Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Applied Electromagnetics for Engineers

Module – 20
High-speed digital signal propagation on T-lines

by

Prof. Pradeep Kumar K
Dept. of Electrical Engineering
Indian Institute of Technology Kanpur

Hello and welcome to the mook on applied electromagnetics for engineers. We were discussing the propagation of step like transient voltages in the transmission line in the previous module. In this module we will consider even more practical case of a pulse propagation. This is the very common case, so take an example of an SPGA or a microprocessor board and look at where the clock would be located, or you generate the clock.

You would see that around the SPGA there would be lot of other secondary components that would be present okay, or even inside an SPGA there would be one unit which would be the clock unit, and this clock would be supplying by our buses, it could be supplying clock to several other sub modules or several other chips, it would be generating. Or if you consider back plane connection that is happening to the named card or the dotted card to the mother card connections, there would be transmission lines which would be, you know where one L would be a clock typically or another digital or an information carrying, or an information symbol.

And that would be mostly in the form of a pulses and these pulses would be propagating on the transmission line okay. Even address changes could be thought of as pulses propagating on the transmission line, you know with the pulses, pulse duration being slightly larger. So it is very important for us to understand what is happening when a pulse or a pulse source is connected on to a transmission line okay.

We can analyze how a pulse would propagate on the transmission line by the same methods that we have used for analyzing the step like voltage transmission line. Remember in the step like transmission what we did, we took a step, we calculated the initial or the first voltage, you know that would be generated because of the step source, propagated no, had multiple reflections because of the miss patches that would exist on the load and the generator side.

And at any point on the transmission line that if you want to know how the voltage would be changing, you would simply had to draw a particular line that would connect the space time direction. So that wet slides would connect the time slides okay, and then you would count whatever the voltage and then you would plot that voltage okay. You can perform the same operation okay, if you imagine a pulse to be composed of step voltage. And so how do we do that, when it is very easy, a typical pulse would be of this fashion right.

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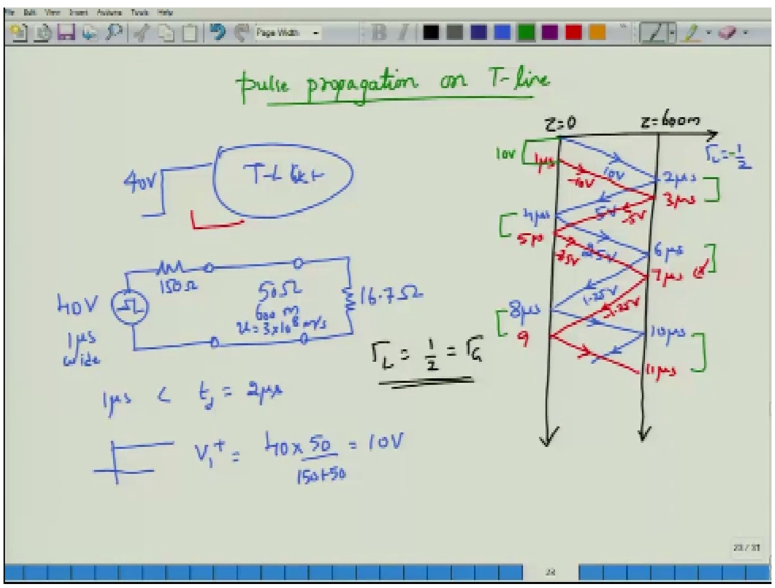

So you would have a pulse of duration T units or T time seconds, and we will call this as the duration of the pulse. It would have some amplitude of V0, but you can imagine that this pulse is actually made out of two step voltages, one step voltage would be V0, and then there would be another step voltage which would be –V0 in amplitude that is exactly opposite to the amplitude here which would begin to propagate at P seconds okay.

So the sum of the voltages, the sum of this first step and the second step would obviously give you a pulse whose duration would be of T seconds. So I can adapt the same lattice diagram construction that I have done, except that I initially propagate this V0, I could construct another lattice diagram and construct the propagation of the –V0 step starting at capital T seconds.

