**Millimeter Wave Technology.**
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**Lecture-10.**
**Guiding Structures (Contd.)**

Okay so welcome back. So the first effect is multipaction effect. Its a resonance type phenomenon. So to understand this phenomenon let us consider a parallel plate system.

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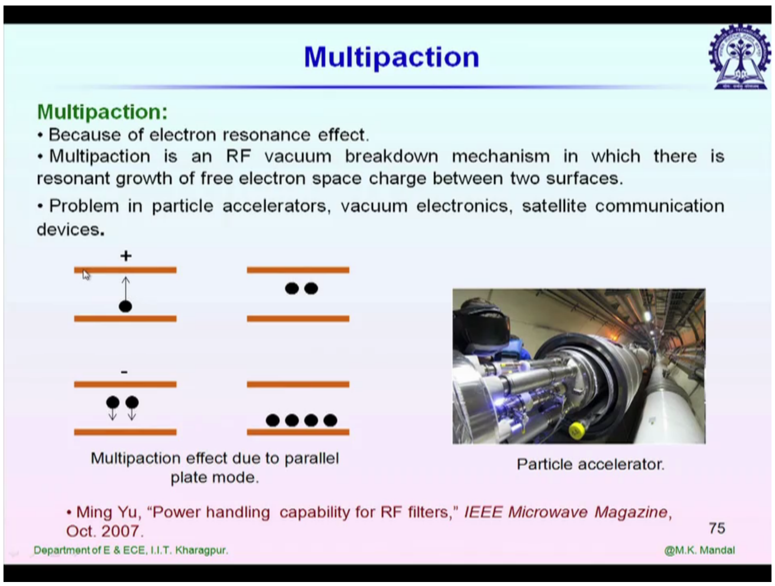


We can represent a rectangular waveguide its stop and bottom plane by this parallel plate, some electromagnetic signal is propagating through this parallel plate. If I consider any time instant lets say at that time instant the top plane it is at positive potential compare to the bottom plate and somehow there is an electron present inside this 2 planes.

And we are considering a vacuum scenario that means we don't have any air particle or any dielectric in between these two plates only the electron is present. So according to field direction electron it will be attracted to higher potential or positive plate and it will gain kinetic energy.

If this energy is sufficient and it is more than required more than that required for secondary emission from this plate then while it will strike stop plane it will generate two electrons. So this second one is due to the secondary emission so for that electron should have sufficient kinetic energy. Now lets say when the instant when this second electron is generated at that point the electro electric field it changes its direction.

Now what will happen both of this two electrons they will be accelerated to bottom plane. So again they will gain kinetic energy from the applied electromagnetic field and if they have sufficient kinetic energy they while striking the bottom plane it will create more electron. So sudden suddenly there is a avalanche of electrons.

So but to do that we should have exact phase relationship that means when this electron just reaches this first plane exactly at that instant it should change the phase between these two plates. Otherwise electrons won't be accelerated towards bottom plane. So that's why we call it a resonance phenomenon.  Without this phase relationship it won't happen.

So as a result of this we have suddenly many electrons which conduct energy between these two planes. And we have an effect of breakdown. So its very probinent, it's very prominent with the device which is inside is vacuum.

For example in particle accelerators or any compo waveguide based component particularly air filled rectangular waveguide based components when we use for space application where we don't have any air. If we use some air or a dielectric material inside then it will disturb this electron trajectory. And we won't have multipaction phenomenon. So multipaction is mainly prominent for the vacuum case.

