Microwave Theory and Technology
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Module - 02
Lecture - 09
Transmission Lines – I: Coaxial Cables, Strip Lines and Microstrip Lines

Hello everyone. Today, we are going to talk about different types of transmission line such as Coaxial line, Strip line, Micro strip line and Rectangular wave guide. You have already heard about different modes in the parallel plane or in the wave guide. So, but today, we will focus upon the practical aspects of these transmission lines. So, let us start with the coaxial cable, I am sure all of you are aware about coaxial cable.

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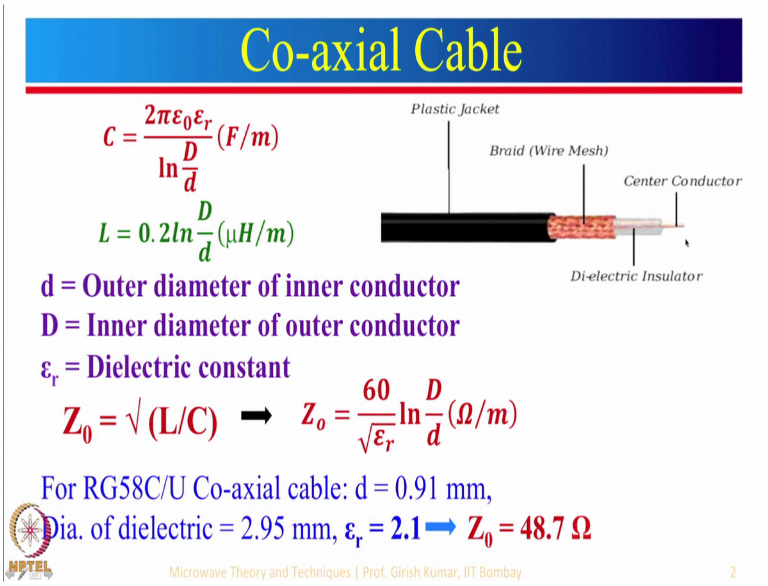

So, a coaxial cable has a center conductor over here on the center conductor, there is a dielectric insulator and then on top of that; there is a it actually shows here braid wire mesh that is not always necessary. It can be just aluminium thing also aluminium rap or it can be a copper file along this one here and then this is actually put on the top is a plastic jacket which insulates the whole thing. Now for this coaxial cable, we actually can define capacitors, we all know that you know that you know that there is a center conductor and we have a metal along that; then this will have a coaxial capacitance.

So, that capacitance is given by this particular formula where epsilon r is the dielectric concept of this particular insulator. Majority of the time this insulator is of teflon material which has epsilon r equal to 2.1. However, there are some low cost coaxial cable where they use plastic as this dielectric material; however, I do not recommend that because plastic is relatively lossy. So, what happens? There are more losses in the coaxial cable; of course, there are some other materials also. In fact, many a times, people do use foam here also and foam has a epsilon r equal to 1.05 up to 1.1 and the foam has an advantage that it has very low dielectric loss.

Now, any wire here will have an inductor so, the inductor of that is given by this particular expression. Now these things; you might have studied in your electro static course or electromagnetic course; what we are interested today here is what is the characteristic impedance of this particular coaxial cable. Now, characteristic impedance of a lossless line is given by square root L by C. In fact, otherwise if it is a lossy cable, then the expression will be something like r plus j omega L divided by G plus j omega C. So, if r is 0 and G here is 0, then j omega will cancel and that gives right to Z 0 equal to square root L by C. So, L expression is there C expression is there, we take the ratio.

So, this is the expression for characteristic impedance. So, let us see; what is this really expression all about. So, you can see that epsilon r is in the denominator; that means, if epsilon r increases then Z 0 will decrease and Z 0 is also you can see that as the outer diameter increases or if the inner diameter decreases, then also characteristic impedance will increase.

So, just to give you some practical application or the just to give you practical example of one of the coaxial cable which is RG 58 C slash U coaxial cable and show you the detail data sheet in the next slide, this has the internal diameter of 0.91 mm and diameter of the dielectric is 2.95 epsilon r is 2.1. So, that gives raise to Z 0 equal to 48.7 ohm that this is known as a 50 ohm coaxial cable. So, you might wonder; why this descript and see the reason for that is that when this copper mesh or this particular copper file is put here, there may be a small air gap over here in between which will give rise to a slightly higher impedance value.

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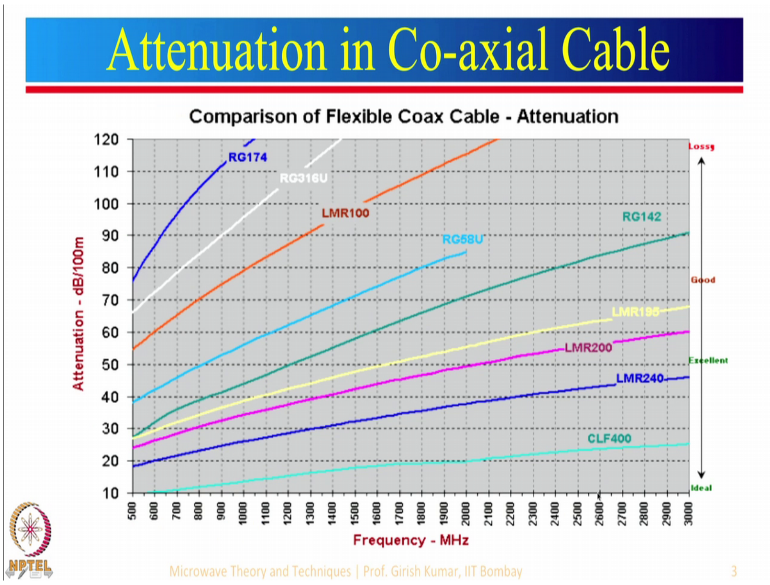

So, let us see different types of the coaxial cable and what are the typical attenuation here. So, what we have here along this axis we have frequency variation. So, one can see here this about 500 megahertz going all the way to about 3000 megahertz or you can say 3 gigahertz and along the vertical access, we have attenuation in dB per 100 meter.

