Saye, Soh

# ECE342 EMC Lab #5. Transmission Line Transients

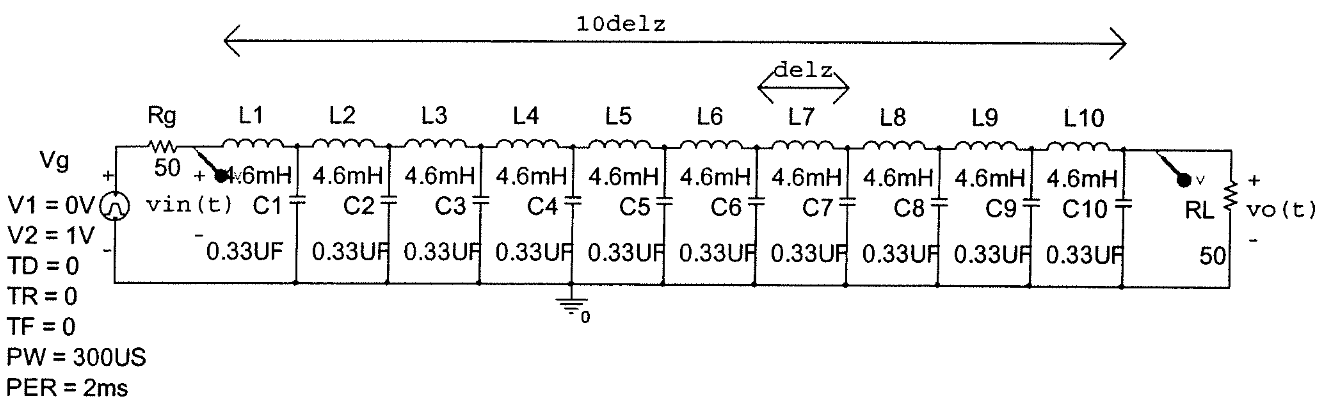
Name:_____________________________ Box:_________

( Individual work! Each student must turn in this lab worksheet with the three requested PSPICE simulation attachments. Each student is expected to bring to this lab session their laptop with Cadence Orcad Lite Version 9.3 PSPICE installed!)

## 1. "LC" Analog Delay Line (Distributed Transmission Line Model)

Consider the "LC" analog delay line, or "synthetic transmission line", shown in Figure 1. It consists of 10 LC sections, where each section is Δz in length. The entire line length is therefore 10Δz. This circuit only approximates the behavior of a real transmission line, since Δz has not been shrunk down to an infinitesimal length (which would require an infinite number of L and C components for a finite length of line!) Note that the inductance per unit length is $\underline{L} = L/\Delta z$, and the capacitance per unit length is $\underline{C} = C/\Delta z$, where in this example, L = 4.6 mH and C = 0.33 $\mu$F.

**Figure 1. Analog "LC" delay line (approximate distributed transmission line model)**




Thus the approximate characteristic impedance and velocity of propagation of this line are approximately given by

$$Zo = \sqrt{\frac{L/\Delta z}{C/\Delta z}} = \sqrt{\frac{L}{C}} = \sqrt{\frac{4.6\,mH/\Delta z}{0.33\,\mu F/\Delta z}} = \boxed{118.1\,\Omega}$$

$$vp = \frac{1}{\sqrt{(L/\Delta z)(C/\Delta z)}} = \frac{\Delta z}{\sqrt{LC}} = \boxed{25666.4\,\Delta z}$$

The propagation delay time Td, or the travel time from the input to the output terminals of the line, is given by

$$Td = \text{Line\_Length} / vp = 10\Delta z / vp = \frac{10\Delta z}{25666.4\,\Delta z} = \boxed{389.6\,\mu s}$$

Adjust the Agilent function generator (with an output resistance of Rg = 50 Ω) to deliver a "short" Vg = 0 V to 1 V step train with a duration of 300 $\mu$s and a period of 2 ms. (*We shall define a "short pulse" as a pulse whose duration is less than twice the propagation delay of the line, thus the short pulse ends BEFORE the first reflection from the receiving end arrives back at the sending end.*) With RL set to about 50 Ω, determine the delay time (Td) using the Agilent oscilloscope with its probes placed at both the sending and receiving ends. Then vary RL until no echo is received back at the sending end. The value of RL that results in no echo must be equal to the characteristic impedance of the line, and the line is said to be "matched". Record your measured values of Td and Zo, and calculate % error between the measured and predicted results. Fill in the blanks below:

Td(pred) = 389.6μS  Td(meas) = 416 μS  % error = ________

Zo(pred) = 118.1Ω  Zo(meas) = 113.8 Ω  % error = ________

In the space below, sketch the observed vin(t) and vo(t) for RL set to 0 (short-circuit termination), for RL = Zo (matched termination), and for RL set to infinity (open-circuit termination). Note that the wave shape of the pulse becomes increasingly distorted as the pulse travels back and forth on the line, since this circuit is *only an approximation* to a true lossless transmission line.

