Microwave Integrated Circuits
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Mod 01, Lec 06
Microwave components

Welcome to another module of this NPTEL mock score. Microwave integrated circuits. In this module we are going to cover just the basic introduction of certain microwave components. Now later on in the course, we will of course cover these components or various microwave components of different number of ports with some more detailed mathematical analysis. But in order to understand a flavour of this microwave engineering, let me show you some of the basic concepts bind these microwave components.

So the first thing that we need before going to the microwave component is the concept or modes in microwave engineering. Now I have not given a solution or discussed about the solution of the Maxwell's equation for various microwave components. I just showed you the basic Maxwell's equation, the homogeneous equation necessary for solving the, solving for the electric and magnetic fields, in the various microwave components. But there is something called modes, which we have to deal extensively when we are in microwave engineering.

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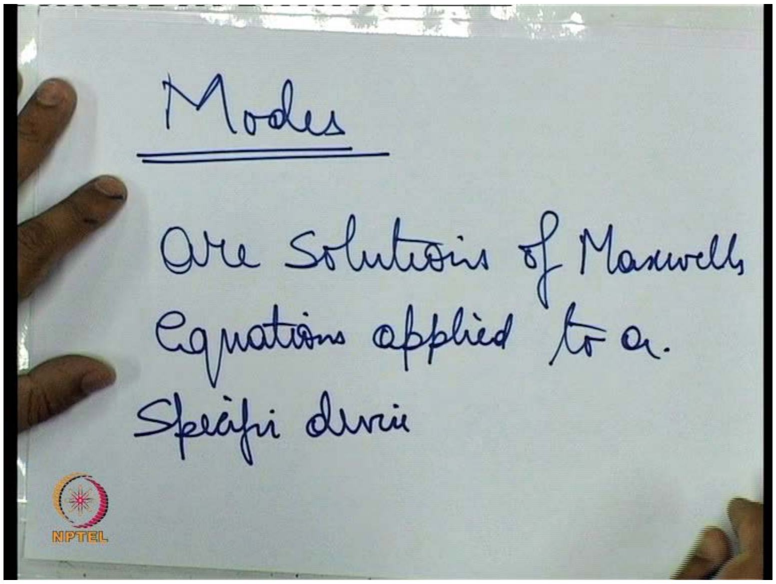

Modes are solutions, of Maxwell's equation applied to a specific device.

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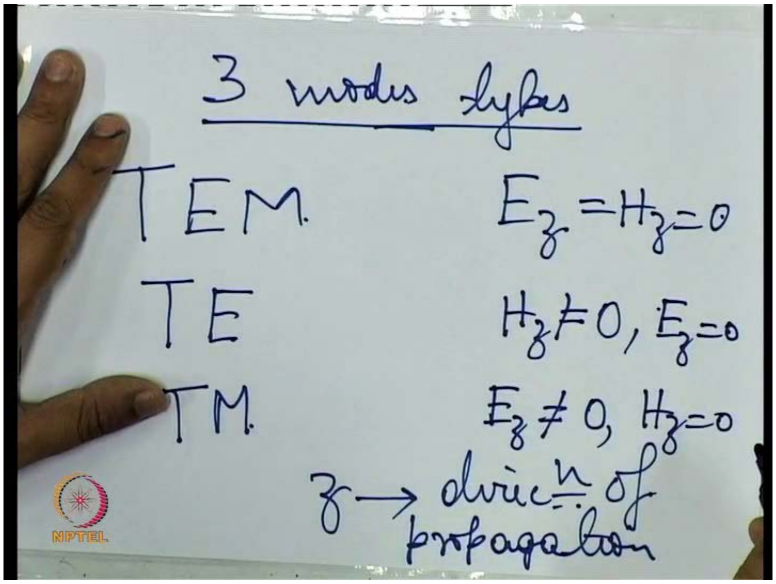

There are broadly classified 3 modes. T or Three modes, types I can say. TEM, TE and TM. TEM modes are where both the electric and magnetic field are perpendicular to the direction of propagation. So we have EZ is equal to HZ equal to 0, where Z corresponds to the direction of propagation. TE modes are where Z is not equal to 0, EZ equal to 0, and TM modes are where EZ is not equal to 0, but HZ equal to 0.

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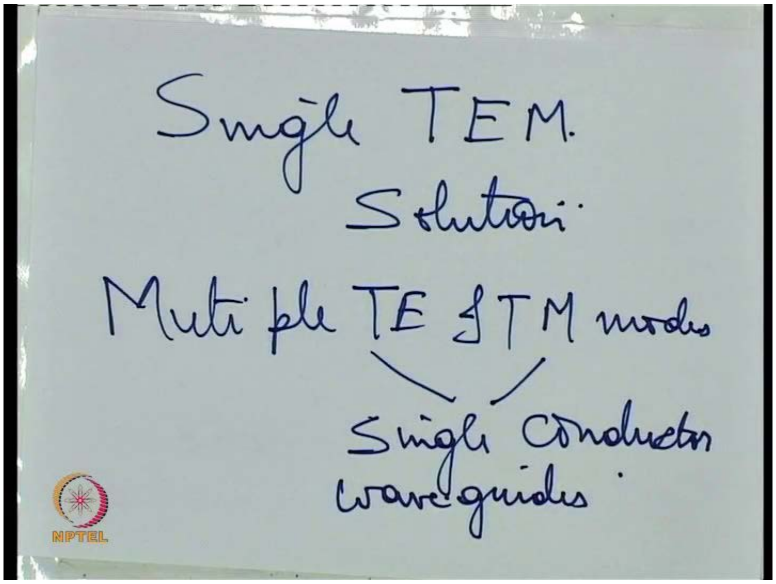