So, if we now look at this particular cable RG 174, you can see that this has highest losses among all of these thing yet this is being used one of the main reason is this is very very thin. So, one actually use this particular thing at thin line wherever weight is important, but otherwise you can see if I just look at it here attenuation dB per 100 meter.

So, for 1 meter attenuation will be of the order of say 1 dB at this particular point and that frequency is around 750 megahertz. And, you can see that they themselves do not recommend that you use this particular cable at very high frequency of even, let us say 2G, 3G, 4G, even Wi-Fi which come somewhere over here. But yet, this particular thing is being used in GSM module as well as GPS module because, there the wire length may be of the order of 10 to 20 centimetre.

So, now let us see the example which I gave that is RG58 right over here, you can see that at about 2 gigahertz, if you see this value here that is close about 85 dB per 100 meter. You can see that these are different different things over here and that would give rise to a much lower; you can say attenuation loss in this particular cable. Now just to give you little bit idea about the prices, typically this RG 58 cable may cost about something like 10 rupees per meter depending upon the quantity.

But it may even cost 100 rupees a buy a smaller quantity. For example, if you want to buy just 1 meter cable, they may charge you anywhere between 50 to 100 rupees. And some of these other cables are very expensive just to mentioned a few years back, we actually bought a network analyser which works at milli meter wave frequency up to 40 gigahertz and for that for coaxial cable for 1 meter, they charges about 1000 dollars. So, you can see that how much price variation can be there depending upon the quality of the coaxial cable. So, it would be a really good idea if any one of you wants to become an entrepreneur, the coaxial cable requirement in India is huge and in the other countries.

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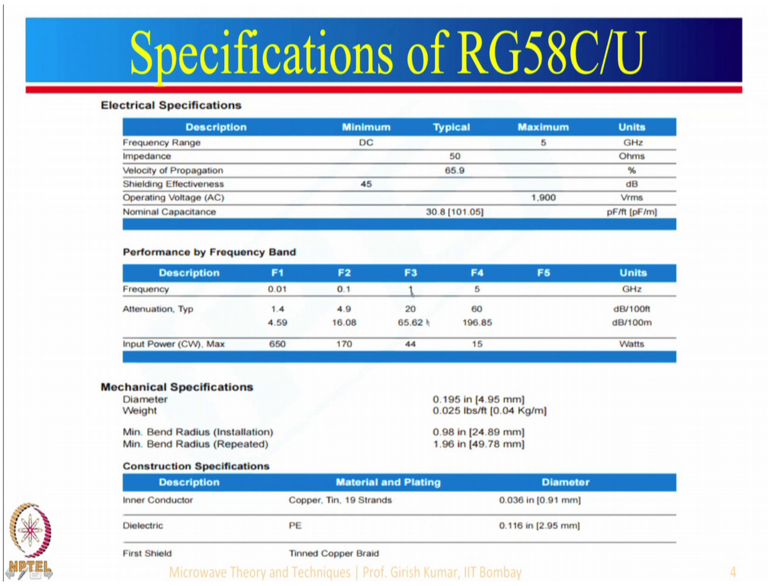

Now, for this co-axial cable, let us see; how the data sheets are define. So, this is RG58 and just to mention from where I took all those numbers. So, you can actually see here mechanical specification diameter is given which is 0.195 from there I have taken the value, it also gives us what is the weight of the coaxial cable per feed, it also mentions about what are the power handling capacities and so on.

So, it is very important before you use these cables for specially commercial use, you must study the data sheet properly and see what are the limitations of that particular cable. Now, these cables cannot be used by itself they have to be connected by different types of RF connectors. So, they are many connectors which are popular.

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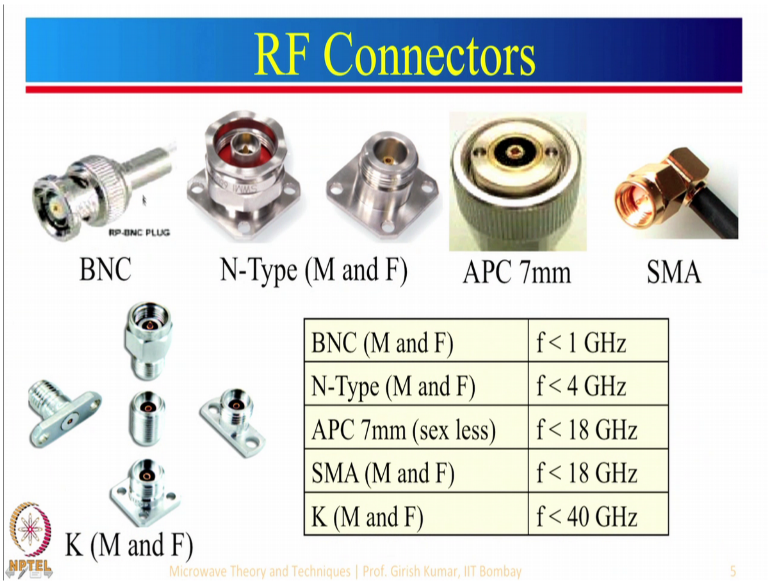

So, the let us start with this here BNC connector, generally these connectors are good up to about 1 gigahertz and. So, one should not really use this type of connector for frequencies greater than 1 gigahertz, then there are N-type connector just to tell you N stands for navy.

