Microwave Theory and Techniques

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Module - 01
Lecture - 02
Microwave Theory and Techniques Introduction – II

Hello everyone. In the last lecture, we have talked about microwave theory and techniques and I had just mentioned about that I will be taking most of the lectures. And then along with me, 3 of my PhD students who are the 3 TA's of this particular course; Rinkee, Rajbala and Vinay, they will be taking some of the lectures.

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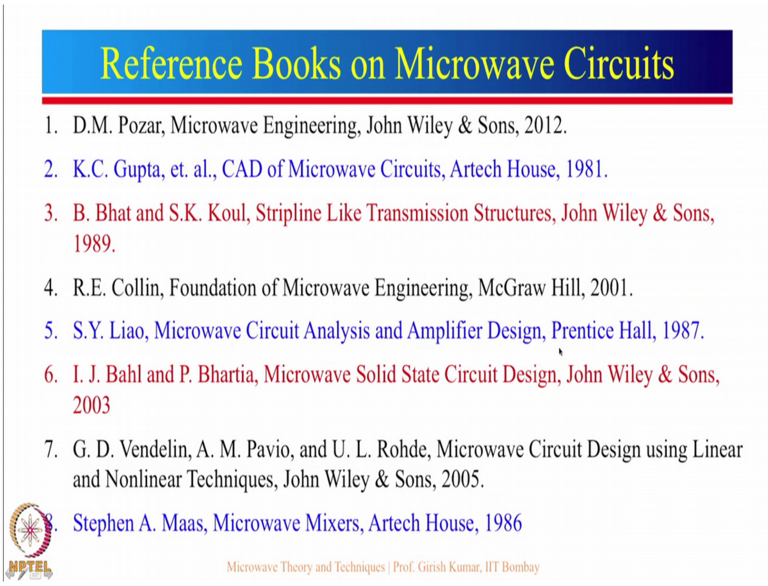

So, what we have done in the last lecture? We had just quickly looked at the course outline, then after that I had mentioned about reference books for microwave circuits as well as for antennas.

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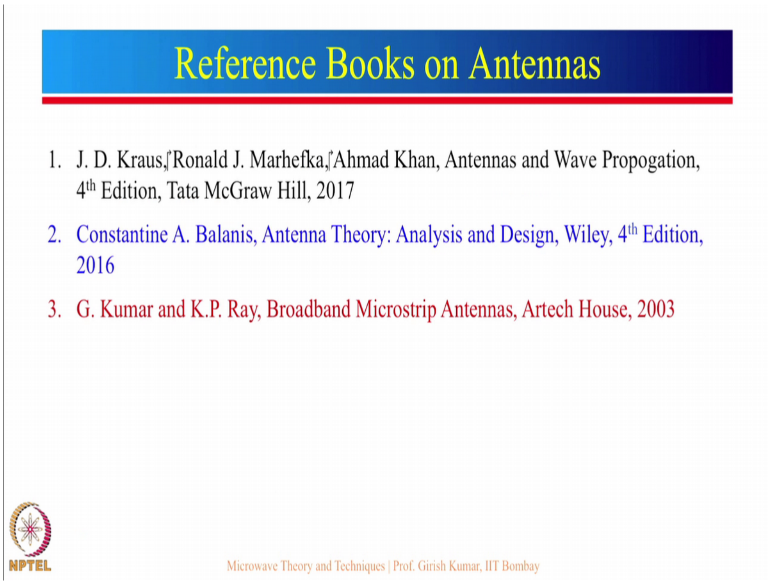

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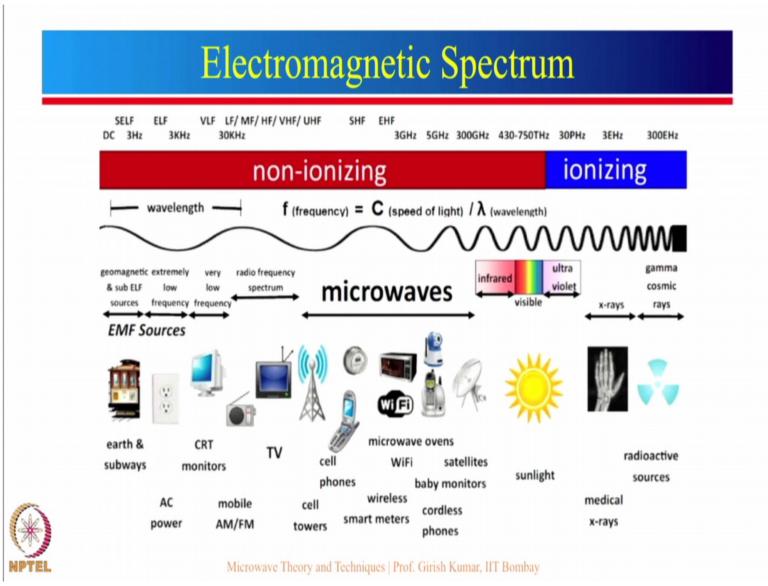

And followed by electromagnetic spectrum and we had mentioned about ionizing and nonionizing radiation.

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And then we talked about several applications and frequency bands in which these applications work.