Now usually, not usually it's always true that there is a single TEM solution. That is we have only one electromagnetic wave which satisfy the TEM conditions. However there are multiple

TE and TM modes. Other interesting thing about these two modes is in single conductor waveguides, only TE and TM modes exist. So we are at low frequency like AC frequency or when we are dealing with a DC battery, we are familiar with electrical power transfer only by means of two conductors.

But then we have also electromagnetic power transfer to vacuum, where there are no conductors. Then we have our microwave components where we have single conductors i.e. single piece of metal is able to conduct power. Obviously we cannot have flow of charges as we know in conventional two wire circuits. So here these single wire conductors, they simply act as a guide for electromagnetic waves. So there is no concept of voltage of current, there is only the concept of electric and magnetic fields.

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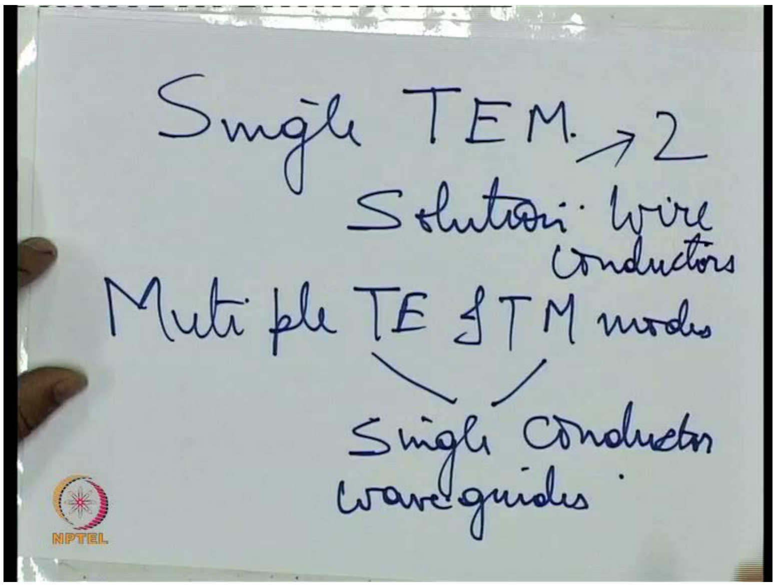

Whereas the TEM solution is applicable only for two wire conductors.

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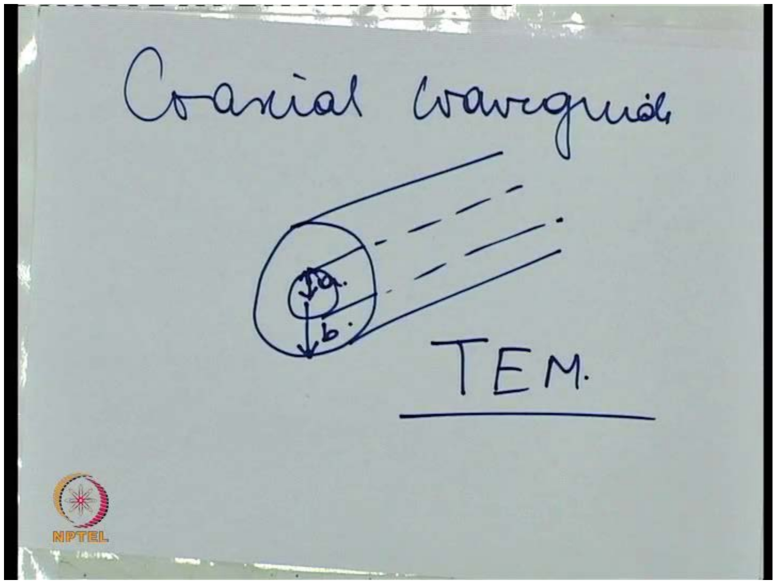

For example, say let us consider coaxial waveguides. A coaxial wave line, waveguide can be drawn like this. Since we have two modes, therefore TEM mode is the primary means of (com) propagation. One other thing I forgot to tell you about this TE and TM modes.

