

ELEC 353

Practice Problem Set #1

1. A transmission line with characteristic resistance 50 ohms and speed of propagation 20 cm/ns is driven by a step-function generator of zero internal resistance. The open-circuit voltage across the generator is zero volts for $t < 0$ and 10 volts for $t > 0$. The transmission line is 5 cm in length, and is terminated in an open circuit.
 - (i) Draw a bounce diagram for the transmission line from $t = 0$ to $t = 1.5$ ns.
 - (ii) Draw a graph of the voltage across the open-circuit load as a function of time for $0 < t < 1.5$ ns.

2. A pulse generator with internal resistance $R_s = 10$ ohms produces a pulse of voltage lasting 1 ns starting at $t = 0$. The open-circuit voltage has amplitude 10 volts. The generator is connected to a load of $R_L = 50$ ohms by a 3 meter cable of characteristic resistance 70 ohms and speed of propagation 250 meters per microsecond.
 - (i) Draw a “bounce diagram” for $0 < t < 65$ ns.
 - (ii) Plot the voltage across the generator $v_1(t)$ and the voltage across the load $v_2(t)$ for $0 < t < 65$ ns.

3. Repeat problem 2 if the generator produces a step function voltage. The generator’s open-circuit voltage is equal to zero volts for $t < 0$ and 10 volts for $t > 0$.

Hint: You can verify your solutions to these problems with program BOUNCE available on the ELEC353 web site.

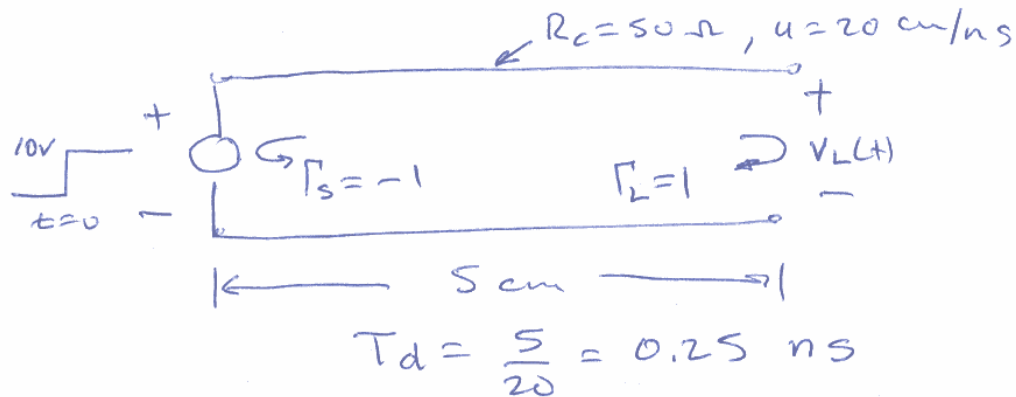
ELEC 353

Solution to Practice Set #1

Problem 1

4. A transmission line with characteristic resistance 50 ohms and speed of propagation 20 cm/ns is driven by a step-function generator of zero internal resistance. The open-circuit voltage across the generator is zero volts for $t < 0$ and 10 volts for $t > 0$. The transmission line is 5 cm in length, and is terminated in an open circuit.
- (iii) Draw a bounce diagram for the transmission line from $t = 0$ to $t = 1.5$ ns.
- (iv) Draw a graph of the voltage across the open-circuit load as a function of time for $0 < t < 1.5$ ns.

Pencil-and-Paper Solution

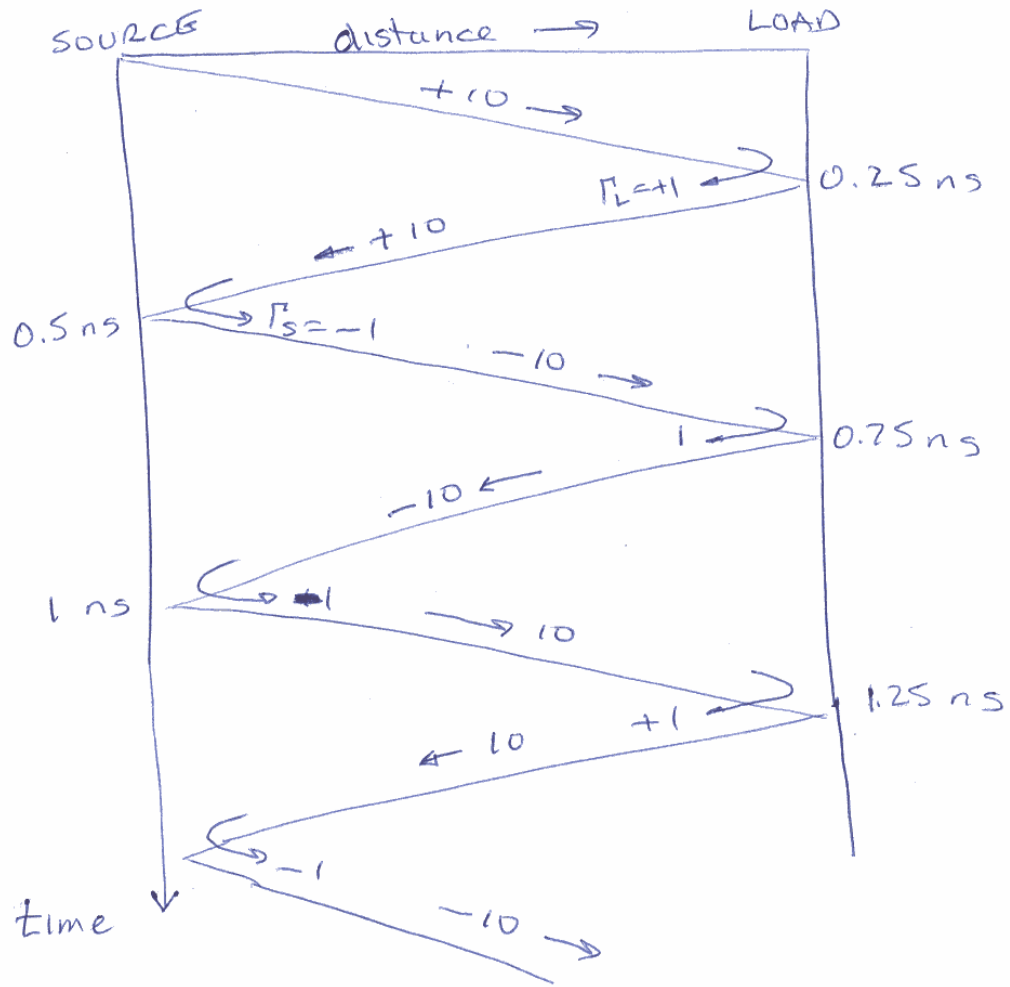


Evaluate the transit time or delay time as $T_d = \frac{5}{20} = 0.25$ ns.