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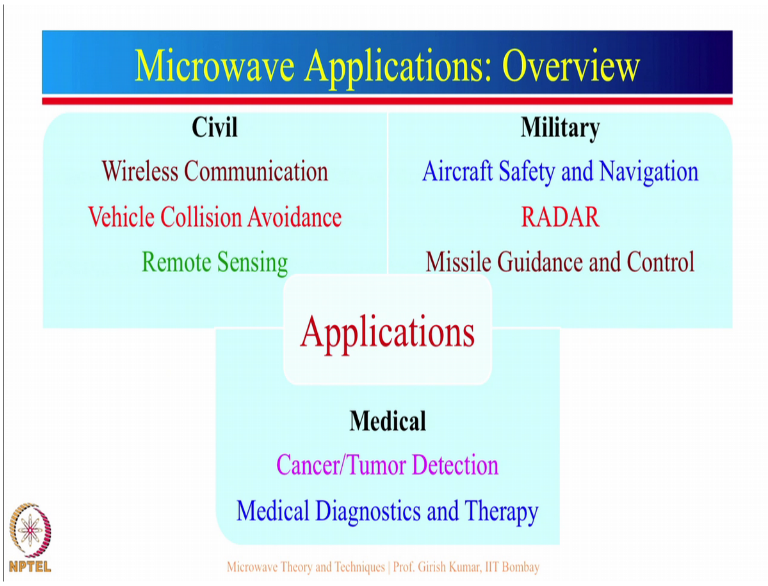

After that; we talked about civil, military and medical applications of microwave followed by history of electromagnetic waves then history of microwave engineering in terms of radio communication.

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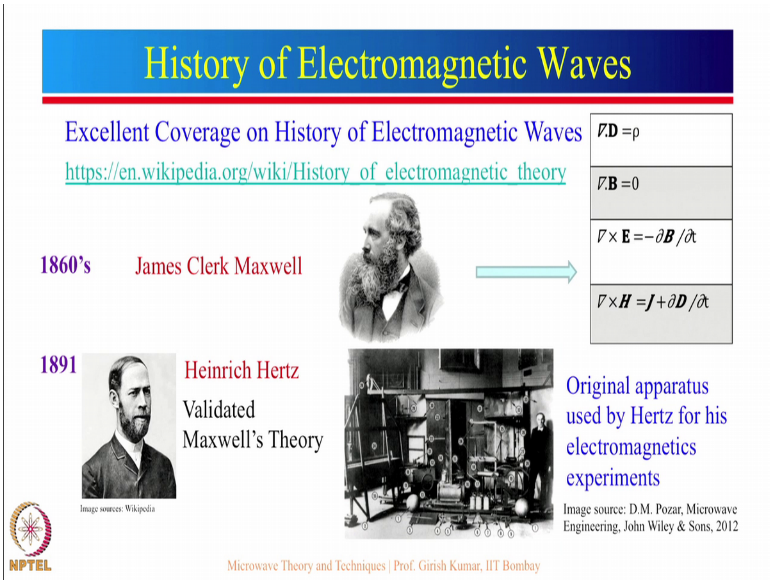

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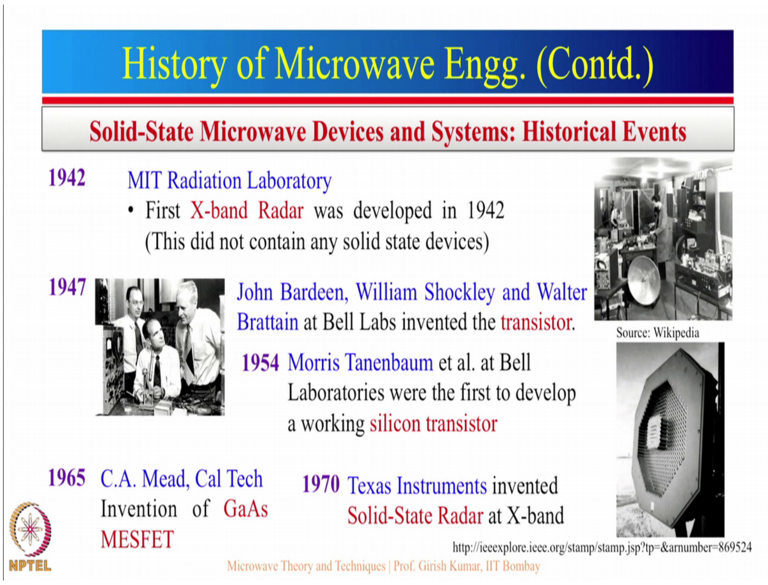

Then transmission line, after that we talked about solid state microwave devices and system.

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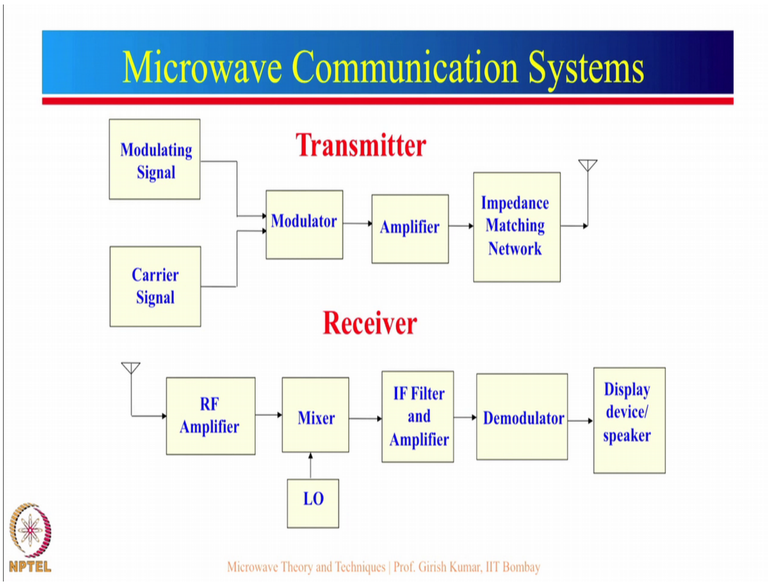

And then we looked at the block diagram of the transmitter and receiver.