Sketch of vin(t) and vo(t) for RL = infinity

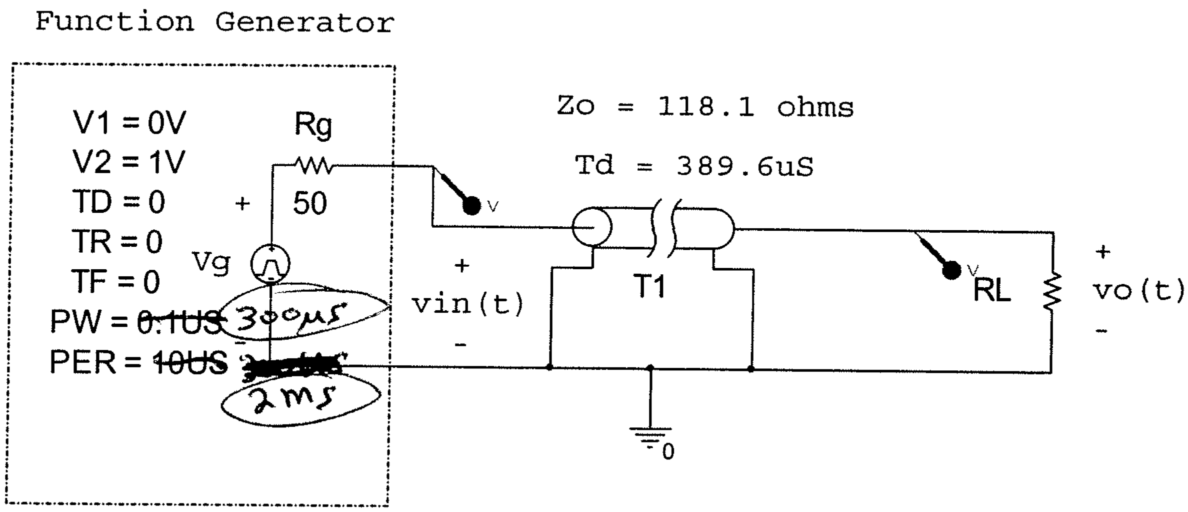
Sketch of vin(t) and vo(t) for RL = Zo

Sketch of vin(t) and vo(t) for RL = 0

Now simulate this circuit using ORCAD PSPICE. Use the VPULSE source (V1 = "down" voltage, V2 = "up" voltage, TD = delay before pulse rises, TR = rise time, TF = fall time, PW = width of pulse, PER = period of pulse train) and a time-domain (transient) simulation. Note that this source generates a train of pulses, but we will focus only on the response to the first pulse out of the generator. Include as **Attachment A** your PSPICE schematic and your PROBE plots of vi(t) and vo(t) for the same three observed cases: RL = 0, RL = Zo, and RL = infinity. Your PSPICE simulation plots should closely resemble the observed plots sketched above. *Note: PSPICE does not like 0 ohm resistors, so the first case must be simulated using a very small resistor, say RL = 0.001 ohms. Also, remember that PSPICE simulations require that a ground symbol with a "0" be used.*

Next, simulate this circuit using ORCAD PSPICE using an ideal lossless transmission line component, which is designated "T" in the PSPICE library. Your circuit should look like Figure 2. Once you have drawn this circuit, single left click on the transmission line symbol to select it (it should be surrounded by a pink dotted box), then single right click on this box and choose "Edit Properties". Scroll to the right to the Zo and Td entry boxes in the Properties Window, and enter the desired values of Zo and Td that you calculated earlier. Include as **Attachment B** your schematic diagram (for just one of the cases) and the three resulting PROBE plots of the sending and receiving end voltages, vi(t) and vo(t) for the three cases considered above (RL = 0, RL = Zo, and RL = infinity). Use the ORCAD "Toggle Cursor" button and "Mark Label" button to label the relevant vin(t) and vo(t) voltage levels directly on your PROBE plot.

