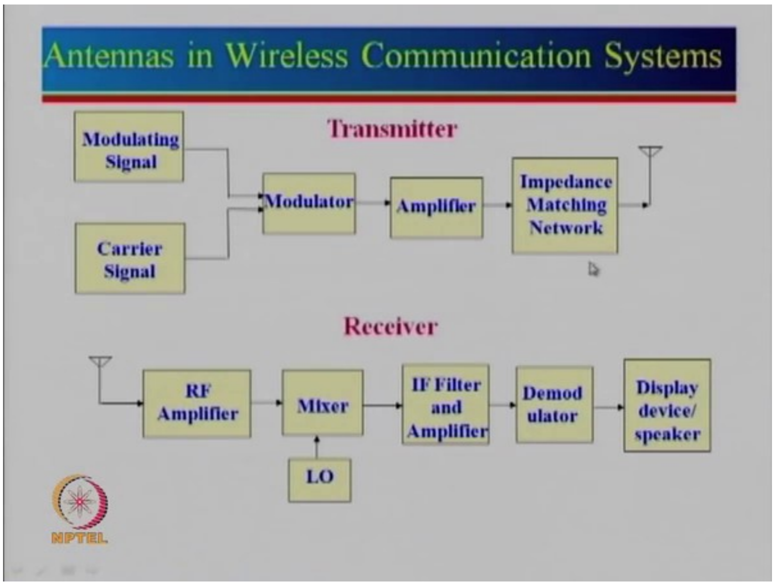

So let us just look at where antennas are used. So, the antennas are used in both transmitter as well as receiver. A transmitter consists of a modulating signal, it is also known as information signal, could be your voice data, could be a analog data, could be digital data, now that is known as modulating signal and that signal is superimposed on carrier signal. Carrier signal is the signal on which it is being carried. So, just to give you an example - for example, let us look at a simple radio signal.

So, now in radio signal, we are going to transmit the voice signal for medium wave and AM radio. The modulating signal frequency is up to 5 KHz. The carrier frequency for AM medium wave radio can vary from 530 KHz to 1620 KHz whereas, for FM radio things are slightly different. Modulating signal has a bandwidth up to 15 KHz that is why FM radios sound a much better and the carrier frequency could be from 88 to 108 MHz and then we take these two signals and do the modulation. So, modulation can be analog or digital modulation, in analog modulation - we can have a amplitude modulation, phase modulation, frequency modulation and in digital modulation - there are so, many techniques are there, for example QPSK, BPSK and so on and so forth.

After that, we amplify the signal. So, we connect that with an amplifier and now, generally you will see in majority of the textbook this particulars is not shown which is impedance matching network; however, it is extremely important thing to be connected between antenna and amplifier. Now, what is the importance of this? Now antenna may be having certain input impedance generally we design antenna for 50 Ω input impedance.

Now, amplifier may require a different impedance matching. So, it may require let us say 1 kilo ohm; also it may require even 10 Ω depending upon what kind of amplifier it is. So, that antenna impedance has to be matched using a matching network and that has to be a lossless matching network. So, lossless matching network generally consists of inductors, capacitors may be transmission lines or coaxial lines, but in general not resistance. However, sometimes, they do use slightly lossy matching network only for broadband impedance matching network. So, once the signal is transmitted through the antenna; it is received by the receiver. So, the receiver antenna receives signal, is very very weak so that must be amplified by RF amplifier. However, there is a one another important thing required either in between or antenna or RF amplifiers should do that job and that is known as band pass filter.

So, sometimes if antenna is a narrow band, it can act as a band pass filter or sometimes band pass filter is built into RF amplifier otherwise a band pass filter should be added over here. Band pass filter is required only to pass the desired band which is required for given application. So, then this amplified signal through local oscillator which is LO; it is down converted using mixer that is, this is the one of the super heterodyne concept - different concepts are there, but this concept is used in majority of the receiver system.

