Transmission Lines and Electromagnetic Waves

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Lecture - 06
Reflections and Reflection Coefficient

In the previous class, when we had run the simulation we had noticed that the top red colour curve which is corresponding to the voltage and the bottom corresponding to the current there are some observations and we are going to build on these observations, ok.

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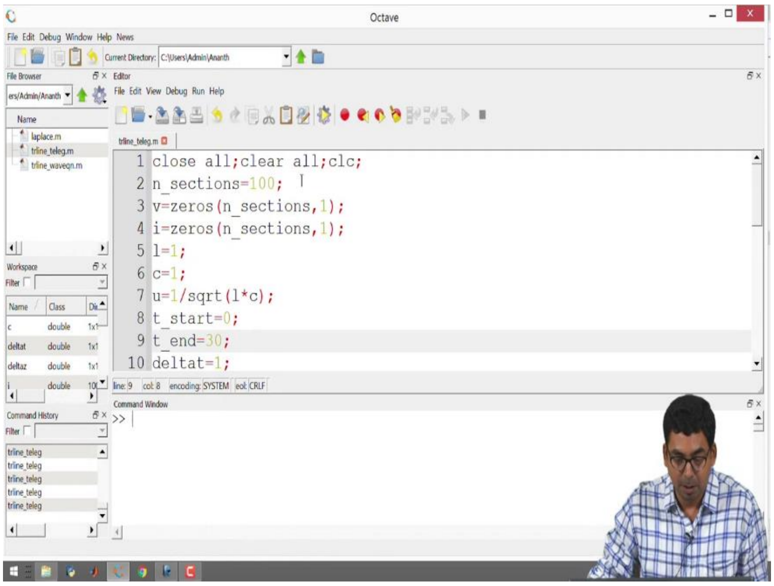

The first thing that we noticed was there is a voltage wave traveling to the right and to the left because the source was kept somewhere in the middle for us to understand this a little bit more.

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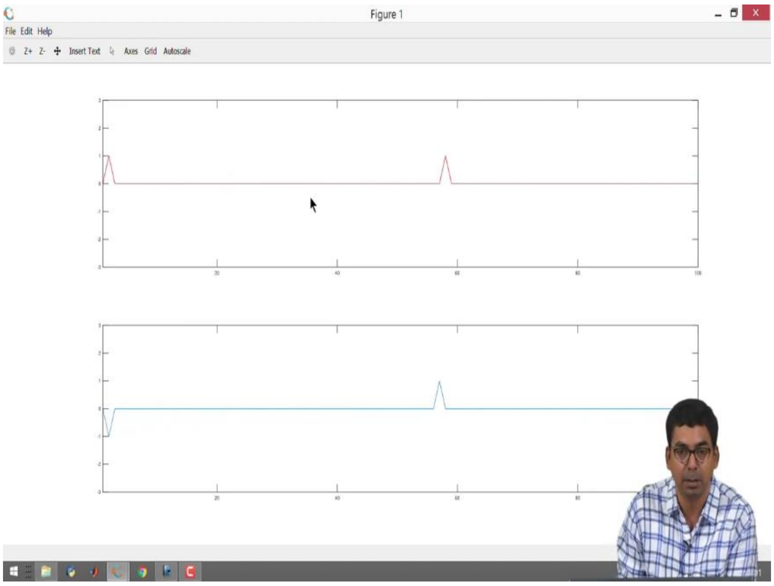

What we immediately noticed was that the current moving to the right is having a positive amplitude, right and the current going to the left is having a negative amplitude. So, we need to sort this out first, right before sorting out the boundary conditions, ok. So, I will start with this and go back to the nodes, ok.

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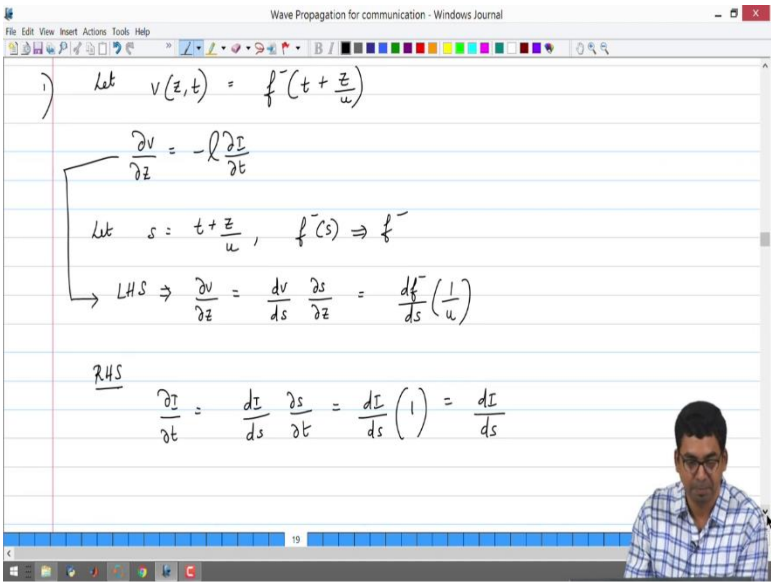

So, in this case, the voltage which was a function of position and time, ok was traveling backwards, all right. If we consider the forward axis to be going from left to right just because of the way we position the source which was very unnatural for a practical experiment, but in simulation you could always do it you saw the voltage wave going in the opposite direction.

So, this means that you can call this to be a backward wave of the form f minus of t plus z by u, right. When we looked at the general solution to the wave equation we had two terms for the voltage,

$$V(z,t) = f^{+}\left(t - \frac{z}{u}\right) + f^{-}(t + \frac{z}{u})$$

We are looking at the case specifically where the voltage is traveling backward, ok.

So, let us go ahead and make some manipulations. The idea is given this to be the voltage, what is the current and what is the inference, ok. So, we can write down the telegrapher's equation where we have

$$\frac{\partial V}{\partial z} = -l\frac{\partial I}{\partial t}$$

It is one of the telegrapher's equations. The procedure that we will follow is similar to what we had done before for proving that the general solution is valid. We can use change of variables methods, ok.

Here we are having two independent variables. We will reduce that to a single independent variable, do some manipulations and then substitute it back. So, what we mean is let a variable s be equal to

$$t + \frac{z}{u} = s$$

If this is the case the function will become a function of, I mean single independent variable. So, you can call this as $f^{-}(s)$. Since, it is a means since is the function of only one independent variable I will simply be referring to this as f^{-}, ok, ok.

So, now let us take the left hand side of the telegrapher's equation, ok. So, I have

$$\frac{\partial V}{\partial z} = \frac{dV}{ds}\frac{\partial s}{\partial z}$$

Since, the voltage is a f^{-} is what we have taken, so you could also write this as

$$\frac{\partial V}{\partial z} = \frac{df^{-}}{ds}(\frac{1}{u})$$

where u is the velocity, right.