So, from the navy, it came and this one also has male and female type. So, these type of connector are female type and this is actually a male type connector and typically N-type connector can be use up to 4 gigahertz. However, there are some good quality expensive N-type connectors which can be use up to about 18 gigahertz a few other things I just want to tell. So, that you also think about the making of this whole thing. So, you can see that this is the outer body over here in between you can see there is a copper center conductor and around that little bit white you can see over here and that is nothing, but suppose to be teflon.

Now, if you just use a normal co axial center conductor then there will be a problem that if you use the connector several times this actually spreads out. And then if this spreads out, then when you make the connection it is not going to be a tight connection there may be a slightly lose connection and then if you do that you will actually see that lot of power is getting loss the signal is not going from point a to b and there may be a loss of 1 dB, 2 dB, or even 10 dB if the things are not proper. So, what you can do if you this thing take a nose player and the thing which has spread out you tighten it, there is a alternate option is also there that instead of using copper as the center thing here you use beryllium copper beryllium copper has a much better elasticity and in fact, that is what is generally used in a better quality connector.

So, you can actually have this thing connection open close open close especially for the laboratory things where you may be doing this connection opening and closing several time this is highly recommended now these type of connectors APC, there also know as sex less connector; In fact, when I use the network analysers almost 4 decades back these network analysers would come with these APC connectors, but nowadays these type of connectors are more prevalent. And then smaller version of this is known as a SMA connector and these SMA connectors again come in the form of male and female connectors.

And these are generally good up to about 18 gigahertz and then if you want to work at milli meter ways, we have to use K connector again in K connectors both the male and female connectors are there and these can be used up to about 40 gigahertz of frequency again just to tell you the typical price. So, these N-type connector may cost anywhere between 1 to 5 dollar or if you want to convert into rupee, it may be anywhere between 50 rupees to even 300 rupees SMA connectors again, it may cost 1 to 5 dollar or between 50 to may be 1 or 200 rupees, but this K connectors to the best of my knowledge nobody is making these K connectors in India as of now.

So, if you are going to import these K connectors this will cost anywhere around twenty dollars or so. So in fact, you can see that it is very small and material cost will be very small. So, all you require as a precision CNC machine and you can do the fabrication all that design details are generally available, you can just do the Google search and you can get all these dimension.

So, all you need is a good mechanical engineer and who is familiar with the CNC machines operation and in fact, these days lot of good software's are available; one of the familiar one is a solid works, you can use that which will draw all these 3D things and that will go straight way to CNC. And you can get these connectors any one of these connectors and if you make these connectors yourself, it may not even cost more than 20 to 30 rupees per connector.

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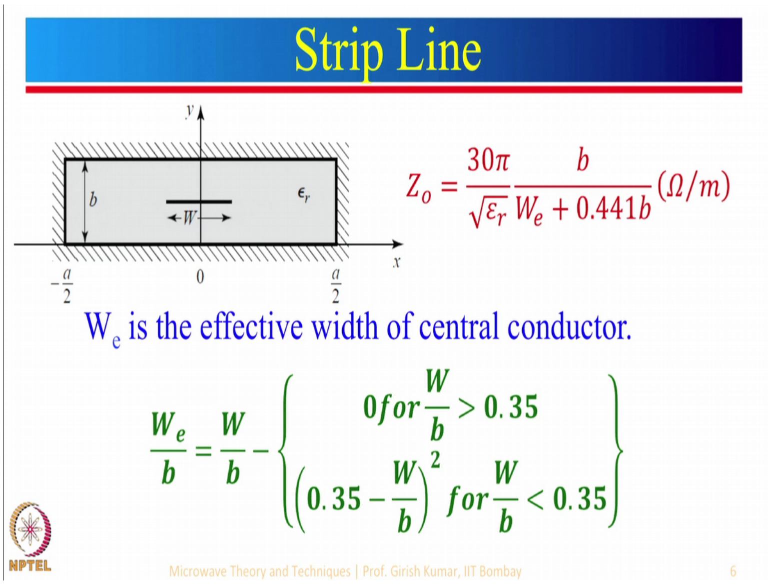

So, now from the coaxial line, let us talk about strip line. Now what is a strip line? Just see over here, there is a one; you can see here rectangular shape shown over here. So, this is a ground play, this is a aground play and sometimes, the side may also be grounded specially when somebody puts a box around this thing, normally, this may not be there the strip line configuration is with this and with this, but of course, these 2 have to be grounded.

So, what we really have here this is a strip here to understand this particular strip line configuration let us just talk about again coaxial cable. So, the coaxial cable what we have this is a circular 1 and there is a center conductor now you make the center conductor very flat which is represented by this line here very flat and then the circular one you make it rectangle. So, this is flat now flat and this is close here.