So, what is done, is that RF amplifier signal which is a relatively higher frequency converted down to the lower frequency. So, just to give you a couple of example for FM radio, this frequency can be 88 to 108 MHz, but IF frequency is around 10.7 MHz. For AM radio- this frequency can be 530 to 1620 KHz and this is about 455 KHz. So, that is why the name is IF that is Intermediate Frequency. So, we filter it out and amplify the signal and then we use demodulator which is reverse of this here. So, if it is amplitude modulator; it will be amplitude demodulator or if it is digital modulation; this will be digital demodulation and then this is connected to the display, device or speaker. So, depending upon whatever is the application. For example, for your mobile phone it may display or it will be connected to speaker. If it is just a radio signal: it will be only speaker and so on.

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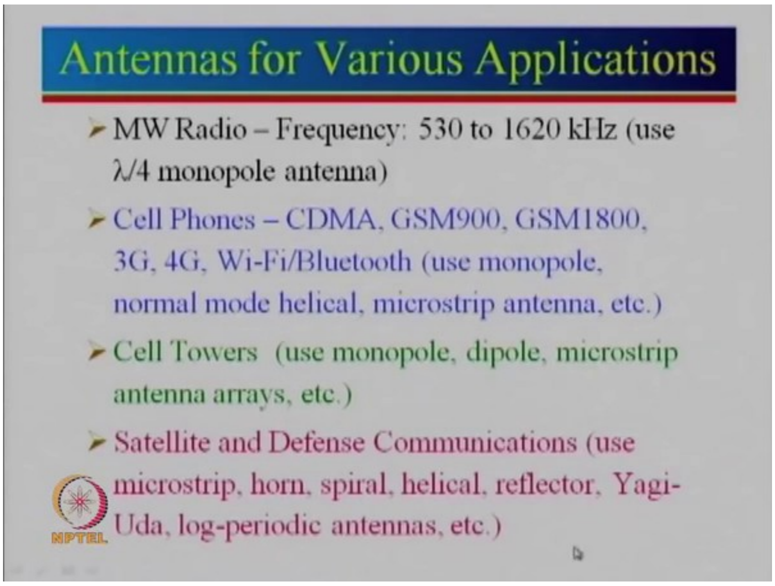

So, let us just look antennas for different application. So, let us look at a simple medium wave radio also known as amplitude modulated wave form that is- radio frequencies from 530 to 1620 KHz and generally the transmitters use λ/4 monopole antenna. Now, let us just take one of the frequency in between. So, in between frequency if we take one of the number let us say 1000 KHz which is equal to 1 MHz, now corresponding to 1 MHz, we can calculate the wavelength - wavelength is given by lambda that is equal to c by f where c is velocity of light.

So, at 1 megahertz the wavelength comes out to be 300 meter. So, if we use lambda by 4 monopole antenna that would require a height of about 75 meter. So, if you just look at one apartment, may have a one rooftop, will be typically about 10 feet height that will be about 3 meter and when we talk about 75 meter height this is almost equivalent to 25 meter tall building. So, it requires a large antenna for transmission.

However, at a reception, we most of the time use loop antenna which has to be very very small. So, when we discuss about monopole antenna and loop antenna, we will look into how these things are designed. Another very commonly used thing is a cell phone. So, let us just look at cell phone it has so many different bands- it has a CDMA band commonly known as 800 MHz band, GSM900 which is 900 band. In fact, the band varies from 890 to 960 MHz then GSM1800 band- actually this consists from 1710 to 1880 MHz. Then, we have 3G, now 3G is again split into two parts transmit part and receive part. So, this band is from 1920 to 1980 and then the other part is 2110 to 2170 MHz. Now 4G in fact, in India we use 4G in 2300 to 2400 MHz, but there are different countries use different bands also.

Now, Wi-Fi, Bluetooth both have the exactly the same frequency as that of a microwave oven which is centered around 2.45 GHz. Typically for these applications, different types of antenna used are monopole antenna, normal mode helical antenna, microstrip antenna etc. So, just again to give an example, when cell phones were initially launched let us say for GSM900, at 900 MHz -wave length is approximately 33 cm. So, if we try to use a monopole antenna, let us say the length is approximately 9 cm.