The right hand side is

$$\frac{\partial I}{\partial t} = \frac{dI}{ds}\frac{\partial s}{\partial t} = \frac{dI}{ds}(1) = \frac{dI}{ds}$$

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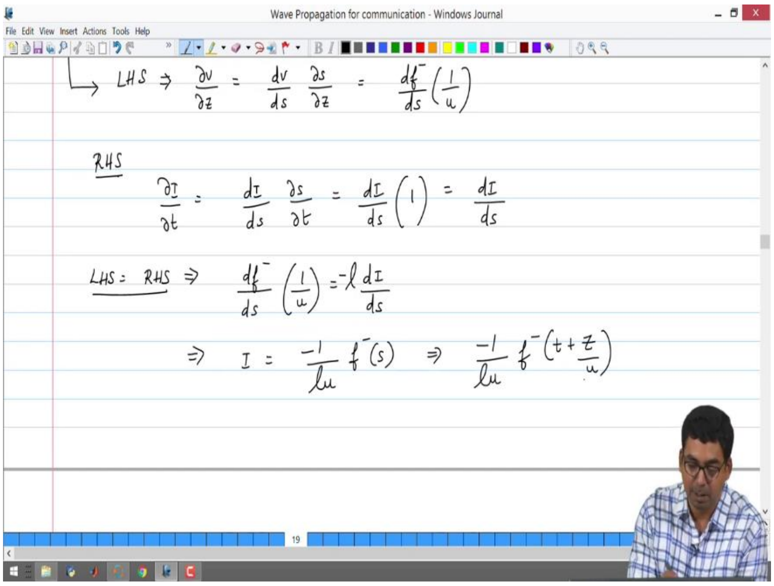

And the telegrapher's equation says that LHS is equal to RHS implies

$$\frac{df^-}{ds}\left(\frac{1}{u}\right) = -l\frac{dI}{ds}$$

So, all we need to do is find out I am from here, all right. Since it is a direct one dimensional ordinary differential equation all you need to do is find out the value of the function of current.

So,

$$I = -\frac{1}{lu}f^-(s)$$

$$= -\frac{1}{lu}f^-\left(t + \frac{z}{u}\right)$$

So, here it is abundantly clear that if you have a backward traveling voltage wave, the method of calculating current is slightly different, ok.

Since, we are looking at this equation in the form of forms like and say I is equal to v divided by r, but it looks like you know lu will have the unit of characteristic resistance or Ohm's, but you are going to have

$$I = -\frac{1}{R_c}f^-\left(t + \frac{z}{u}\right)$$

characteristic resistance multiplied by the voltage, right.

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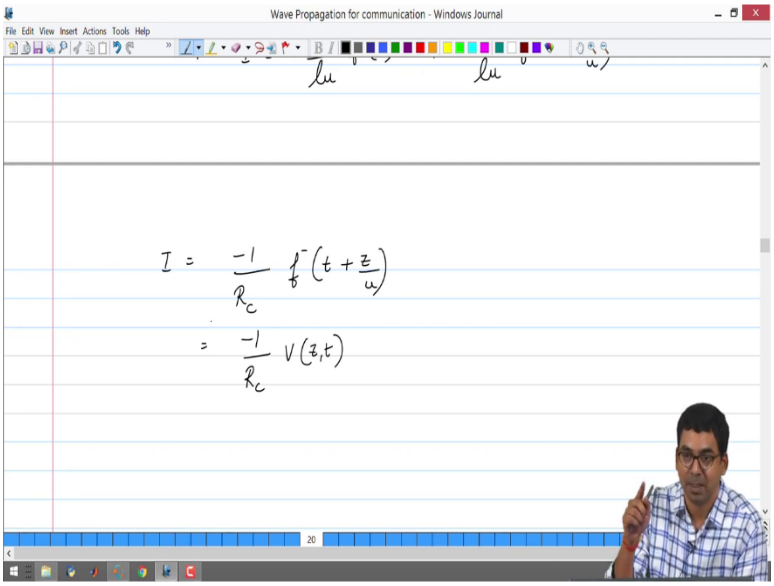

So, in other words, ok

$$I = -\frac{1}{R_c} f^-\left(t + \frac{z}{u}\right) = -\frac{1}{R_c} V(z,t)$$

where R_c is the characteristic resistance of your transmission line. This is a rewritten form of an Ohm's law, but I wanted to put this clearly, so that you know why the current is flipped when traveling on the left hand side, ok. It is a consequence of the telegrapher's equation itself, ok.

So, it is a very critical thing that you will have to bear in mind, ok and this has more consequences as we go along with the course, ok. So, for the forward traveling voltage wave, the current will be simply

$$I = -\frac{1}{R_c} V(z,t)$$

which means that if you have to write down the expression for the total current in your transmission line you will be having some positive current for the forward traveling, all right minus some current going in the other way.

So, in the case of the general solution for the voltage you had

$$V(z,t) = f^+\left(t - \frac{z}{u}\right) + f^-(t + \frac{z}{u})$$

So, the general solution is slightly different for the current. One has to keep this in mind, ok. That is why when we ran the simulation at the impulse at the starting point itself you would have noticed that along the positive direction the voltage was positive and the current was also positive.

So, let us go back to that once again, ok. But as there is an impulse going to the left hand side you are having the current to be flipped, ok. So, this is the first thing.

The second thing that we were noticing in the other class was that as it goes and hits the boundaries something starts to happen we were starting to see reflections and the reflections were altering both the you know reflections were altering the sign of the voltage or the current also. We need to start looking at this in more detail, right. So, I will start with a circuit diagram that will allow me to do this, ok.

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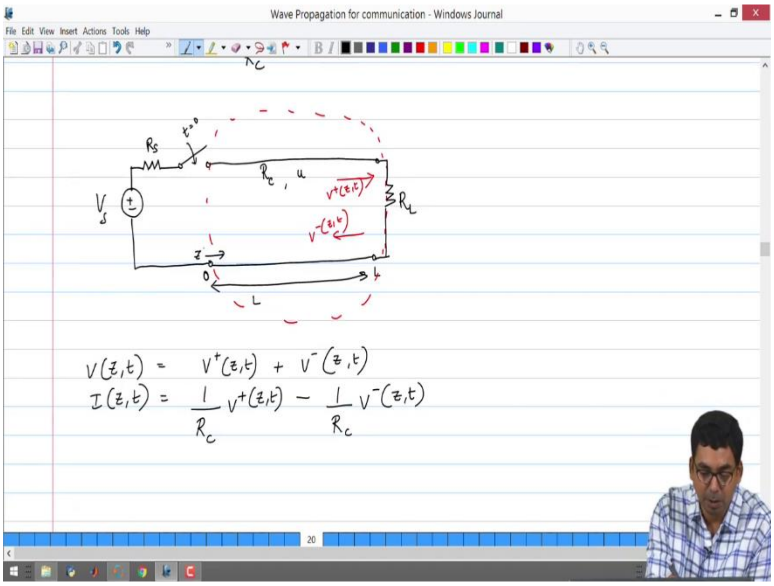

So, I am having a source voltage of V_S, ok and I am having a series internal resistance say R_S, ok and I am having a switch that closes at time t equal to 0 and I have a transmission line. The other end of the transmission line is connected to a resistance, the value of the resistance is R_L, ok.

