Millimeter Wave Technology.
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Lecture-08.
Guiding Structures (Contd.)

So welcome back. Next we consider another scenario we call it parallel plate case.

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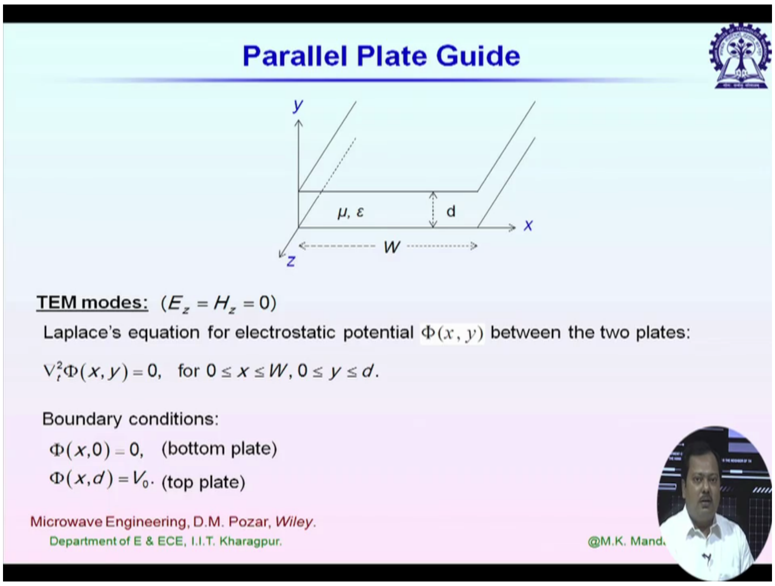

When we buy substrate from market or printed circuit boards another name is also laminate. It basically a dielectric slab and it comes with top and bottom copper plane or copper cladding. So this type of substrate with top and bottom metallisation it can also support surface wave mode and in this particular case we have all the TEM, TE and TM mode propagation. So among this 3 TEM mode it does not have any cut off frequency. But for TE and TM they have a cut off frequency so let us see then.

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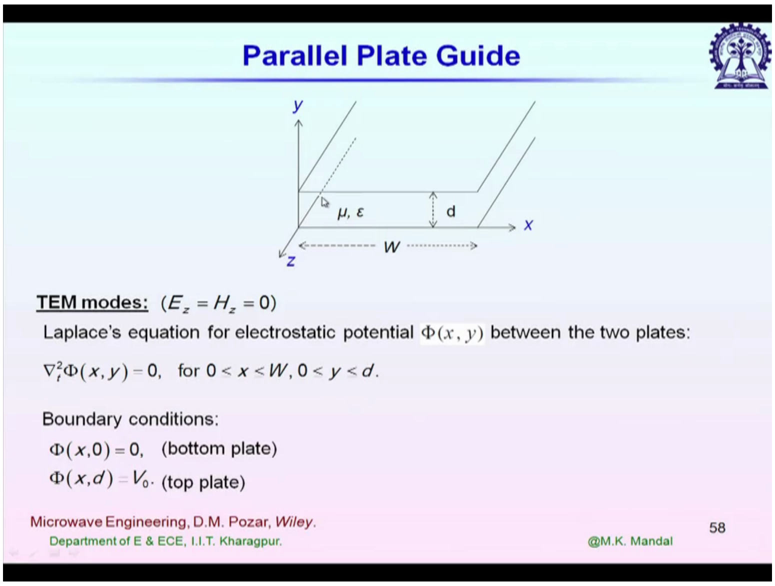

This figure shows 2 parallel plates this plates are in ZX plane again we are considering wave propagation in Z direction and the plate separation is D inside we have a dielectric material whose which is given as Mu and epsilon or most of the dielectric material Mu R is equal to 1. So we can simply replace Mu by Mu nought.

So let us first consider TEM scenario by definition in the direction of wave propagation we don't have any electric or magnetic field component. So the solution we can to solve for the electric and magnetic field we can start with the Laplace's equation for electrostatic potential Phi within 2 plates. So we are not going for any solution let us let me show you directly the field plots.