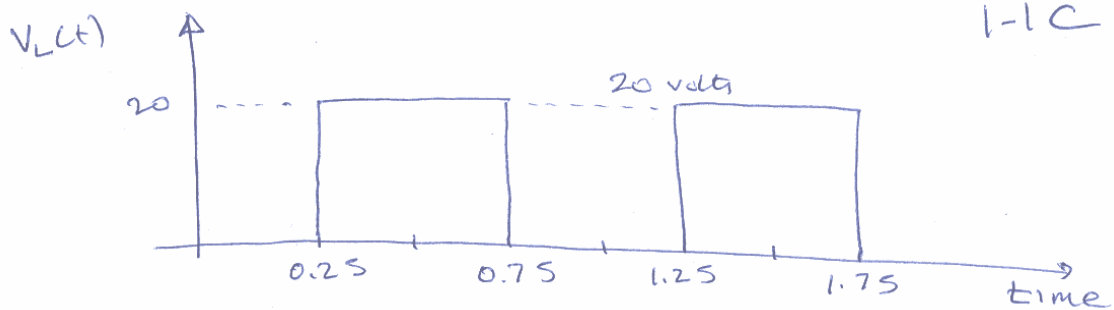
Evaluate the reflection coefficient at the generator as $\Gamma_s = \frac{R_s - R_c}{R_s + R_c} = \frac{0 - 50}{0 + 50} = -1$

and at the load as $\Gamma_L = \frac{R_L - R_c}{R_L + R_c} = \frac{\infty - 50}{\infty + 50} = +1$

Draw the Bounce Diagram up to 1.5 ns:

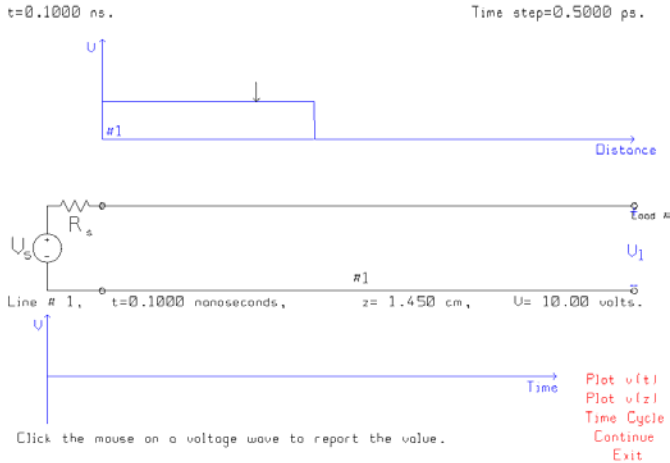


At the load, find the sum of the incident and reflected wave as each arrives at the position of the load:

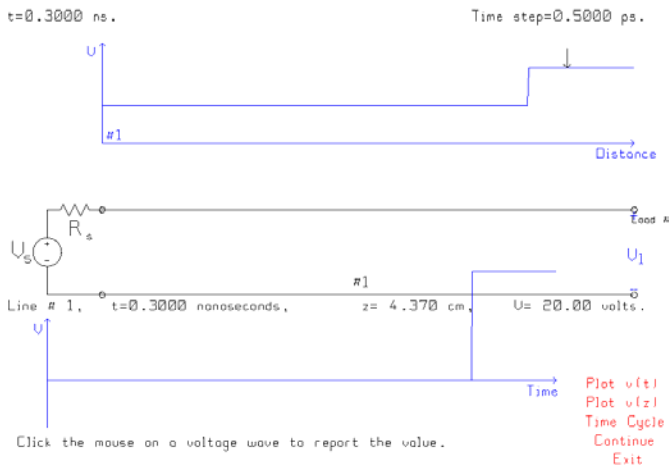


Verification with BOUNCE

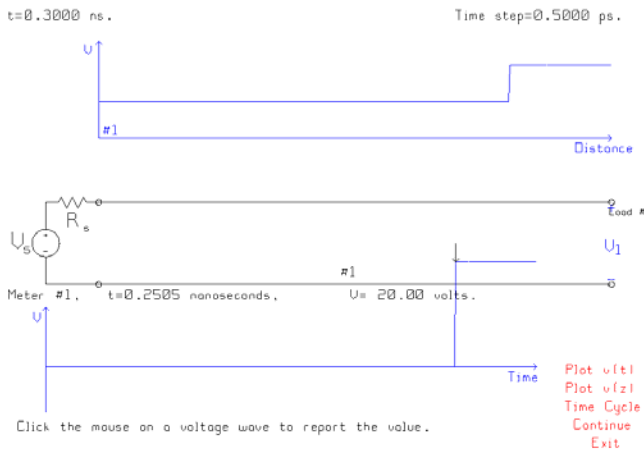
Start BOUNCE and select the generator, transmission line and load circuit. The class notes, set #2, have detailed step-by-step instructions on running BOUNCE.



The program pauses after 0.1 ns. Click the mouse on the step function at the top of the screen to “read back” the amplitude of the step as 10 volts. Then click “Continue”.