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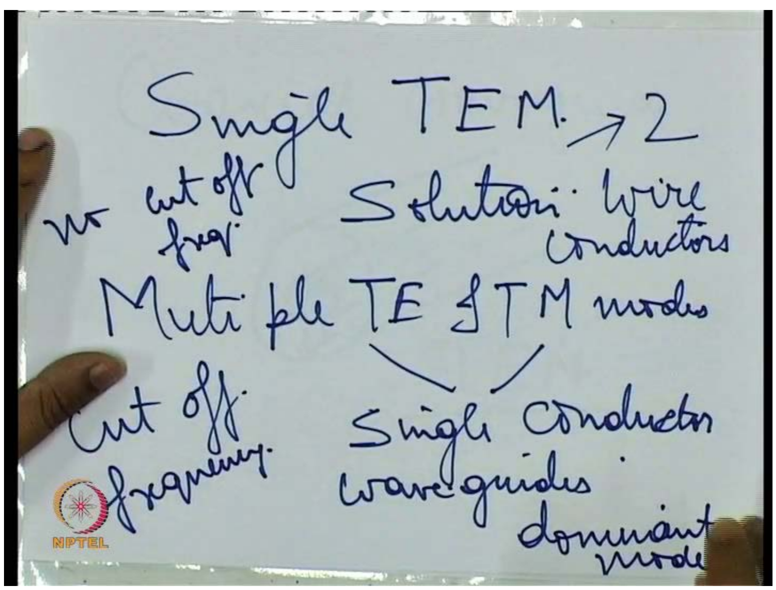

If I can go back to the previous slide, is that for TE and TM modes, they have something called a cut off frequency? So cut of frequency is the frequency below which the TE and TM modes cannot transmit. For TEM mode no cut off frequency is there. So they can transmit over any frequency. Now the mode as I said the TEM and TM, there are multiple solutions possible and that TE or TM mode for a particular waveguide which has the lowest cut off frequency is called a dominant mode.

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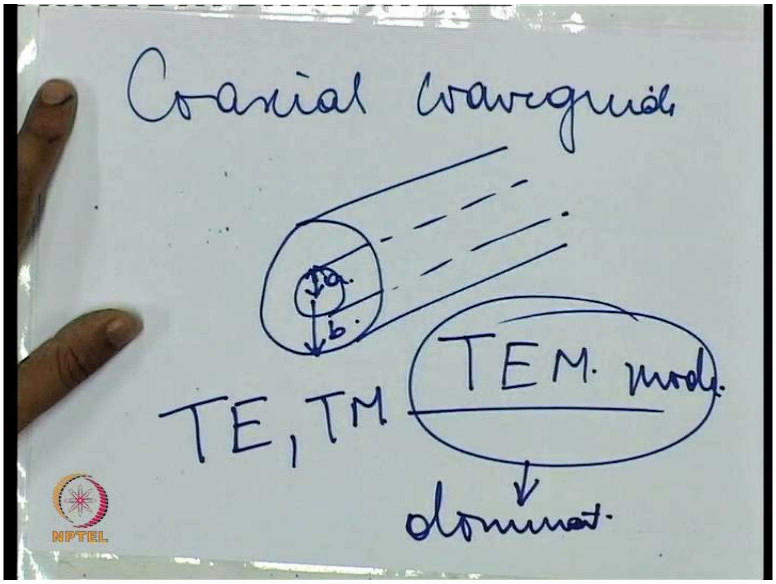

So then, since in a coaxial waveguide TM mode can exist, hence it can transmit over the entire range of frequencies. Hence even though there might be some TE and TM solution, TEM mode is the dominant mode.

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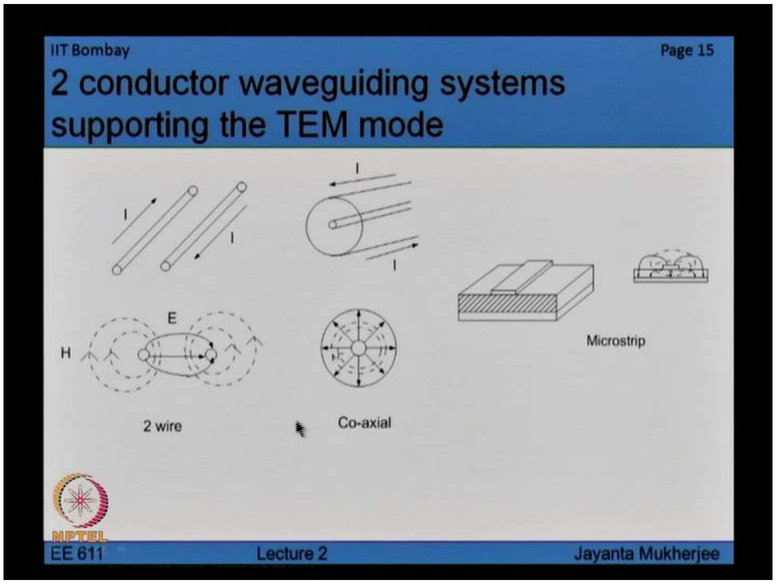

Some examples of this two conductor waveguides if you can go back to the slides, for a moment, these are some examples of two conductor waveguides. This is a simple two wire line. This is a coaxial waveguide and a microstrip line, which is similar to a PCB board where dielectric is switched, where a dielectric is present between two layers of metal. It is the top layer metal and bottom layer metal. Here also since we have the ground plane and a conducting plane. So this is somewhat similar to a two wire conductor.