However, we can in fact to both of them on the same lattice diagram the suggestion would be to use different colored ends okay, to distinguish the propagation of a +V0 voltage and the –V0 voltage okay.

So let us see by the way of an example how this is performed okay. We consider a pulse source, so I am using this one to denote the pulse source. Let us assume that the pulse is about 40 volt okay. And a 1 micro second wide pulse, I have purposely chosen this one to show you a certain concept that would arrive in the pulse propagation. In practical situations this voltage would be around 0 to 3 volt okay, as long as we are considering digital circuit boards.

And the pulse switch typically nanoseconds okay. This pulse voltage source is connected by a 150ohm generator impedance and connected to a transmission line okay, I am no longer writing a T=0 kind of a switch, because the pulse itself will be again T=0 and will be terminated at T=1 micro second. We consider a 50ohm transmission line, we do not bother too much about what is the length of the transmission line, except that we want the pulse width here which is 1 micro second to be less than the time delay.

So let us consider say 600 meter long transmission line with the velocity of 3×10^{8} m / s we already know that the delay here will would be about 2 μs so we consider the same parameters as in the last module except that now the voltage source have become a pulse we will consider a resistance or regressive termination with a resistance of 16. 7 Ω obviously this value of 16.7 Ω was picked for mathematical convenient why because it makes γ L = + ½ okay.

And γ G would also be = ½ we calculate this and verify that this would indeed give the case, so this is just to show you know make the numbers look better if you have a calculator or if you can write the program in order to automate the entire thing we do not have to necessarily do all this convenient cases okay how do I write the lattice diagram let me erase this equivalence of a step voltage and the pulse voltages so that I can make some space in order to draw the lattice diagram.

So I have the space time diagram or the lattice diagram i8n which the z axis is starching from z = 0 to 600m now I began to propagate the first voltage which is V1+ corresponding to a positive step, so I am going to began propagating the positive step of V1 + voltage the first voltage which is given by 40 x 50 / 150 + 50 of course this one is nothing but 50/ 200 so that would be 5/ 4 so 4 and 4 that would be about 10 v right.

So this would be the pulse amplitude that would began propagate so let us began a 10 volt propagation which goes up to 2 μs at this pointy it gets reflected becomes only 5 v because γ L = -1/2 there will be further reflection of 5v from the general précised so this will reach the generator at 5 μs and there will be further reflected and the reflected voltage amplitude will be ½ of 5 will is 2.5 v then there will be further reflection which would be 1.25 v and this continues to happen like this.

Right so this would be happening at 6 μs the change here will appear at 8 μs then there will be 10 μs and so okay this so far look almost like what we have been doing in the earlier time right in the earlier modules we had a step voltage of 40v applied to the transmission lines circuit so this was our transmission line circuit and we have just looked at the propagation but now remember there will be a second step that we are going to apply and this time the step that we are going to apply will be at 1 μs so as soon as I am done transmitting this 10 v here I need to next start transmitting – 10p v okay that could be the initial voltage okay this should be the initial forward voltage because of the -10 volt step that is appearing at 1 μs right.

And this would reach the 600m nodes section at 3 μs get reflected reach at 5 μs further get reelected reach here, at 7 μs what is the reflected voltage here – 10 and ½ so that could be -5 v – 5 v getting reflected further by ½ we will make to – 2.5v and – 2.5v reflecting further will give -1.25 v and so from 7 this will reach at 9 μs and form 9 this would reach at 11 μs so -1.25 v and further reflection.

So you can see that I have kind of compressed both the blue lines as well as the red lines the blue line corresponding to the step at t = 0 and the red line here corresponds to step at t = 1 μs okay so in fact what I have done is taken this pulse whose high was 10 v and transmitted down there so that is what I have actually done so I have taken the this initial pulse and transmitted so there is actually a reflected pulse here then there will be 1 more reflection reflected pulse another reflected pulse and so okay. Now let us plot what would do the voltage at the source side what would be the voltage if the generator end.