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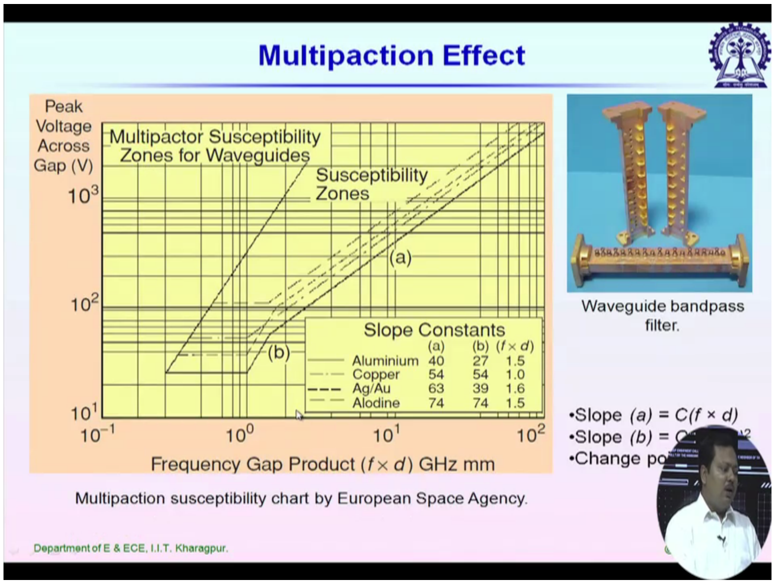


Now how to predict multipaction or what is the threshold voltage needed for multipaction? Its really difficult to calculate the multipaction threshold voltage because it depends on many factors. It depends on type of metal because the secondary emission threshold energy needed for secondary emission it depends on type of metal, surface of metal and presence of any other molecule inside the rectangular waveguide structure.

So instead what people does? They use a chart. This chart is given by European space agency. They did some experiment or different types of metal and for different gaps between 2 plates and for different voltage values and they produce this chart, this is from the major data it shows peak voltage across the gap along the Y axis and along X axis it is frequency gap products.

This is interesting. It not only depends on the frequency but also a function of gap between 2 plates. And the unit here its gigahertz millimetre so frequency is being measured in gigahertz and the gap between two plate its in millimetre and we see the multipaction phenomenon its more prominent at lower value of F into D. So for a given device if the gap compare to its lambda is very small.

Then multipaction probability it increases. How to read this data? We have several curves for different types of metal. For example they considered aluminium, Copper, Silver, Gold, Alodine.

So for Aluminium this is the graph this is the plot. Then we have for the Copper and right side we have 2 different slopes. For this A region slope is given as 40 for Aluminium.

For this B region it is given as 27 and for the A region it varies as C into F into Dand for the B region it is actually F into D square. So we call the right side part of this curve is safe region where multipaction will not occur. And left side you can see one more plot one more line here so in between this left and right line these zone is susceptible to multipaction that most probably multipaction will happen.

And left side of this line where we can say a sure multipaction will happen. So we have to avoid these two regions. So here is one example. Fabrication example umm these are bandpass filters designed in rectangular waveguide technology so most probably you can identify there is a quarter view we have many cavities inside. We have 1,2,3,4,5,6,7,8,9,10. 10 cavities inside.

Its a ten pool bandpass filter and on top of a broad side wall, you can see there are many screws so this screws are used to adjust the coupling and as well as the operating frequency and inside we have air so when it will be sent to any orbit where we don't have air, so inside will be have will have vacuum. So before sending to space we have to go through this multipaction test.

We have to first see is there any multipaction effect or not. So this type of structure is very prone to multipaction. Why? Because of this screw and because of the cavity you see there are many metal plates inside so the D separation effective separation it decreases and the multipaction probability it increases.

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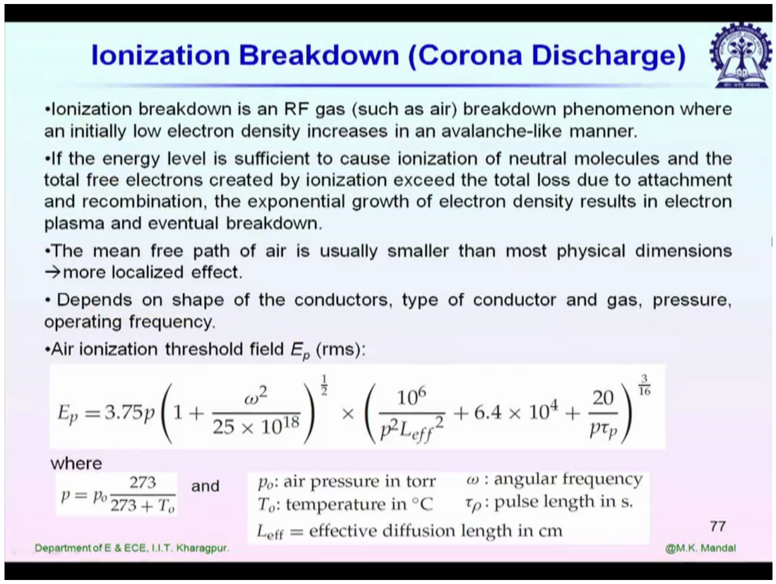