**Figure 2. Precise transmission line modeling in PSPICE using the "T" (lossless transmission line) component**



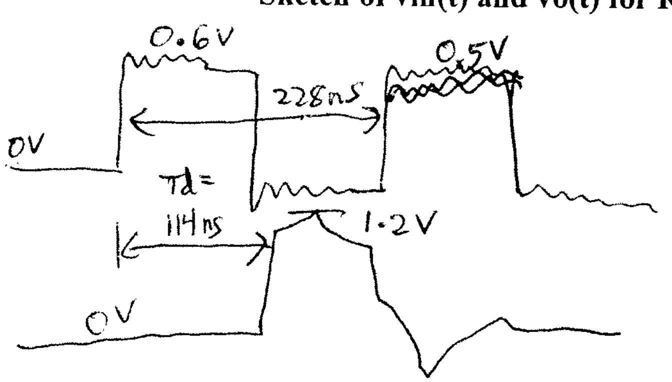

Agilent 33220A Period = 10µs, AMP = 1 Vpp, Offset = 500 mVdc, width 100ns

## 2. Transients on a Real Transmission Line

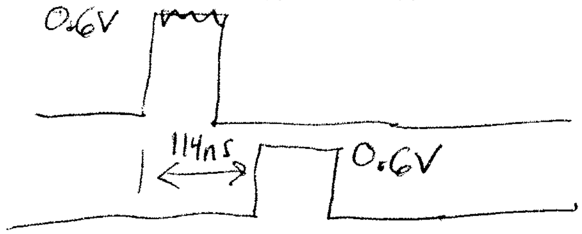
In this section of the lab demo, we will be working with a rolled up coaxial cable that was acquired as military surplus. It was used to provide a precise analog delay in a radar system. This "Mystery Line" is somewhat cryptically labeled "Short Delay Coil 25 m". Let us assume that this coaxial cable uses polystyrene dielectric, as do most coaxial cables. Polystyrene has a relative permittivity of $\epsilon_R = 2.25$, and thus vp = 1/sqrt($\mu\epsilon$) = 3 x $10^8$ / sqrt(2.25) = 200 m/$\mu$s. We shall adjust the Agilent function generator to deliver a Vg = 0 V to 1 V "short pulse" (PW < 2Td) with a width of 0.1 $\mu$s, and a period of 10 $\mu$s, using the circuit of Figure 2. Then RL is adjusted until there is no echo pulse received back at the sending end. The propagation delay time is measured between the sending and receiving end.

Sketch the observed sending and receiving end voltage waveforms for a short-circuit termination (RL = 0), for the matched condition (RL = Zo), and for an open-circuit termination (RL = infinity).

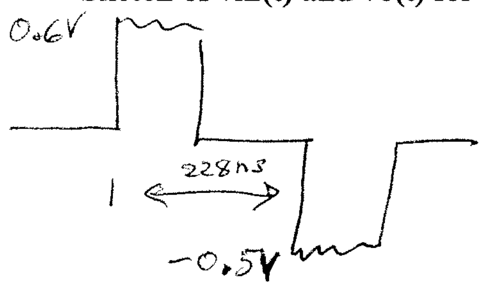
**Sketch of vin(t) and vo(t) for RL = infinity**



**Sketch of vin(t) and vo(t) for RL = Zo**




**Sketch of vin(t) and vo(t) for RL = 0**




Also, record the observed values of characteristic impedance, Zo, and propagation delay, Td. From this calculate the length of this "Mystery Line", assuming vp = 200 m/$\mu$s.