So, you can see that the strip line is somewhat similar to a coaxial cable; however, all the design equations as slightly different and another thing is that these strip lines are printed on a dielectric substrate. So, what we have here there is a substrate over here and from that substrate, you print this particular line and then you take a another substrate put on top of that and then we have to ensure that when you put the 2 layers together, there should not be any air gap.

So, you really have to tightly clamped from the top and the bottom side. Now for this particular strip line, the characteristic impedance formula is given by this particular thing over here. So, you can actually see that again Z 0 is inversely proportional to square root of epsilon r and also if W increases, then Z 0 will decrease. So, this is the expression this W is really here is W effective why W effective because there will be some fringing fields from here.

So, because of the fringing field there will be fringing fields here effective W is slightly greater than W. So, W effective is given by this particular expression. So, here is the W which is the physical dimension depending upon the value of the W you have to use either this or this particular thing. But now, these days strip line instead of using strip line people are actually preferring to use micro strip line, I will tell about what is a micro strip line, but first let us just look at what are the different types of substrate use for these strip lines or micro strip line.

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Microwave Substrates

Substrate	ε_r	$\tan\delta$	Manufacturer
Foam	1.07	0.0009	Many
PTFE (Teflon)	2.1	0.0004	Many
RT5880	2.2	0.0009	Rogers
R03003	3.0	0.001	Rogers
R03006	6.15	0.002	Rogers
R03010	10.2	0.0022	Rogers
R04003	3.38	0.0022	Rogers
TLC-32	3.2	0.003	Taconic
DiClad 870	2.33	0.0014	Arlon
Glass-Epoxy	4.4	0.02	Many

Substrate Thickness = 1/64", 1/32", 1/16", 1/8", 1/4"

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So, these are the different types of substrate for example, foam substrate is there which may have a epsilon r anywhere between 1.05 to 1.1 typical vale is 1.07 and the tan delta is small you can see 0.0009 and there are many manufacturers I did mentioned about teflon which is used inside the coaxial cable.

So, epsilon r is 2.1 tan delta is 0.0004 and gain there are many manufacturer; however, what are more popular these days are these substrates most of these are available from Rogers; Rogers is again not an Indian company and these substrates are in general very expensive for example, RT5880 this has been approved for space application and I will also mentioned about the low class substrate first which is a glass epoxy substrate this is the typical substrate which you will see inside your mobile phone or inside laptop and other thing. So, typically for that epsilon r is 4.4, but you can see here tan delta is 0.02 and there are several manufacturers in the world, but compare to glass epoxy substrate all these substrate may be 30 to 50 times more expensive. So, you have to now decide what is the application.

So, most of the time for commercial application we use glass epoxy substrate and for the defence and space application where performance is really very very important cost of course, is important, but one can pay more cost to get a better performance. So, you can see that there are different types of substrates are there epsilon r 2.236; 10, 3.38, of course, there are other competitors also Taconic there was another competitor Arlon.

But now, Arlon has been bought by Rogers. So, competition has really reduces and these substrates the standard dimensions of these substrates are typically 1 by 64 inches or 1 by 32 inches or 1 by 16 inches 1 by 8 inches, 1 by 4; 4 inches. Now also, these substrates are available in different form, also sometimes, they also say 10 mil substrate; what is mil? M I L is milli inches. So, if I said 10 mil 10 mil is equal to 10 by 1000 inches which is 0.001 inches and which really corresponds to 0.254 millimetre.

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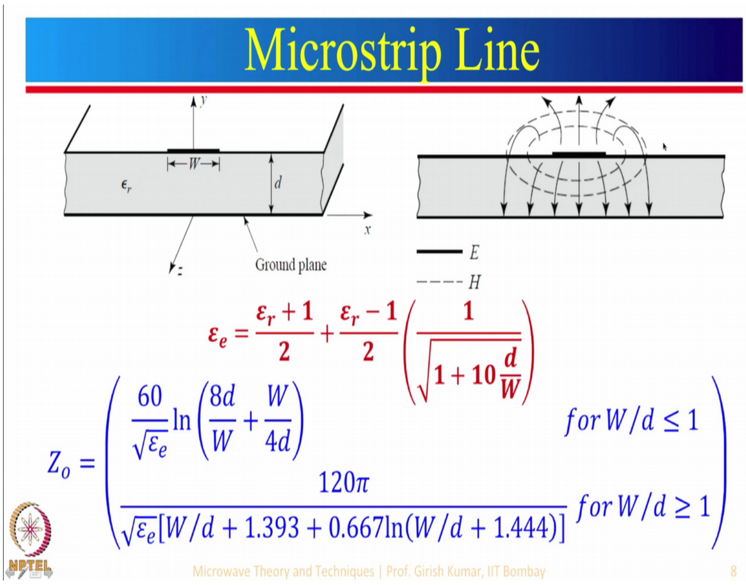

So, now let us just see; what is a micro strip line and then let me first tell; what are the differences between a strip line and micro strip line. So, in the case of micro strip line, we have a ground plane over here so; that means, you maintain the copper here and on the top you can see this I the line and this of course, line will be something like this.

So, just shows the only this part here, but this line will be something like this going here and then way will be propagating from here to this here. Now, in this particular case, what happens? The fringing fill is a shown over here, you can see that from this line, it just like a parallel plate capacitance. So, if I have a metal plate and I put another metallic plate over there will be fringing field and there will be a capacitance between the 2 plane.