So, earlier the mobile phones would actually have a something like a monopole hanging up there and this would be the height of roughly about a 9 cm. Now, this was very inconvenient and it would break many a time. So, then people came out with their normal mode helical antenna. Normal mode helical antenna is nothing but you take a wire wrap it around and in fact, that height of the antenna was reduced to just about two centimeters so that used normal mode helical antenna.

Now later on people were not satisfied with that also. So, then a microstrip antenna and printed monopole antennas came into picture and now those antennas are hidden inside the mobile phone itself. In fact, two decades back, there used to be a one add whereas scissor would come and it will come here and it would cut this particular thing and it will actually show no antenna.

But in a reality antenna was inside the mobile phone itself and now because of so many bands, inside the mobile phone there is not just one antenna, there is a dual band antenna, tri band antenna, quad band antenna. Now, even they have penta band antennas also. Then for cell phones to communicate, we need cell towers and in India, we have roughly about 5 lakh cell towers and it may use monopole antenna, dipole antenna, microstrip antenna, arrays etc. So, depending upon the application to application, typically a monopole antenna is used when omni-directional coverage is required, but majority of the time coverage is sectoral. So, it may cover about 90° sector or 120° sector so then sectoral antennas are required.

So, on one rooftop many a times you will see that there is a one antenna facing this side then there is a another antenna and then there is another antenna. Each of these antennas will cover about 120° and the total coverage will be 360° and then of course, antennas are required for satellite and defense communication, so they use all kind of antennas - microstrip antenna, horn antennas, spiral antenna, helical, reflector, Yagi-Uda, log periodic antennas and so on and so forth.

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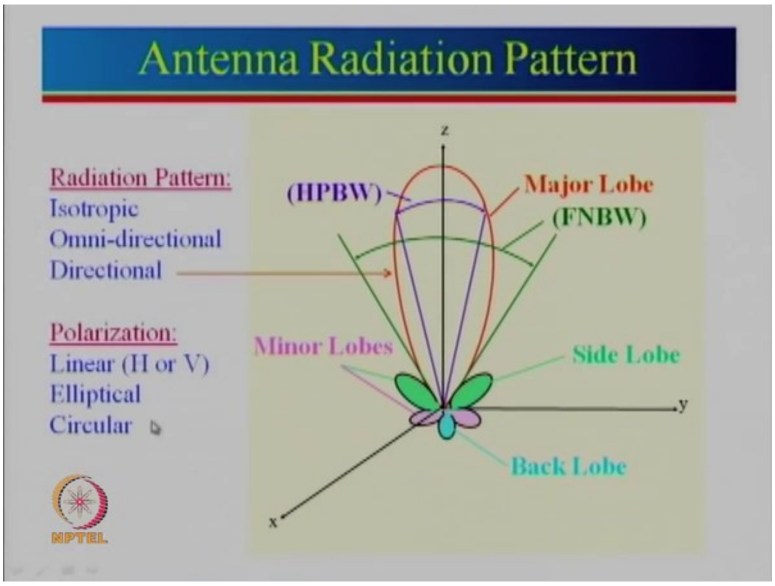

So, let us just see, some of the basic things about the antenna. Predominately when we talk about, we need to know what is the antenna radiation pattern? Now, antennas radiation pattern - divided into three main categories - isotropic antenna is an antenna which radiates equally in all the directions so in fact, it is actually radiating in the entire sphere; however, just to tell you there is a no isotropic antenna exists as such. Of course, there is a lot of research going on and they call these antennas as quasi isotropic antenna. Then, Omni-directional antenna - some of the examples of Omni-directional antenna are for example, dipole antenna, monopole antenna, slot antenna, normal mode helical antenna. They come under the category of Omni-directional. Why the name is Omni-directional? Omni-direction means equally and in the other plane, they radiate in one direction that is how the name Omni-directional came into picture. Then, there are directional antennas, so I have just shown one sample radiation pattern over here. So, this is the direction so you can see that the maximum radiation is in this direction and a little bit of a side radiation is there in the other direction. So, the radiation where there is a maximum radiation is known as a major lobe and all other things are designated as minor lobe, so minor lobes are again subdivided as side lobe - the lobes which are adjacent to the main lobe and back lobe which is in the back side of it.