And if we see the field lines, for a two wire conductor, the solid line represent the electric field and the dotted line represents the magnetic field. For the coaxial also similarly the solid line represent the electric field and the dotted line represents the magnetic field and same is the case of microstrip line. Now electric field is of course always perpendicular to the magnetic field. This is the basic notion on which Maxwell's equations are derived.

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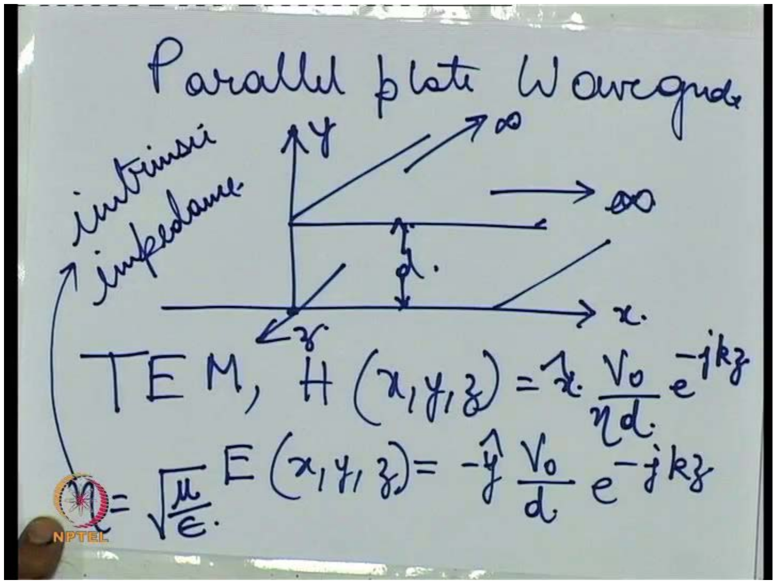

And, if we can go back to our page, to our written page, now an interesting example of a waveguide is what is known as a Parallel Plate Waveguide. A Parallel Plate Waveguide is a waveguide which has two parallel plates and these plates are infinity long and infinitely wide. The only finite dimension is the distance D, separating the two planes. Now the TEM wave solution for this parallel waveguide is given like this.

The Solution for the TEM waves are given like this. Here HX is oriented only along the X direction and E is oriented only along the Y direction. E represents the electric field, H represents the magnetic field. Eta is given by square root of mu over E, is called intrinsic impedance. That is the impedance due to the material properties. So this is the TEM solution and as we can see there is only a single solution. We don't have multiple solutions.

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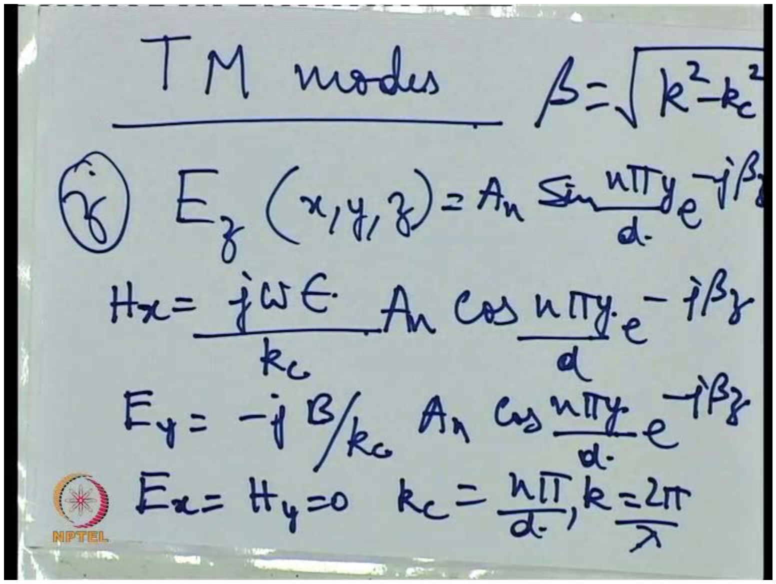

If we try to find out the other solutions, for example the TM solutions, the solutions are given like this. The reason I am writing explicit the solution is because I want to show you some of the properties of these equations. See, the values of this electric and magnetic fields, first of all H is oriented only along the X direction, i.e. Perpendicular to the direction of propagation Z and E has components, both along Z and Y.

And note there is a variable N in this equation. What this variable N does is, for different values of N you get different solutions of EZ, HX and EY. And these various solutions for every new values of N are called the various modes. So we don’t have a single solution, we have multiple solutions. And then all of these will have certain cut off frequency and the one that has the lowest cut off frequency will be the dominant mode. So we will have modes like say TM 1, TM 2, TM 0 and so on.

