Lecture 01

Introduction and Types of Transmission Lines

Hello and welcome to NPTEL MOOC, on Electromagnetic wave propagation, in guided and wireless media. In this week one, module one, we are look at, transmission lines. In this week, we are going to study, a few characteristics of transmission lines, understand its frequency domain and time domain behavior. And then in the next week, we are going to apply these concepts, to some practical applications, mainly to do with, signal integrity and for RF and microwave design. Okay? What is a transmission line? To put it simply, a transmission line, is any structure, a physical structure, which usually made out of a conductor, which can guide, electromagnetic waves, from point a to point b. The most familiar type of transmission lines that you have seen

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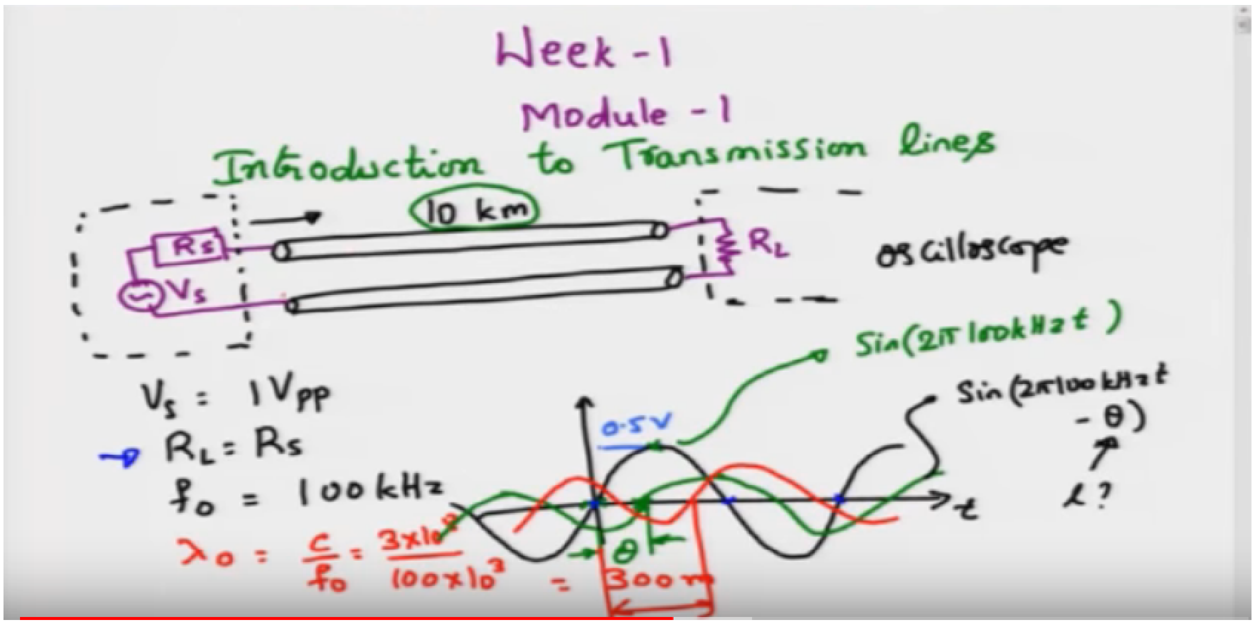

corresponds to a pair of, wires. Okay? Which have, in this case I have shown you, that they have a certain cross section and then they are essentially uniform along one of the directions. And these pair of wires carries voltages and currents, from one point, to another point. Of course we talk about Electromagnetic waves, and now you may question, as to, why am I talking about voltages and current? It terms out, that, in this transmission line theory, it is possible for us to still deal with, the voltages and currents, and only when the frequency increases so much, that compared to the structure that we are looking at or the wavelength reducers so much, to the structure that we are looking at, that we need to really bring in, the concepts of electric field, magnetic field and to consider the electromagnetic field behavior. So, for, for the case that we are considering here, it's not necessary that we study the fields or we are concerned with the fields of the transmission lines. Although, we are in some sense, as we will see later on. But the description in terms of voltage and currents is, is very good, it is and approximation, but it is an excellent approximation. And it will tell us many things, about waves, that, we can apply later on, when we study Electromagnetic waves, as well. Okay? So, coming back to the transmission line, we have a pair of wires, although it's not visible, I am not really written it nicely, the wires are assumed to be uniform, along one of the directions and we really assume that, these waves are, quite, or rather, sorry. These lines are, essentially extending, to quite a long distance. Okay? Of course I want to launch certain voltage or current. The wave I will do it, is to connect these wires to some source, and let's say the source as certain voltage source, or sorry, certain internal resistance Rs. Okay? A then, this will usually be, the pair of wires is usually used, to connect, to a load, who's resistance, I'm assuming it to be equal to RL. So, I've taken this simple resistances, in practice, the load may consist or include a few inductive and capacitive parts, as well. For simplicity, we have a assumed that load consists of only RL and this is RS. Now as I'm writing these pictures, I want you to picture an experiment in your mind, where this Vs, Rs, comes from the function generator. So, you may imagine that you actually are, sitting on a table, or you are actually, you know, standing in front of a table. I am sorry. And then you have a function generator kept, you know. And that Rs, is of course internal to the function generator, so it is not a accessible to you and you are taking out a pair of wires. Okay? They could be, instead of these two wires, there could be a coaxial cable, but the basic idea still remains, the same. I've taken two pair of wires or pair conductors, and then I have connected them load. And the load could simply be an Oscilloscope. Okay? So, the load that I have here, written as RL, could simply be one of the channels of an Oscilloscope. So, it just imagine, this