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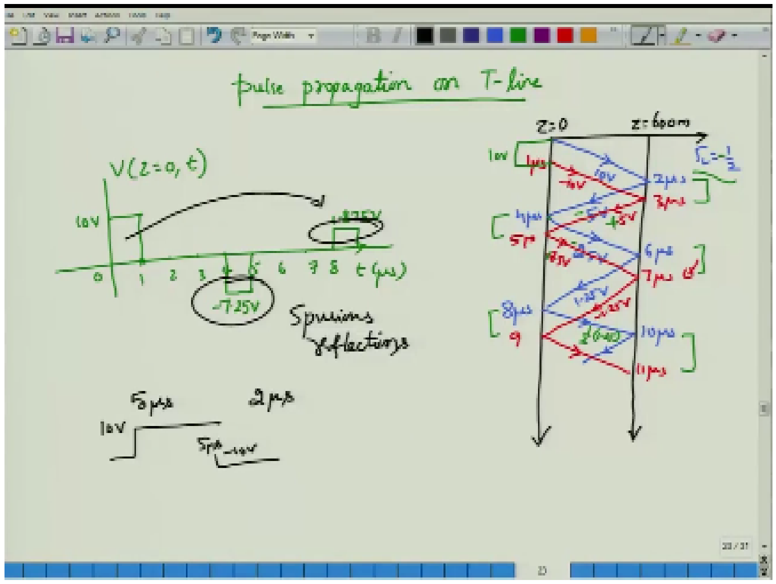

So let us mark the time access so what we now have is a 10 volt signal that is propagating okay however there will be -10 v step propagating at 1μs so initially I began propagating at 10 v but immediately at 1 μs after the propagation of 1st voltage I need to propagate – 10 and 10 and – 10 it make the total voltage go to 0 and therefore you will actually have a pulse of duration 1 microsecond, so if I mark all the time access in terms of microsecond there will be a 1 microsecond pulse of height 10 volt that would have propagated okay. So this is what has propagated because the change to the blue line is happening at 4 microseconds, so by 4 microsecond the sending and side pulse is completely extinguish.

So the change that would happen now let us mark out 2,3,4,5,6,7 and microsecond so the change that would happen will happen at 4 microsecond at 4 microsecond what would be the voltage that would be propagated it would be 5+2.5 okay, so it would 5+2.5 so this would actually the 10 volt reflected as -5 volt, reflected in -2.5 volt, reflected back here is +1.25 volt which is alright and then this would again the reflected as half of 1.25 voltage.

So how much is 1/2(1.25) that is about 0.075 voltage, similarly a -10 volt here would propagate and then it would be reflected into +5 volt okay, a +5 volt could be reflected by and makes it +2.5 volt, a +2.5 volt further gets reflected by +2.5 and -1/2 which is -1.25 and further in that fashion. So now what happens, at 4 microseconds what is the total voltage that you are receiving, you are receiving the -5 volt and you are sending out -2.5 volt, so the total voltage at this point would be -7.5 volt and that would be negative voltage, right.

So at 4 you begin to have a -7.5 volt propagating but immediately at 5 microsecond okay, you would receive a +5 and the +2.5 that is +7.5 you will receive which means the voltage again goes back to a pulse like manner, so this would be -7.25 volt. The next change will happen at 8 microsecond varying you are receiving 1.25 and transmitting or sending half of 1.25 okay, and that could be about 1.875 volt distant could be positive and it would last from 8 to 9 microsecond.

So this is 1.875 volt and so on okay, so this is how the voltage would look at the source side so you will see a sequence of pulses being propagated okay, so if the transmission line length is much larger is the propagation time is much larger than the pulse with that you have considered there will be multiple reflections of the pulse and it is actually a big problem for you because if this pulse goes and then there will be this spurious reflections your sender might not really work correctly because it is now receiving the -7.25 volt whereas it is simply does not expected you want the 10 volt signal to simply go to the transmitter whereas this spurious reflections that you are going to see are actually going to create problems for the entire links.