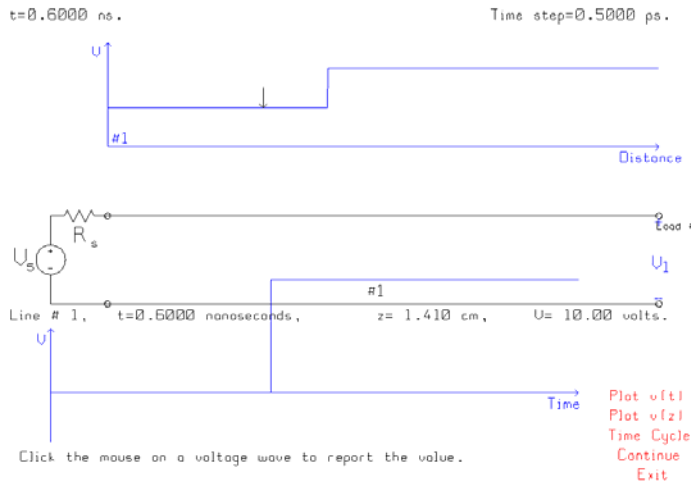


At 0.3 ns, the step has been reflected from the load. The graph across the top of the screen shows the voltage on the transmission line as a function of distance. A step up from +10 to +20 volts is propagating across the screen from right to left. This has been reflected from the load and is travelling back to the source. Click the mouse on the voltage to verify that it is 20 volts.



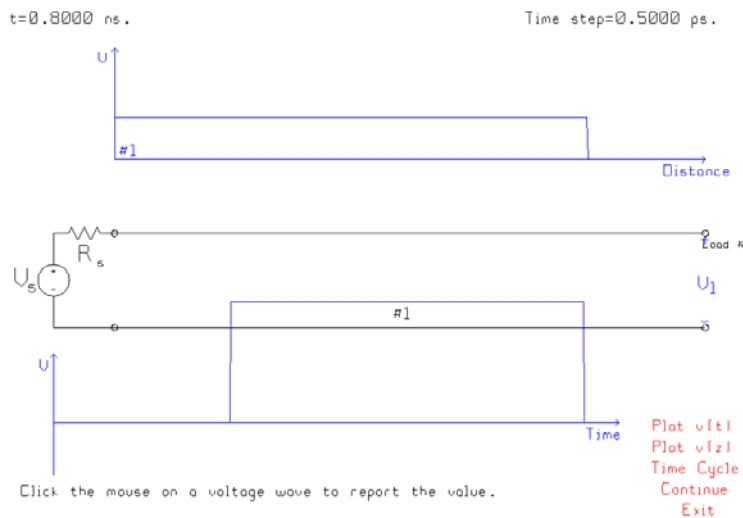
The graph across the bottom of the screen shows the voltage at the voltmeter location, which is across the load at the end of the transmission line, as a function of time. Click the mouse on the leading edge of the step to verify that the voltage here is 20 volts, as expected.

Then click Continue to let the reflected wave propagate back to the generator, and be reflected from the generator:



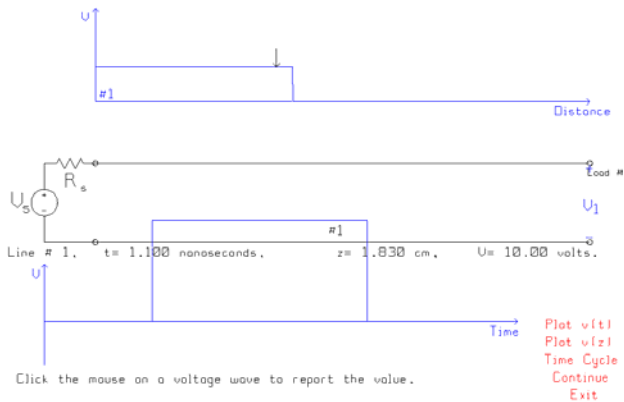
The reflection from the generator is a step of -10 volts, so the voltage on the transmission line steps down from +20 to +10 volts.

Click Continue to let the wave propagate to the load:



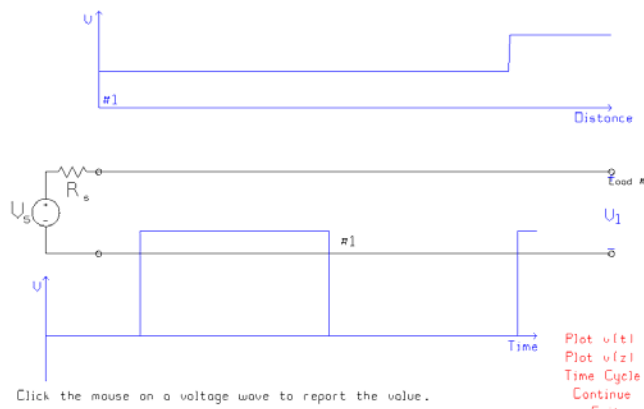
The reflection from the load is a step down of 10 volts, so the voltage on the transmission line steps down from +10 to 0 volts. At the voltmeter, the voltage steps down by the sum of the incident wave (-10 volts) plus the reflected wave (-10 volts), so steps down by 20 volts. So the voltage at the load drops to zero volts as shown in the time graph at the bottom of the screen.

t = 1.100 ns. Time step = 0.5000 ps.



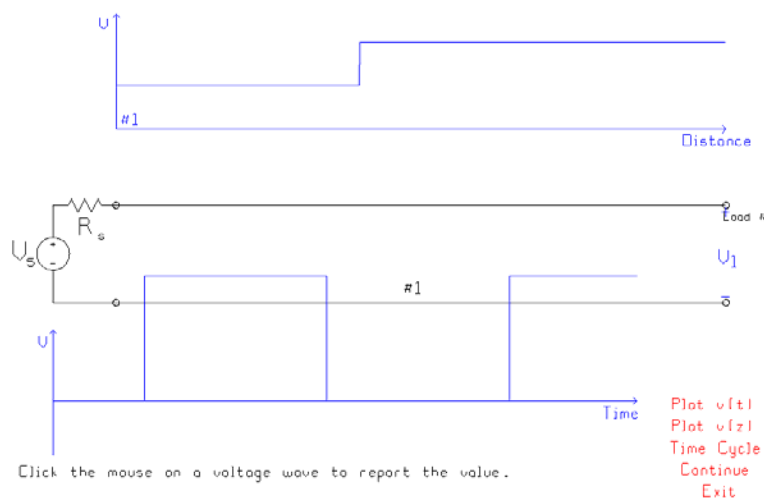
Let time advance to 1.1 ns. The -10 volt step reflected from the load is re-reflected from the source, with a reflection coefficient of $\Gamma_s = -1$, to become a step up of 10 volts. So the voltage on the transmission line steps up from 0 to 10 volts.

t = 1.300 ns. Time step = 0.5000 ps.