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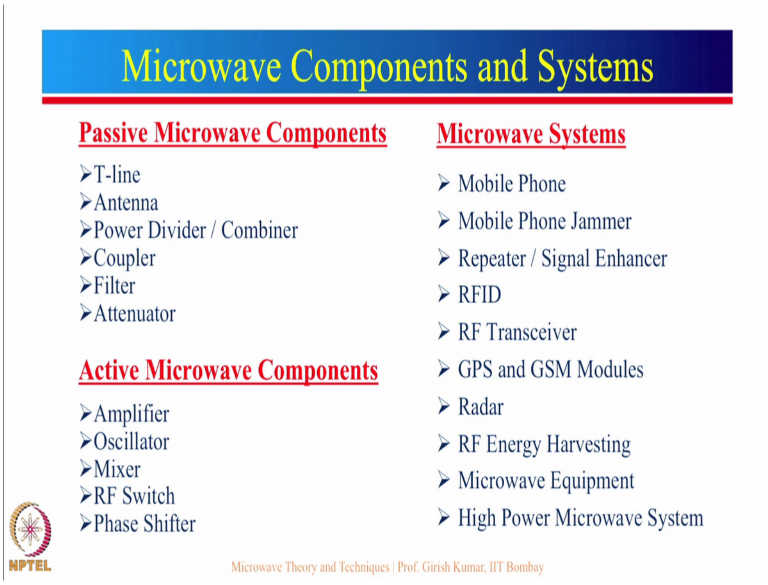

And in these block diagrams there are several passive microwave components and active microwave components followed by microwave systems. So, let us look very briefly about all these passive microwave components today.

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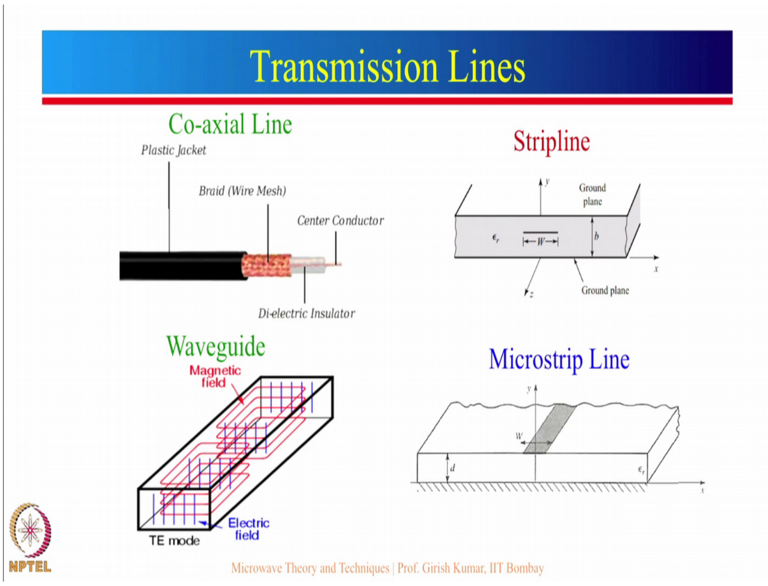

So, we start with transmission line. So, in that transmission line, we have a coaxial line. So, I am sure, most of you might have seen the coaxial. So, it has a center conductor, on that we have a dielectric insulator and then on that there is a metallic, you can say, sometimes a copper or even some times aluminium and followed by there is a plastic jacket on that. So, this whole unit becomes a coaxial line, then you might have also studied in the electro-magnetic course about waveguide.

So, this we have shown here fundamental mode of the wave guide. So, fundamental mode of the waveguide is TE 1 0 mode and this is how the propagation takes place. And then we will also talk about strip line and micro strip line, but just to tell you; what is really strip line. So, what strip line is that you actually see here; there is a metallic line here which is actually considered as ground plane, there is another top layer which is also a ground plane and in between, we see there is a flat micro strip or line here, but the combination is known as strip line configuration. Now this whole thing can be actually understood, think about this coaxial line. So, in the co axial line we have a center pin and along the center pin, we have got a ground plate.

Now, you just think about that the center pin which is a round has been made plat and the 2 ground planes and now separated. So, the circular ground plane separated like this and separated here and the curved line here is actually put dominated into the metallic vertical one. So, basically a strip line is nothing, but you can say as one substrate here and on the substrate we print the line and then we have another substrate and then we put these two things together, we have to ensure that there is a no air gap between the this particular substrate and this.

It has to be tightly put over there. Now from here, we will ship with the micro strip line, in case of micro strip line, you can actually consider it as a half of strip line. So, this ground plane remains as before substrate is there as before line is there as before except that. Now, there is a no top substrate now because there is a no top substrate here. So, most of the feel actually will be within this particular region, but there will be some fringing fields which will be outside and because part of the fringing fields are outside.

We define for this particular line epsilon effective for this, we have a epsilon r which is of it electric concern. So, we will see when we talk about transmission line in detail way, I tell you how to calculate epsilon effective for micro strip line. But micro strip lines are more popular these days compared to strip line because first of all, it requires only one substrate it does not require other substrate to be clump the cost gets reduce.

And also there is a possibility that you can mount the components more easily compare to in case of strip line.