So the fidelity of the link is completely compromised because of this spurious reflections okay, let us consider the opposite scenario that is we will consider the case where the propagation found is much smaller compared to the pulse with itself okay, so for that what we can do is we will consider all the parameters to be the same except that the pulse will be 5 microsecond wide okay, the propagation delay is 2 microsecond for this circuit.

Whereas the pulse itself is 5 microsecond what it means is that there will be a positive step of 10 volt in the initial voltage that has, that is launched and there would be a -10 volt launched at 5 microseconds at 5 microsecond there will be a -10 volt launched. So what will happen to the lattice diagram, let us rewrite a lattice diagram here.

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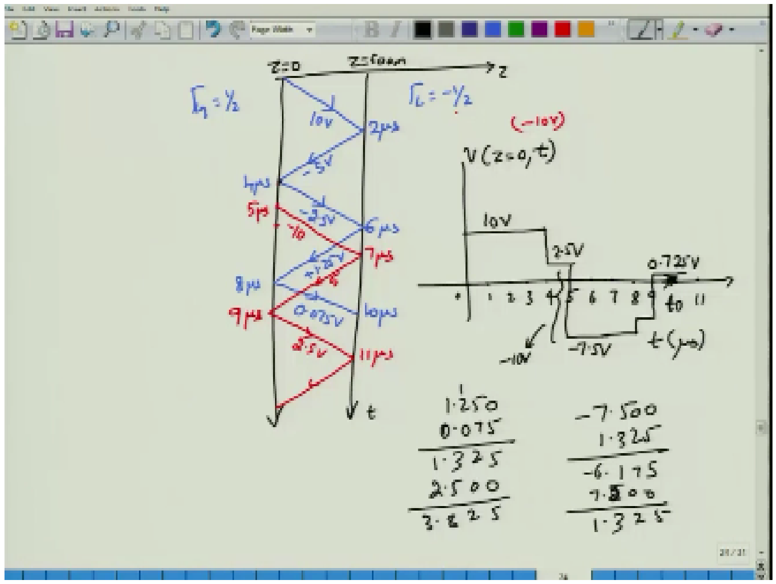

So this time this is the lattice diagram that I am drawing okay, so we have z=0 and z=600m this is the z axis this is the time axis. Let us begin the propagation, so first we will have a 10 volt signal propagating or 10 volt step propagating this would reach at 2 microsecond to the load there it would reflected to become -5 volt, why would it be -5 volt please remember Γ_L is -1/2 here and Γ_G=1/2 so the reflected voltage at 2 microsecond would reach the generator at 4 microsecond where it would promptly be reflected further to -2.5 volt which will reach the receiver or the load side at 6 microsecond.

Where it would again be reflected 1/2 with the value of +1.25 volt and there would one more propagation because this would reach at 8 microsecond this will reach at 10 microsecond with 0.075 volt. So this is how the first v0 has propagated, now what about the second v0, where should the second v0 step begin or –v0 step begin it should begin at 5 microsecond, so if this is 4 and this is 6 so let us begin here at -5 the initial launch voltage is -10 volt and that is what begins to propagate.

And it would reach the receiver side at 7 microsecond, so it begins at 5 microsecond reaches the receiver where it would be reflected back by the receiver, so this is -10 volt okay, the reflected voltage will be 5 volt because -10x-1/2 so that makes it 5 volt again there will be one more reflection this 7 microsecond reflected a step voltage will reach here at 9 microsecond and this one will again change or this will again reflect back okay, what would be the reflected voltage here 5 and ½ that would be 2.5 volt and there would be further reflection this one would reach her at 11ms and it would be further reflected and so on.

So you can see that the red curves are starting after at least the first forward voltage are actually come back reflected from the generated end. So it would be very interesting for us to see what kind of the voltage distribution that would exist again at the source side okay you can write down the voltage of different points on the transmission line especially at the lower side as a exercise this, you mark the points here at 0 this time because you have all the changes happening so let us mark it has 12345678 9 okay may be we can also mark this last point as 10 okay so we have 11 this is y time axis this all time axis is a micro second.