Next one is ionization breakdown sometimes also we called it corona discharge. In this case we are considering another scenario where air is present inside rectangular waveguide. If we have dry air, usually we don't face any problem. But if we have water vapour inside we have a problem so how this breakdown occurs? This is due to ionized molecules and water vapour.

Its very easy to ionized. So let's say the electric field which is applied between top plane and bottom plane it is sufficient to ionize the molecule. You can compare the effect with zener breakdown and avalanche breakdown of any PN junction so here the electric field value is so high that it can clear out electrons. From the molecules and that is how the molecules become ionized.

So the main condition is that the electric field should be higher than a threshold value. And that threshold value it depend on again the shape of metal surface. What material you have inside, what is the pressure of the gas whatever you are using inside, what is the frequency of operation so what is the distance? So there are so many factors and again its really difficult to calculate the actual value but here at least we have one closed form expression or threshold electric field. So lets see.

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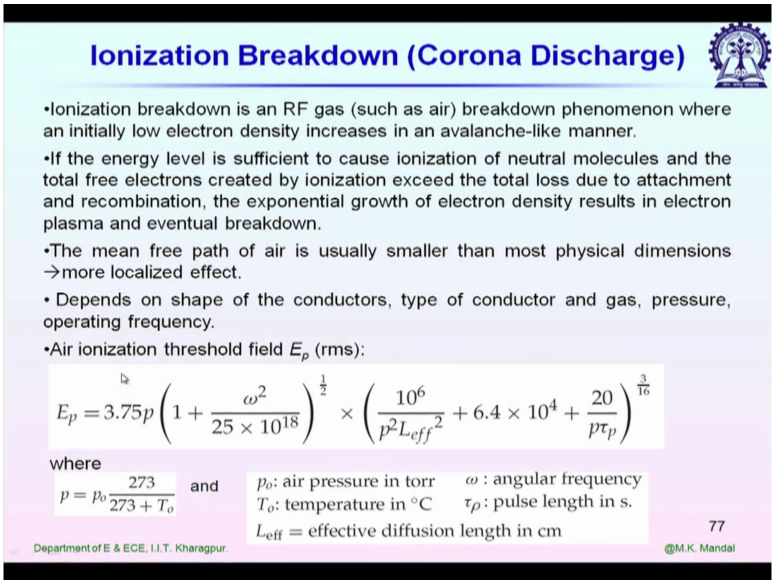


So air ionization threshold field EP RMS value it is given by this expression. This is a closed form expression so we have the parameter p which represents air pressure. P is equal to P not into 273 by 273 plus T nought where T nought is the temperature in degree centigrade and P nought is the air pressure in tort. Omega this is the operating frequency angular frequency and we have some other factors like L effective.

L effective represents the diffusion length in centimetre. And tou P it’s the pulse length in seconds. So if you look at the expression, if I send a pulse through a rectangular waveguide, it will have some duration. Tou P is the duration of the pulse. So if I increase tou P value what will happen EP will decrease? So ionization will ionization breakdown it can occur at much lower electric field value.