Let time advance to 1.3 ns. The +10 volt step is reflected from the load with a reflection coefficient of +1, as a +10 volt step. The load voltage steps up by the sum of the incident step plus the reflected step, by 20 volts.

t = 1.600 ns. Time step = 0.5000 ps.

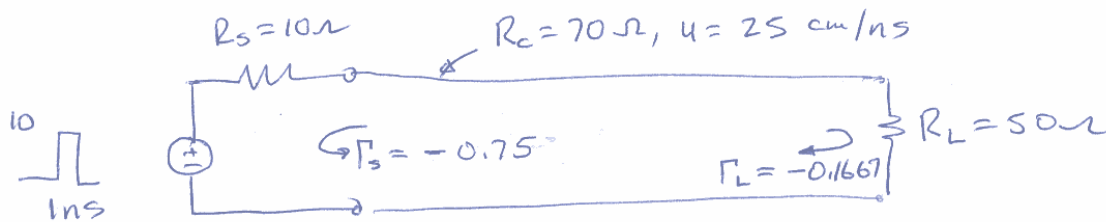


Letting time advance to 1.6 ns, we see the +10 step reflected from the source. It becomes a step of -10 volts and so the voltage on the transmission line steps down by 10 volts.

Note that the oscillation of the leading edge of the step back and forth between the source and the load will continue indefinitely. This is because the generator resistance is exactly zero and the load is 10000000 ohms, effectively infinity. If the generator had a small finite resistance, and the load had a more realistic but large impedance, the magnitude of the reflection coefficients would be somewhat less than unity, and so amplitude of the step trapped on the transmission line would gradually decrease with time.

Problem 2

5. A pulse generator with internal resistance $R_s = 10$ ohms produces a pulse of voltage lasting 1 ns starting at $t = 0$. The open-circuit voltage has amplitude 10 volts. The generator is connected to a load of $R_L = 50$ ohms by a 3 meter cable of characteristic resistance 70 ohms and speed of propagation 250 meters per microsecond.
 - (iii) Draw a “bounce diagram” for $0 < t < 65$ ns.
 - (iv) Plot the voltage across the generator $v_1(t)$ and the voltage across the load $v_2(t)$ for $0 < t < 65$ ns.



Calculate the one-way transit time as $T_d = \frac{300}{25} = 12$ ns.

Calculate the voltage launched onto the transmission line as

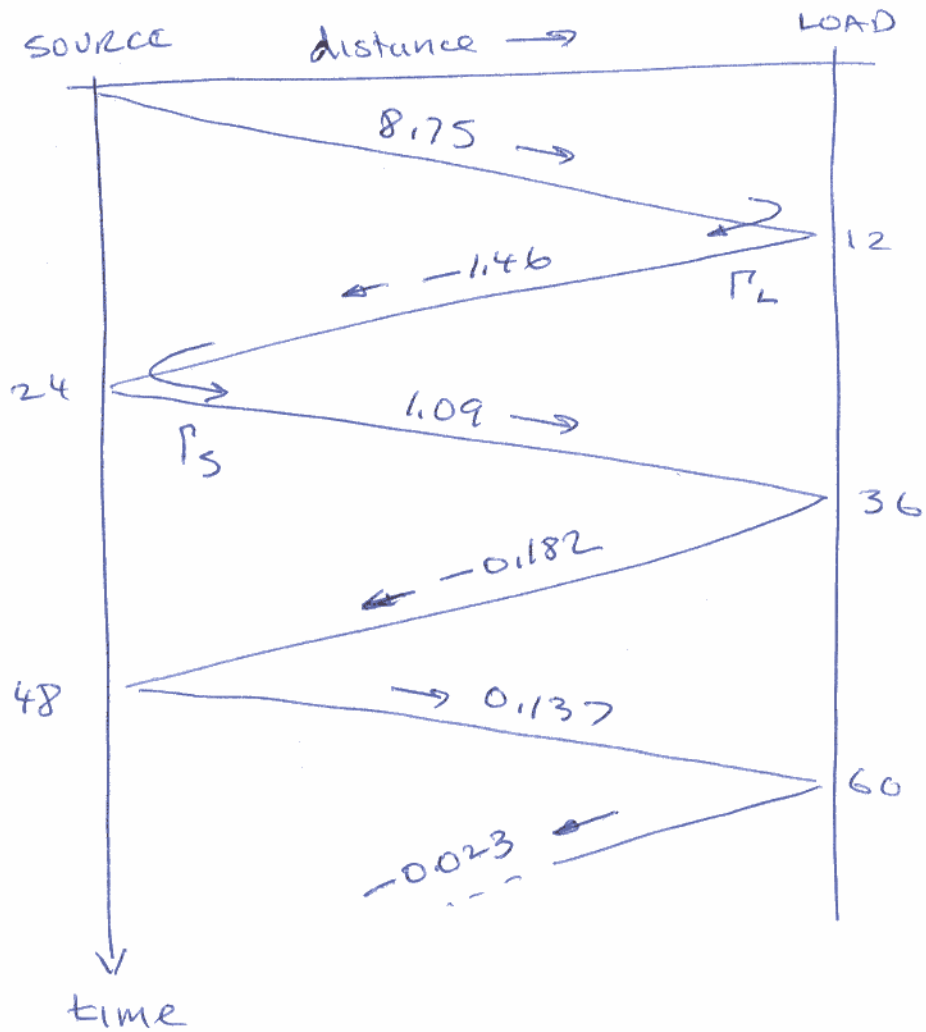
$$V(z=0) = \frac{R_c}{R_c + R_s} V_s = \frac{70}{70 + 10} \times 10 = 8.75 \text{ volts}$$