In order to indicate that I am dealing with transmission lines I will make some subtle changes to my circuit diagram. First of all I have marked some regions with the you know circles over here to indicate something, on top of that I can also say that its characteristic resistances R_C, velocity is u m/s. I can also say that the length of the transmission line is going to be L and to be precise one can always say that you will have to mark this to be 0 of your transmission line and L of your transmission line, ok, ok.

So, here what we are going to do is we are going to close the switch at t equal to 0 and then at steady state we are going to try and calculate the value of the voltage in your transmission line. So, the equivalent circuit of your transmission line in steady state dc will be really simple, your capacitor will get open circuited, your inductor will get short circuited, right. So, it is going to be easy to imagine what will happen in dc.

So, we can say that

$$V(z,t) = V^{+}(z,t) + V^{-}(z,t)$$

$$I(z,t) = \frac{1}{R_c}V^{+}(z,t) - \frac{1}{R_c}V^{-}(z,t)$$

This is how the voltages and the currents are going to be in the transmission line, ok.

Now, let us zoom into the part where the load resistor is connected, ok. Let us focus on this part. Let us more closely look at the load end, all right. You will be having some forward voltage going towards the load, we can call this as

$$V(L,t) = R_L(I(L,t))$$

$$V^{+}(L,t) + V^{-}(L,t) = R_L[\frac{1}{R_c}V^{+}(L,t) - \frac{1}{R_c}V^{-}(L,t)]$$

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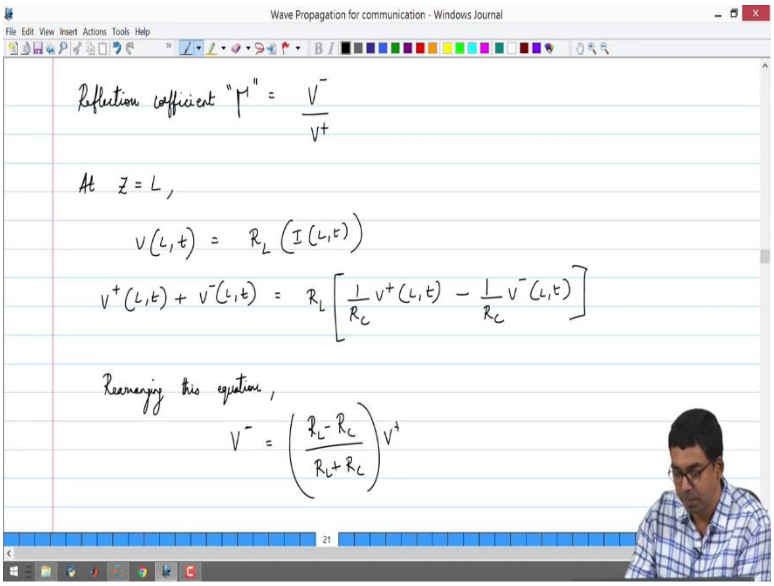

Now, the reflection coefficient is defined as is given by

$$\Gamma = \frac{V^{-}}{V^{+}}$$

It is the value of the voltage that is traveling backward to the value of the voltage that is traveling forward. Conventionally, the letter Greek letter that is used to represent the reflection coefficient is a gamma, capital gamma, ok.

So, $\frac{V^{-}}{V^{+}}$ is the reflection coefficient and let us look at the load end. So, I am going to start with that. The position Z is equal to L, ok. So, I will also mark what my z axis is, this is my z axis, right. At Z equal to 0, I will be at the source end. At Z equal to L, I will be at the load end, ok.

So, at Z equal to L, ok I can write down the voltage at position L

$$V(L,t) = R_L(I(L,t))$$

$$V^{+}(L,t) + V^{-}(L,t) = R_L[\frac{1}{R_c}V^{+}(L,t) - \frac{1}{R_c}V^{-}(L,t)]$$

At the load end I am just applying Ohm's law. The voltage is going to be equal to current times the resistance at the load, ok.

We can write the expansion for the voltage at that position. You will have a forward voltage V^{+} and you will have a backward voltage V^{+} . So, the left hand side has to be written as a superposition of a forward, right.

$$V^{+}(L,t) + V^{-}(L,t) = R_L[\frac{1}{R_c}V^{+}(L,t) - \frac{1}{R_c}V^{-}(L,t)]$$

One can go ahead and rearrange this equation, right. You will have

$$V^{-} = \left(\frac{R_L - R_c}{R_L + R_c}\right)V^{+}$$

I am not going through all the steps. You can do the rearrangement on your own, right.

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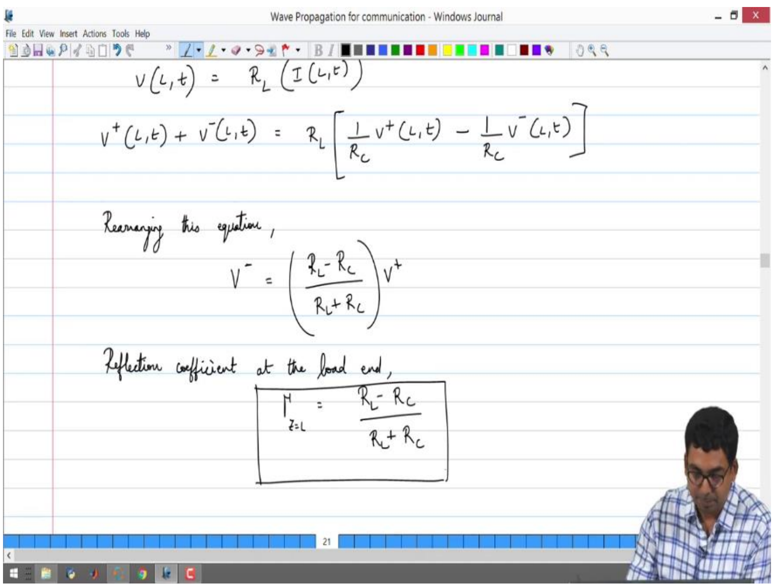

And the reflection coefficient, I will be very specific at the load end, right. So, to indicate that I am at the load end I will just mark as gamma at Z equal to L, all right is

$$\Gamma_{z=L} = \frac{R_L - R_c}{R_L + R_c}$$

Now, this is the expression for the reflection coefficient that you have at the load end when your load resistor is R_L and your characteristic resistance is R_c.