So, one can actually see that these are the electric fields and you can see most of the electric fields are confined within the substrate material, but part of that is actually in the air and these are the magnetic field lines around the strip line over here. Now difference between micro strip line and strip line is that in the micro strip line, there is a only 1 substrate, there is a no top substrate, whereas, in strip line, there is a another substrate on top of that.

So; that means, strip lines will cost approximately double of the micro strip line because you need 2 substrate another problem with the strip line is that you have to mechanically align the to substrate with the bottom substrate. So, there should not be any air gap at all; of course, there are advantages of strip line that in that particular case, since we have a ground here and ground here the radiation leakage is very very small, but over here.

Now, there will be some radiation over here. In fact, this is where the difference comes. So, 4 micro strip line, we would like the radiation to be as small as possible, but there is a another type of things which is known as a micro strip antennas and in this particular course, we will talk about micro strip antennas also. So, in micro strip antennas we want most of this thing to radiate whereas, when it is a micro strip line we want very little to radiate.

Now, since part of the fringing field is in the air and the wave is propagating here little bit is in the air. So, now, instead of defining epsilon r, but now we have to actually define epsilon effective. So, epsilon effective is given by this particular expression over here and just to make things little bit quick simple here, suppose you have W is infinity.

That means, if this is very very large; that means, you can say that fringing fields are almost negligible. So, let us see what happens if W is very large if this goes to infinity this term will be 0. So, this will be one and this term here now if you see if we add that to epsilon e will become epsilon r. So, if W is very very large epsilon e will tend to become epsilon r now thing the other extreme case suppose if W is very small if W is tending toward 0 then this term will become infinity 1 by infinity will be 0.

So, this term will be 0. So, epsilon effective will be given by this particular expression, what this expression tells here that now epsilon effective will be average of the 2 medium. So, below it is epsilon r above it is air. So, epsilon effective will be epsilon r plus 1 by 2, but in reality W will never be equal to 0. So, you can in general say that epsilon e will be slightly less than or equal to epsilon r value. So, now for a given value of W depending upon whether W by d what is d here? d is this particular depth over here, but later on I am also going to use another symbol which is H. So, H is height of the substrate. So, please do not get confused because different books use W by d or some other books used W by H.

So, you should be familiar with both that things. So, if W by d is less than or equal to 1, you have to use this expression to find the characteristic impedance and if W by d is greater than 1, then use this particular expression. Now, here the advantage of this particular thing is that you can design a micro strip line for almost any characteristic impedance theoretically practically; you can design these micro strip lines for characteristic impedance from 10 to 15 ohm up to 150 or 200 ohm. So, you can actually design this micro strip line in wide variety of the cases. Now this is known as a analysis equation where W is given d is given.

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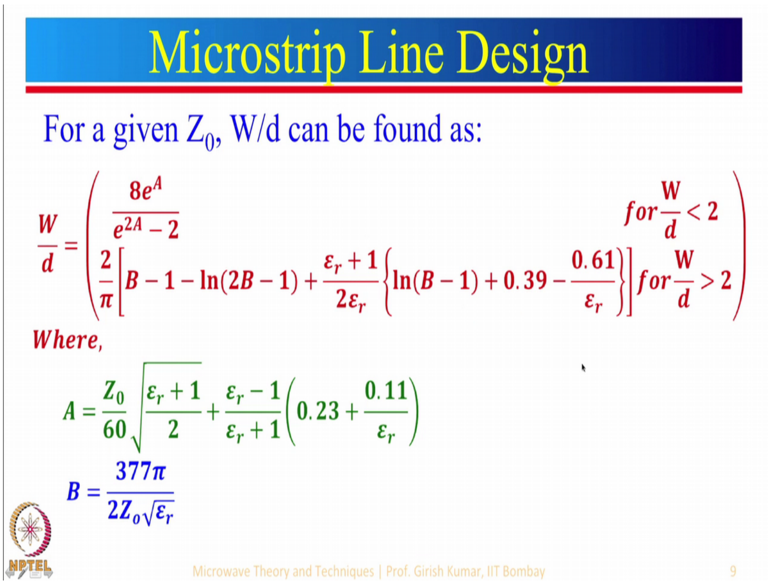

Now, many a times, you may be actually asked that for a given Z 0 which could be 50 ohm or hundred ohm find out the value of W by d and generally speaking you will chose the substrate. So, as I had mention there are substrates of different epsilon r and these substrates are available in different thicknesses. So, you are going to chose the substrate thickness and substrate and then for that particular case we know d. So, we have to find the value of W. So, for a given Z 0, you can find W by d by using this particular expression. So, you can see over here that this is a little bit over here W by d less than 2 or W by d greater than 2.

Now you may not know, beforehand which one to be used. So, you have to us any one of this formula in the beginning and then check whether this is valid or this is valid and then you may have to use another expression and you can see over here the term A is there and term B is there. So, A is given by this expression and B is given by this particular expression