experiment in our mind, and when see, what happens as we, let the voltage source, be applied, from by turning, on the function generator. Now as soon as the function generator is turned on, there is something that is going to happen, which we are not going to look at it, at this moment. What we'll assume is that, this source has been turned on quite some time, you know. May be, about ten, fifteen, days ago, it was turned on and then you are viewing this, right now. Okay? So that is the basic idea. Though the ten, fifteen, is not really practical, what I am saying, but mathematically, we will assume that source has been turned on, for quite some time and what we call as transients, have all died down. Right? You do remember that transients. Right? When you turn the switch on, on any circuit, you will see that the solution will, even, you know, will oscillate a little bit, or will change a little bit, what is called as, 'Transient Response'. And eventually settles down, to what is called as, 'Steady State response'. and I'm interested in that Steady State response, in this particular problem. To give you some ideas, to actually what I'm looking at, I will mention that the voltage source, is about, 1 volt, peak to peak, so it is generating a sinusoidal sequence of 1 volt, peak to peak. And then, I will assume that, RL is equal to RS. We don't really want to bother about, you know, the ratios or anything like that. So RL, we will make it equal to RS. And I will take the frequency of the source, this is sinusoidal signal. So the sinusoidal signal, has a frequency of, let us say, about, 100 kilo hertz. Okay? I have a 100 kilo hertz, source, and I have turned it on, for quite some time and I m going to look at this, on an oscilloscope. Right? So I'm going to look at this, as an oscilloscope. If you don't have an oscilloscope, it's fine. This is just a thought experiment. Okay? Of course you can also write? I mean, do this experiment. But when you think of this, this is what, you are expected to see. Right? So, this is a 1 volt, peak to peak. Therefore this is about point 5 volt and this is nicely the way, in which your sinusoidal signal, from the function generator, would look. Right? And this is what the Oscilloscope would, oscillate say channel 1, of the oscilloscope, would show to. Right? This is point five volt, because I assumed, one volte, peak to peak. Alright, now let me mention that, the length of this tow piece, I mean wire, is about 10 centimeter. Right? So, this length is about 10 centimeter, now for 10 centimeter length. Right? That, let us calculate the frequency F naught, that we have calculate, I mean that we assumed is, about hundred kilo hertz. Right? What could be the corresponding wave length, Lambda naught? Wave length Lambda naught will be, C by F naught and C is basically, 3 into 10 to the power 8 and the frequency is about 100 kilo hertz So, that is, 100 into 10 to the power 3 so this will be equal to about, 300 meters. Right? The wave length of this source, will be about, equal to about, 300 meters. So, at this point, wave length doesn't really matter to us. I mean, or it won't, it seems that is doesn't matter to us and you don't have to really worry about the wave length part. Okay? The importance of the wave length will come out, shortly. But look at this thing. So, I have a wire, which about 10 centimeter long and then I have a signal, whose frequency is about 100 kilo hertz, who's wave length, of course is about, 300 meter. I mean, this is just a number, of, at this particular point. Okay? Now, what will be the voltage that I am going to the see, at the load? That is an interesting question. So let us look at, what we are going to see on the load. Right? What do you expect? now from the circuit theory point of view, the answer very simple. There is a voltage generator, VS, there is resistance, RS. these conductors been ideal. Right? No losses that we have assumed. Therefore there