There are a number of things that this a is that can be interpreted from this first of all the numerator has a negative sign in between two terms. So, there is a good chance that your gamma can be positive, gamma can be negative or gamma can be 0, ok. So, we will write down these 3 conditions, ok.

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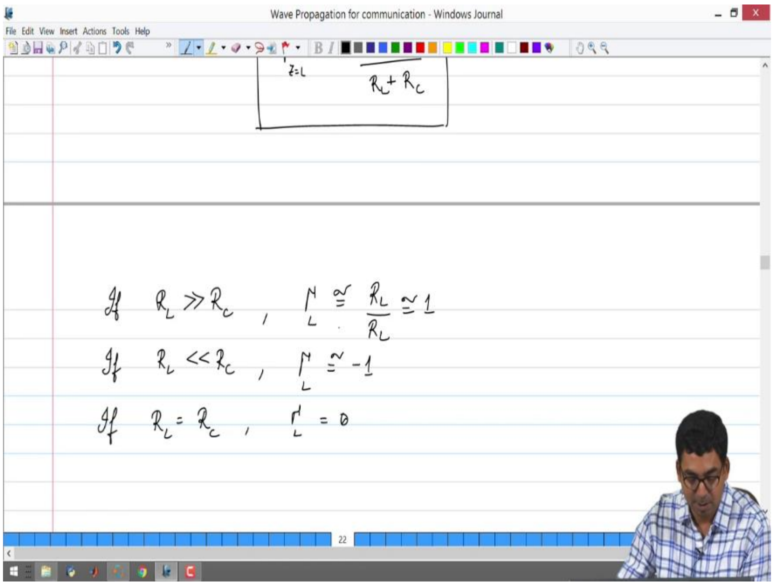

You can say that if R_L is much greater than the characteristic resistance, ok can say that. So, your reflection coefficient is going to be equal to 1 if you are R_L is much greater than R_c. In even more practical terms you can think that if your load resistor is not even connected and there is an open circuit in your transmission line and on the other side, your reflection coefficient is going to be equal to 1, ok.

Now, this reflection coefficient also needs a little bit more explanation as to what we are doing. The reflection coefficient here is corresponding to $\frac{V^-}{V^+}$, so a clearer way of saying that is a voltage reflection coefficient. So, generally when people talk about reflection coefficient they are talking about the voltage reflection coefficient, ok. So, it means that the reflected voltage wave will have the same sign as the forward wave that was going to the load resistor, ok.

If R_L is very much less than R_C, ok then your Γ_L will become minus 1, ok which means that if at the load end your say load resistor becomes 0, in other words you are shortening the ends of the transmission line conductors you will have a voltage reflection coefficient of minus 1, ok. And if R_L is equal to R_C, Γ_L is equal to 0, ok. It means that there is no reflection or no backward wave traveling from the load back into a transmission line, ok. These are the 3 cases that are possible with the reflection coefficient.

Now, we can have a look at our simulation and decide what is going on, ok. We can go back to your simulation, fire it and just look at what we expect the voltage reflection coefficient to be on each side. Let us just do this very quickly, right. So, I will just make this, ok.

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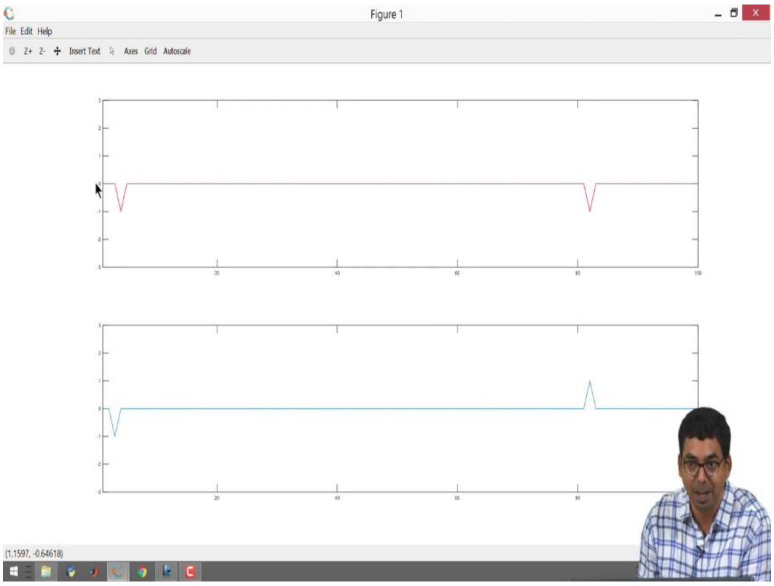

Let us concentrate only on the voltage, on the left hand side it did not flip, ok, on the right hand side the voltage flipped in between something happened here also, all right, ok. So, let me reduce the amount of time to prevent that from happening, but let us also think we can keep track of what happened. The impulse went to the left side it did not flip, ok; that means, your gamma was plus 1, all right.

That means, on the left hand side your R_L was very much greater than R_c or you can say that on the left hand side you had an open circuit condition according to the way we have programmed. On the right hand side, the voltage actually flipped. If it flipped your reflection coefficient was minus 1, ok. That means, on the right hand side you had a condition of R_L very much less than R_c or you had a short circuit condition.

Remember, that we had two different boundary conditions for simulating this particular section of the transmission line. On the left hand side, we have imposed one condition. On the right hand side, we have imposed the opposite condition, ok. Now, this also has an impact on the way the current is going to be flipping back and forth, ok.

And correspondingly one can calculate current reflection coefficients, but you can derive the current reflection coefficient from the voltage reflection coefficient because you can apply your Ohm's law and also the sign changes for your forward and backward a currents and you will be able to figure out what is going on.

So, if one way to look at this transmission line section and try to derive information, ok. We can always say that the right hand side was having maybe a short circuit or open circuit, I do not remember. On the left hand side, it was the other case, right. What is the use of such a scenario? Suppose, you are having a very long transmission line, all right and the transmission line is not functioning correctly, that is there is no data being sent to the other side, all right, and we want to identify at what distance what kind of fault has occurred on the transmission line.

This could be say an underwater or undersea transmission line connecting two different continents, all right. It is very exaggerated, but it would be wise for us to figure out where the problem has occurred. Maybe the transmission line is broken or maybe it is broken or the insulation is breaking down and something is shorting the one I mean forward and the backward conductor, all right.