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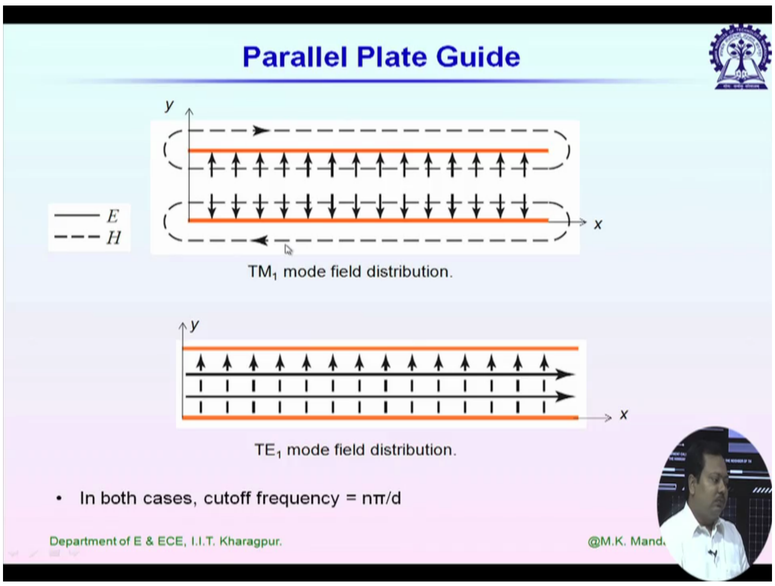

So we have 3 scenario this figure shows the electric and magnetic field plot for TM 1 mode and TE 1 mode for transfers magnetic mode if you look at the electric field they are having maximum values on this 2 metal planes. And the wave propagation you remember its in Z direction. And for transfers electric field components electric field are parallel to the metal plates so obviously on the metal plates the electric fields value is 0.

And its having maximum value on the central plane now if I compare this 2 scenario can you predict in which case alpha C attenuation due to conductor will be higher. So in the first one transverse magnetic case since the electric fields have maximum on the conductor plane it will induce maximum surface current so it is associated with higher loss. Because in the second case electric field maximum value it is on the central plane.

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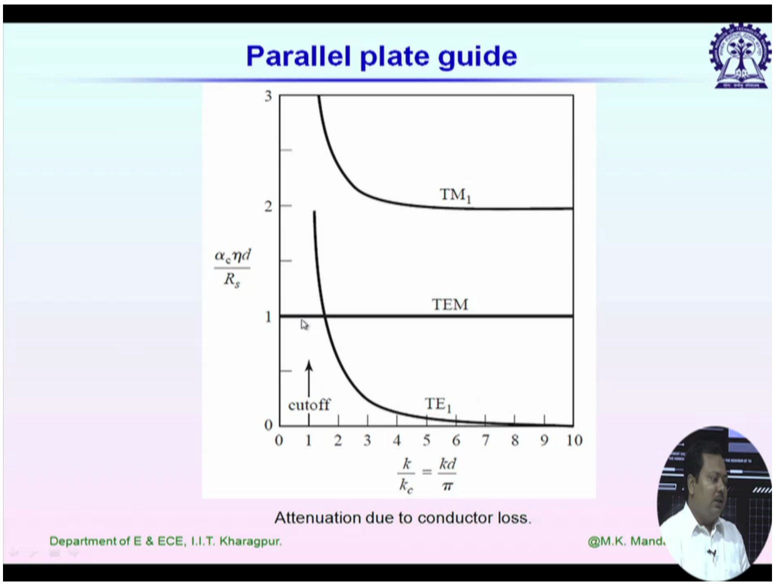

Now let us look at the plot. For TEM so this is along Y this is the normalised attenuation constant you can think as if it simply alpha C and along X its K by KC or it increases with frequency. So for TE 1 you can see the alpha normalised alpha C is much smaller compare to other 2 modes as we expected.

At cut off normalised alpha C is going to infinity for TEM throughout the frequency its constant and it does not have any cut off frequency for both TM and TE the cut of frequency is same and due to the perpendicular field component for TEM 1 we have higher conductor loss.