Calculate the reflection coefficients:

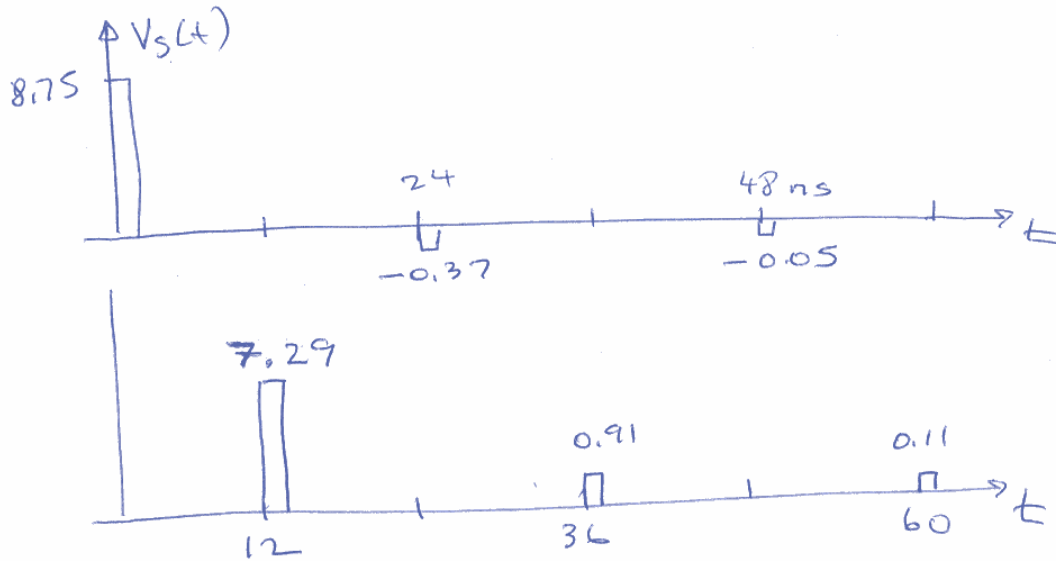
$$\Gamma_s = \frac{R_s - R_c}{R_s + R_c} = \frac{10 - 70}{10 + 70} = -0.75$$

$$\Gamma_L = \frac{R_L - R_c}{R_L + R_c} = \frac{50 - 70}{50 + 70} = -0.1667$$

Draw a Bounce Diagram:



Examine the voltage pulses that arrive at the generator and at the load, and draw the voltages vs. time:



Verify the Solution with BOUNCE

Set the generator to a pulse of amplitude 10 volts, internal resistance 10 ohms, and pulse width 1 ns. Set the transmission line to 70 ohms characteristic resistance, 25 cm/ns speed, and 3 m length. Set the load to 50 ohms.

Click the mouse on a red name to change the properties:
 Generator Line #1 Load #1



Choose an action by clicking the mouse on a red text string:
 Choose the time step and the number of steps.
 Choose the number of time steps per cycle.
 Choose the generator.
 Place a voltmeter to find $v(t)$.
 Draw the current on each transmission line.
 Draw the incident and reflected voltage waves.
 Save the circuit to a data file.
 Choose a new circuit. GO - compute the solution
 EXIT from the program.

Click the "Choose the time step" menu:

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*** BOUNCE ** VERSION 1H(d) **** Jan. 9, 2003 ****
**** Discretization Menu **** Discretization Menu **** Discretization Menu ****
      Time step: 25.00 picoseconds.   Number of Steps: 200

This program divides each transmission line into cells. The cell size
is chosen such that the distance travelled by a wave in one time step
is the same on all the transmission lines. The length of each line
is rounded off to an integer number of cells. Rounding the length
introduces discretization error into the solution.

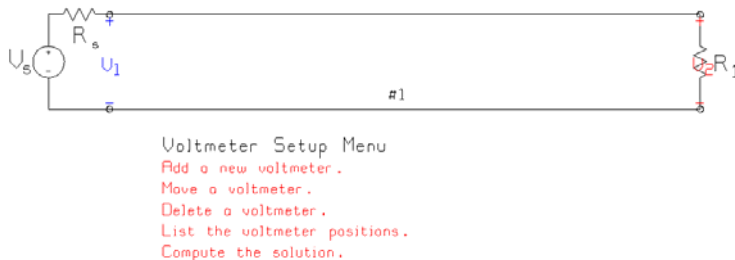
Line #   Actual   Phase   Cell Size   Number   Discretized
        Length   Velocity Cell Size   of Cells   Length
          m      m/microsec   cm
  1      3.00      250.00   0.625000    480        3.00

Type F1 to update the table.
Type F2 to choose a time step automatically.
Type F10 to continue.

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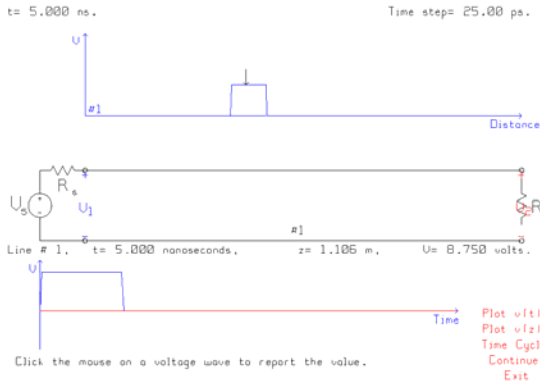
Set the time step to 25 ps. Then the number of cells on the transmission line is 480, within our guideline of about 500 cells. A time cycle or “number of steps” of 200 makes the BOUNCE program stop after each reflection.

Click the “Add a voltmeter” button. Click “Move a voltmeter” and move voltmeter V1 to the generator. Click “Add a new voltmeter”, and click the load as the position of the new voltmeter.