If we know the location and if we know the kind of fault that we are looking for then it makes it easy for us to go to that particular place and fix something, ok. So, what people can do is they can take a transmission line, launch some voltage from one side, wait for the echo from the other side, if it is not flipped then they know that it is corresponding to gamma is equal to 1 or the load resistance is going to be open circuit. So, there is a breakage of the transmission line somewhere.

We also know that the velocity in the transmission line is going to be equal to u. So, you take the time at which you sent the pulse, all right you will calculate the amount of time for you to receive the first echo and then figure out how much distance it travelled to and then figure out the location of the fault. So, it gives you the location of the fault and the kind of fault that has occurred. The same thing can be done for the short circuit also.

This method of finding out a fault in a transmission line is known as time domain reflectometry, ok. All you are doing is launching a pulse, waiting for the reflection and then you are trying to figure out what the reflection can tell you. Tells you typically what kind of fault has occurred and at which location. So, this is known as time domain reflectometry.

There is a lot of research that happens with time domain reflectometry. Here we are considering the very ideal cases, all right. In reality there will be losses in the transmission line. There will be other parameters that you will have to consider for example, dispersion of the line and all that. But in the simplest form this is it, ok. It is a time of life measurement and you also figure out what kind of a fault you are having on the other end, ok.

Now, having gone this far, ok. We can take a small example and try to push the boundaries of what we know, ok. So, let us try to work out a problem with some small numerical you know quantities plugged into it and apart from all these things can we figure out something else, ok.

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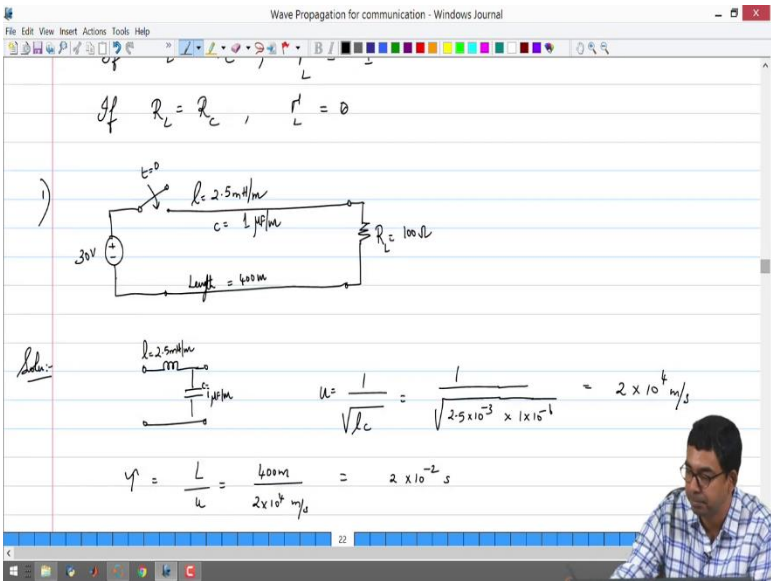

So, I will write down the formulation of the problem. It is a very simple problem. Says that I am having a voltage of say 30 volts on one side. Let us say that there is a weird condition that the series resistance is very low or almost 0. I have a switch that closes at t equal to 0, ok. I have a transmission line and I have a load resistance, ok. I am going to write down the value of the load resistance that is given is 100 Ohm's, ok.

And in order to specify that this is a transmission line some other information is added to it, L is equal to 2.5 mH/m, c is equal to 1 uF/m, ok and the length is given to be 400 meters it is a long distance, ok.

So, there are a lot of things that can be calculated. So, I will ask the question each time and then I mark the solution, ok. So, if you want to write down I mean draw the equivalent circuit ladder equivalent, all right for 1 unit cell you will draw a series inductor of 2.5 mH/m and a parallel capacitor. So, we can start with knowing the henry circuit of a lossless transmission line, so if we have to draw the unit cell off a ladder we can say what it will look like.

So, this looks like 2.5 mH/m this is 1 uF/m, ok. The second thing that we can calculate from l and c is we can calculate the velocity. We know that the velocity u going to be

$$u = \frac{1}{\sqrt{lc}} = \frac{1}{\sqrt{2.5 * 10^{-3} * 10^{-6}}} = 2 * 10^4 \ m/s$$

The next thing that we can calculate from this transmission line from whatever we have learned is there is going to be a transit time, all right, it is going to take a finite time because the velocity is $2 * 10^4 \ m/s$ meter per second. If you launch a signal on the left hand side what is the time at which it is going to the other end of the transmission line. So, we can calculate the transit time T, ok.

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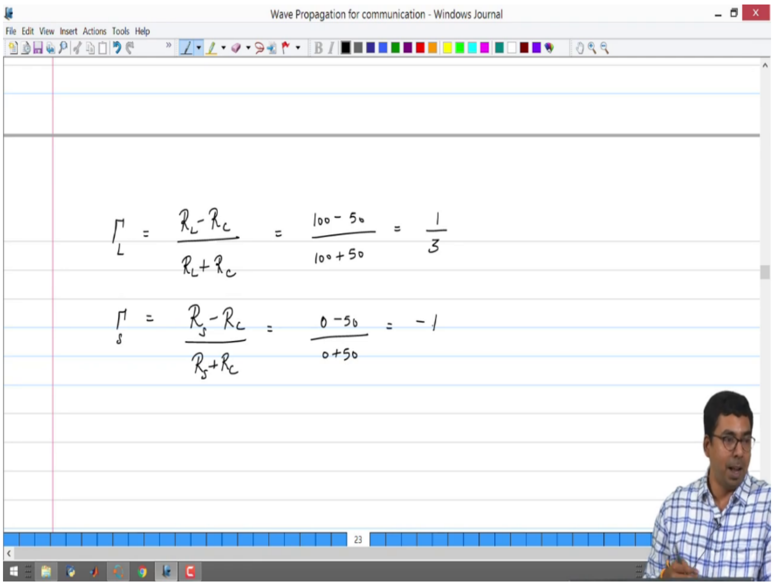

Transit time T is going to be

$$T = \frac{L}{u}$$

L is given as 400 meters and u is 2 times 10 to the power 4 m/s, ok. It comes to

$$T = \frac{L}{u} = \frac{400}{2 * 10^4} = 20\ ms$$

And we can go ahead and calculate a few more things from whatever we know, all right.