is nothing that these conductors are doing or the pair of wires are doing. So, the entire thing is actually equivalent to a circuit, and the load, should be exactly equal to the source voltage here, because these are all resistors as such. But the amplitude will be of, of what the source voltage is. Why would it be half, because RS is equal to RL. So, the voltage gets divided between RS and RL. And therefore, you would expect this kind of a voltage. Right? So, you would expect this voltage to come out. So you should actually expect that the voltage would be about a sinusoidal signal and it peaks, where ever original signal is peaking. And it goes to the zero, wherever the original signal is going to zero. Right? So, if there are two waves or there are two voltages that are in this particular manor then these two are called as, voltages being, in phase with respect to, each other. So, this you would actually expect. Right? Fine, this is all seems to be alright. Now let me change the length from 10 centimeter, I am, and I am going to make this one into, about a kilo meter. Right? So I am going to make this one into, about 1 kilo meter or maybe about 10 kilo meter. Now you are, you can again think of this experiment. You know, you have kept the function generator; you have kept the load unchanged. But then you have to wrap, 10 kilo meter copper pair of wire. So, how you do it, is something you can do it or you can go and grab an electrical power line cable line, that is running over a length of ten kilo meters, and connects your, sources on a non oscilloscope at the other end, but this is, the thought experiment so, do know? Have do any of that, but from your, circuit theory point of view, can you take a moment, pause the video if you want, but take a moment, think has a situation changed really right? just because, I changed the length of the wire, from say ten centimeter to, ten kilo meter, from circuit theory point of view, as my situation changed, as anything changed at all. If you have paused thought about it, and then now you say, that there is no change from circuit theory point of you, you will be absolutely correct. Circuit theory simply does not care, what length of the line that you have used? For it, a ten centimeter line, is a same thing, as about an ten kilo meter line, in fact in doesn’t even worry about the shape of the line so, you could for all practical purposes, take this pair of wires and then bend them, twist them, do whatever, that you want, from the circuit point of you it’s still remains, the same, the voltage at the load end, oscilloscope display, on the oscilloscope will still continue to be a sinusoidal signal of the same frequency, and the amplitude of half, with the important point that peaks, where the original wave, peaks and or at the original voltage peaks and goes to zero, where the original voltage goes to zero, when I say, original I mean the source voltage. Right? But, what you actually, see if you want to do this experiment, what you actually, see you will be, something that will be about would I say, I would radically different yes, that’s a good word, what you would see is that the amplitude is still Okay? I mean it small, but then the wave seems to be not starting, at the same point it is not, source where the wave is going through a peak, the sources is already gone to a peak before, that where the waves, is starting at this zero, for the voltage at the load, is starting after a certain delay it seems that where at least, there is a face difference between the two waves, and this face difference we will do not it by theta and this face difference is actually because, of the physical delay in sending the voltage from the sources side, to the load side. Right? And this difference would be, negligible or would not even scope on your oscilloscope, if the line length are to be, very small. Right? So, if there wires that if connected, appears to be very, very small, when