Then, we define a few additional quantities here and that is what is the half power beamwidth of the antenna? So, when the antenna field is reduced by 50%, so this one here is a E-field pattern so if this is one this is approximately 0.707 which is $1/\sqrt{2}$ so power will be half. So, this is the half power beam width, given by the angle subtended which means these two values so that is a half power beam width. Then, another quantity which is defined which is FNBW that stands for first null beam width. So, you can see that this maximum goes to the null and then there is a minor lobe, maximum goes to the null then there is a minor lobe. So, beam width between the first null that is known as FNBW.

Then, we also define all the side lobes, so what is the level of these side lobes here. Then there are different types of polarization - polarization can be linear, elliptical, circular. In a linear, there is a designation as horizontal or vertical. So, most of the time polarization is defined in terms of electric field. See an antenna has both electric field as well as magnetic field.

So, we could define antenna by its electric field or magnetic field. The convention is to define the polarization by the way how electric field is radiating. So, when we say horizontal polarization; that means, electric field is horizontally polarized. If we say vertical polarization; that means electric field is vertically polarized and then elliptical and circular - even in circular there are two types of polarization, one is known as the left hand circular polarization; another one is right hand circular polarization. So, we will see all these things one by one in time to come.

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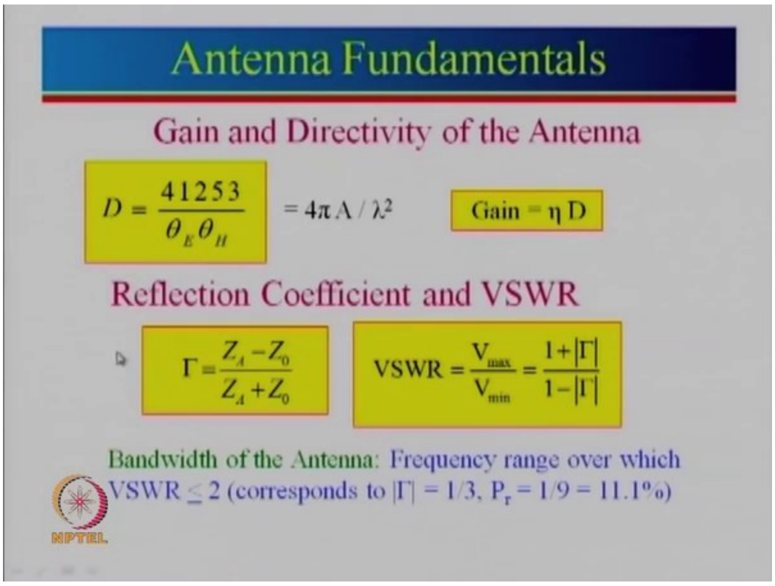

So, the other part - once we know the radiation pattern the next thing which is important, is what is the gain and directivity of the antenna? In fact, the directivity of the antenna can be calculated from the half power beam width in E-plane and H-plane. So, if you know what is the half power beam width in the E-plane and what is the half power beam width in the H-plane then we can use this particular expression. Now, here in this expression both theta E and theta H are in degrees; however, a simplified version is also there which is

$$D = \frac{4\pi}{\theta_E . \theta_H}$$

Here, θ_E and θ_H are in radian. Directivity is also defined in terms of its aperture area.