Let us say that we want to calculate the load reflection coefficient Γ_L, it is

$$\Gamma_L = \frac{R_L - R_c}{R_L + R_c}$$

First of all we need to estimate R_C, ok. The value of R_c can be determined because we know the value of l and c, all right. So, in this case it is going to be 50 Ohm's. So, I have made it right. So, this is going to be

$$\Gamma_L = \frac{100 - 50}{100 + 50} = \frac{1}{3}$$

So,

$$R_c = \sqrt{\frac{l}{c}} = \sqrt{\frac{2.5 * 10^{-3}}{1 * 10^{-6}}} = 50\ \Omega$$

So,

$$\Gamma_L = \frac{100 - 50}{100 + 50} = \frac{1}{3}$$

which means that the reflection coefficient is going to be positive and it is going to be of the value one-third, ok. Now, there is one more question that we can ask that we have not seen. So, the idea is to keep building up on whatever we know, right granted that we have calculated the reflection coefficient on the load end, ok.

Now, there is going to be a backward wave traveling from the load towards the source, ok. Is it possible that as it comes to the left hand side edge of the transmission line again some portion of it will get transmitted some portion of it will get reflected, all right? So, there is going to be a reflection coefficient on that edge also, right. So, we can call this as gamma suffixes or at the source, all right at the end of the transmission line, all right.

And that is going to be you will just replace R_L with your series resistance of the battery. In this case we do not have a series resistance. So, I will just write this as

$$\Gamma_S = \frac{0 - 50}{0 + 50} = -1$$

So, at the source and the reflection coefficient is minus 1, ok.

So, there are other things that can happen also, all right. So that means that here you will be launching a voltage, ok on the left hand side of the transmission line, it will go to the load, two-third of it will get transmitted, one-third of it is going to get reflected back. So, that one-third is going to come entirely to the other side of the transmission line, flip in its amplitude and go to the right hand side again.

Once it reaches the right hand side one-third of it is going to get reflected back and then it is going to flip and so the voltage profile in a transmission line for such a simple circuit is going to change with respect to time, all right. It is going to change dramatically, all right. And one of the ways to track what is happening in the transmission line is by drawing what are known as bounce diagrams, ok.

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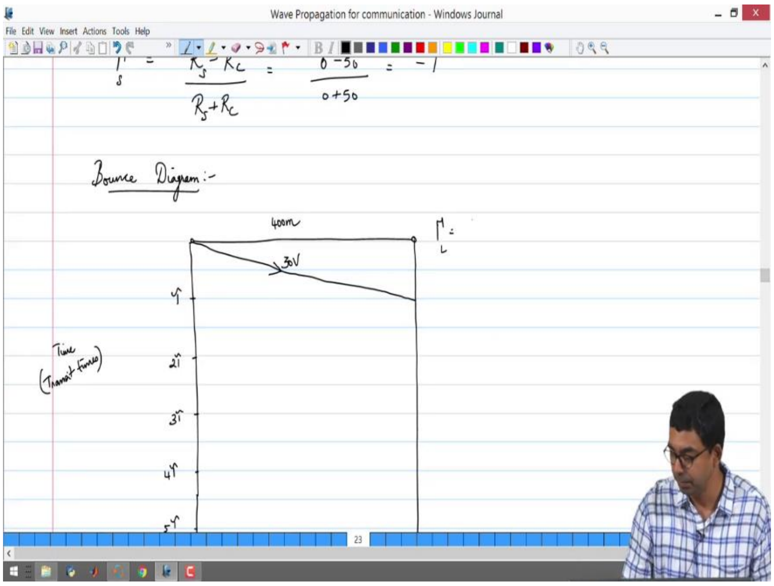

You can start with the bounce diagram. So, the bounce diagram you will start with the length of the transmission line say marked on the top like this. So, this will be a 400-meter-long transmission line, ok. The left hand side of the transmission line is connected to the source end, the right hand side is connected to the load end, right. The y axis is marked downwards, ok and it represents the time unit of transit times.

So, instead of a unit of seconds you will have 1 transit time, 2 transit time, 3 transit time extra, ok. So, the way it is constructed is first you will have a transit time say marked as T, 2 T, 3 T, say 4 T, let us do it for 6 transit times, ok. On the other side also you will have an axis that is going to denote your transit time.

And the way we do this is we just make arrow plots going from one side to the other side, ok. In one transit time, ok the voltage on the left hand side here we are going to be launching some 30 volts will reach the other side of the transmission line. So, what we do is we take the coordinate corresponding to one transit time on the other side, so it is going to be here and we draw a line connecting this and we mark an arrow saying that the voltage is traveling in this direction in the transmission line, ok.

And in order to be clear about the value you can just indicate the value as 30 volts traveling from left to right the transmission line. Once it hits the load end, ok it sees the reflection coefficient Γ_L equal to one-third or minus one-third, ok.

Student: One-third.

One-third, ok, sees a reflection coefficient of one-third, all right.

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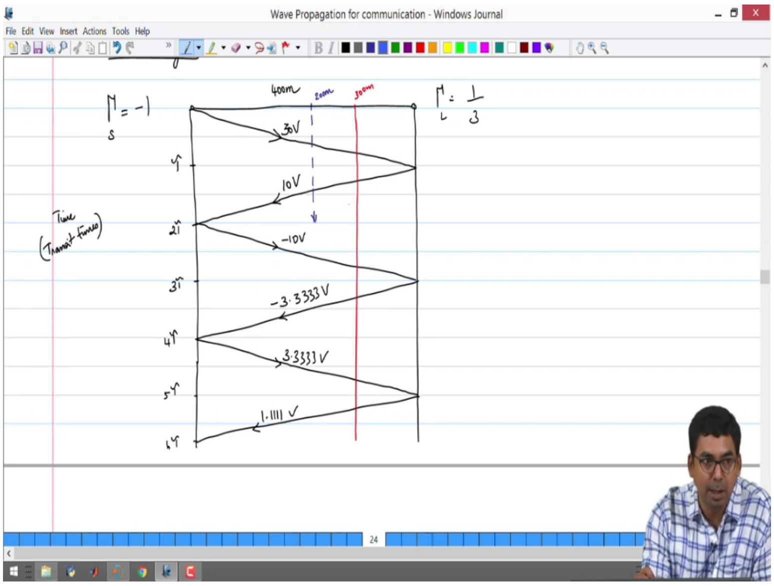

So, the next transit time one-third of it is going to go towards the source end of the transmission, ok. So, I can go ahead and connect these two, right. One-third will mean that this will become 10 volts, ok and once it reaches the source end there is going to be a reflection coefficient again. So, I will write gamma as is equal to minus 1, right. So, I will be having minus 10 volts going to the other side, ok, and then you will have a reflection coefficient of one-third. So, I will be having minus 3.3333 volts, ok.

Once again the reflection coefficient at the source is going to be minus 1, so I will be having and it keeps going. You can also have marked 6 transit times. So, let us just finish this diagram for the 6 transit times, 1.1111 ok. This is what is known as a bounce diagram, right.