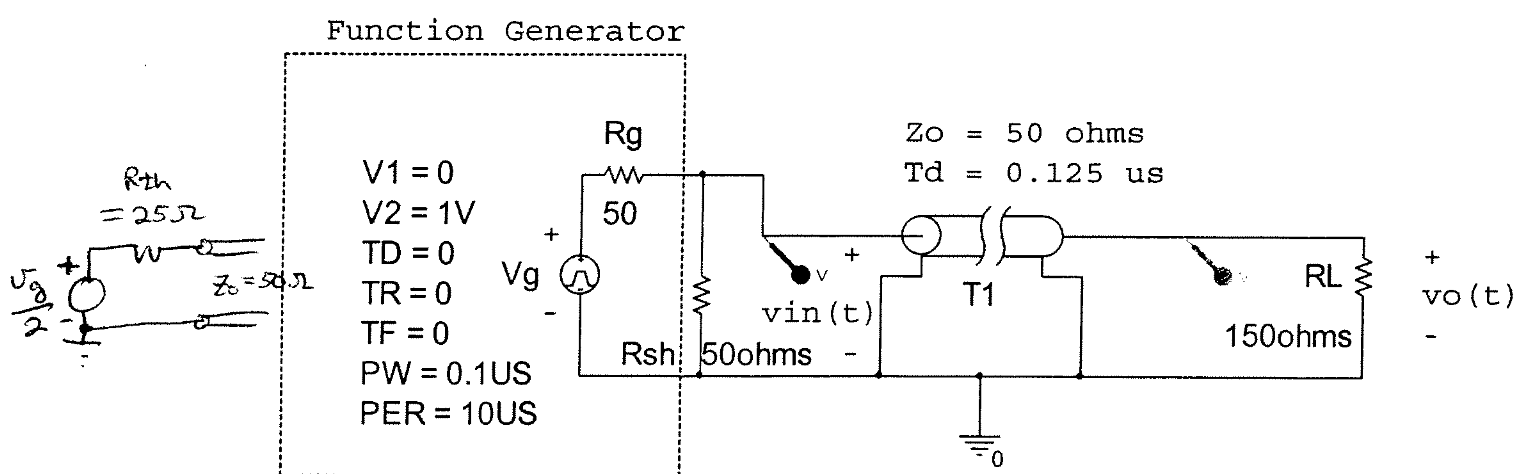
$$\ell / v_p = T_d \qquad \ell = T_d \cdot v_p = (.114\mu s)(200\,m/\mu s) = 22.8\,m$$

**Zo =** 56Ω **Td =** 114 ns **Line_length =** 22.8 m

## 3. Short pulse excitation of a transmission line

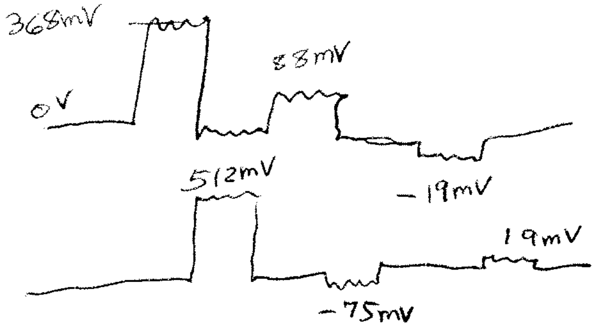
Keep the function generator set to deliver a Vg = 0 to 1V short pulse with a pulse width of 0.1 $\mu$s, and a period of 10 $\mu$s. Connect the generator to the circuit of Figure 3.

**Figure 3. Circuit for studying short pulse transients on a mismatched transmission line ($Rg_{EQUIV}$ = 25 Ω, and RL = 150 Ω) Note PW < Td**



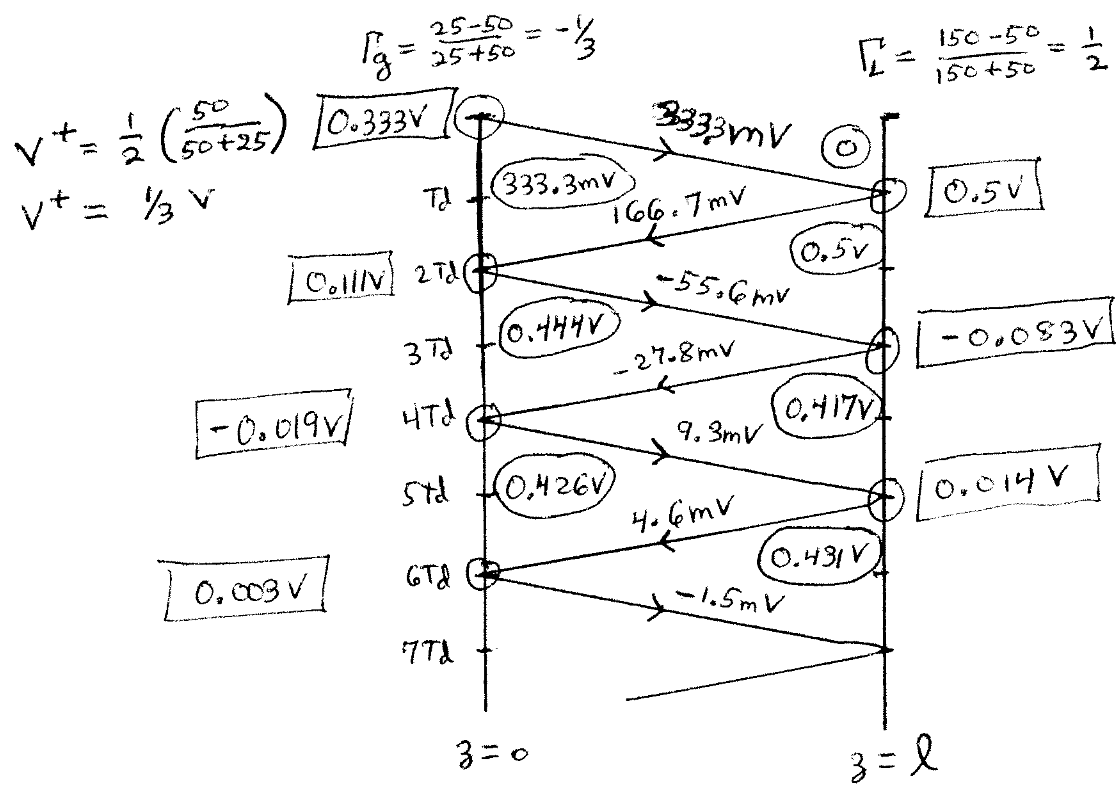
Sketch the vin(t) and vo(t) waveforms for 0 < t < 1 $\mu$s in the space below, making sure to indicate the amplitude of each voltage pulse.