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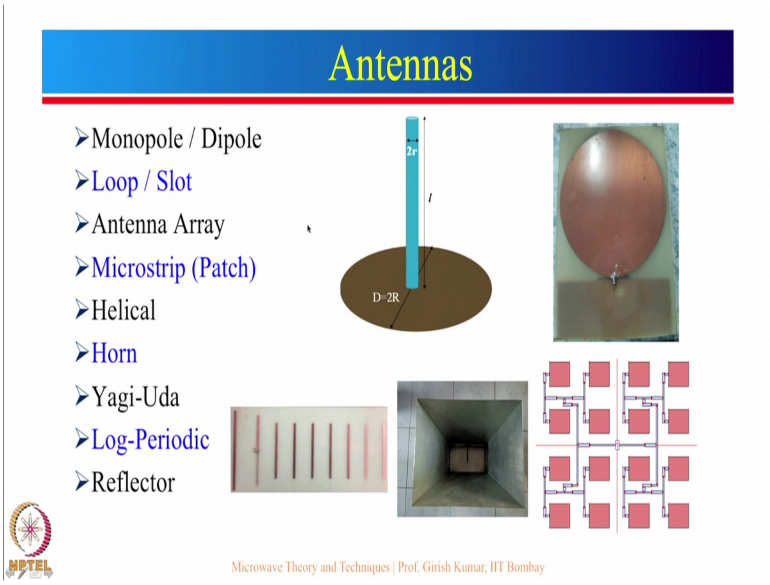

Then we will talk about several antennas in this particular course, we will talk about monopole antennas dipole antennas loop slot antenna; antenna array, micro strip; patch antenna, helical, horn, Yagi-Uda, Log-periodic and reflector antenna. So, just to show you, this is a monopole antenna which is generally considered as a lambda by 4 length over infinite ground plane, but majority of the time the size of the ground plane will be small.

So, in many cases, we will see that the size of the ground plane is very large in that particular case, a length of the monopole may be greater than lambda by 4, this is the printed version of a monopole antenna, it is actually a very broadband monopole antenna, what we see over here as these are micro strip antennas and there are 4 by 4 array. So, it a array of micro strip antennas, this is a one antenna and this one here is actually speaking a Yagi-Uda antenna where one antenna is only fed, you can see here there is a fit point and this one acts as a reflector and these are all directors larger number of directors imply larger gain.

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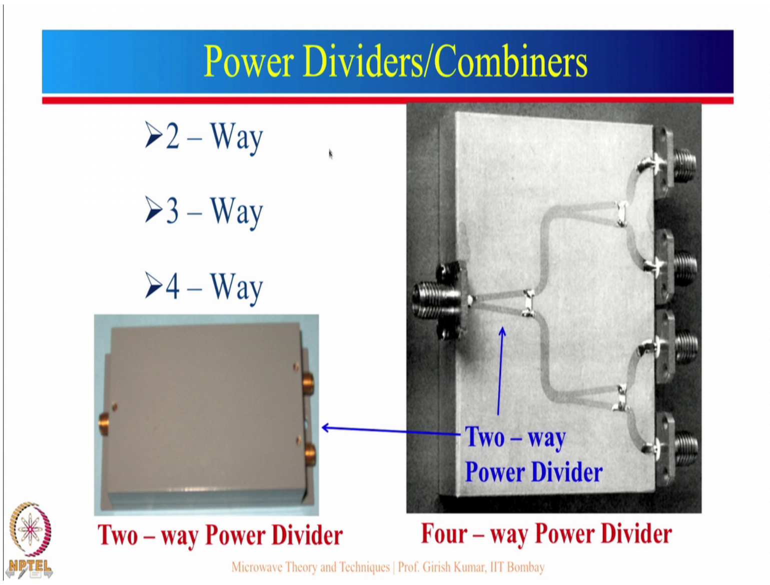

Then we will talk about power dividers and combiners there can be two-way power divider three-way power divider four-way power divider it can be even eight way or sixteen way also, but just to show you something simple in the way that two-way power divider if you see from here so, from this point, if let say we give the input. So, half power will go here half power will go here; what is this over here this is actually known as isolation resistant. So, if you just look at only this particular portion and that has been realize at a different frequency over here.

So, you can see that there is a SMV connector here and this is SMV connector at the output side and in between this particular thing has been designed at a higher frequency, this has been designed at a lower frequency. So, hence size is large, but this one here instead of a two-way. Now each two-way is further divided into two-way power divider. So, it basically combination becomes one is input and this is a four-way power divider, now if these things are designed properly.

Then a power divider can also act as a power combiner; that means, suppose if we fit the power at these 4 ports we can get the output over here. So, the general concept is suppose if I fit let us say 1 watt, 1 watt, 1 watt, 1 watt, ideally I should be able to get 4 watt of power and when we discuss power divider combiner in more detail I will tell you what are the real things we get.

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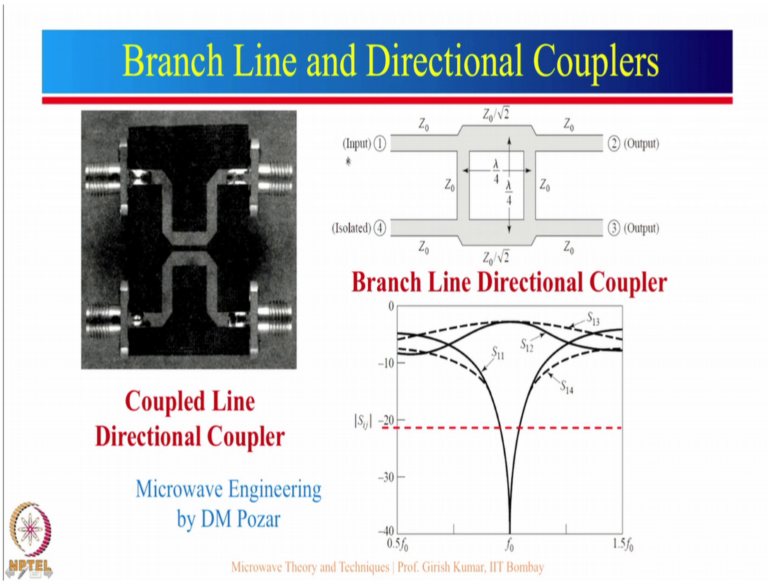

Then we will talk about the branch line and directional coupler. So, what you see that picture over here, you just imagine here, this is a 1 micro strip line which is going over here. So, we are feeding this input and this is the output. Now, what has been done here; another micro strip line has been put which is gap couple to this particular line now because of the fringing fields along this particular line part of the power gets coupled.