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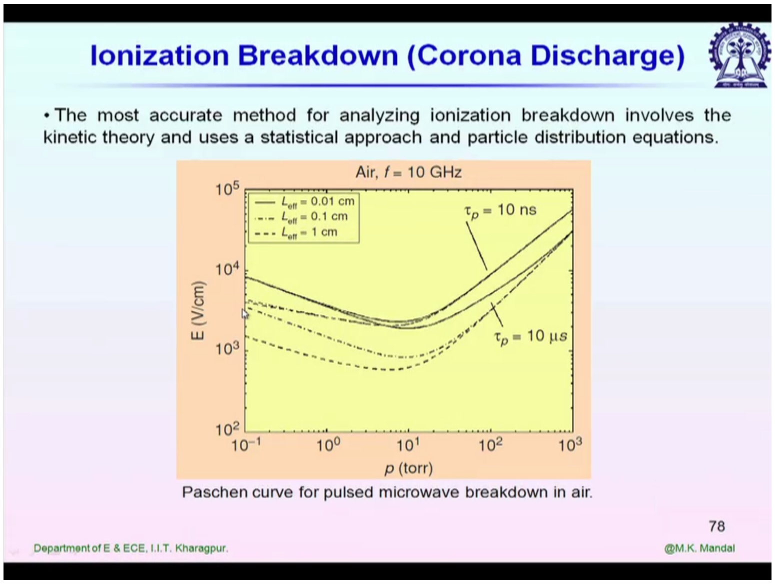


So we have a curve here for umm the threshold electric field value versus pressure plot this is called paschen curve for pulse microwave breakdown in air for different L effective values. L effective will changes with of course pressure so L effective this is sorry L effective it depends on the type of molecules or the type of gas inside.

L effective we are considering three values here point 01 centimetre to 1 centimetre and now we are considering it for two different pulses for one case tou P is 10 nano second and in second case pulse with is 10 micro seconds. So as we expected from the previous expression for longer paschen threshold electric field it decreases so if we have any electric field above this then for sure ionization breakdown will occur.

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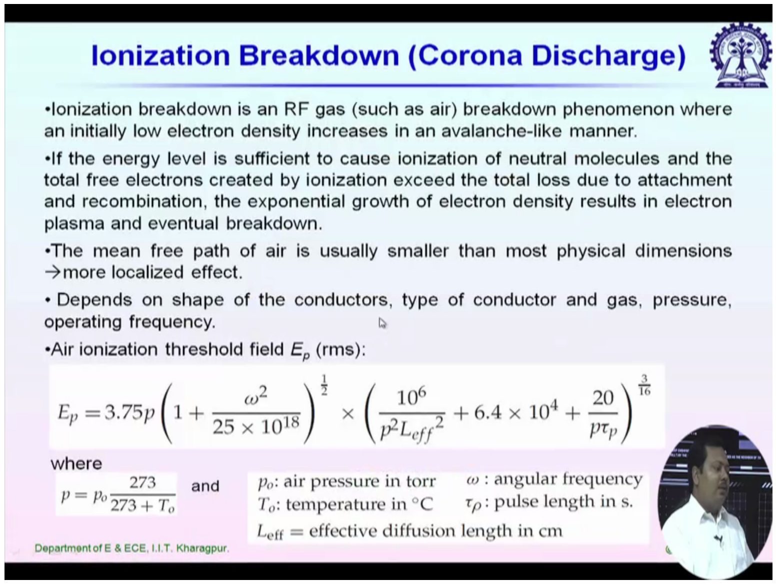


And one more thing ionization breakdown it is a localized phenomenon. Because we have gas molecule inside and usually the main free path of air is smaller than most of the physical dimension so that is why its a localized phenomenon.

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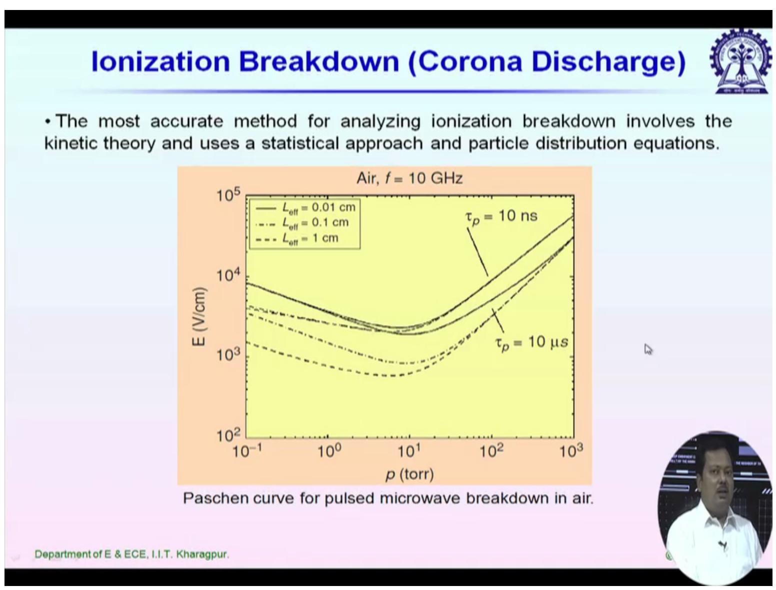