So, you could be given say a set of parameters for the transmission line like a circuit has been drawn here and you could be asked to find out I mean draw the bounce diagram. So, you will have to find out the reflection coefficient at the source reflection coefficient at the end, you will have to find out what is the transit time, all right and then you will have to construct this diagram, all right.

You can also ask a question. Actually you know you can say that at a position 200 meters from the source by which happens to be the midpoint of this transmission line, ok, ok at a position 200 meters' question can be asked. a Let us say that at the two transit times what is the value of the voltage, all right or you could be asked at the position 300 meters how does the voltage change with respect to time, ok. These are the questions that can be asked.

So, you can start with a scenario where you have 200 meters and after two transit times from the time your a voltage was launched to the left hand side. So, all you need to do is you have to draw a line going from top to bottom like this and as you go down you need to simply add the voltages that you are going to be encountering, ok. So, you will be having 30 volts, ok coming from the source side, 10 volts coming back from the load side. So, at that instant of time, say after two transit times at z equal to 200 meters you will be having 40 volts, ok. So, ok.

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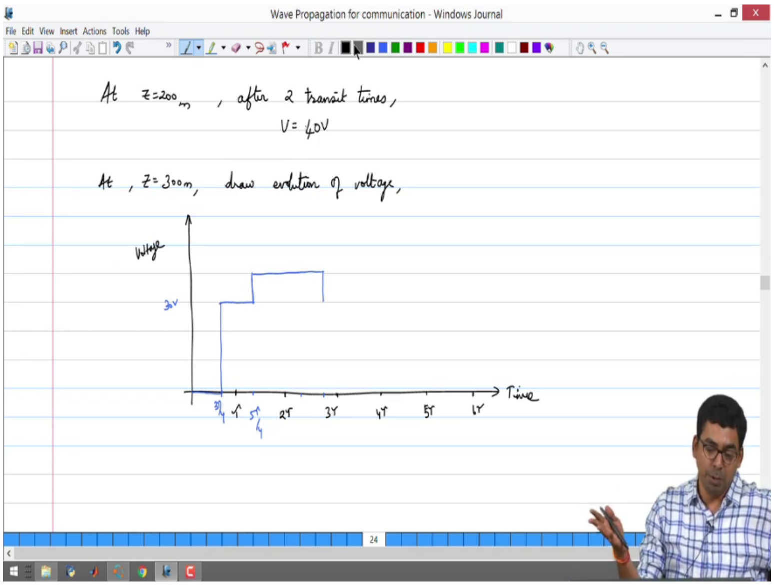

Another thing that can be done as say at a position 300 meters or so, right. It can be asked, how does the voltage evolve from 0 to 6 transit types, ok. So, the graph that is asked to draw the evolution of voltage is what is asked, ok. So, the graph that is asked is on the y axis you will be having voltage, on the x axis you will be having time, in units of a transit time so you can mark it as T, 2 T, 3 T, 4 T, ok.

So, we can look at this diagram and then say that the incident voltage, ok is going to reach this point, ok at some instant of time and that is going to be three-fourth of your transit time because 300 meters out of 400 meters, three-fourth of your transit time it is going to reach. So, till then the voltage will be 0 there. And once it reaches three-fourth of a transit time the voltage will go up to 30 volts which is your incident voltage, ok.

And after that if you look at the bounce diagram it remains at 30 volts, ok, because the source is continuously supplying 30 volts, right it remains at 30 volts. And then after some time 10 volts get added to it, so that means, you have to calculate the time that it took to go here and then come back, all right and then you will have to add 10 volts at that place. So, this is the 100 meters, this is another 100 meters, 200 meters that is half the transit time, ok. So, you can go ahead $3T/4$ and half the transit time. So, that is going to be $5T/$ 4, all right.

So, till that place your voltage is going to remain fixed at 30 volts, and then at that point it is going to spike to 40 volts, ok and then it remains as such for a while, all right. So, then you have the 10 volts going here, right. So, it remains at 40 volts till this wave actually goes from this point at 300 meters, goes to the source side, gets reflected and comes back.

So, this is going to be 300 meters and 300 meters, that is going to be about 600 meters, all right. So, it is one transit time plus another half a transit time, so one and a half transit times from this place. You will be subtracting the 10 volts, ok. So, we will take the diagram. So, from here one transit time will be 60 by 4 and half will be 60 by 4 plus another something, so that becomes one and half transit times is going to be somewhere about here. It is going to drop down to 30 once again, all right.

And then one can keep drawing as you go from top to bottom in your bounce diagram how the voltage is going to involve. So, a typical question that can be asked is to draw the evolution of the voltage, all right. And you know there can be other questions as to is it possible that the voltage in the transmission line is higher than what you supplied.

Obviously, here we supplied only 30 volts because of the way it is configured, the way you have the source and the load resistance is connected you can have 40 volts in your transmission line at some point of time. So, if one were to design insulation for your cables, you will have to be aware of what kinds of values of voltages are possible and then decide accordingly what material to use, ok. So, this is a bounce diagram and this is how you will draw the a you know time evolution of voltage.

More questions can also be asked. For example, you can always ask what the current bounce diagram would look like, ok. You could construct a current bounce diagram. One can also ask what the evolution of current would look like, ok. So, but those are not very commonly asked questions. So, just for curiosity you can go back and draw it, ok.

So, I think at this point you should be very comfortable with dealing with these aspects of the transmission line. You should be able to calculate the transit time, characteristic resistance, if you know the source resistance and the load resistance you should be able to calculate the reflection coefficients, you should be able to tell whether the voltage is going to have a positive sign or a negative sign going from one side to another side, you should be able to draw the time evolution of voltage in a transmission line and you should be able to do some basic simulation to validate for these ideal cases.

Thus far, we have not considered any termination in your simulation, that is we did not put load resistance equal to say 150 Ohm's or something like that. But you should be able to at least guess for an open circuit and short circuit what quantity will flip what will not flip, ok. So, at this point that is where you should be, ok.

Now, what are we going to do next? Towards the end of the class I was telling that you could be a little bit more creative in the way you set up the source. So, I will go back to the simulation, all right.