you don’t even see this, difference theta, although for all I know a theoretical purposes this delayable always exists, and this delay there is nothing, mysterious about it, it is simply saying minute simply the fact that, the line or the pair of wires, which have been connected, have to physically, take electromagnetic the waves from one point, to another point and in doing so the length essentially gives, you're delay. Right? And that delay in the case of a sinusoidal signal turns out to be in the form of a face delay or face shift theta so, if the voltages here at the source side can be written as say some sin 2, phi hundred kilo Hz, t. Right? The voltage at the load side can be written as sin 2 phi hundred kilo Hz, which is still the same thing, I mean the frequency is not changed, but there is face theta. Right? So, there is a face delay, that or a face shift that, this voltage at the load experiences, when compare to the voltage that we will see, on the source. Right? So, these two or essentially, shifted by a factor of theta, and the load voltage is actually deled by, the factor or by, the face value of theta. now, again think a little bit carefully, is this theta dependent on the length of the wire? it would certainly seem so, like if a instead of considering a ten kilo meter pair of wires, if I consider hundred kilo meter, pair of wire I mean the pair of wires having a length hundred kilo meter long, then surely the amount of face shift, or the face delay that you're going to see, you will also change, perhaps the face shift will be looking at like this now. Right? So, this be the new face shifted, I m seeing or maybe I did not, tried it correctly, but this the face shift but I m seeing and this face shift certainly, in is a function of the length of the wire that is connecting the source and a load. All these things, the fact that there is a face shift between the voltages at the source, or face shift between the voltages at the source and the load, is thought really predicted by, the circuit theory so, circuit theory will tell you that does in matter it whether it is thousand kilo meters, or one million kilo meters, the voltage at the load will always, go through zeros, where the voltage at the source will go through zeros, and the two voltages could always be in face with respect to each other they, or not shifted by, any face what's to our but, physically we know, that it cannot happen, it physically, they as to be certain delay, and that delay will cause the face to, shift or face to change, and that face difference is something that is depended on the length as well, of course as I said, I have also assume that the structures, or this wires or smooth, they don't change their cross section, they are not twisted, and there are not done anything, at we also assume that this two or essentially loss, list at this particular point, but in practice you cannot find a conductor which is zero loss, Right? I mean they, or those super conductors, but even those exhibits some amount of loss so, it is certainly possible and it is in fact, will happen that the wires, or the materials, at we used the conducting materials, that we used will always be lossy, and one has to take in to account that amount of loss, when thinking about the model for, this situation more over as I told you while that two, I know? Wire transmission line is the simplest one that is not,

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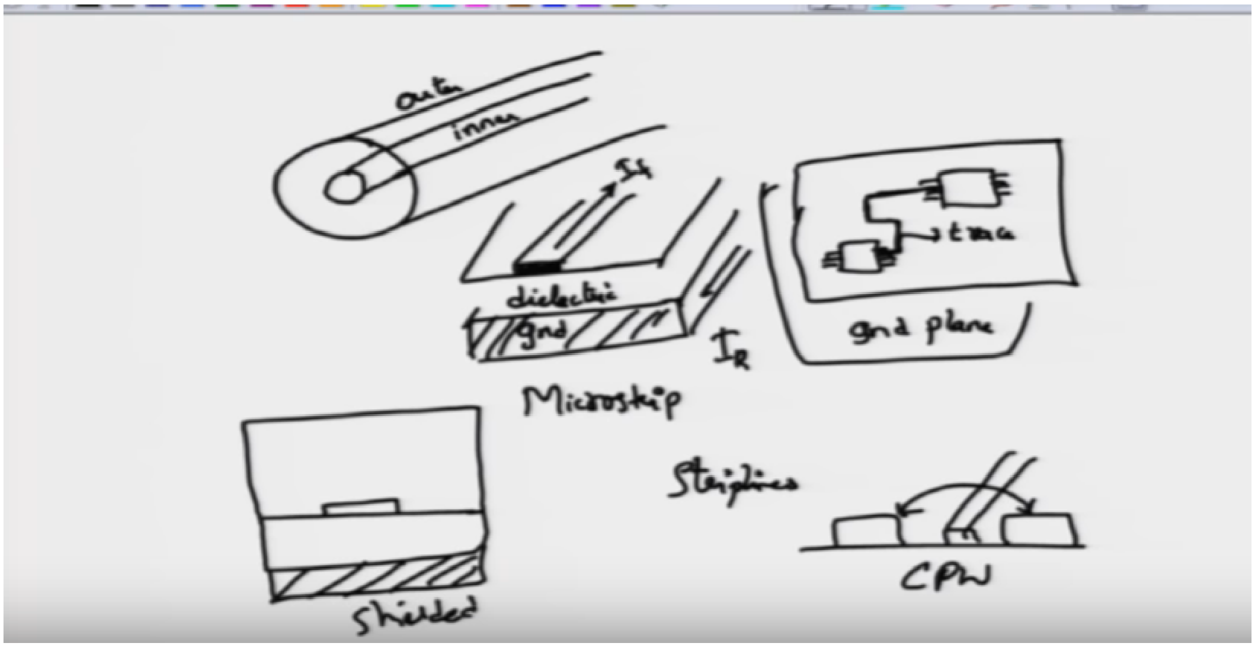