Now lets consider one interesting thing.Lets say we are testing a waveguide bandpass filter and its design in rectangular waveguide technology now ionization breakdown may happen or multipaction breakdown may happen so from this structure under test how do we understand which breakdown occurs fast so once a breakdown happen after that we open the structure.

And then look at the burning mark if its in small region and dark that then it is due to ionization breakdown and if its spreads over a longer area larger area and umm the marking is usually faint in that case it is due to multipaction breakdown . So looking at the burning mark then you can decide this is due to ionization breakdown or this is due to multipaction breakdown. So next

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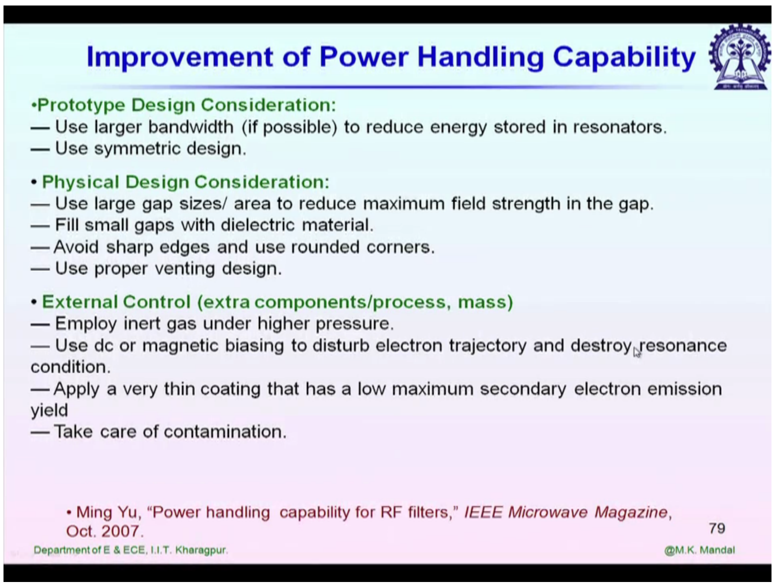


How then we can improve power handling capability for any rectangular waveguide based structure. First when we are designing prototype we have to use larger bandwidth if possible. What is the advantage of larger bandwidth? Then we can spread our energy over different fre frequencies so it will umm decrease the threshold field electric value.

It will decrease the electric field value. We have to use symmetric design if possible then physical design consideration. If we have small gap then obviously electric field value increases. So if possible we have to use larger gaps. If we have smaller gap which we cannot avoid then in that case we can fill up those gaps by some solid dielectric material.

So solid dielectric material it will not allow ionization breakdown or multipaction breakdown. Then avoid sharp edges. Use rounded corners it will avoid ionization breakdown. Use proper venting design. Then some external controls employ inert gas under high pressure but remember it should be avoid of any water vapour.

Then use DC or magnetic biasing to disturb electron trajectory and destroy resonance condition. So what is the advantage of that multipaction we have seen its a resonance phenomenon. So if we can disturb the electron trajectory most probably it we can avoid multipaction breakdown.

Then apply a very thin coating that has a low maximum secondary electron emission yield. So that is how we can increase the threshold voltage for multipaction breakdown and then finally take care of contamination.