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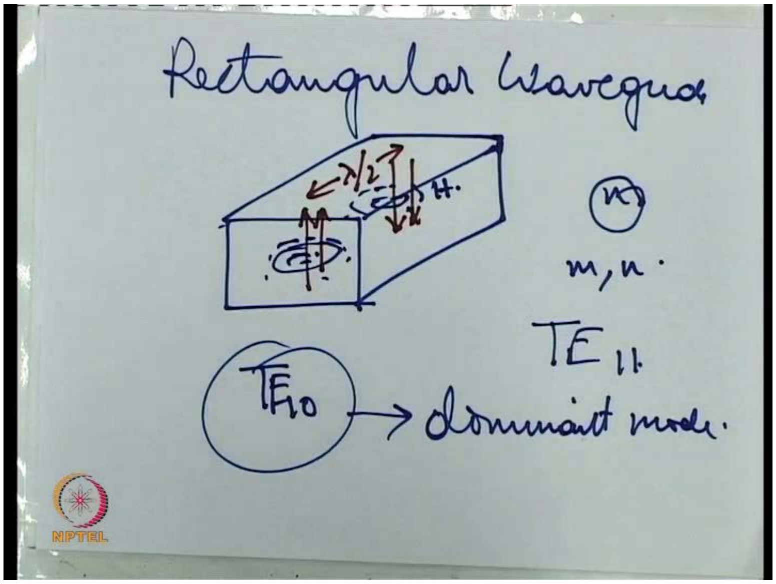

Now for a rectangular, similarly no, for a rectangular waveguide, there is a device called, or a component called a rectangular waveguide, which is just a hollow of a rectangular pipe, like this. It is a pipe like structure which is hollow inside and the dominant mode for this is TE 10 that is because whereas for the parallel plate guide we had solutions that varied only with the single variable N, in the case of this rectangular waveguide, we have two variables M and N.

So we will get modes like TE 10, TE 11 and so on. So TE 10 is the dominant mode. That is it has the lowest cut off frequency. So for TE 10, the field lines, if I can draw them, the magnetic field are concentrate like this and the electric field are like this. So lambda by two separation will cause electric fields and the magnetic fields to rotate. So the magnetic field will rotate in the opposite directions and the electric fields which are perpendicular to the direction of propagation, they will also be oriented in an opposite direction.

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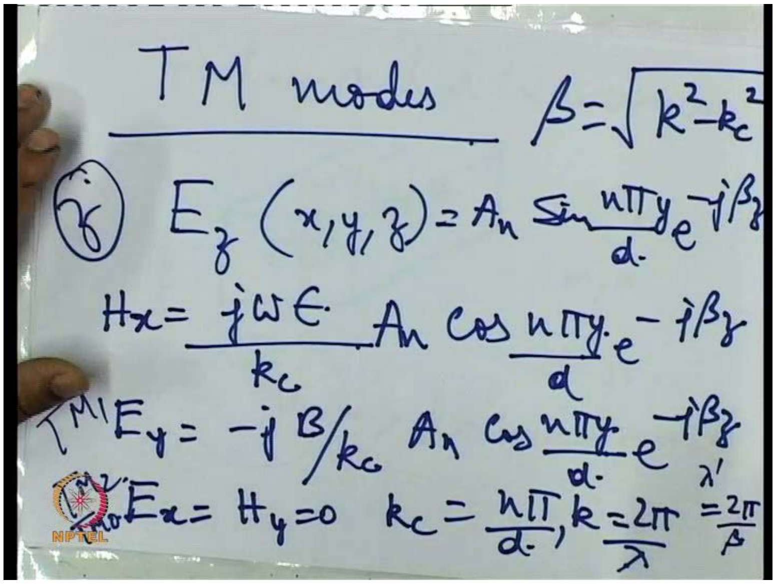

Now the consequence of this if you can go back to the solution for the parallel plate waveguide. Now we see that the propagation constant Beta is given like this, where K is related to the actual wavelength that we see and KC is a constant. It depends on N and the value of D. D is the separation between the two plates. Now this is for a parallel plate waveguide, once again. Now what you see is that this propagation constant Beta, which is the, which is kind of the apparent wave length that we observe. Because Beta is a spatial frequency in this equation.

So this expression will repeat itself after every one, after every beta value, after every lambda dash value, given by two Pi upon beta. So if beta is a spatial frequency but then the actual real, wavelength that we have inputted into the waveguide is lambda. So there is an apparent dichotomy or something, it is not matching.

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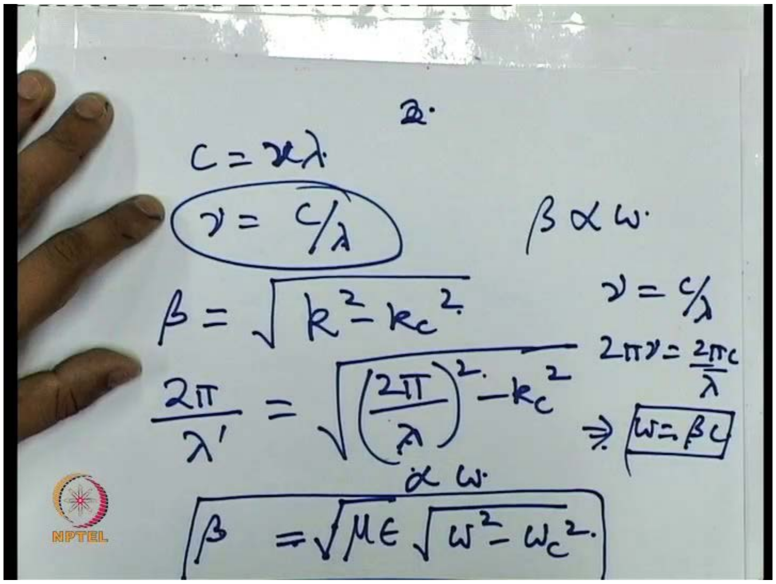