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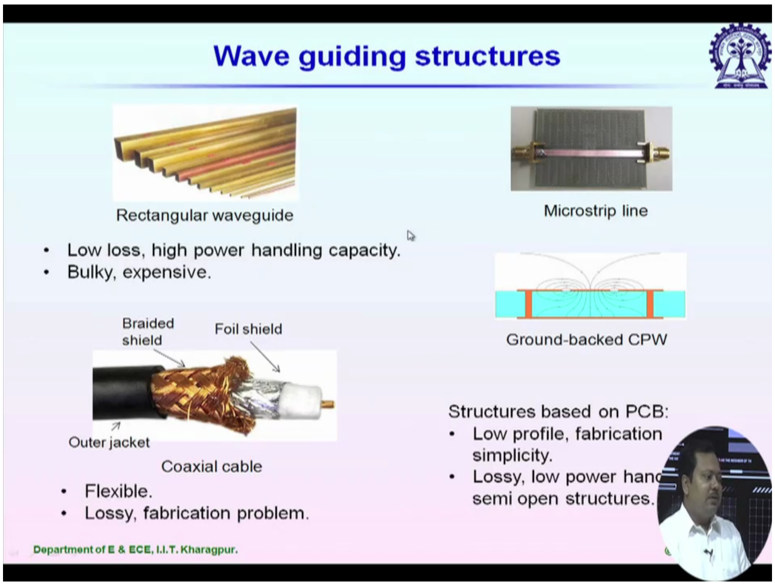

Now let us start the popular wave guiding structures which we use at millimetre wave frequencies. So this picture shows 4 of them. The first one is rectangular wave guide this is nothing but hollow metallic pipe and the cross section it its rectangle so it comes with different sizes for different frequency bands and as we know the frequency band it is determined by the cut off frequency FC of the wave guide which is a function of physical dimension.

So what are the advantages and disadvantages of this rectangular wave guide it provides lowest loss among all these 4 different types of guiding structure. It has the highest power handling capacity but the problem is its bulky, its very heavy also its expensive. And fabrication procedure it is also complex, we need bulk machining for this.

The second example coaxial cable as you can see it has one central conductor made up of metal and one outer conductor. Usually we use braided shield and this the outer jacket so electromagnetic wave it propagates through the dielectric layer which is shown by a white colour here and which seats in between the inner and outer conductor. At millimetre wave frequency coaxial cable is very lossy.

We try to avoid them but the main advantage of coaxial cable is that its flexible. So that is why most of the instruments they comes with coaxial cable for connection. This is the third example micro strip line this is the top view of the fabricated micro strip line and you can see the strip copper strip it is connected to 2 connectors or adapters.

And below this dielectric slab which is shown by black colour we have the metal ground. So here I don’t have any autograph for the ground backed CPW here it shows the cross sectional view of a CPW ground backed CPW so what is the difference between a conventional CPW and ground backed CPW is that we have one more additional ground plane here.

Below the top CPW line and not only that the top left most and right most ground they are connected to this bottom ground by periodic via. You can see shown by orange lines the main advantages for this printed circuit board technology is its low profile structure. Fabrication is very easy, very simple and cost effective.

And the problems its lossy compare to the rectangular wave guide they have much lower power handling capability and this is a semi open structure so you can see on top we have flinging field for the CPW line. So we cannot use anything very near to CPW line on the otherwise will be having coupling between this CPW or micro strip line and with that nearby structure. So we don’t have this type of problem with coaxial cable or rectangular wave guide. Since its a close structure enabiliting we have inside this structure.

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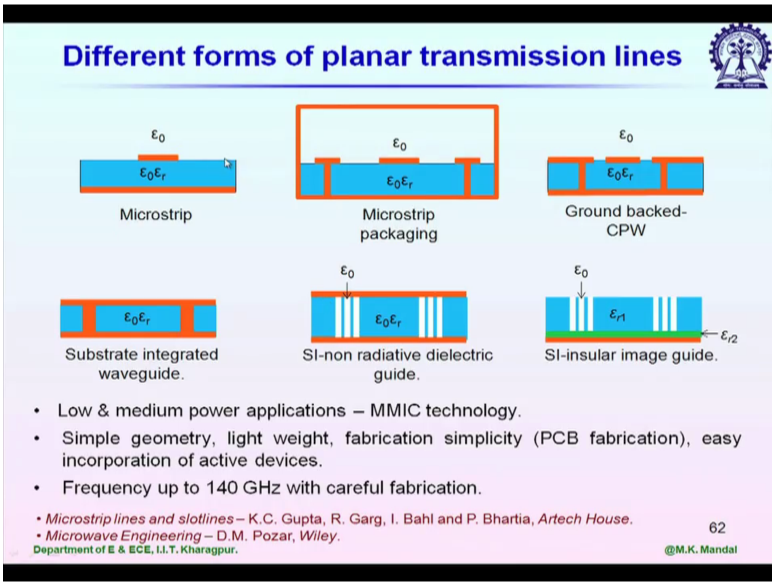