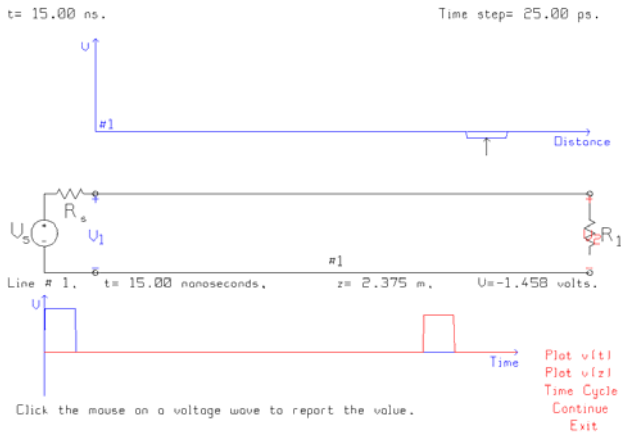


EXIT

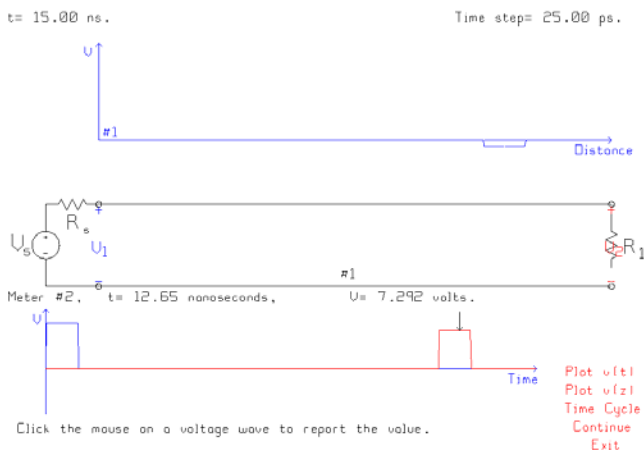
Then click Compute the Solution.



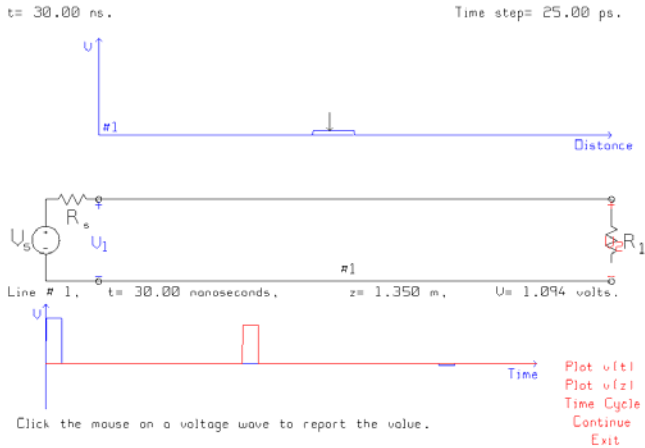
After 5 ns, the program pauses and we can click the mouse on the pulse traveling along the transmission line to verify that its amplitude is 8.75 volts as expected. We see that at the V1 location, across the generator terminals, there is a pulse of voltage, as expected. Continue the solution:



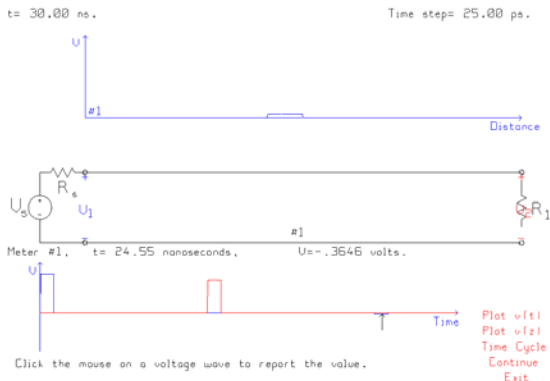
At 15 ns, we have the first reflection from the traveling back along the transmission line towards the generator. The amplitude of this pulse is -1.46 volts as expected. Click the mouse on the red voltage-vs.-time curve at the bottom of the screen:



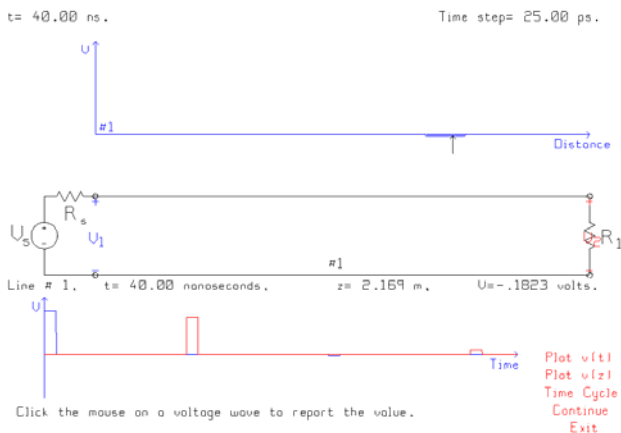
We find that the first voltage pulse at the load has amplitude 7.29 volts, as expected. Let time advance to see the next reflection from the source:



The pulse reflected from the generator has amplitude 1.09 volts, as expected. The blue curve at the bottom of the screen shows a small, negative pulse at the generator. Click the mouse on it to discover the amplitude:

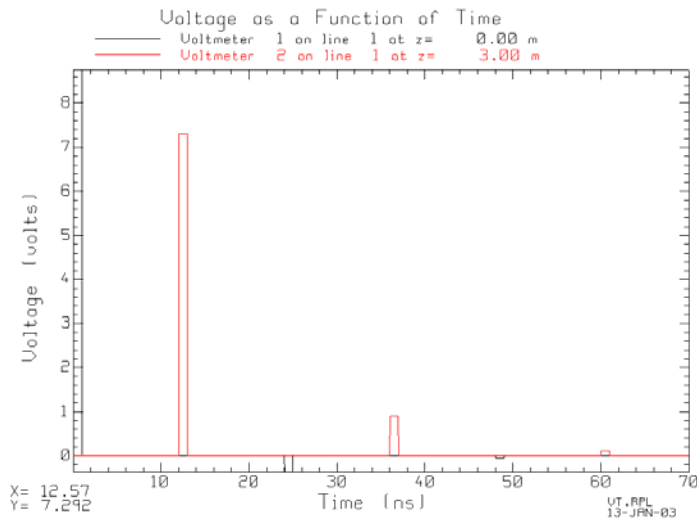


The amplitude of this pulse is -0.365 volts, close to the bounce diagram's value of -0.37 volts. Advance the time once again:

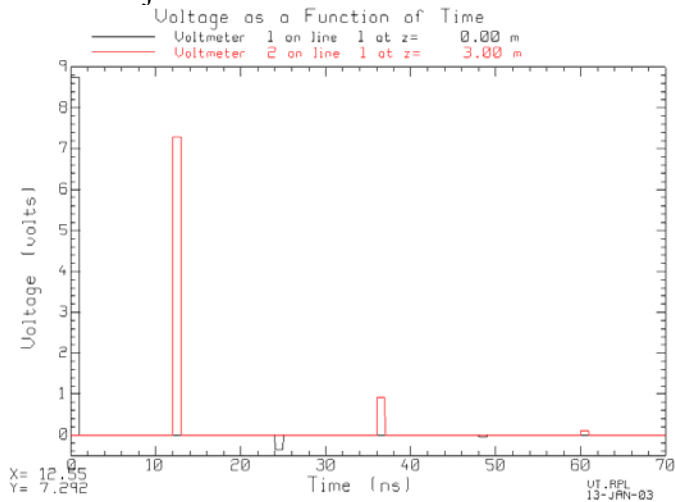


The reflected pulse on the transmission line has amplitude -0.182 volts.

If you click the mouse on "Plot v(t)" then BOUNCE starts RPLLOT.exe. We get a well-labelled graph of the voltages at the two voltmeters as a function of time. When RPLLOT starts, type F10 to read the file, then F9 to plot all the curves:



You can adjust the axes to make the curves easier to see:



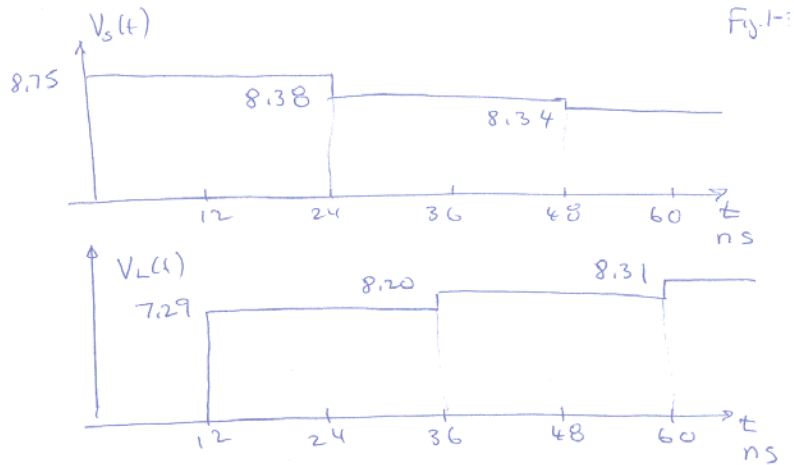
Click the mouse on the peaks of the curves to “read back” the values. If I click the mouse on the peak of the first red pulse, then in the lower left corner the program reports that the time (x coord) is 12.55 ns and the voltage is 7.292 volts.

Problem 3

- Repeat problem 2 if the generator produces a step function voltage. The generator’s open-circuit voltage is equal to zero volts for $t < 0$ and 10 volts for $t > 0$.

Pencil-and-Paper Solution:

We can use the same bounce diagram as in question 2. The traveling wave amplitudes on the bounce diagram are the values for the leading edge of the step function that travels back and forth on the transmission line. The voltage at the generator or load is the sum of all the step functions that arrive there.

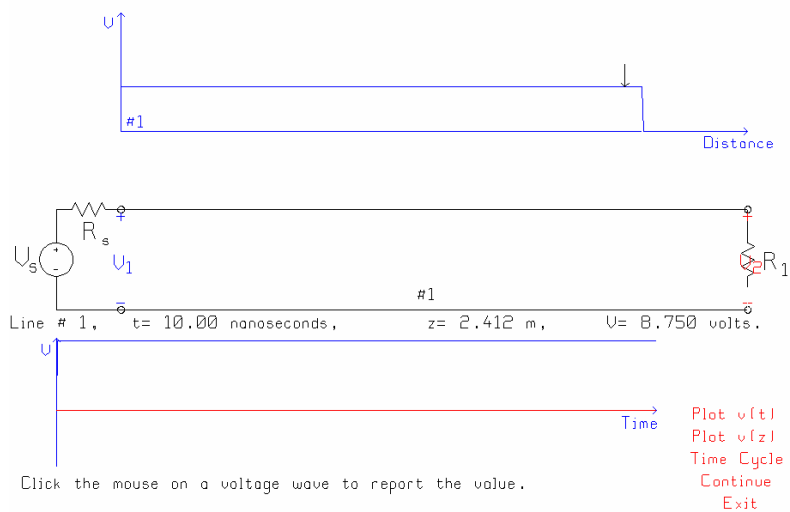


Verify the Solution with BOUNCE

Change the source used in Problem 2 to a step function generator.

$t = 10.00$ ns.

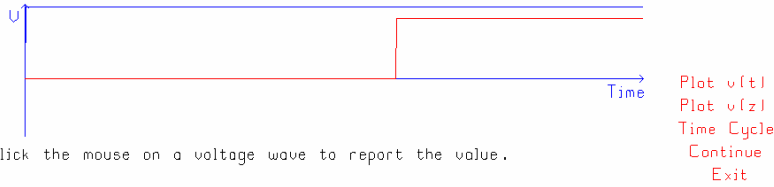
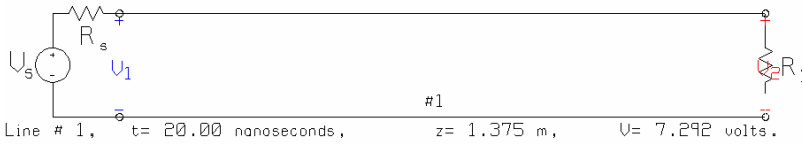
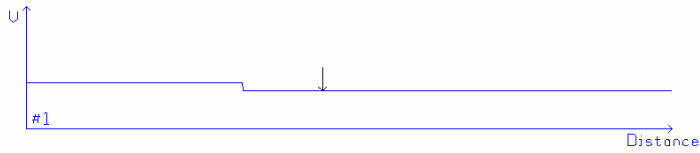
Time step = 25.00 ps.