Usually as you know the frequency is related, as you know the speed of, suppose C is the speed of light then we have, that is given by new lambda. Where new is given by C upon lambda. So new and lambda should be inversely proportional to each other. By this relationship of beta is equal to K square minus KC square, Where beta is the apparent wavelength and K is the real inputted wave length, related to the inputted wavelength is given by this relationships. Now this of course is related to the, is directly proportional to the frequency of input. So then the simple relationship, simple inverse relationship that exists before doesn't exist anymore. This is the apparent wavelength and this term is related to the frequency like this.

So if we actually plot, in fact this equation is given like this. So we see that beta and omega are related by a complex equation. Of course for high values of omega beta is again proportional to omega. So 2 Pi, initially the relation we were expecting was New equal to C upon lambda, on in other words 2 Pi new is equal to 2 Pi C upon lambda. This implies omega is equal to beta C. So here we had expected a lender relationship between omega and beta. But what we are actually observing is a relationship like this.

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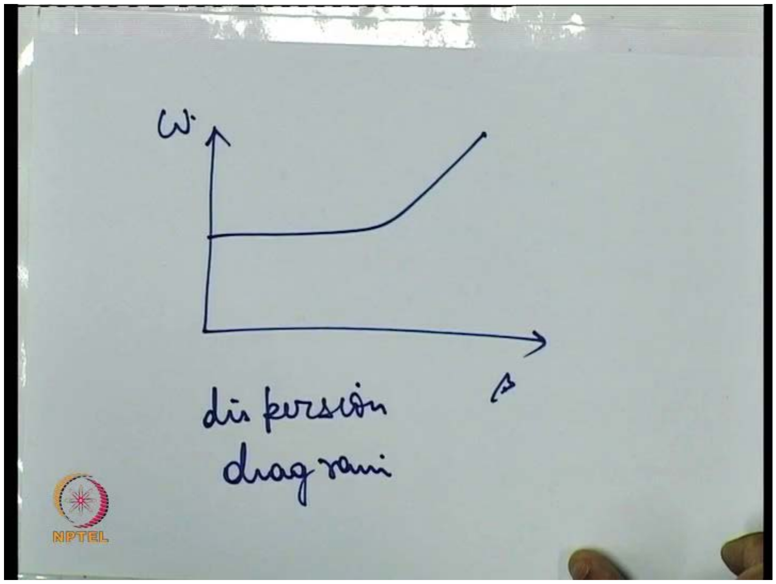

Note that as I said, for high values of omega, the relationship will again be linear. But for low values of omega, we get a kind of complex relationship and if you plot this curve between beta and omega, then we get a curve like this. This is known as the dispersion diagram.

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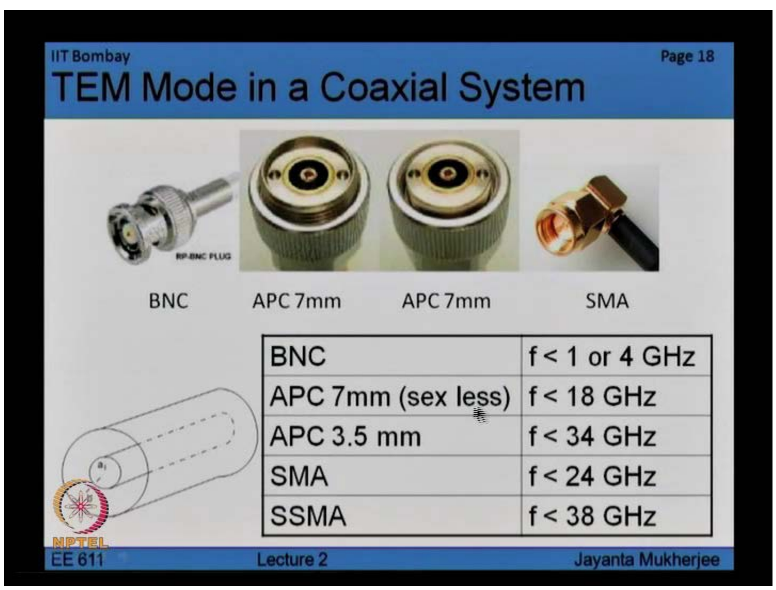

So if you can go back to the slides for a moment. Here are some example for the two conductor waveguides, where the dispersion relationship is linear between beta and omega and TEM is the dominant mode. These are examples of coaxial cables various standards and these are frequently used. Each had 2 complimentary portions what we refer to as male and female portions for each of these connectors.