$$D = \frac{4\pi}{\lambda^2} . A_e$$

So, A_e is the aperture area divided by wavelength square. So, what it really implies is that for a given frequency, lambda will be fixed, if we keep on increasing the area of the antenna; that means, directivity will keep on increasing and if the directivity increases we can see that the half power beam width will reduce. Now gain is related with the directivity in a very simple manner that is

$$G = \eta D$$

So, if efficiency is 100%, gain will be equal to directivity and lot of effort has to be put to design an antenna with as high efficiency as possible. The next thing which is important for antennas is what is the reflection coefficient and VSWR. Let us just first look at the reflection coefficient. How do we define a reflection coefficient? So, reflection coefficient is defined by

$$\Gamma = \frac{Z_A - Z_o}{Z_A + Z_o}$$

Z_A is input impedance of the antenna and Z_o is characteristic impedance of the line with which we are feeding the antenna. So, many a times, we feed the antenna with let us say 50 Ω line.

$$\Gamma = \frac{50 - 50}{50 + 50} = \frac{0}{100} = 0$$

What reflection coefficient 0 imply? Well power reflector is given by gamma square. So, if gamma is equal to 0; that means, power reflector will be 0; that means, maximum power will be transmitted. In fact, you might be familiar with the maximum power transfer theorem. A maximum power transfer theorem says that the power delivered to the load will be maximum when the load impedance is equal to the source impedance. So, it is actually same as that. So, reflection coefficient is defined by this, but in general antenna impedance will be a complex quantity. So, it is not always going to be 50 or 60 or 70 or whatever the other number could be, I will just give you some example for example, a lambda by 2 dipole antenna Z_A is given by 73+ j 42.5. So, one has to calculate what is the reflection coefficient?

Once a reflection coefficient is known we can actually calculate what is VSWR? What is VSWR? The full form is Voltage Standing Wave Ratio, it is defined as in terms of maximum voltage divided by minimum voltage

$$\text{VSWR} = \frac{V_{max}}{V_{min}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

One can obtain this thing from the reflection coefficient given by the above expression. Now the reflection coefficient magnitude can vary from 0 to 1; that means, VSWR can vary from 1 to infinity and then we define; what is the bandwidth of the antenna. In fact, bandwidth of the antenna is defined in many different ways, it is also related with the gain also many a times if we say the bandwidth of the antenna is that the bandwidth over a certain band over which the gain changes by maximum 1 dB or 2 dB it can be defined even for polarization also, a circular polarization bandwidth over which actual ratio is less than 3 dB or so.

Here, we are defining bandwidth of the antenna in terms of its reflection coefficient and VSWR. So, we define bandwidth as frequency range over which VSWR < 2. Now many applications also specify VSWR < 1.5 or some application even VSWR < 1.2 but why VSWR < 2? This actually corresponds to

$$\Gamma = \frac{1}{3}$$

$$\text{VSWR} = \frac{1 + \frac{1}{3}}{1 - \frac{1}{3}} = \frac{3 + 1}{3 - 1} = 2$$

So, what will be power reflected that will be

$$\frac{P_{ref}}{P_{in}} = |\Gamma|^2 = \frac{1}{9}$$

$$\% \frac{P_{ref}}{P_{in}} = \frac{1}{9} * 100 = 11.1\%$$

In fact, actually the alternate way is also there. Many a times that define a reflection coefficient $|\Gamma\Gamma| < -10$ dB , all these things will be clear when we talk in more detail about antenna fundamental. So, right now, we are going to introduce different types of antenna and then we will talk in much more detail about these antennas fundamental. So, do not think that I am covering everything today itself.

But just to summarize in this particular course we are going to talk about different types of antennas which are required for different-different applications. Emphasis will be on the design and also on the performance and we will also try to see how these designs without sacrificing the performance can be fabricated or designed in a low cost manner. So, we did look quickly at the antenna radiation pattern, half power beam width and side lobe levels and also how we define directivity gain and reflection coefficient, VSWR. In the next lecture, we will look into a quickly about different types of antennas and then we will get into more detail about each and every aspect.

Thank you very much.