The initial step that travels out from the generator has amplitude 8.75 volts.

t= 20.00 ns.

Time step= 25.00 ps.

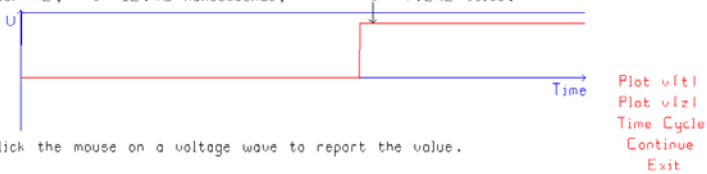
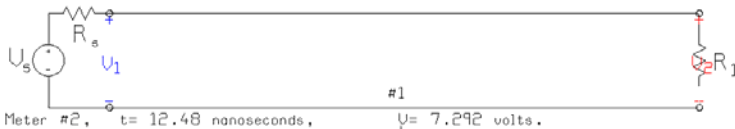


Click the mouse on a voltage wave to report the value.

After the first reflection from the load, the transmission line voltage steps down to 7.292 volts.

t= 20.00 ns.

Time step= 25.00 ps.

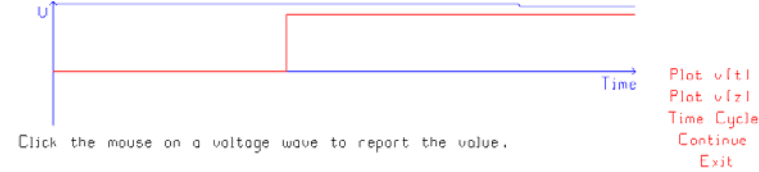
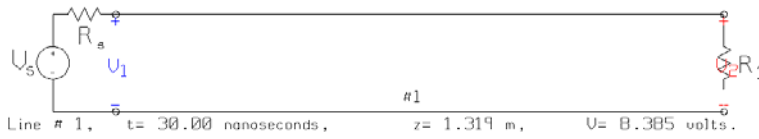
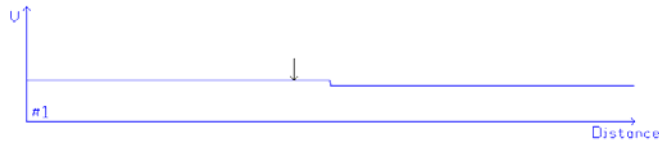


Click the mouse on a voltage wave to report the value.

The load voltage steps up to 7.292 volts. "Continue" the solution to see the 1st reflection from the source:

t = 30.00 ns.

Time step = 25.00 ps.



The voltage on the transmission line steps up to 8.385 volts.

t = 30.00 ns.

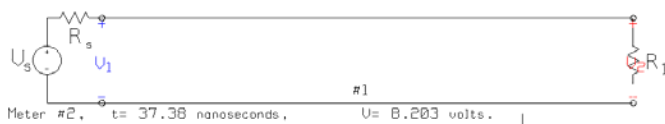
Time step = 25.00 ps.



The voltage at the generator (blue curve in the bottom graph) steps down to 8.385 volts. Continue the solution until there is another reflection at the load:

t = 40.00 ns.

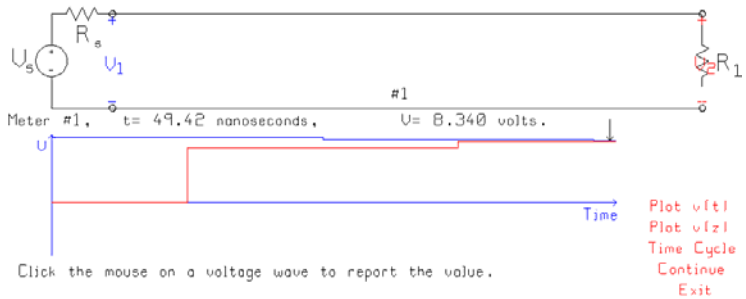
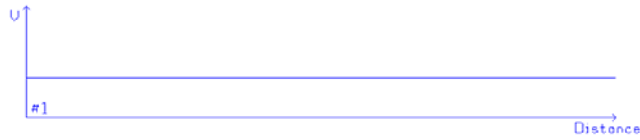
Time step = 25.00 ps.



The load voltage steps down to 8.203 volts. Continue until there is another source reflection:

t= 50.00 ns.

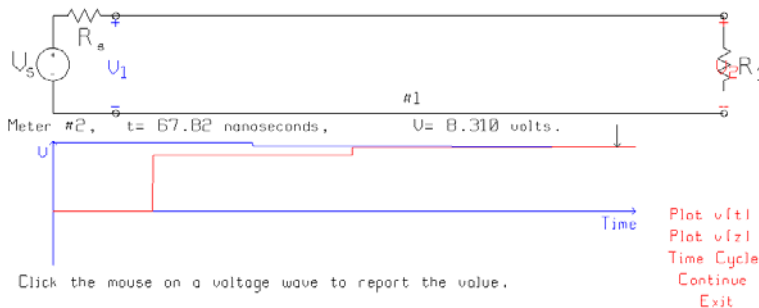
Time step= 25.00 ps.



The reflection from the source is small. The source voltage steps down to 8.34 volts. Continue until there is another load reflection:

t= 70.10 ns.

Time step= 25.00 ps.



The load voltage steps up to 8.31 volts.

If you click the mouse on “plot v(t)”, then BOUNCE starts program RPLOT.exe (which you can fetch from the web site) and we get a well-labelled graph of the voltages at the “voltmeters” as a function of time:

Voltage as a Function of Time

— Voltmeter 1 on line 1 at z= 0.00 m
— Voltmeter 2 on line 1 at z= 3.00 m