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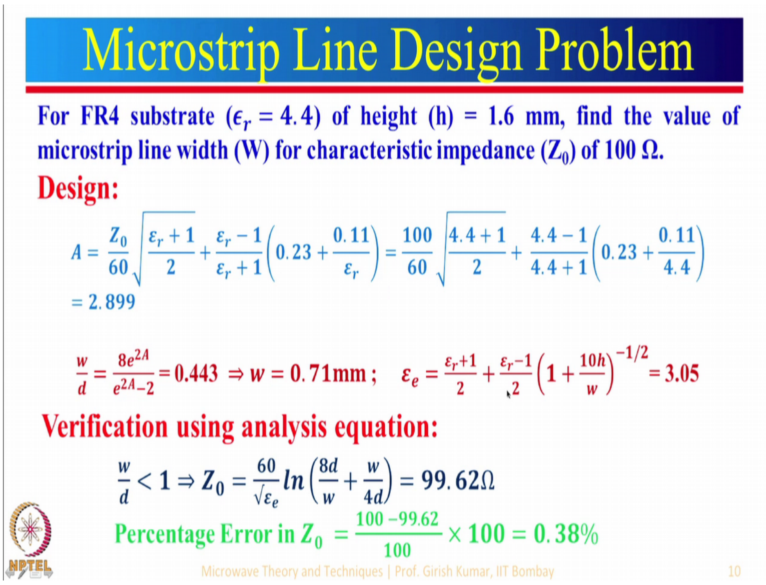

So, let me give you actually a micro strip line design problem itself. So, that you can do little bit practice for other value. So, here that design case, we have taken is for FR4 substrate epsilon r is 4.4, we have taken height as 1.6 mm which really corresponds to 1 by 68 inches. So, what we want we want to find the value of micro strip line width for characteristic impedance of 100 ohm.

So, here we find the value of a you can see that A is required for the first part we will just check it. So, A is given by this expression we substitute the values epsilon r as 4.4 Z 0 as 100, we do the simplification it comes out to be 2.899. And then, we find W by d which is given by this particular thing and here we can see w by t is less than 2; so, hence this particular formula is valid.

So, for the given value of d or we can say h as I mentioned, these 2 are same thing w is coming out to be point seven one mm and we have also calculated epsilon e here which is coming out to be 3.05. So, you can see that this value is definitely less than 4.4 and if I take the average if the width is very small, then what would have been the average value epsilon r plus 1 by 2 which will be 5.4 by to 2.7.

So, have W been equal to 0, this would have been close to 2.7; since W is relatively small this value is 3.05. So, let just verify this particular design thing, I have given you already that analysis equation. So, here we are just showing you that. So, w by d is less than one. So, we can use this particular formula and you can see this value conserve to be

99.62. So, really speaking this value is very close to 100, but if somebody is interested to calculate percentage error one can see that this percentage error is very very small.

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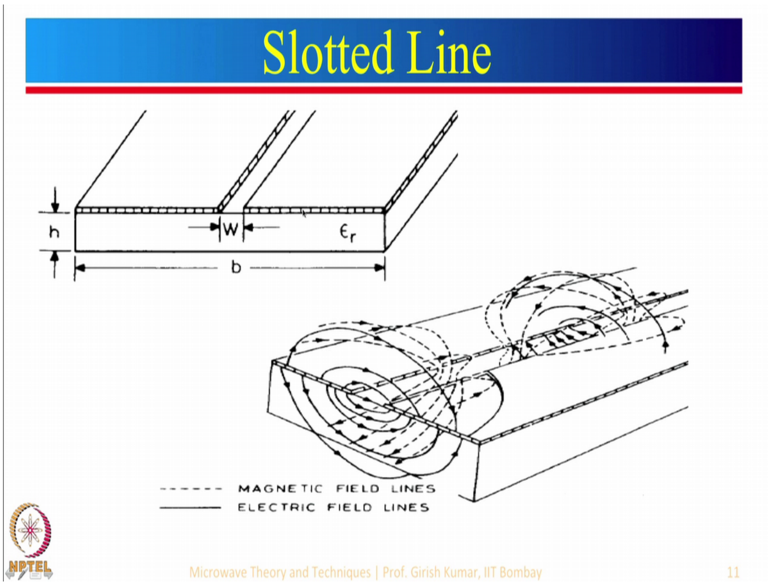

Now, there are variations are there in micro strip line also, there are something like known as a slot line. So, where basically a slot is cut and that is what acts as a slot line and you can see over here, these are the fringing field.

However, I generally do not recommend this particular thing specially for micro strip line application because there is a radiation leakage from this side as well as radiation leakage from this side so. In fact, slot antenna is a better option rather than using a slotted line because of the leakage and if there is a leakage then the power from point A to point B will not be going properly part of that will get radiated.

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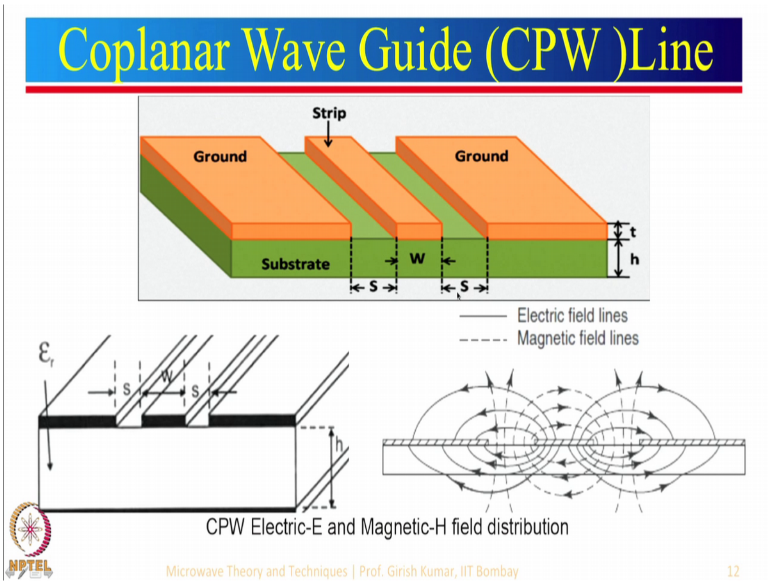

There is another variation also which is known as coplanar wave guide. So, in this case the difference between the micro strip line and this particular thing is let us first see the what is a micro strip line would be micro strip line, would have been just this particular width here and there would be ground plane down here. But in case of coplanar wave guide, there is no ground plane at the other side, now there are ground planes on either side of this particular thing over here.