So these are some more structures micro strip line then we have packaged strip line. So since micro strip line or CPW line its semi open structure. So for practical use always we have to use some sort of packaging. This figure shows the cross sectional view of such a package. So micro strip line it is placed inside a rectangular pipe like structure and you can say left turn right side we have that arrangement to suppress TM 0 mode you can identify the strip.

And the grounded via which will suppress that perpendicular electric field component. Similarly right side we have ground backed CPW this is shown without any packaging scheme we learn later we have also PCB form of rectangular wave guide. This is we call synthesised wave guide or substrate integrated wave guide also we have PCB form of some other popular wave guide at millimetre wave frequencies.

Like NRB non radiating dielectric guide and insular image guide so we can we have already PCB form of the different 3 dimensional guiding structures. So the advantages why we want to design it in PCB form? Because in PCB form always it becomes a low profile structure as well as the fabrication procedure is much simple and its much cheaper and we can use this types of structure up to 140 gigahertz with careful fabrication.

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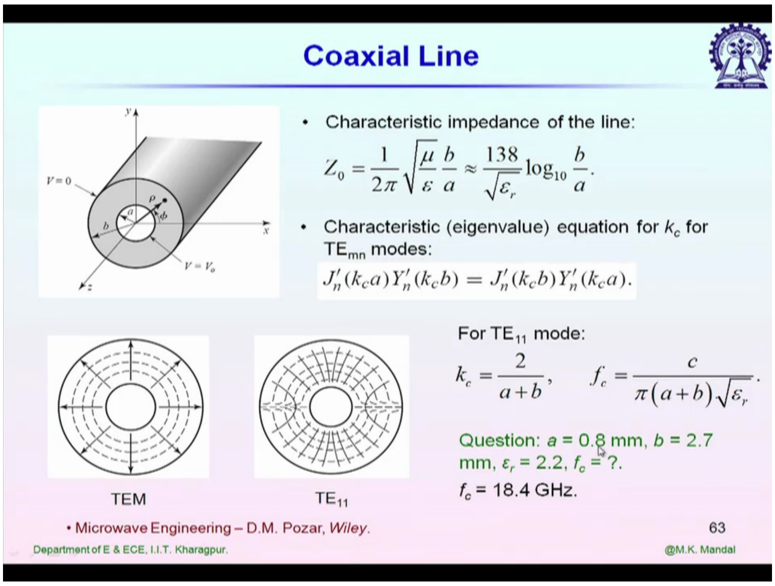

So let us start with coaxial line. For coaxial line as we discussed this grey colour it shows the dielectric inside we have a conductor or radius A. And also we have one outer conductor the inner radius of outer conductor is given as B and electromagnetic wave propagates through this dielectric. If you look at the field diagram we the coaxial cable it can support TEM as well as TE and TM mode but for TE and TM mode.

We have cut off frequency and below cut off frequency we have only the TEM mode and this is the field diagram for TEM mode. So electric field its starts from the central conductor and terminates at the outer conductor and magnetic field it encircles the central conductor. So in this case also we can easily calculate the potential difference between the central conductor and outer conductor. Just we have to take one line from central to outer conductor and then integrate E dot DL we can also calculate the current we have to consider one close loop encircling the central conductor and then calculate H.DL so we can characteristics impedance for a coaxial cable. The characteristics impedance the closed form formula is given here Znought this is equal to 1 by twice pie root of Mu by epsilon into B by A. B and A they are radii and epsilon is the dielectric permittivity of the dielectric which is used inside so approximately this is equal to 138 by root epsilon R log base 10 B by A.