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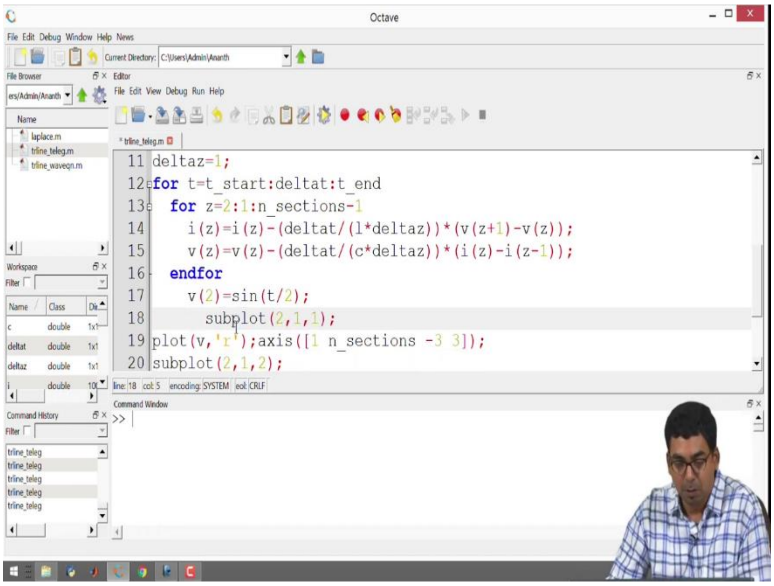

So, I will just change a few portions of these simulations. So far we have not dealt with frequency at all in our lectures. So, we will be trying to see steady state transmission lines and how they are working. So, I am just giving a sinusoidal input.

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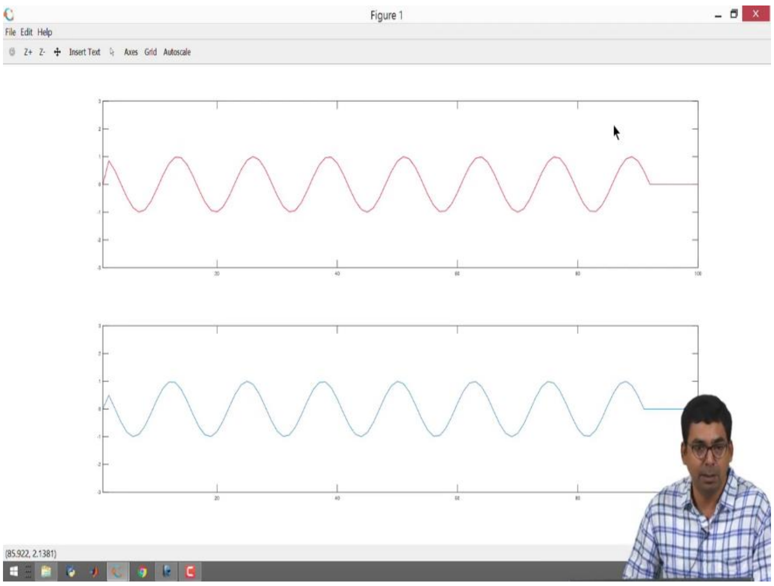

So, you will be having a transmission line excited with the sinusoid and we are going to make a steady state analysis of this kind of configuration and we will also be drawing doing the same thing as what we did. We will be calculating characteristic impedance instead of characteristic resistance, right.

And we will be calculating reflection coefficients which will have signs positive and negative. On top of that we are also going to see if it is possible to have a phase for a reflective reflection coefficient other than 180 or 0 degrees.

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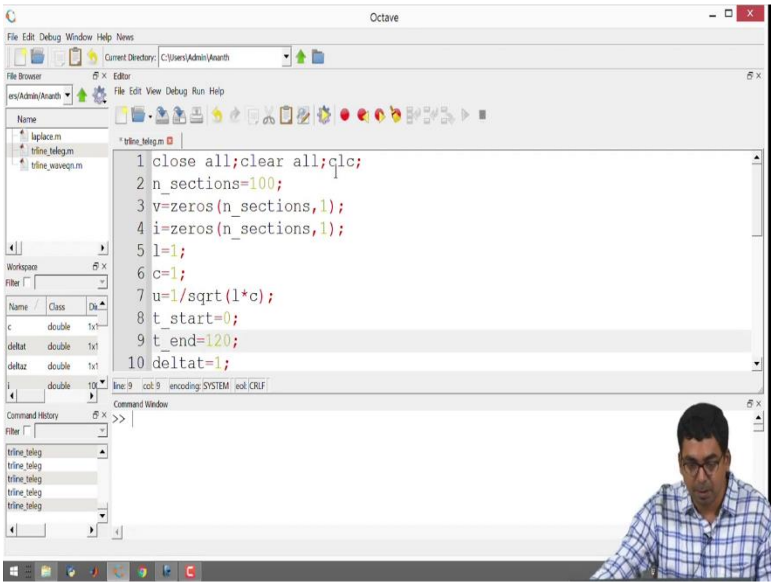

And let me increase the time a little bit and show you what we are going towards, ok, ok.

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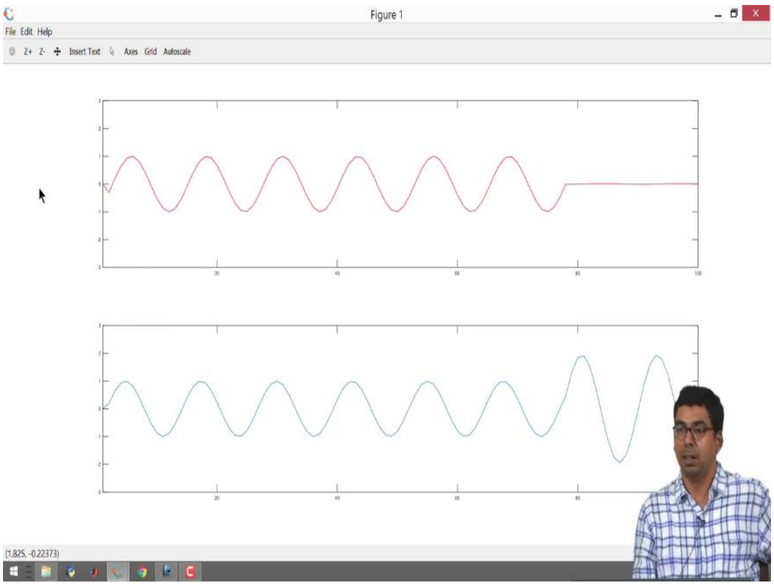

When you are excited with sinusoid, some peculiar things will start to happen and we will have to analyse them, right. So, here the voltage wave is traveling from one side to the other side it is going to get reflected completely on the right hand side and it is going to superimpose and you are going to get what are known as standing waves, ok. There will be some specific nodes, specific antinodes for your standing waves and we are going to deal with them.

On top of that we are going to also understand how the impedance of a transmission line will change with length because some portions are going to have always say 0 voltage or some portions will have 0 current, what does it mean to have impedances, does the impedance vary across the length of the transmission line; if it does vary, how does it vary, all right. And then we will be starting to look at different lengths of transmission lines, what kind of impedances they will have and how to make use of them. This is the plan for the next few lectures.

So, I will stop here, right. Go back and try plugging in some different values for load resistance, volts resistance, see if you are comfortable in doing a few problems. A tutorial will also be having some problems along this line, all right. So, that you can just practice calculating different things, ok.

I will stop.