**Sketch of observed vin(t) and vo(t) waveforms for 0 < t < 1 $\mu$s for short pulse (PW < 2Td)**




Predict each voltage pulse amplitude in the vin(t) and vo(t) waveform in the space below by constructing a bounce diagram, and compare your predictions with the observed values:

**Bounce diagram analysis of the circuit of Figure 3**



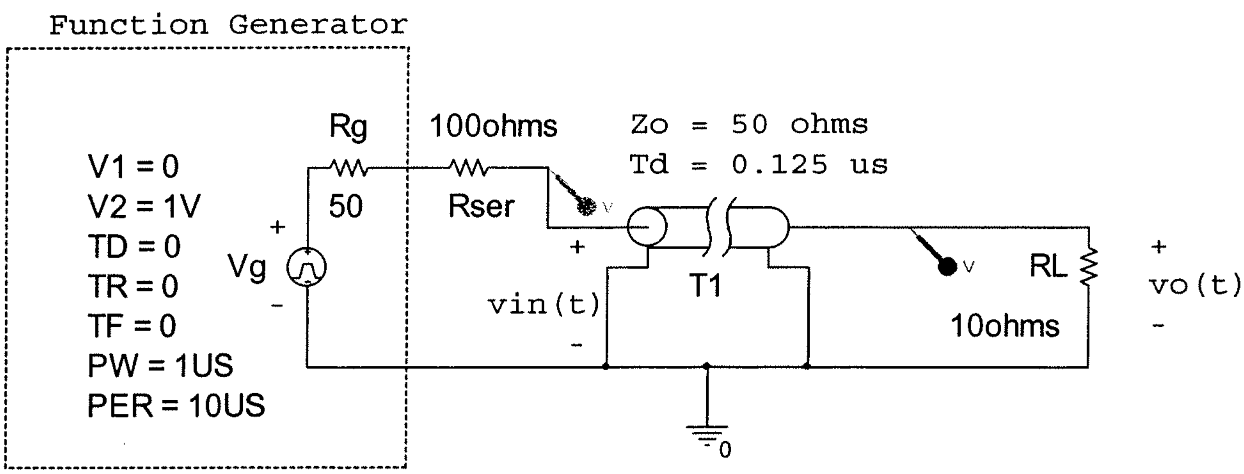

| vin(t) | observed | predicted | vo(t) | observed | predicted |
|---|---|---|---|---|---|
| 1st pulse | 0.368 V | 0.333 V | 1st pulse | 0.512V | 0.5V |
| 2nd pulse | 0.088 V | 0.111 V | 2nd pulse | -0.075V | -0.083V |
| 3rd pulse | -0.019 V | -0.019V | 3rd pulse | 0.019V | 0.014V |

Check your predictions using PSPICE simulation. Include your PSPICE simulation results (PSPICE schematic and PROBE plot) as **Attachment C**. Use the ORCAD "Toggle Cursor" button and "Mark Label" button to print the relevant vin(t) and vo(t) voltage level values directly on your PROBE plot. Your PSPICE simulated values should precisely match the predicted values entered in the table above.