So, now again let see what is happening you can see that there is a lot of fringing field going up and going down. So, I generally do not recommend again coplanar wave guide for micro strip circuit A because of the leakage here. However, it does have some advantages and that is why it is being use. So, for example, let say this is wave is going from point a here. So, let say B and we want to add some series or shunt component. So, series component can be very easily put.

So, what you do you remove this particular thing just out and you can solder the series component we want to put shunt component the shunt component can be easily put from here to here because this is ground or you can put between this center. So, component mounting over here is much more easier whereas, in case of a micro strip line what you need to do that ground plane is down here. So, putting a series component is not a problem, but if you have to put a shunt component the there are certain issues are there because now, one has to drill a whole here.

So, these days because of the plated through technology also known as pth things are become relatively simple. So, in a case of micro strip line what to you do you make this let say patch here and you have multiple pth here plated through whole and you can also have multiple plated through whole.

So, now, this ground is basically come through over here; so, this also acts as a ground play and then you can connect shunt component or you can connect series component. So, micro strip line in general has several of the advantages compare to some of these other thing. So, in this particular course most of the time we will concentrate on the micro strip line now micro strip line how we draw is also very very important. So, let us just look at 1 or 2 cases here.

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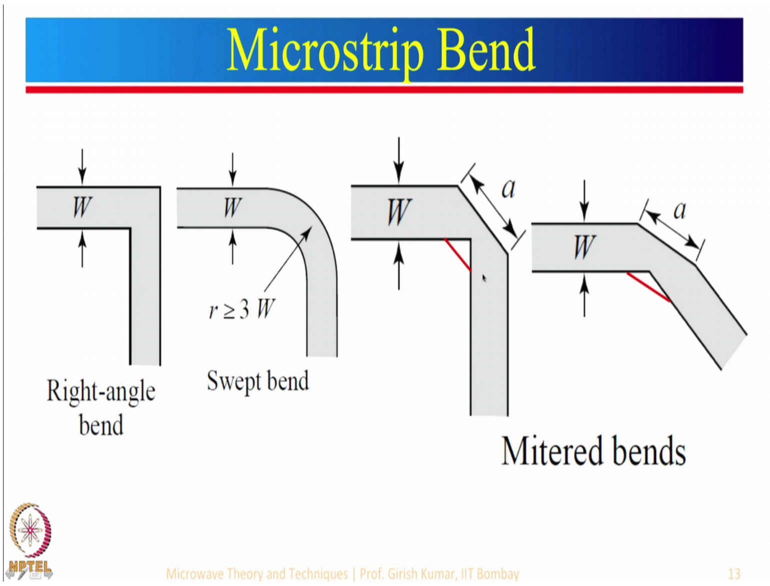

Let us say we want to use a bend in a micro strip line now one possibility is that we use right angle bend I generally do not recommend this particular thing. Because what happens the wave is which is coming through here it gets reflected from here part of that will go back and other thing will go there. In fact, some tends to understand current flow in these line you can actually thing about a water flow in a pipe. So, if there was a pipe over here and if the water is flowing like this there will be some turbulence over here. So, instead of using this if you look at your home most of the time if there is a bend they never use bend like this they always use something like this bend.

In fact, this kind of a configuration is highly recommended that when you are doing a PCB layout try to use as much as possible this kind of a bin inside of this; however, if you are not able to use this I strongly recommend you can use something like mitered bend just to tell you. So, this is what has been proposed in one of the book over here. In fact, you might remember that if I have a 45 degree cut over here at this angle, then what happens the wave comes remember the optical loss of the light comes here if it is a 45 degree it will reflect over here. So, this is something similar to that slightly more than 45

So, it goes here and comes here; however, I do not recommend this the reason for that is when wave is propagating it is actually let us say wave is propagating. So, field will be like this. So, now, the field is travelling like this and then field will be going like this and it will travel here. Now, at this particular point, you can see that it will see a much smaller width compare to this width over here and we have just seen that if width is decrease impedance will change. So, it is not going to see uniform impedance. So, this red line; I have added over here. So, I strongly recommend use particular thing wherever possible if you can use please use something like this here.

So, that you can see now the way which is travelling like this most of the time it will see approximately this particular W the same thing instead of 90 degree angle, let say the angle is different again and one of the book they have recommended something like this that I actually recommend that you use something like this over here. So, that you know that width seen by the this particular wave is almost uniform throughout.