So, now I am sure you know the concept of that suppose if I fit the current like this here then the induce EMF will be coming like this. So, that is that primarily principle of this particular the additional coupler. So, we fit the input here that is a power goes here part of the power gets coupled and that poles over here and this is known as isolated pole and these couplers are generally go to for.

Let us say 10 dB coupling, 20 dB coupling, 30 dB coupling; now 10 dB coupling actually is not plus 10 dB. In fact, that is just a nomenclature in a reality; what we would get minus 10 dB or minus 20 dB or minus 30 dB theoretically output power here should be 0 which go response to minus infinity dB. But, when we talk about this we will see what practically, we get now since this particular coupler is more applicable for minus 10 dB or minus 20 dB or minus 30 dB coupler and if we want a strong coupling. So, what do we do to get a strong coupling these lines are connected.

So, over here you think about again, we have a one through line, then there is another line and these 2 lines are connected with 2 lambda by 4 line. So, these are known as branches hence the name is branch line directional coupler and this particular branch line coupler has been design such a way that suppose if we give a input here half power comes here half power comes here and theoretically no power goes over here. So, one can actually see that that centre frequency power couple to this put is very very small. So, what you see over here is a reflection coefficient at this put here and what we see here and here is this particular plot here. So, you can see the power going to these 2 port is equal.

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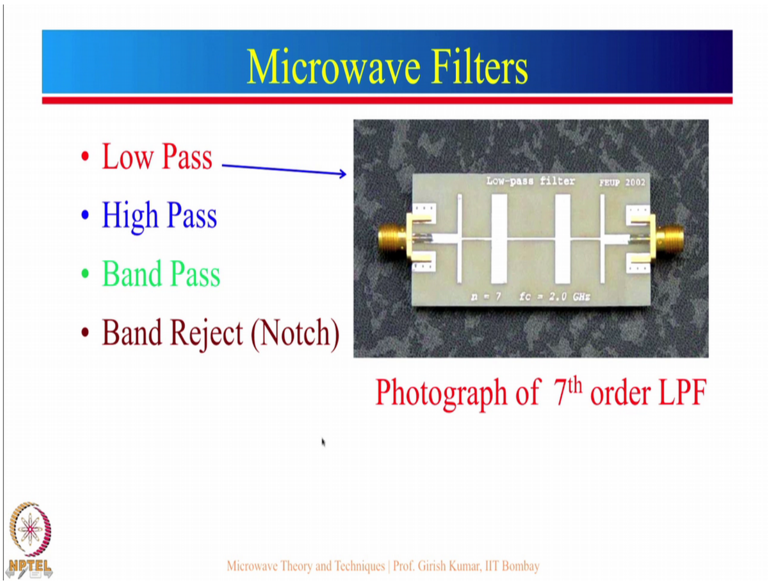

So, we will talk about different type of filters; low pass filter, high pass filter, band pass filter, band reject filter which are also known as notch filter. In fact, these band filters are also known as band stop filter also. So, generally a low pass filter what require inductor capacitors and so, on, but when we do the micro strip realization as you can see over here. So, all you see the bottom part here is actually speaking a complete ground plane and what you see on the top is just these micro strip lines edged and these micro strip lines just to tell you.

So, this particular line here this represents capacitance this represents inductor, this is a capacitance this is a inductor capacitance inductor capacitance. So, here these are the inductors which are series inductor and these are the capacitors which are actually shunt capacitor because these things provide capacitance between this and the ground play. So, this is the photograph of the 7th order low pass filters.

So, as you can see that at micro wave frequency realizing low pass filer is very very simple, you do not need inductor capacitor and so on and we will tell more things about other filters when we discuss filters in detail.

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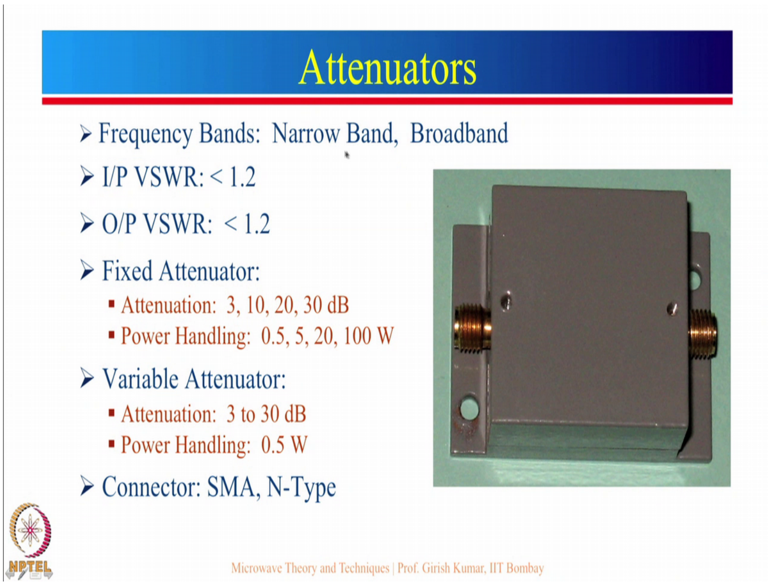

Then there are different types of attenuators are there are narrow band attenuators broad band attenuator. So, what is the purpose of the attenuator? Attenuator basically attenuates the signal. Now you might wonder why should be attenuator signal, I tell you the reason. So, attenuator will be something like opposite of amplifier in amplifier we amplify the signal in attenuator we actually attenuate the signal or reduce the signal. So, there are types of attenuator like 3 dB, 10 dB, 20 dB, 30 dB and so on. So, these attenuators find lot of application specially many a times, these I use at the input size where you actually have an attenuator. So, that it will act to more like a gain control.