The only transmission line, in fact you probably, have already seen, have already mention this, in the introduction video, this is what is called as a coaxial cable, and a coaxial cable will actually, look something like this, it will have an inner conductor, and then it have the outer conductor, here Okay? I am then surrounding the outer conductor is a plastic sheet, just to, kind of give it a mechanical production and also it, contain the fields, with in that, and this is an example of a transmission line, and on a printed circuit board if you look at, from the top, you will see that, there is a I know? IC here, this IC, to another IC, let say at this point these to pins, or actually connected by a pair of or by a conducting path, which is called as a trace Okay? So, this is called as a trace, or PCB trace, and then below this somewhere on the PCB, will be a what is called as a ground plane, Okay? The ground acts as a reference, and if you look at the trace in the cross section, wise we will see that, this is what it would look like, so this is your trace. Right? This is the trace, and this is your ground plane. Okay? So, this your ground an in-between of course is, whatever the material that, the PCB material is made out of so, this is the dielectric, and currents or being carried by, this trace Okay? So, I'm just extending this to show you? How the structure would, look like. So, this trace would carry a current, forward current If as would call it, and this ground plane would carry, what is called as a reverse current, of the return current. Okay? And this structure, this transmission line structure is called as a micro strip, and instead of considering a micro strip you may, also consider, what is called as a shielded micro strip, a shielded micro strip is essentially there you know? It is essentially a box kind, of a structure that is, that is surrounded, that is surrounding the top trace. So, that the field which are radiated, we will come to those, things, later on, the field which are radiated are not compiling no coupled, outside and then calls, in to mantic in difference to the next, components so, these are called as shielded micro strip planes, you will also find additional types, as I have told you strip lines, then you will also find that, there is, what is called as a complainer line. Okay? So, this is the main line and these to or essentially the ground lines so, all these variations, that we consider so, these or called as CPW lines, this is a shielded micro strip line. So these transmissions lines, or essentially characterized by, the certain common characteristics.

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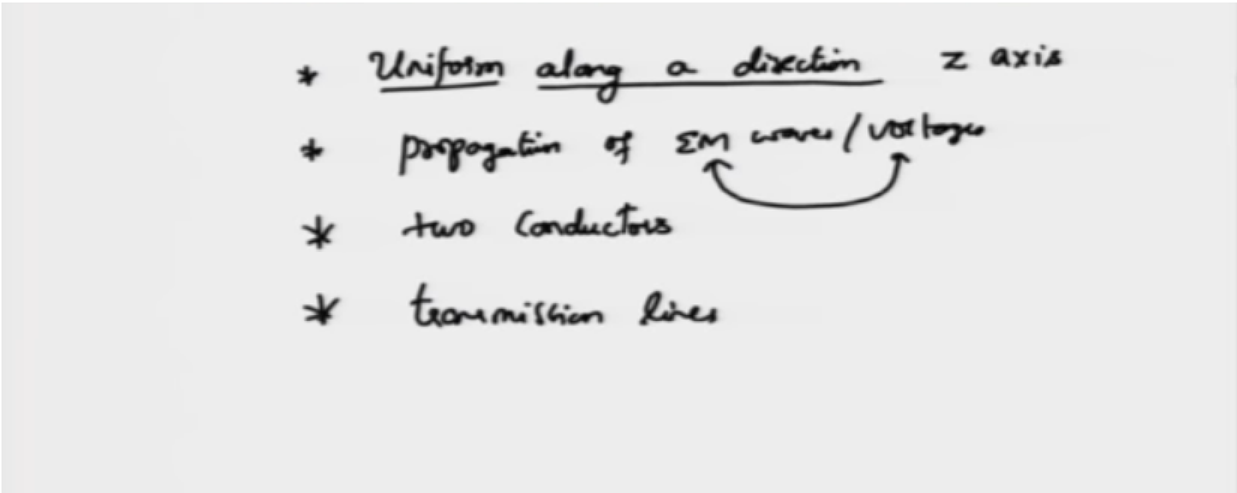

So, one of the characteristics is that, they are uniform along at list one direction right? So, along a particular direction that is the cortication remains the same weather I am looking at the whirs now or whirs, I mean whirs hear, after a certain length. Right? So, there is no sudden change bump are you know deprecation are some set of trusting are carling are bending none of those thing are happening, so these lines. So, we call them as, uniform transmission lines and they are a uniform along a particular direction, which we traditionally associate with Z axis are zee axis. Okay? This is what we have. The second characteristics is that, this lines are and this is actually because of the first characteristics itself, these lines are what is called as propagation or transmission lines in the since that I explain in that a mint. So, they are cosine with propagation of electromagnetic waves or voltages and current of course in this particular case , voltages and current and the they don't They are not meant t to radiate any of this voltages, actually voltages don't radiate ,what radiate are electromagnetic fields? and there is a relationship between determatatic, quantys ,electric fields and magnetic fields, to voltages and current ,which we are go and exposited latter on but ,are proposes because this stature uniform ,what we expect only propagation of the waves? Not relay they kind of you know, radiation that is associated with antenna, although practical transmissions do radiator little bite we do telling worry about that part until quite some time. Okay? Than a strit, strit seines transmissions do only propagate waves because, there uniform along a particular direction. Okay?