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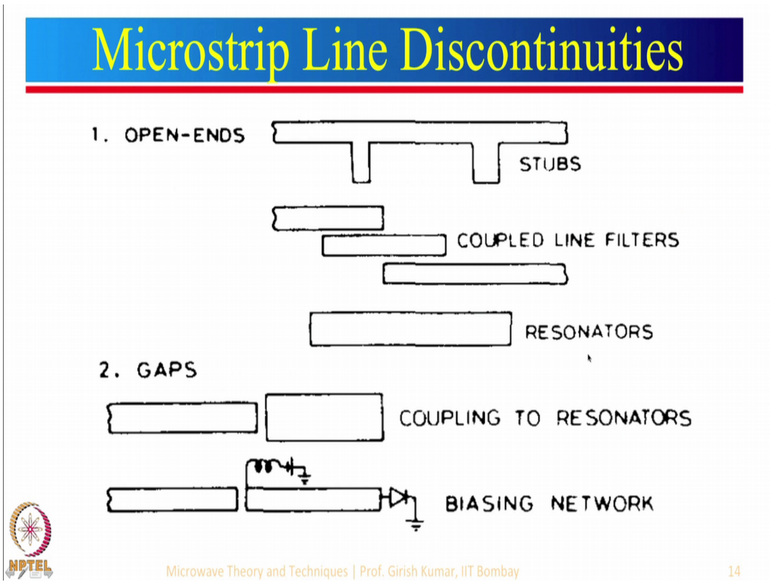

Now, let us also look at some of the other discontinuities. So, there are several micro strip line discontinuities are there like for example, there is a open end, we can see here that there is a microstrip line. These are the open end these are used as stuffs we will see later on all of these things one by one again these are the examples of open end you can see here that these are the open end, these are known as coupled lines, now there could be a open end resonators.

Now, there may be a gap between the different thing now these gaps can be represented by a capacitance. So, that can be used for coupling to resonator or that gap can be also used for biasing the network

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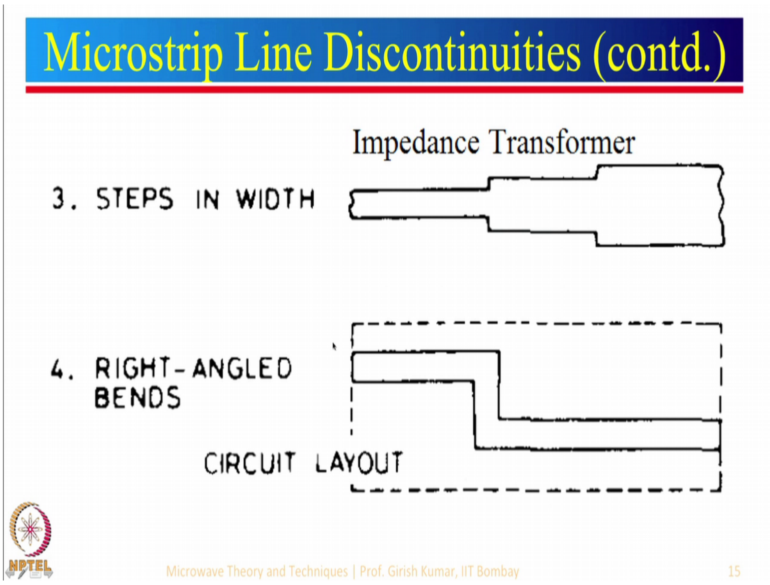

Let us look at some other discontinuities there may be a step in the width. So, for example, this may represent let say hundred ohm line this may represent. For example, 70 ohm line this may represent 50 ohm line and something like this is actually required for impedance matching now it just shows right angle bend, but as a recommended do not use like this use curved lines.

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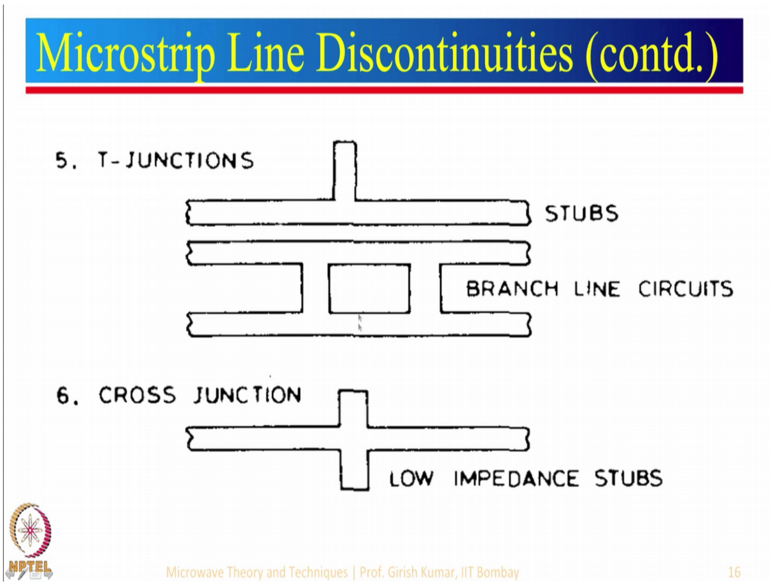

Now, there are T junctions, you can see here t junction can be use as a stuff we will also look into later on various application this is like a branch line circuit. So, there are 2 lines are there and these are the branches coming through here. So, you can see there are several T junctions are there and then of course, there is a cross junction.

So, today we have looked into various types of line, we have looked into coaxial line, we have looked into strip line. But we have looked more in detail about micro strip line, we have looked into what are the analysis equations and what are the designed equation. I did take a case of 100 ohm line, but I strongly recommend that you people practice for let us say 50 ohm line and 70.7 ohm line when we take examples, later on you will realize the importance of these particular thing. In the next lecture, we will also talk about now rectangular wave guide and basic transmission line theory.

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