So, that you can get a fetch thing it can be even connected at the output side. In fact, many a times attenuators are also use specially these high power attenuators we are let us say we have a power amplifier which is giving a output of 20 watt. And we want to measure is it really 20 watt and let us say, we connect that amplifier output to at the rate spectrum analyser or let us say network analyser. Now, spectrum analyser or network analyser generally, they are design for maximum 100 milli watt of power. So, if we actually put 20 watt power.

Those input receivers of these equipment will burn. So, what you do? Let us say we have a 20 watt power and if we actually give let us say a 20 dB attenuator would mean, it will attenuate by 100 type. So, 20 watt output will actually become 0.2 watt or we can use 30 dB, then 20 watt will actually become 0.02 watt and that is safe to give to either a spectrum analyser or network analyser. So, there are fixed type of attenuators, these are the variable attenuators and as I mention. That variable attenuators are actually use for gain control.

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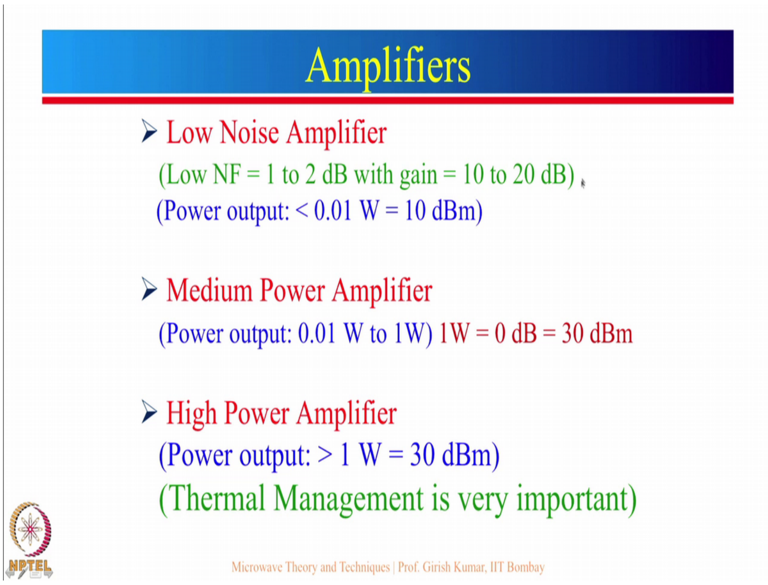

We will talk about several different types of RF amplifiers. So, here we have a loan wise amplifier most of the time these low noise amplifiers will be the first amplifier at the receiver end because at the receiver the signal received is generally very very small and just to give you an idea how small it is. So, let say for fm radio the input signal could be few microwatt whereas, for mobile phone.

The input signal could be nano watt or even pico watt are even smaller. So, we really need a low noise amplifier. So, generally we define an amplifier by its noise figure and that can be 1 to 2 dB. However, now recent technologies are coming where noise figure even less than 1 dB is possible and the gain should be typically 10 to 20 dB. After this low noise amplifier, there are more amplifiers come into picture.

So, we have a now a medium power amplifier typically a medium power amplifier would have a power output of 0.01 watt to 1 watt other value 0.01 watt also corresponds to 10 milli watt to not say one thousand milli watt and here we just want to convert into dB. So, 1 watt is actually 0 dB, but this is also defined as 30 dBm. So, this m is with respect to the milli watt power now high power amplifier in general I define power output should be greater than one watt and one watt is equivalent to 30 dBm now 4 high power amplifier.

Thermal management is very very important. In fact, when we design some of these high power amplifiers like 10 watt, 20 watt and so on in the beginning we did not take percussion of thermal management and we ended up burning lot of power amplifiers and these are not cheap. So, the cost lot of banning; so, one has to really plan properly about the thermal management 0.

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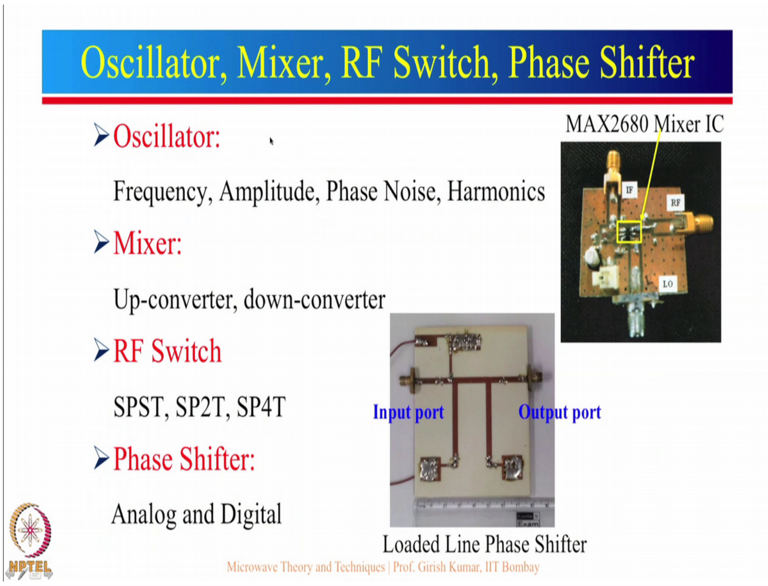

Then we will talk about the various other things which are integral part of any RS system. So, oscillator you can thing oscillator as nothing, but also a microwave generator and we are talking about a microwave generator, there are different things which are important what is the frequency at which it is oscillating of course, there are other things are there which are known as VCO voltage controlled oscillator.