And I mean this another important characteristics, they all contain two conductors, no don't let me wrong, it is passable have more than two conductors. Okay? however the fundamental transmissions line the theory on, on is contain two conductors transmissions line, extension two multi conductor transmissions line is other important topic which is very piratical as well because real scenario you will see many, many conductor on a printed circuit board diftatelly you are going to see more than two conductor and any two pairs of conductor can , actually be considered a transmissions line and therefore, multi conductor transmissions line theory is an important topic, which unfortunately we will not going to cover in this particular course. So, for as all transmissions line that we consider have only two conductors and this is other very important characteristics they transmissions lines are really the transmissions lines. Right? Now, you maybe pasaldust what I am taking about hear, let me give you what I am taking about

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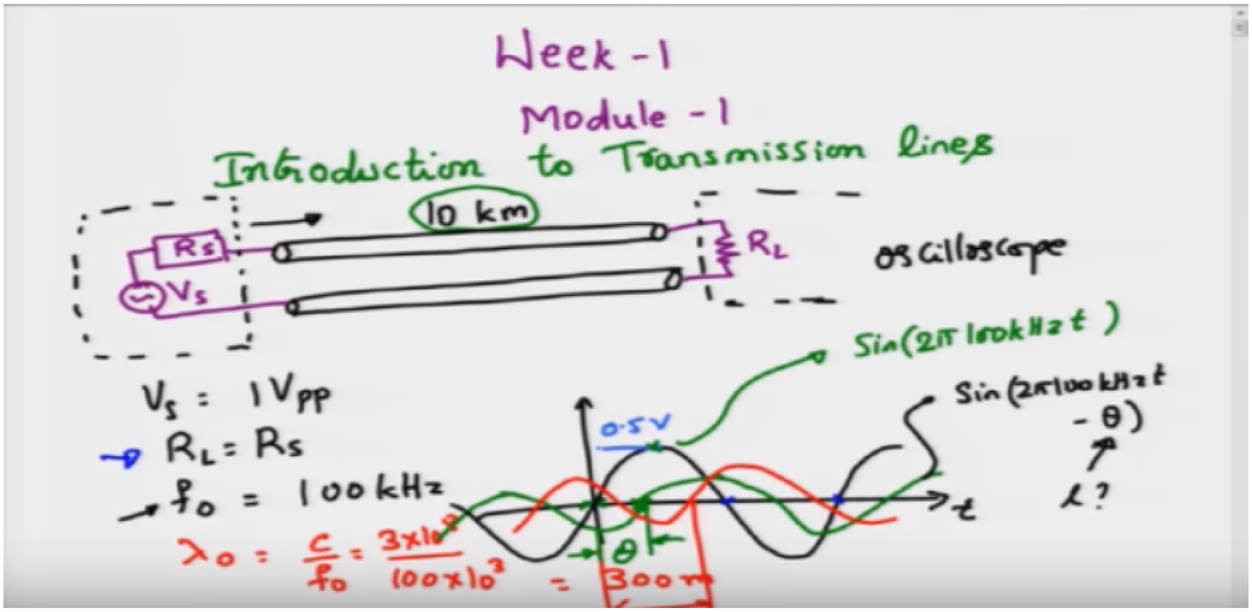

We saw in the first you know, slides hear that you had a source and load. Correct? an then the frequency we mansion that to be about 100 hats and corresponding wave length although you may not really worry about what the wavelength is the wavelength turned out about 300 metros right?