And for various frequencies, for various power levels, you have different kinds of connectors. SMA is a very commonly used connector, there is also a similar connector called K connectors and 2.92 connectors are also available. So I just wanted to show you this diagram because this is very frequently used in microwave engineering.

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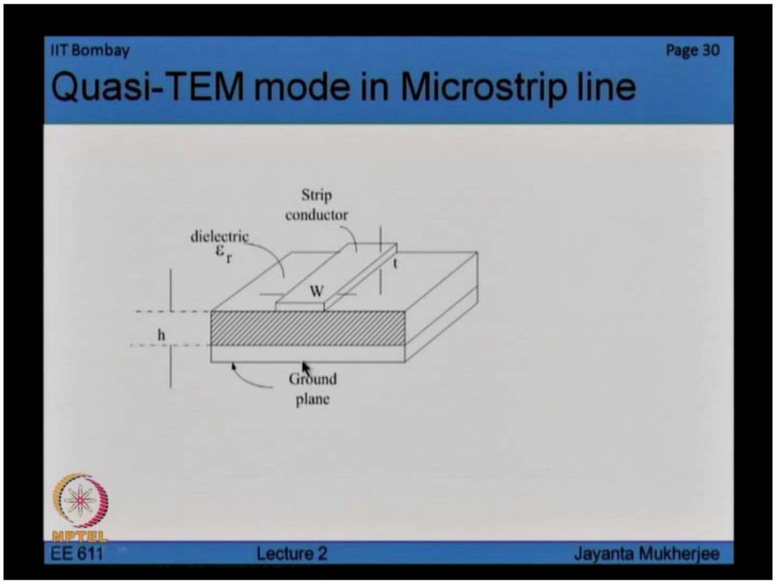

Now another component, I would like to stay with the slide for sometimes. Another component that is frequently and most widely used in microwave engineering nowadays is the microstrip line. So the microstrip line consist of a ground plane with a toplayer metal with a sub strip comprising of some Dielectric like Teflon or glass epoxy or ceramic in between. This is the construction of a microstrip line.

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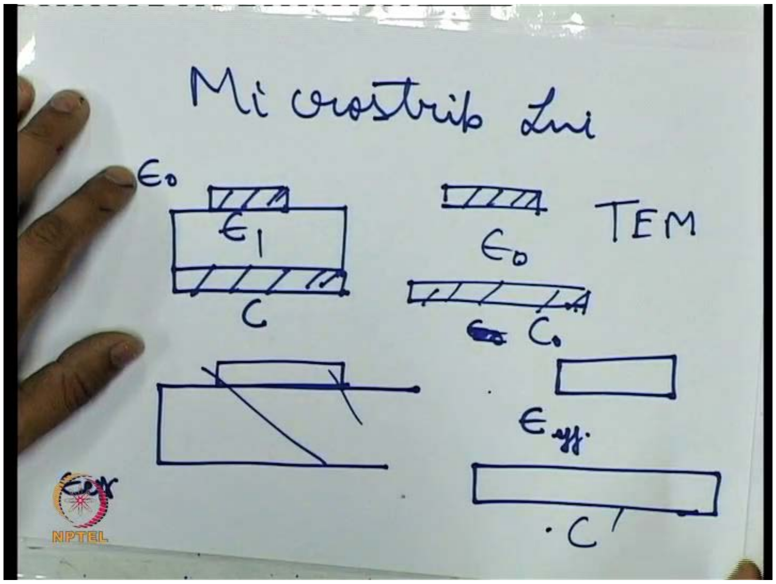

The problem with microstrip line, is that, if you can come back to our written slides. The problem with the micro strip line is that, it is, since it consist of two different conductors, two different dielectric materials. Even though it has two conductors, the modes are not strictly TEM. So in a microstrip line, you have, if you take a cross section of a microstrip, which I showed in the previous slide. It is something like this. Two metal layers sandwiched between some dielectric constant epsilon 1. If we had just air in between, then it would look something like this will all epsilon 0.

If air were there, then it would be a two conductor waveguide and TEM would be the dominant. But since it is not so, we have another dielectric material in between. What we usual do is we assume as if there is neither air nor the dielectric material present. But sorry, but this entire space outside and inside of this metal layer is covered with a material having a dielectric constant epsilon effective.

Is suppose C is the capacitance between these two plates, with just this dielectrics present and C 0 is the capacitance between these two plates with air present and C dash is the capacitance with, with this effective dielectric with dielectric material having epsilon effective present, then we can, you know we can find out a relationship for this epsilon effective, in terms of this measured values of C and C0.