So, basically voltage control oscillator will give us variable frequency output then oscillators are governed by what is the output amplitude and generally, it is preferable that output amplitude remain same over the frequency range of operation and then of course, oscillators are also characterized by what is the phase noise.

And what are the harmonics. So, in general harmonics level should be 20 to 30 dB down. So, if you recall the Fourier series. So, if a wave form is not a perfect sign wave, then it will have second, third, fourth, fifth, sixth harmonics. So, we want a perfect sinusoidal wave form and for a perfect sinusoidal wave form there will be no harmonics; however, nothing is perfect. So, there will be some harmonics.

So, we want these harmonics to be as small as possible then we will talk about mixers mixers basically what we do in the mixer we give to input signals and you can see over here a simple configuration here. So, there is a RF signal and there is a LO signal. So, what are these? So, RS signal is the input signal and LO is the local oscillator frequency and if we do that if mixer generates basically sum and difference of these 2 frequency. So, if you use sum it is known as up converter if you use the difference then it is known as down converter and most of the time this down converter frequency is known as if frequency or inter mediate frequency.

Now, many a times, we need RF switches. So, you can think in a simple way RF switch can be in very simple way just like the way you switch on or off a light and that particular on and off is actually something similar to SPST single pole single throw. So, basically this particular switches are actually use so, that you can switch on or off. So, let say whether the power should go or it should not go then we have SP2T, this is known as single pole double throw SP4T; single pole 4 throw. So, the purpose here is that the input will either go to one put or the input will go to the other put.

And in this particular case the input may go to port number 2 or 3 or 4 or five and then we need phase shifter. So, phase shifters can be analogue or digital phase shifter and these phase shifters can be realize using diodes it can be realize using transistors, it can also be realize using RF MEMS. So, here is one of the picture of a loaded line phase shifter you can see here this is the input put and this is the output put. And we can actually you know get the phase difference by switching on or off in case of the digital, in case of analogue we can vary; let say a vector diode which has a variable capacitance and then we can have a phase shifter because of that.

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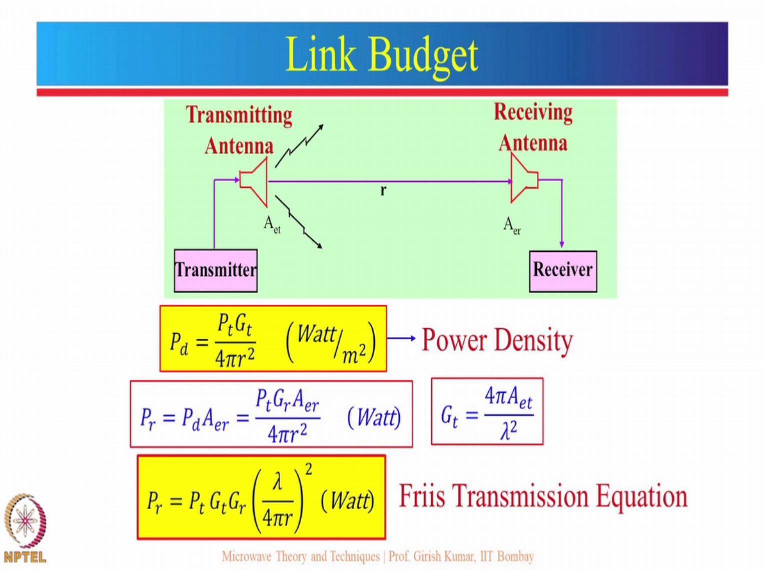

Then before we look into the microwave system we have to looked at the link budget it is very very important before you even think about designing any microwave system. So, we must actually speaking look at the link budget. So, what really is a link budget let just look at one by one things here. So, here is a transmitter.

So, this transmitter we have just talked about transmitter block diagram. So, the transmitter consists of that entire block diagram which is connected to the transmitting antenna and let us say now, the wave is propagating. Now, we have a receiving antenna or receiver antenna and this receiver antenna then goes to the receiver and we need to cover let say from here to here distance r. So, what we need to do we need to see the derivation how we define this will. So, the derivation is actually given by Friis transmission equation.

So, over here fist of all, let just look into the, what is the power density at this particular distance over here. So, power density at a distance can be found by what is the transmitted power. So, the power transmitted is symbol is P t and then what is the gain of the antenna multiplied by that and divided by 4 pi r square; So, just to tell you let say we want to transmit A power P t and in that beginning let say if you are transmitting the power P t. So, this whole power may go in all the direction. So, if I actually look at the spherical area. So, the area of the spare is 4 pi r square; so, power transmitted divided by 4 pi r square will be the power density now we are going to transmit this within antenna.

Now, antenna has a gain the gain can be 2 dB or 10 dB or 20 dB or 30 dB depending upon type of the antenna and this particular antenna will transmit the signal in this particular direction. So, in order to find out the maximum power transmitted in this particular direction, we multiply with the gain G t. So, that is the power density.

Now, the received power will basically now receive the power in terms of power density multiplied by what is the aperture area of that particular received antenna. So, the power received by the antenna will be equal to nothing, but power density multiplied by the aperture area and there is a relation between aperture area and gain of the receiving antenna. So, that particular relation is given over here and the relation is that gain is nothing, but equal to 4 pi A by lambda square.