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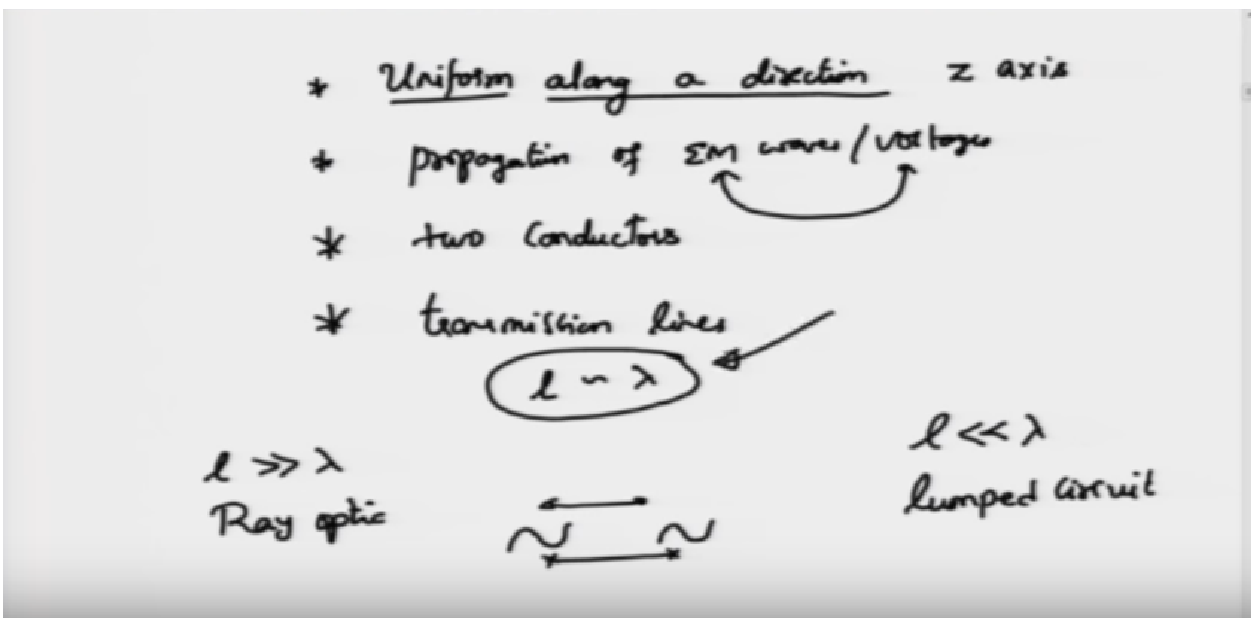

Transmissions line theory, formally is applied to any structure okay? Which interact with electromagnetic waves, when the length those structures, are essancily in the same order of magnitude of wave length lambda? Okay? You have seen two different casus of actually, one you could have seen they case where you have seen two different cases actually. One you would have seen the case where L is much, much larger than lambda. This is what is called as a, 'Ray Optic Approach', meaning the Physic, the wavelength of the electromagnetic wave is so small, that the structure looks very big. Right? It is like a bulb that is there at the center, of this particular room, whereas the room is in few feet's, right or about meters or so. The wavelength of the light is just about 600 nano meters or point 6 micro meters. So if you look at the ratio of, L to lambda that is actually a very, very large number. And in that case, you can think of electromagnetic waves. Light being, one of the electro, I mean, light being an electromagnetic wave, as well, as being propagated in straight lines. And their familiar phenomenon of, no reflection, refraction of light, is essentially part of this particular thing called as, 'Ray Optic Approach'. Okay? You can apply ray optic approach to any structure, whose length is much, much larger than, lambda. On the other hand, you would have also seen the case, where length is much, much, much smaller than lambda. And this is what is called as a, 'Lumped Element Regime', and this is called as a, 'Lumped Circuit Regime'. Meaning, that my wavelength, that on the structure, the physical delay, between two points, right? So if you have a sinusoidal wave here, the sinusoidal wave will actually be the same, at the other point, on the line as well or on the wire as well. Simply because the length of the wire is so small, that the distance and the corresponding faceshift, is considered to be, Zero. Right? In and ideal scenario, L is much, I mean, the lambda is actually infinity, meaning that, when you change voltage a particular point, the wire immediately reflect the other end, the wire reflects the change in the voltage and therefore you are going to see, this voltage, to be the exact, same thing in face with the, this one. So what we are actually considering is transmission lines. Meaning that, the length of those structures, are comparable to wavelength. They're not very large with respect to wavelength nor are they very small with respect to lambda. And it is in this region, we are going to talk about, the transmission lines. And we actually start, the study of transmission lines in the next module, by first considering a model for this transmission line. Now let me point out an important thing. When we write down a resistor, we have circuit symbol for that. We write this as, resistor R. But physically that is not a resistor. Right? Physically it is actually composed, of a material, a resist material. Right? With a certain characteristic, such that, the Leads when you, when they come out, this is the actual physical resistor. The physical resistor that you have, will have certain amount of resistance R and if there is a certain current, i, through the resistor and the voltage, V, across this particular resistor, what circuit theory will tell us is there? As the voltage increases, the current keeps on increasing for a constant resistance. Or, the ratio of this one will be, R. Right? It doesn't matter, whether the voltage is 10 volts or 100 volts or 1 million volt, the corresponding current, will always be given by, V by R, and that will also, keep changing. But on a physical resistor, that is not going to