## 4. Long pulse (step) excitation of a transmission line (Bounce Diagram)

Now increase the pulse width to 1 $\mu$s, which is >> Td and the pulse repetition period to 10 $\mu$s. We shall focus on the response of the line to only the *rising edge* of the pulse, and thus we shall observe the "*step response*" of the line. Consider the mismatched line of Figure 4.

**Figure 4. Second circuit for studying transients on a mismatched transmission line ($Rg_{EQUIV}$ = 150 Ω, and RL = 10 Ω) Note PW >> 2Td**



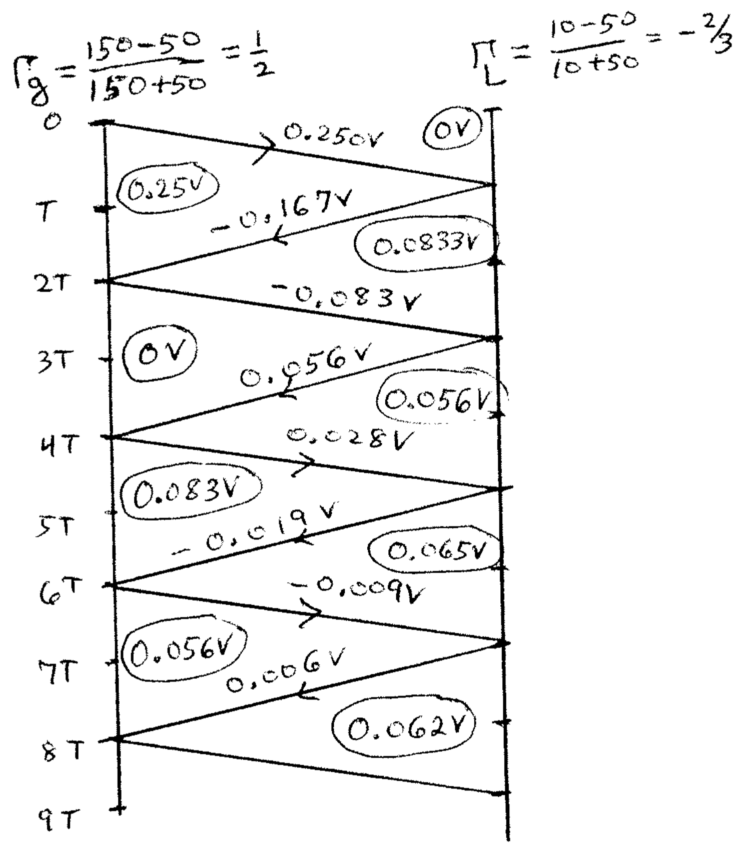

Sketch the observed vin(t) and vo(t) waveforms from 0 < t < 1 $\mu$s, thereby focusing on just the rising-edge step response of the line.

**Sketch of vin(t) and vo(t) for 0 < t < 1 $\mu$s (PW >> 2 Td)**

In the space below, construct a bounce diagram that predicts the voltage steps at the sending and receiving end for the Vg = 0 V to 1 V step change.

**Bounce diagram analysis of the circuit of Figure 4**

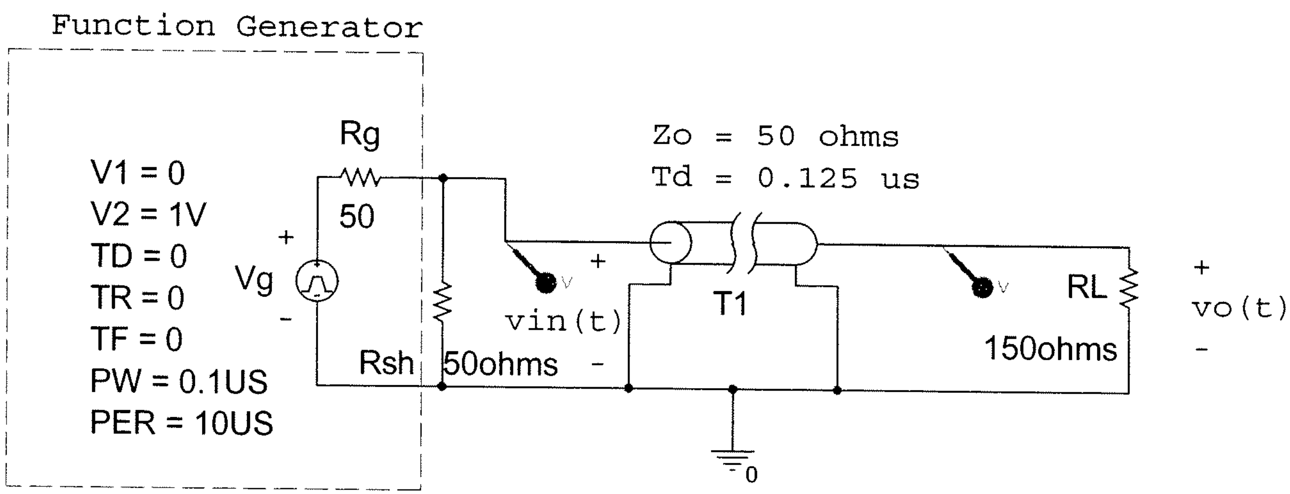
$$V^+ = 1\,V\left(\frac{50}{50+150}\right) = 1/4\ V$$