So, if we substitute the value of A over here. So, this is what would be the power received and this whole expression is simplified over here. So, what is power received is nothing, but P t multiplied by G r into G t and then within the bracket lambda by 4 pi r square so; that means, power received at a far away distance depend upon the transmitted power. So, larger the transmitted power larger will be received power it depends upon gain of the antenna.

So, larger the gain larger will be the power received and it depends upon the frequency is coming in the form of lambda so; that means, if frequency is high lambda will be small so; that means, power received will be reduced and r is the distance. So, you can see that that if r increases power reduces by r square factor. So; that means, instead of 10 meter, if you go to 100 meter power received will be reduced by 100 times. And if you go to kilometre compare to 10 meter power will reduce by 100 square which is 10,000 times.

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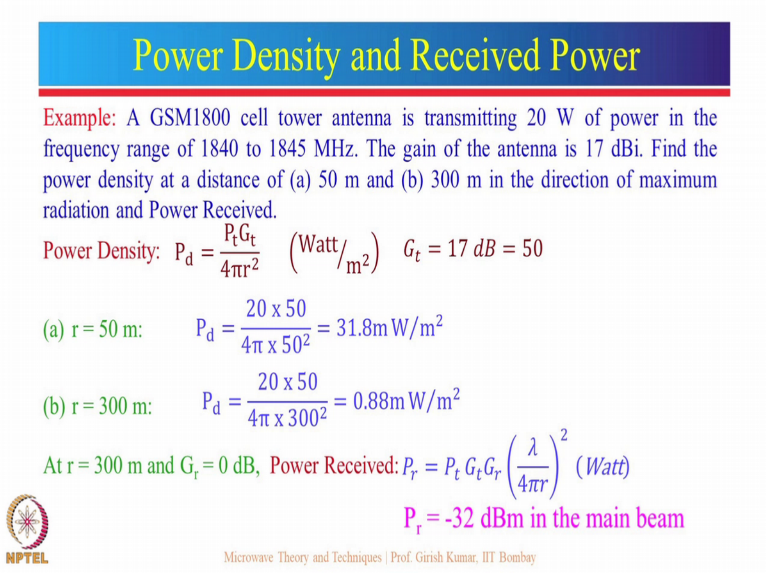

So, let just took one practical example. So, practical example here is a GSM cell tower is transmitting 20 watt of power in the frequency range of 1840 to 1845 megahertz, I just to tell you in India, we allow these seller operators to transmit 20 watt of power typically the gain of the antenna at this particular frequency is about 17 dBi. So, what we want to do we want to find out the power density at a distance of 50 meter and at a distance of 300 meter in the direction of maximum radiation and what is the power received at that particular distance.

So, power density formula we already have just looked into the derivation and here 17 dB gain is nothing, but numerical value is equal to 50. So, we substitute the value of 50 in the previous thing. So, we can now calculate P d at r equal to 50. So, P d will be nothing, but a 20 which is the transmitted power into 50 which is gain of the antenna and divided by 4 pi r square. So, r is 50. So, that gives us a value of 31.8 milli watt per meter square and for r equal to 300 meter, instead of now 50 we write 300. So, at 300 meter distance the power density received is 0.88 milli watt per meter square.

So, now just to tell you there are various studies are there all over the world. So, there are some study for example, there is a Austrian medical association which actually says that even 1 milli watt per meter square is not safe for 24 hours exposure whereas, in India we have the radiation norm of 450 milli watt per meter square. So, when I talk about the radiation health hazards.

I will cover these points in more detail, but let see what is the power received at a distance of 300 meter and we talk about the distance now we have to also look at what is the gain of the antenna. So, here I have assume the gain of the antenna to be one which is equal to 0 dB and in that case, we can say what is the power received as you can see in the main beam power received is going to be minus 32 dBm.

So, one may think this is small power which is in the true, but; however, this is a very large power for reception of a mobile phone mobile phone typically will give let us say mobile phone has these bars one 2 3 4 5 bar. So, actually speaking even at minus 70 dBm, it shows full strength and it works even at minus 100 dBm. So, if you not take the difference between 32 dBm and 100 dBm if I just say approximately 70 dB 70 dB actually implies the 10 million times.

So, this particular signal is 10 million times more stronger, then what mobile phone really is required? So, why people transmit more power because. So, that taken cover large distance, but because of this people leaving in the close vicinity of the tower are developing lot of health problem: what are those health problem; you will see it after couple of lectures. So, just to summarize today, we will looked at various microwave components which are used in a given system.

And then we also looked at the link budget. So, which is very very important a few more things I want to tell about link budget the link budget equation which I have given to you it is valid only for free space. So; that means, you are transmitting the signal receiving the signal there are no hindrances in between, but if there are any other objects coming in between or if the weather conditions are not good.

For example, if it is raining heavily. So, rains will provide some attenuation. So, we have to when we do the link budget we always actually speaking keep a gain margin of about 10 dB and this is universal situation that where for the verse case situation you do it. In fact, you have notice also many a times when you are watching a cable TV and these days, we are using a 11 gigahertz receiver. So, in that case, you might have notice that when it is raining heavily you may not get the TV signal properly the main reason is because rains will attenuate the signal and hence the received power reduces.

So, one has to provide a little better gain margin in those cases which should take care of the rain attenuation also. So, we will just stop at this particular point, but with just a brief thing that in the next lecture we will look about several microwave system.

So, the whole concept is that you get a little bit over view of various components and you look at what are the different systems and that will motivate you go through the entire theoretical process. However, in this course, I would like to just mention that my logo is that theory is very important to solve practical problem. Also we are going to emphasis more on the design part so, that you can actually speaking work on the real product and see how these products can be designed.

So, thank you very much, we will see you next time, bye.