happen. If you apply, say, 100 volt to a ¼ Watt resistor, you would have almost burnt out the resistor. What you would have actual see, is nice, smoke coming out, from the resistor. This is not what you want. And in that sense, this physical resistor is no longer dictated by the mathematical equation that applies to the ideal resistor. Right? So this is your physical structure. Right? This is a physical device or a physical structure and this is a symbol and this relationship, given in the graphical format, is the mathematical model. Right? Mathematical model tells you, that the voltage across the resistor, R, is given by V equals Ri. Keep changing one of the quantities and this is what you are going to get. So this is the mathematical relationship and this relationship actually breaks down. And if you want to little clever about the mathematical relationship or the mathematical model, you would say, as long as the power across the resistor, is less than about say, one fourth of a, Watt. Right? So if you supplement the main equation by this auxilary condition, then you have improved the improved the mathematical model. Right? You may even improve it further, by considering that these lines which are coming out, they are actually Leads. Right? So these leads which are coming out, they actually have a little bit of a inductance. Right? And this inductance, plus the lead being made out of a certain physical material, will also have its own resistance, R. Right? This is your inductance, of the lead and this lead resistance. There will also be, an inductor on this side and there will be a resistor here, so you again have a lead and for the simplicity, assuming that both Leads have the same value of L and R. And along with this, there is a made, actual value of the resistance, R. So if you were to, look at the complete model or a better model, you would find that the model actually consists of, the value of R, for which the resistance is rated or it is taken. Plus there are this, inductance and you know, additional resistances, additional inductance, additional resistance, that comes as part of being the physical wires that are coming out or physical leads that are coming out. Okay? So with that, what I want I want to emphasize is that, in the following weeks, when we talk about, we are mostly talking about the mathematical models. We are of course going to look at the physical aspects of the devices or the structures as well. But we are going to make lot of assumptions. Those assumptions are usually well chosen. I mean, if I don't choose, choose my assumptions correctly, then I can predict all kinds of nonsense thing out there. But those assumptions are chosen, such that they explain the phenomenon, with, as little as possible, those assumptions are. And, while I'm looking at that, you have to always keep in mind, that when I draw a transmission line by writing two straight lines, form of actual transmission line will be different and perhaps, whatever I'm doing on the paper here, by drawing two lines, is not adequately representing that particular physical device. It, it is, it will, represent in, that device in, many, many cases, to very good approximation, but you should also remember, where these approximations break down and how to go about improving those approximations. So that is the division between or that is the device between, what is called as a, 'Physical Device and its Mathematical Model.' Those wires which I'm drawing, they are all symbols. Right? So in the next module, we begin formally, to look at models of transmission line. And it is surprising that all these different types of transmission lines, can be given or can be described, by almost same, set of equations, as we are going to see, next.