For most of the dielectric we can consider Mu equal to Mu nought. Now we can use a given coaxial cable till some higher frequency. That highest frequency of operation is determined by the lowest cut off frequency of TEM TM mod. If you look at the mode chart the mode among all TE and TM modes which appears fast is TE 11.

The electric field and magnetic fields for TE 11 is shown here. So we have to avoid this TE 11 mode excitation for mono mode operation because TEM this is the desired mode we don't want any other mode to be excited inside and since the cut off frequency for TE 1 mode is lowest so we will consider the cut off frequency of TE 11 as the highest frequency of operation for any given coaxial cable.

And the cut off frequency is cut off wave number is given by KC equal to 2 by A plus B. So from this we can calculate what is the cut off frequency? For TE 11 this is C by pie into A plus B into root of epsilon R. So its a function of A and B. Let us say we have a coaxial cable the inner radius is given point 8 millimetre and is 2.7 millimetre, epsilon R of the material used in between the conductors is 2.2 then what is cut off frequency of TE 11.

If you just put the values here we will get FC equal to 18.4 gigahertz. We will consider a margin of let us 5 to 10 percent and this given coaxial cable we can use let us say to maximum frequency of 18 gigahertz or 18.4 gigahertz. Above which we will not use this coaxial cable otherwise what we expect? That there will be multiple modes TEM as well as all these undesired modes.

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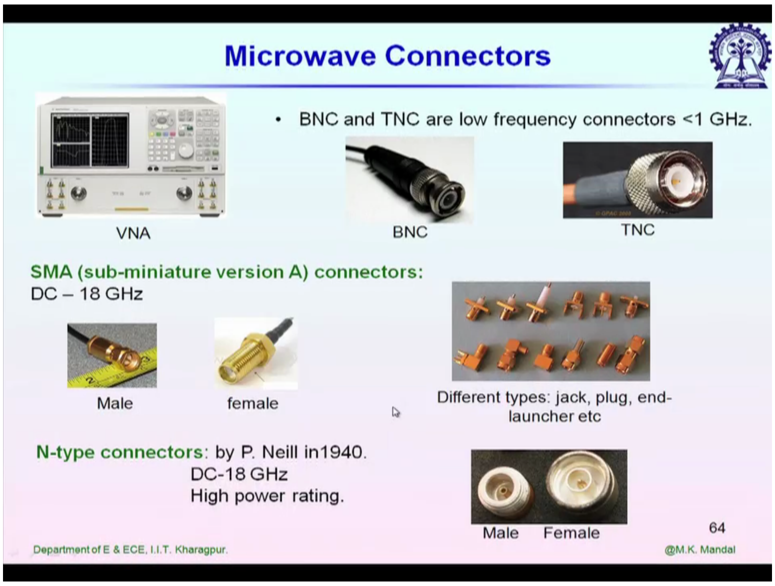

Some application whenever we measure this structure this is showing one vector network analyser which we use to measure this scattering parameter of any wave guiding structure as well as of any components it can be microwave or millimetre wave components. Now as we discuss that the guiding structure that this instrument is used is coaxial cable. But let us say we are designing something in microstrip line then how to measure my component by using coaxial cable. So we need adapters adapters here we have already seen one.

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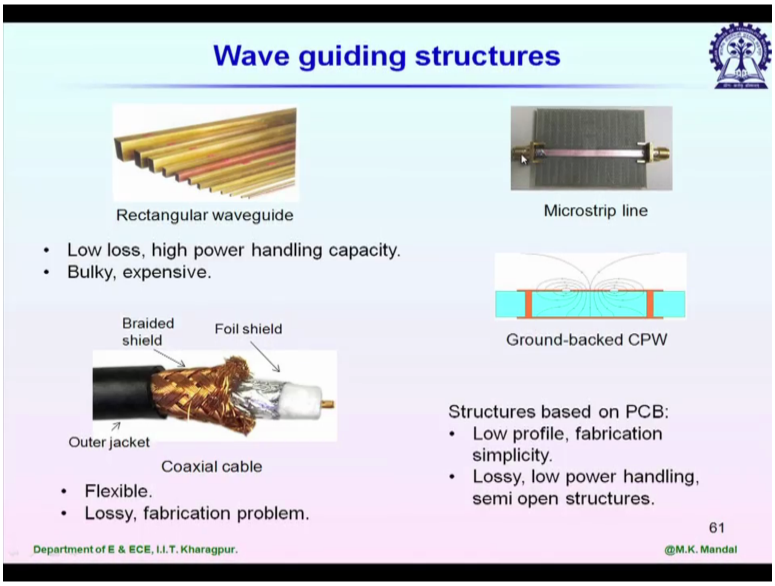

You see this is the micro strip line and this is called adapters so it will change coaxial mode to micro strip line mode. So we are using this adapter to for measurement purpose. Now we can easily connect our coaxial cable to left hand side or right hand side or measurement purpose.