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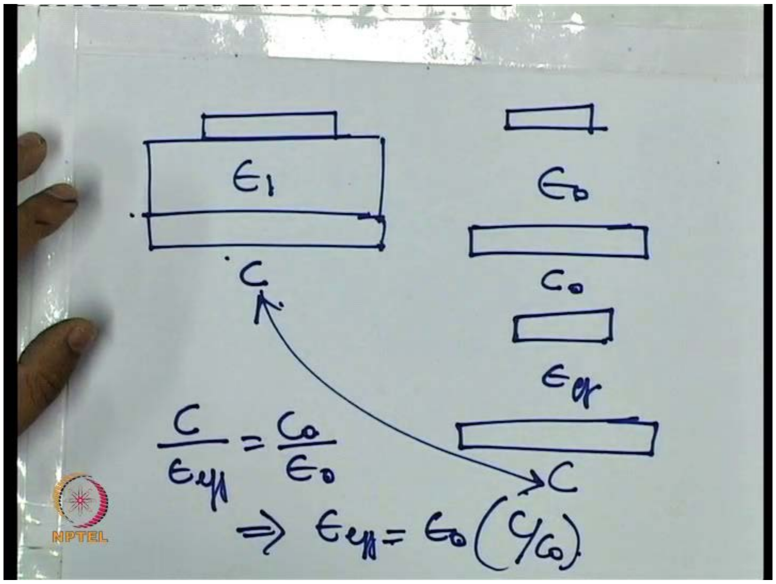

For example, so I was discussing the three types of conductor, three types of microstrip lines for analysis. One where there was a dielectric material with epsilon 1, other where air was present between the lines. And the third where we had an effective dielectric material having the dielectric constant epsilon detective present.

Now suppose C is the capacitance for this case, C 0 is the capacitance for this case and suppose with the effective dielectric constant epsilon effective also the net capacitance value that I obtain is like this, then I can write C upon epsilon effective is equal to C 0 upon epsilon zero, from which I can write epsilon effective is equal to epsilon 0 C upon C 0. So this is the relationship for the dielectric constant. This imaginary dielectric constant that is surrounding the inside and outside of these metal plates and it is related to the values of C and C 0, with this relationship.

Now before ending this lecture just one small concept, I want to stress is the concept of impedance. As you saw, we have single conductor wave guides for microwave propagation but then there is no concept of voltage or current. Yet we inherently know that, impedance, the concept of impedance is related to voltage and current. However there is something called an impedance, when we deal with various waveguides.

So the question is what is this impedance that we are talking about? Since voltage and current are not effective concepts we really cannot define impedance in terms of voltage and current always.

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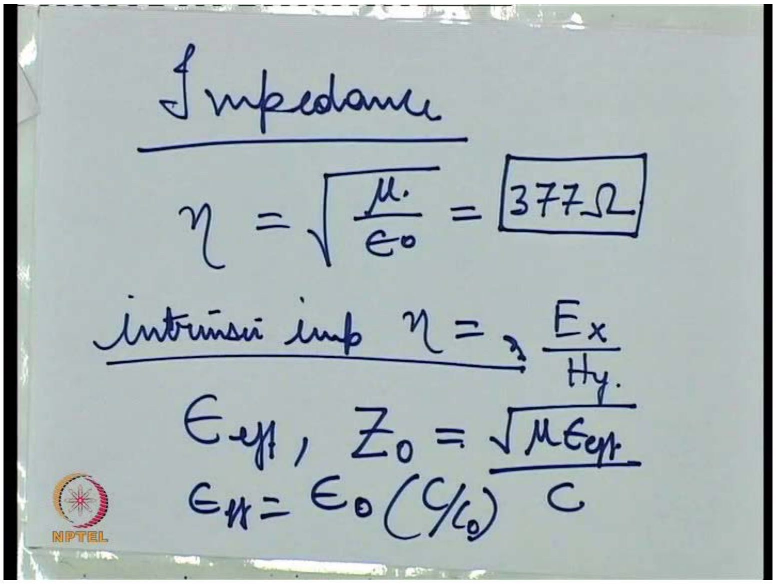

We have already got a hint of something called intrinsic impedance which is related to the property of the material, and that is given by mu upon epsilon. So this is a value of an impedance which is purely dependant on the properties of the material. In addition we also have something called electromagnetic impedance which is the ratio of the electric to the magnetic field. So here instead of voltage divided current, we have EX divided by HY and this is also an effective way of expressing impedance.

In fact for air this intrinsic impedance comes out to be 377 ohm. That's why antennas which are interface, often considered as interface between air and waveguide. The waveguide has to be basically designed to produce an impedance matching. The waveguide or the antenna has to be designed to produce and impedance matching of 377 ohm. Now this is intrinsic impedance. For a microstrip line that we were discussing we have found out what is an E effective and for a microstrip line that is the value of Z 0 is often given by this formula where epsilon effective as we found was equal to epsilon 0 C upon C 0. Where C is the measure, capacitance between the plates of the actual microstrip line and C 0 is the capacitance between the microstrip metal plates, had air been the dielectric medium.

So just to summarise this lecture, in this lecture we have covered some basic concepts about microwave engineering like impedance, modes, dominant modes, TEM, TE and TM modes and also introduced some of the devices that are commonly used in Microwave engineering. We will of course cover devices in more detail. But as a starting point these concepts are very, it is very important to understand, this concepts. Like what is dominant mode, what are the TM and TE modes and, so with that we come to an end of this module.

Thank you.