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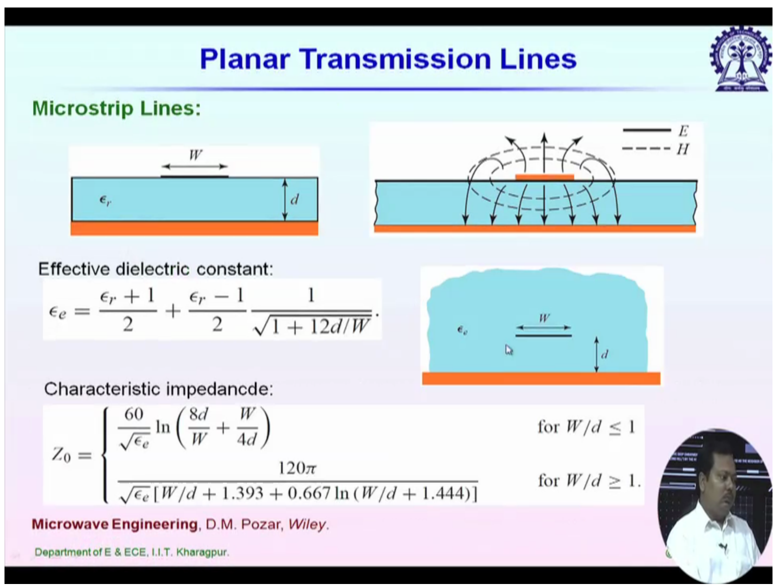


So after this rectangular waveguide next will start the printed lines. So among the printed lines most popular even at millimetre wave frequencies are microstrip line and CPW line. For microstrip line and CPW line what we expect that loss alpha value will be much more compare to rectangular waveguide and then what is the use of microstrip and CPW line?

The main advantage is its low profiles structure its fabrication is much easier and its cheaper. So obviously if we use microstrip line it wont be long we will use mainly for chip to chip connection or as interconnects. So keeping this point in mind so lets first discuss then what are the basic characteristics of a microstrip line and what are the different sources for a source of losses for a microstrip line.

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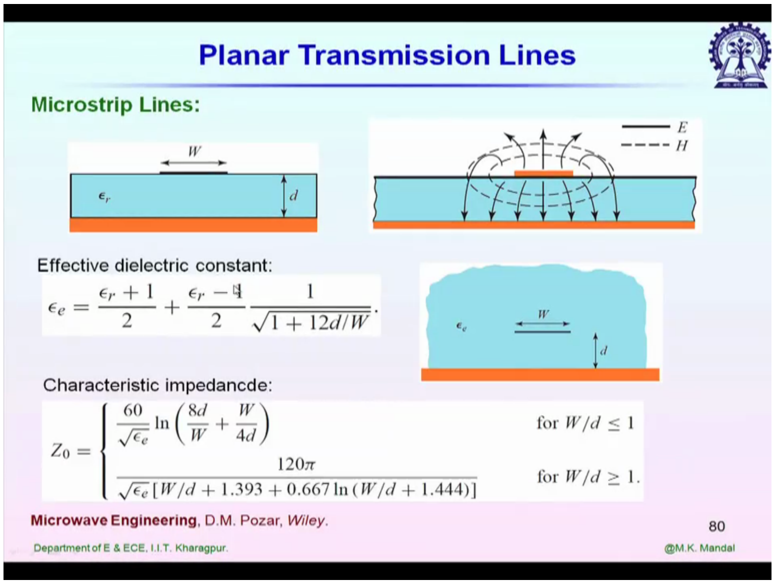


So if I go back this first figure it shows a cross section of a microstrip line. So we we have a top strip metallic strip. It sits on a dielectric layer and below we have a ground plane. This is the plot of electric field and magnetic field. Most of the electromagnetic energy it lies its confined inside the dielectric and below this strip we have some flanging field in air so these are semi opened structure.

So keep in mind that we cannot place any other structure like packaging wall near the central strip. When you have any other metallic structure very umm you have to maintain some separation between that structure and the central strip. Otherwise there will be power coupling and it will change the characteristics of microstrip line. Microstrip line it supports quasi TEM mode.

Its not exactly transfers electromagnetic because of this flanging fields. Because we are dealing with two different epsilon R values so epsilon R inside it is that of the  dielectric material and outside epsilon R is equal to one it is of air. So because of that we call it quasi TEM but since most of the electromagnetic energy is confined inside dielectric so the properties of microstrip line is mainly determined by the dielectric constant of the dielectric slab.