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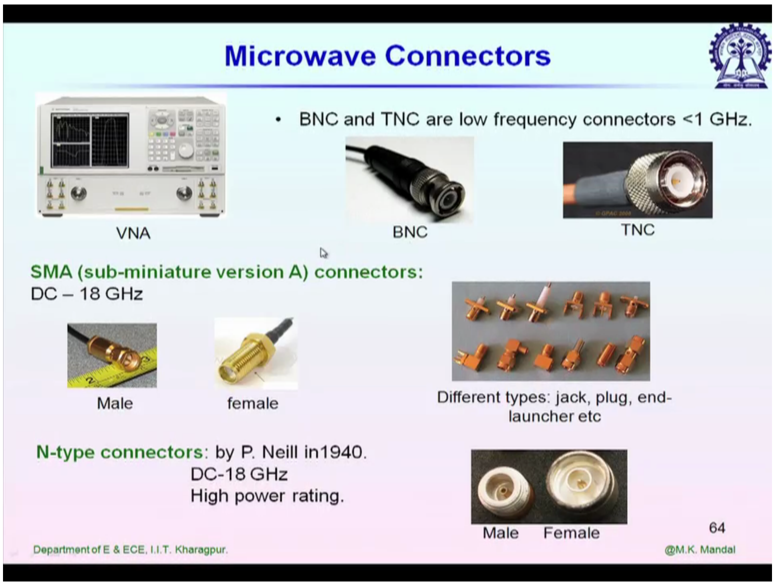

So one end of this adapter then always a coaxial line now you see we have different types of adapters available. The first example are called BNC connect sometimes they are also called as connectors and this is the threaded portion of BNC we call it TNC they are typically used below 1 gigahertz. So we usually used this type of connectors for low frequency operation or for a biasing active devices or biasing the low noise amplifier or power amplifier at millimetre wave frequencies.

And then we have some popular guiding structu adapters the first category is SMA or sub miniature version A typical operating frequency range is DC to 18 gigahertz. And how we determine this highest frequency of operation? So you remember that it depends on A and B and also epsilon R you can see the white material inside. This is actually Teflon for which dielectric constant is approximately 2.1.

We also have N type connectors so N type connectors was designed in 1940 it came long time back and typical operating frequency DC to 18 gigahertz. Here we have pictures for male and female type N type connectors. So among this most popular connector at microwave frequency is SMA or sub miniature version A. It came in 1960 so right side this picture shows different types of the first line different types of we have male and female type and when you are ordering for different connector, you have to very careful about the male about the mate.

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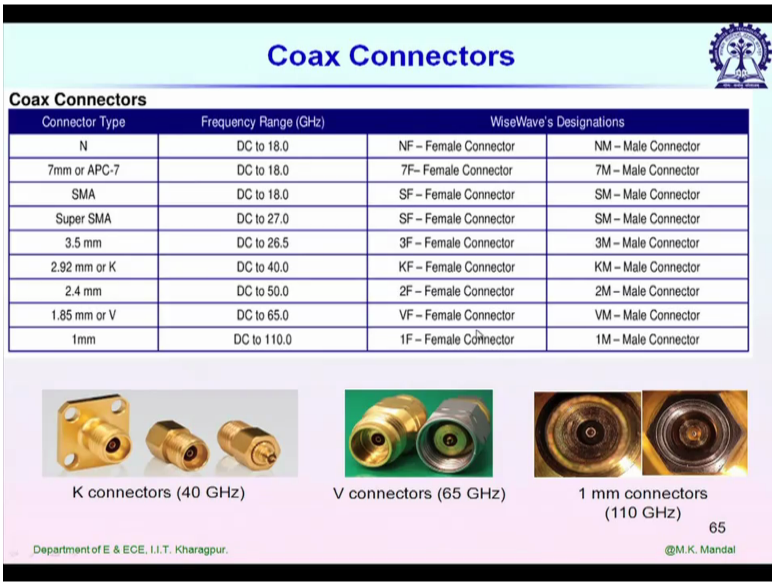