So time axis is a micro seconds okay. Look at what happens initially the voltage would be 10 volt and that would continue to remain until 4ms times until 4ms you have launched at 10 volt step which would continue to propagate but at 4ms here total voltage should decrease because there is a -5reflected and a -2.5 so the total voltage here will be 10 -5 is 5, 5- 2.5 is 2.5 so this has to drop down to 2.5 volt.

And until what value this would remain it would be the same case until you reach up to 8 ms and 8 you would receive a +1.25 and you would send out a 0.075 so to already 2.5 you would receive a +1.25 +0.075 this would be 5 2 3, 1.325 +2.5 that you already have the total voltage that you are going to get will be 3.835 if it would jump to 3.825 and it would continue to be receive case at 9ms there will be so completely forgot what happen at 5ms okay.

So this would continue at to up to 2.5 ms whereas 5 you will actually have launched the -10 volt right so because if you launched a -10 volt this total voltage would now be reduced this should actually become -7.5 volt because there is a jump of -10 volt okay and at 8ms you would receive a +1.25 and a + 0.075 so this would be 1.325 so -7.5 you need to add 1.325 okay so this becomes 1 and this would be -6.175 voltage.

So it would just go up at become -6.25 but at 9 you would receive a 5 volt + at 2.5 that is 7.5 volt you would receive. So 7.5 volt you would receive so the total voltage would be 5231.325 so this change would have made at 9 the voltage value of 0.725 volt. So you can see that the voltage is actually getting distorted because of this multiple reflections okay. So in both cases in one case you have pulses multiple pulses between the transmission line propagating and coming back and in this case you have the transcending in pulse that is completely distorted because of this transmission line effects okay.

You would not except this negative big large pulse but unfortunately that is what you have going to get okay, before we close the discussion of pulse propagation and we go to the other module I have an important kind of a set up that I would like to consider okay.

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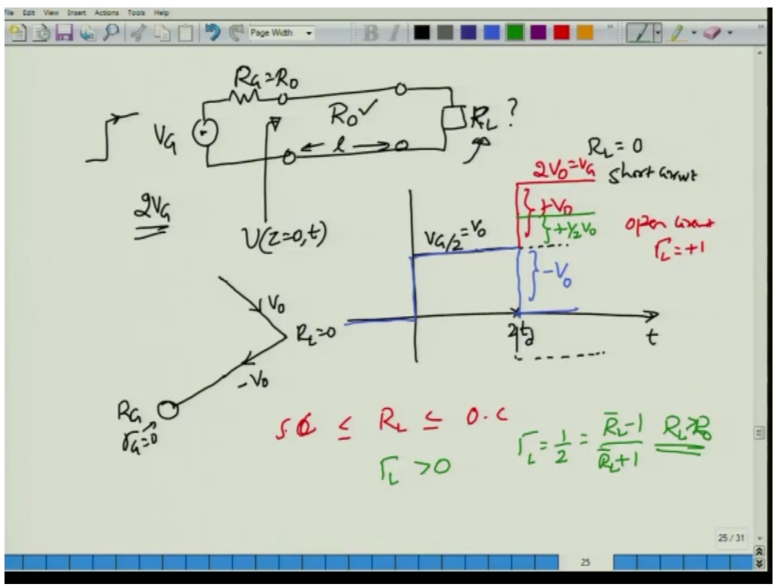

Here let me assume I have some voltage that is some Vg which of course I am going to now not assume a pulse I am assuming a step voltage and it has some RG but this time we chose RG = R0 okay and then connect this one to a transmission line circuit and monitor the voltage at the input terminals of the transmission line so I am monitoring the voltage at V = 0 we have V = 0 as the function of time.

Let the characteristic impedance of the transmission line will be R0 which is completely known however the transmission line whose length is known to me okay I do not know what load is connected on the other side so RL the connecting load or the terminating load I have no idea. I am assume let me assume step voltage of value VG okay so clearly if I have to write down the matrix diagram what I would observe is that an initial voltage of VG /2 will be launched at the input terminals of the transmission line at the reflection because of the reflection the load side the voltage that would be coming back will be γ l times VG/2 assuming γg to be real it could be the positive or negative but it could be real because of the resistive termination.