Let us consider to simplify the analysis it the strip it is inside one effective dielectric material surrounded by this effective dielectric material for which we are defining some effective dielectric constant epsilon E. So its value obviously will be more than air and it will be less than epsilon R. since its the effective epsilon eE then we have a closed form expression for epsilon E.

Epsilon E this is equals to epsilon R plus 1 by 2plus this factor. You see its a function of the dielectric thickness and also a function of the strip width W. The characteristics impedance of the microstripline Znought for W by D less than equal to 1, you can use this first formula. So if you know thickness of the dielectric, width of the strip and the effective epsilon E then we can calculate Z not from this expression and when W BY d is more than one.

We use second closed form expression. So what we see from both of this expression for a given thickness if we increase W then what will happen? Characteristic impedance will decrease, for a given E if I increase thickness then what will happen? So if I characteristic impedance will increase. So in this case then for a given characteristics impedance we can choose W value for a given substrate material.

Because substrate for a given substrate D is fixed for usual microwave or a millimetre wave system always we deal with 50 m characteristic impedance. Its always 50m if unspecified. For very low frequency applications like coaxial cables used for television the characteristic impedance we use is 75 ohm. But for microwave and millimetre we use 50ohm.

So there is a reason for that if I calculate the minimum attenuation for an air filled co axial cable attenuation is minimum when the characteristic impedance is approximately 75 ohm, but power handling capability is maximum when the characteristic impedance is approximately 30 ohm . So we use 50 ohm it is somewhat in between 30 and 75 ohm. And its a standard value used everywhere.

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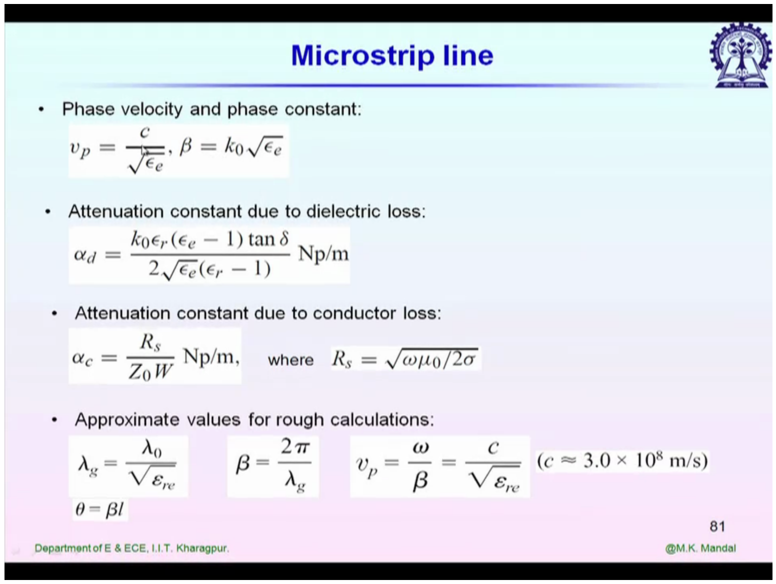


So now once we have epsilon E we can calculate phase velocity VP. This is C by root of epsilon E. Now epsilon E is always more than one. That means VP is always less than C. So microstrip line it supports slow wave mode not fast wave mode. We have closed form expression for attenuation constant due to dielectric loss alpha D this a function of epsilon R tan delta as well as frequency because we have a term K nought here.

So as frequency increases then alpha D also increases, the attenuation constant due to conductor loss alpha C it is surface resistance divided by Z nought into W. So if I increase frequency RS will increase obviously alpha C will increase. So that means at millimetre wave frequencies we see that alpha D and alpha C both will increase.

Not only that in addition to this two different sources of losses we also have surface wave loss and we have seen the detrimental effect of TM0 mode and always there will be TM0 mode excitation so power will be lost to TM0 mode. Now we can keep TM0 mode excitation to a minimum value only if the height or the thickness of the substrate is much smaller compare to lambda g.