Now at millimetre wave frequencies we have similar characters the first one its called K connectors. If you look carefully inside it looks like one SMA connector but its dia its inner dimension is different not only that you cannot see any dielectric inside. It is actually air and the central conductor it its as its hanging in air. It is supported by very thin layer of dielectric actually and this is called K connectors since they are popular for K band operation all this three K bands.

Next we have V connectors for V band operation the highest frequency of operation is 65 gigahertz so left side is female right side is male. We also have 1 mm connectors its outer diameter is just 1 mm for 110 gigahertz operation. So this is the chart for different types of connector. We have N type, we have 7 millimetre or APC 7. APC 7 its a sexless connector.

SMA we have super SMA it used still 27 gigahertz 3.5 millimetres 26.5 so you remember the highest frequencies it is determined by the cut of frequency of TE 11 mode. So when you order your coaxial cable a you be careful about the highest frequency of operation.

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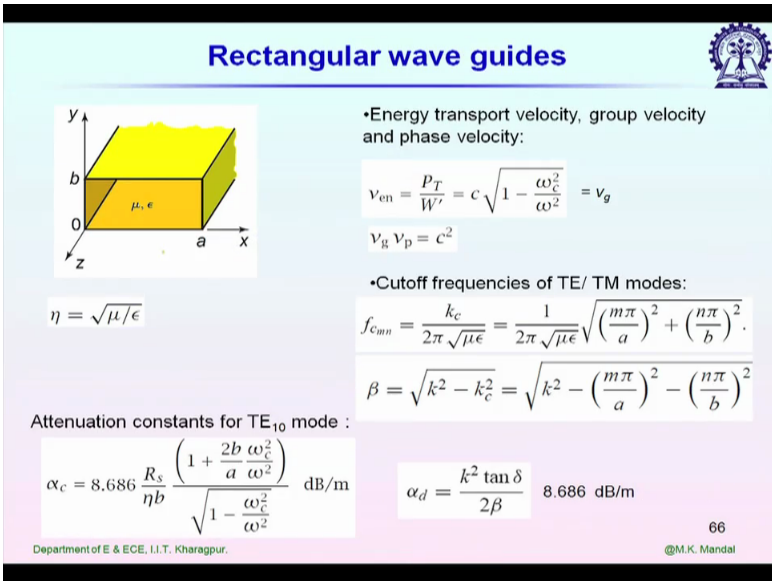

Next wave guiding structure is the rectangular wave guide. At millimetre and terahertz frequency most probably it is the most used structure a typical rectangular wave guide it can be air filled or it can be dielectric field. So here let us start with 1 dielectric field wave guide so inside we have a dielectric material which is define by its Mu and epsilon. Now a rectangular wave guide already we know it can support TE mode as well as TM mode.

If you and which one is the fundamental mode it is TE 10 mode right. So TM mode its appears later and for normal operation we always use this TE 10 mode so let us go through the basic relationship then we will consider what are the problems or characteristics we have at millimetre wave frequencies?

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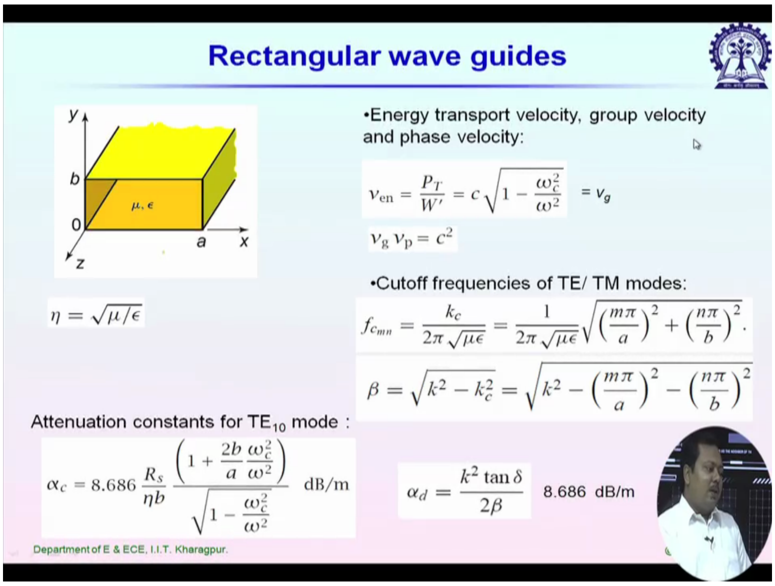