The receiving side voltage will undergo at total change the receiving side voltage will undergo a change of γ l x VG / 2 will there be further reflections here unfortunately there would not be any further reflection because we have made γ G = 0 γl is some real number it could be -1 less than γl less than 1 but I do not have an idea of what the value exactly equal to. So my goal would be to look at the voltage or monitor the voltage at the source end and try and figure out what would be the load that is connected, can I do that?

Yes indeed I can do that, let us first consider the general case you know and then start looking at let us consider the special cases and then develop the idea of how to do that they look at the voltage you know that would be launched from the generator site then initial voltage step that would be launched will be VG/2 why would it be VG/2 because RG is equal to R0 so the voltage divide itself into half.

In some cases people actually instead of using VG there will be 2 VG so that the step voltage is VG/2 but it does not matter I mean you can call VG/2 equal to V0 okay let us call as VG/2 equal to V0 so this is launched and when will you see a change in this voltage the change will happen at 2Td right at 2Td there should be a change happening suppose RL is equal to 0.

That is short circuit what would be the meaning of a short circuit we launched a V0 voltage however the receiving or the reflector voltage because of the load RL is equal to 0 will carry a – sign eight so whatever the voltage that you are receiving will be multiplied by –1 and it will be reflected back and this reflected voltage reaches it could be completely absorbed at the source side because γ G is equal to 0.

So the voltage change that would happen will happen at 2 Td where –Vo voltage is reflected already Vo was propagating now –v0 is reflect therefore the total voltage that you would see would dropped down to 0 so this is what the voltage that you would so whenever you see such drop you can immediately figure out what was the voltage jump that you fall that –V0.

You could immediately figure out that the actually short circuit which may complete the voltage at the generator side dropped down to 0 that is at the transmission line the voltage completely drops down jumps by –V0 now suppose I tell you that the voltage did not jump down by –V0 but rather jumped up by +V0 that is the voltage here that you are seeing is 2 times V0, 2 times V0 is of course equal to VG right.

So what is the type of load that would have given you are jump here of magnitude equal to V0 that load could only be a open circuit load because for a open circuit load γ L will be equal to +1 so therefore you would say jump if RL happens to be answer between the short circuit to the open circuit right it can anywhere between short and open circuit jump accordingly will be less than V0 or in the negative direction or it would be a positive direction.

However the magnitude would always be less than V0 suppose I tell you that jump has been at ½ V0 that is the jump of the voltage has been half V0 and it was actually on the positive site now what can you conclude clearly you can conclude that γ L must be positive only the γ L as positive can give you a positive jump at 2 Td right.

From the initial launched voltage you can jump only for that so clearly you can by measuring the voltage jump also figure out from γ L is positive and this equal to ½ this means this equal to RL bar -1/Rl/+1where Rl bar is the normalized load that I am considering you can solve this and then find out what would be the corresponding load impedance but you know that RL has to be greater than R0.

Otherwise you would not get as a positive quantity suppose I tell you that voltage instead of jumping up jump down by say-1/3 V0 then you know that γ L is equal to -1/3 again this would be equal to RL bar -1/RL bar+1 clearly in this case RL was less than R0 you can find out what is the exact value since you already know what is γ L.

So this is something that you can do you know if you are measuring resisting terminated loads and you do not know what is resistance terminated load that is connected to the transmission lines circuit in fact manufactures have come up with the nice product that cannot not only tell you what is R but can also tell you what is ZL that does not rely on the steady state behavior of the line so there is no more slotted line type of measurement.

But this measurement is happening in the time domain and this divide which can tell you what is the value of unknown load by making measurements in the time domain you usually it will not be step voltage it would be pulse voltage because the processing become slightly easier for the pulse case compare to step cases and that instrument which is available in the market and used by the many pc designers is called a time domain reflective meter. It is more or like radar however the complete discussion of time domain reflective meter we will take it up in another application oriented module until then thank you very much.

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