Compare the observed and predicted voltage steps at the sending end, vin(t), and the receiving end, vo(t) by filling in the table below:

| vin(t) | observed | predicted | vo(t) | observed | predicted |
|---|---|---|---|---|---|
| 1st step | 0.296V | 0.25V | 1st step | 0.088V | 0.0833V |
| 2nd step | 0.009V | 0V | 2nd step | 0.066V | 0.056V |
| 3rd step | 0.091V | 0.083V | 3rd step | 0.075V | 0.065V |
| 4th step | 0.065V | 0.056V | 4th step | 0.068V | 0.062V |

Also, check your predictions using a PSPICE simulation of the circuit of Fig. 4. You need only plot the rising edge step response between $0 < t < 1\ \mu s$. Include your PSPICE schematic and PROBE plot as **Attachment D**. Use the ORCAD "Toggle Cursor" button and "Mark Label" button to label the relevant vin(t) and vo(t) voltage levels directly on your PROBE plot. Your PSPICE simulated values should precisely match your predicted values entered in the table above.

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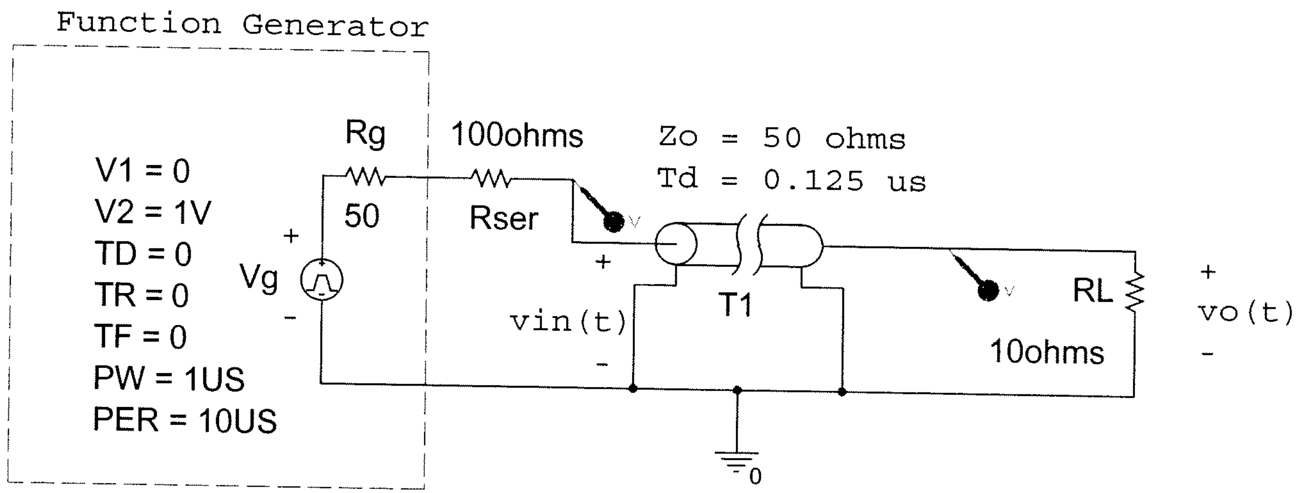
| Date: | Wednesday, October 19, 2005 | Sheet 1 of 1 |