So the energy transport velocity or group velocity its can be given as C into square root of 1 minus omega C square by omega square. So group velocity it becomes a function of omega. Right it varies with omega so its always dispersive. Once we have group velocity we can easily calculate phase velocity they are related by this expression.

And now in general the cut off frequency of TE and TM modes can be given by this expression so M and N they represents the mode number sorry. And A and B they are the rectangular wave guide dimension so sorry A is the broad side dimension and B is the thickness of this rectangular wave guide. And then it is associated with a cut off wave number.

Beta it can be given by square root of K square minus KC square we can put the values of KC here this is the cut off wave number. If you look at the attenuation constant the close form expression alpha C this is equal to 8.686 into RS by eta B. RS this is the surface resistance eeta intrinsic impedance, B is the thickness of the rectangular wave guide. And it is again a function of omega.

Look at this expression at omega equal to omega C this factor cancels out. So at cut off alpha C it becomes infinite as we increase frequency alpha C it decreases alpha D it is equal to K square Tan delta by twice beta. But at cut off again beta is zero so alpha D it is also infinite at cut off frequency and its a function of frequency as well. So we see what alpha C and alpha D both are functions of frequency.

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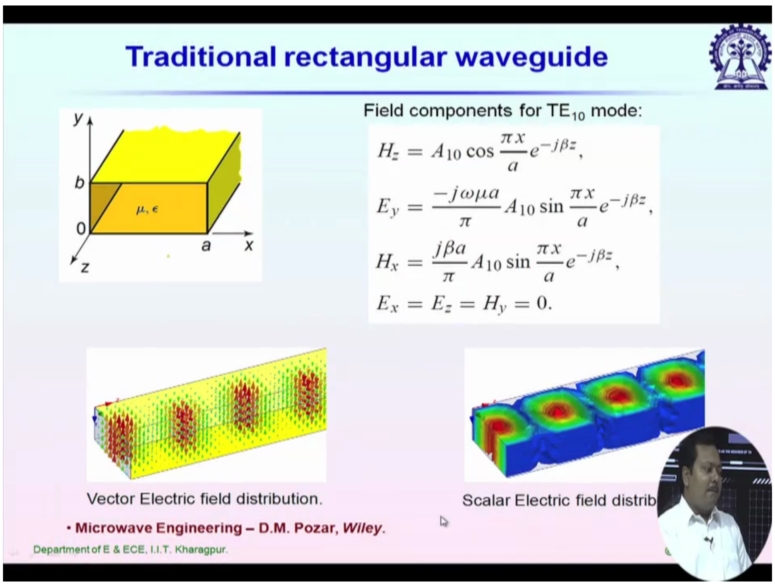

Now let us consider the fundamental mode TE 10 mode so for this one we have if the wave propagation in Z direction then by definition EZ equal to zero and if we solve for the other fit components we can show that here we don't have any EX components. We have only the EY field components and variation of EY it can be given by this sinusoidal relationship.

So at X equal to 0 and at X equal to A electric field that is zero and it is maximum on the central plane. So it shows the vector electric field distribution inside a rectangular wave guide. So if you follow this line along the direction of propagation they are not only maximum on the central plane and you see they are varying periodically along the direction of propagation.

So its maximum here then it decreases minimum then it changes its direction and again it decreases. So its also varies periodically direction of propagation we can also plot the scaler electric field distribution inside the rectangular wave guide. This is the plot so this is specially field strength versus X and Y. We have maximum shown by this red line and the minimum values are shown by blue lines. So let us take a short break then we will discuss about alpha C and beta variation with frequency and how it behaves at millimetre wave frequencies.