Typically 1 by 100 times so which is not possible at millimetre wave frequencies so at millimetre wave frequency typically while keep on increasing frequencies then the thickness of the substrate, it will also increase with respect to lambda g. So in that case surface wave excitation will increase and surface wave loss will increase and its a problem not only at millimetre even at higher microwave frequencies also.

So if we fabricate anything in PCB technology whatever loss we are expecting from these expressions so that is not enough we also have to consider the surface wave and the structure it becomes very lossy. That is why we cannot use a microstrip line or a CPW line or long distance transmission we only use for as interconnects or for chip to chip connections. So some other parameters,

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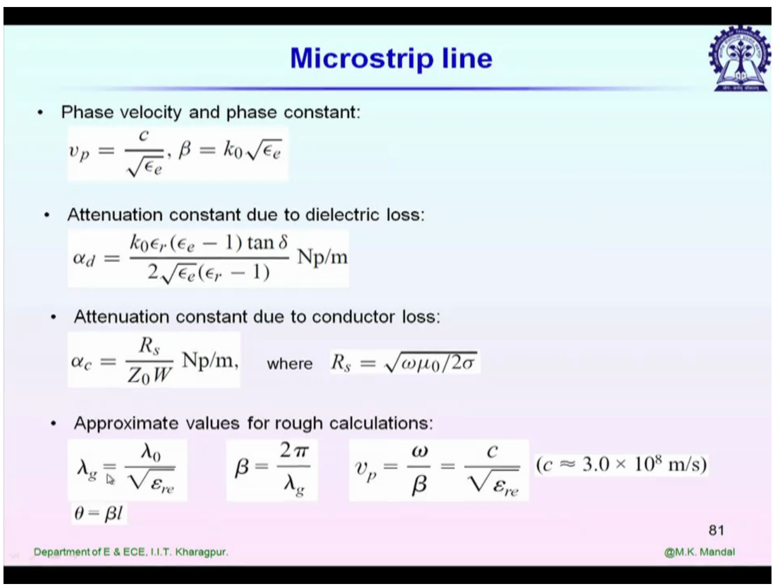


Some approximate values lambda g this is equal to lambda nought by square root of epsilon RE. This is beta 2 pi by lambda g and a theta is equal beta L. Since we are assuming it as TEM mode we can use the formula whatever we learnt for a 2 air transmission line.

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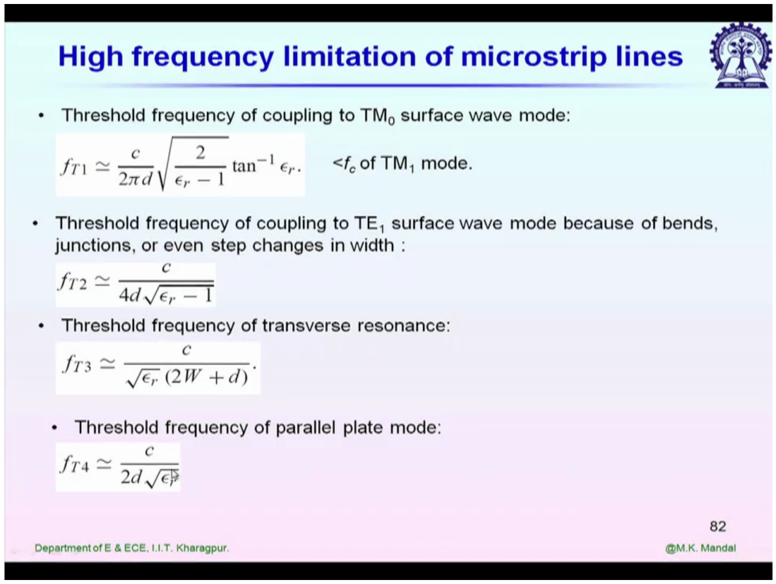


So in next we will see there are some other factors which determine highest frequency of operation. Just like the co axial cable. We have to avoid surface wave mode generation to some extent we have to avoid any higher order TE mode or TM mode generation. So from these conditions we have some limit high frequency limitations of microstrip line. Thank you!