(A) lab6p3-SCHEMATIC1-keh.dat (active)
Attach. C. Short Pulse Response
600mV
400mV
200mV
0V
-200mV
(184.615n,500.000m)
(60.000n,333.333m)
(558.462n,-18.519m)
(310.769n,111.111m)
(681.539n,13.889m)
(432.308n,-83.333m)
0s
0.2us
0.4us
0.6us
0.8us
1.0us
□ V(T1:B+) ◇ V(T1:A+)
Time

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| Date: | Wednesday, October 19, 2005 | Sheet 1 of 1 |

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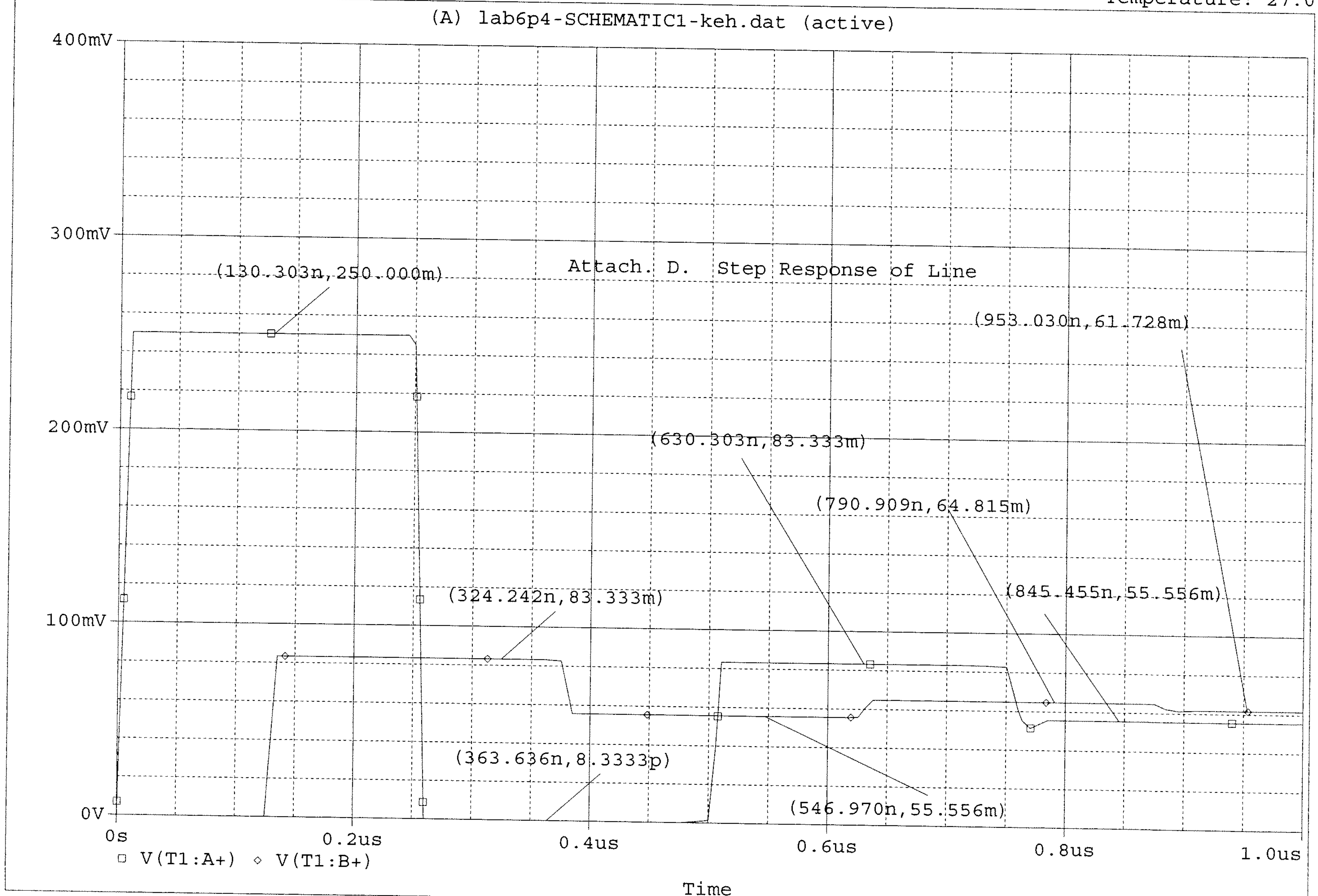


Date: October 24, 2006



Time: 15:32:08