Quickline: A Transmission Line Simulation Package

by

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Abstract: *"Quickline" is a simulation package which evaluates the voltage on an ideal transmission line terminated at various loads. The considered terminations are series and parallel combinations of resistors, inductors, and capacitors. The code is written in BASIC with a graphics capability suitable for the IBM PC/XT/AT.*

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TABLE OF CONTENTS

I. INTRODUCTION

"Quickline" is a simulation package which evaluates the voltage on an ideal transmission line terminated with various loads. The excitation of the transmission line is provided by a DC voltage generator.

This software has been developed to aid undergraduate students in understanding transient effects on ideal transmission lines (T.L.) and has been written for IBM/PC/XT/AT personal computers. The program evaluates and displays the voltage responce of any loaded ideal T.L. for a given excitation as a function of time and distance. The terminations treated in this package are series and parallel combinations of resistors, inductors and capacitors. There is a choice of two different excitations (p=pulse, s=step) and six loads. The structure of the programing is such that more terminations or other excitations may be added as needed.

This package will become the basis of a number of homeworks where the students will have to run many elaborate and meaningful examples in order to understand the effect of various circuits element on the behavior of ideal transmission lines. The interactive nature of the program will allow the advanced student to experiment with problems he/she may find interesting.

II. RUNNING THE PROGRAM

A. Overview

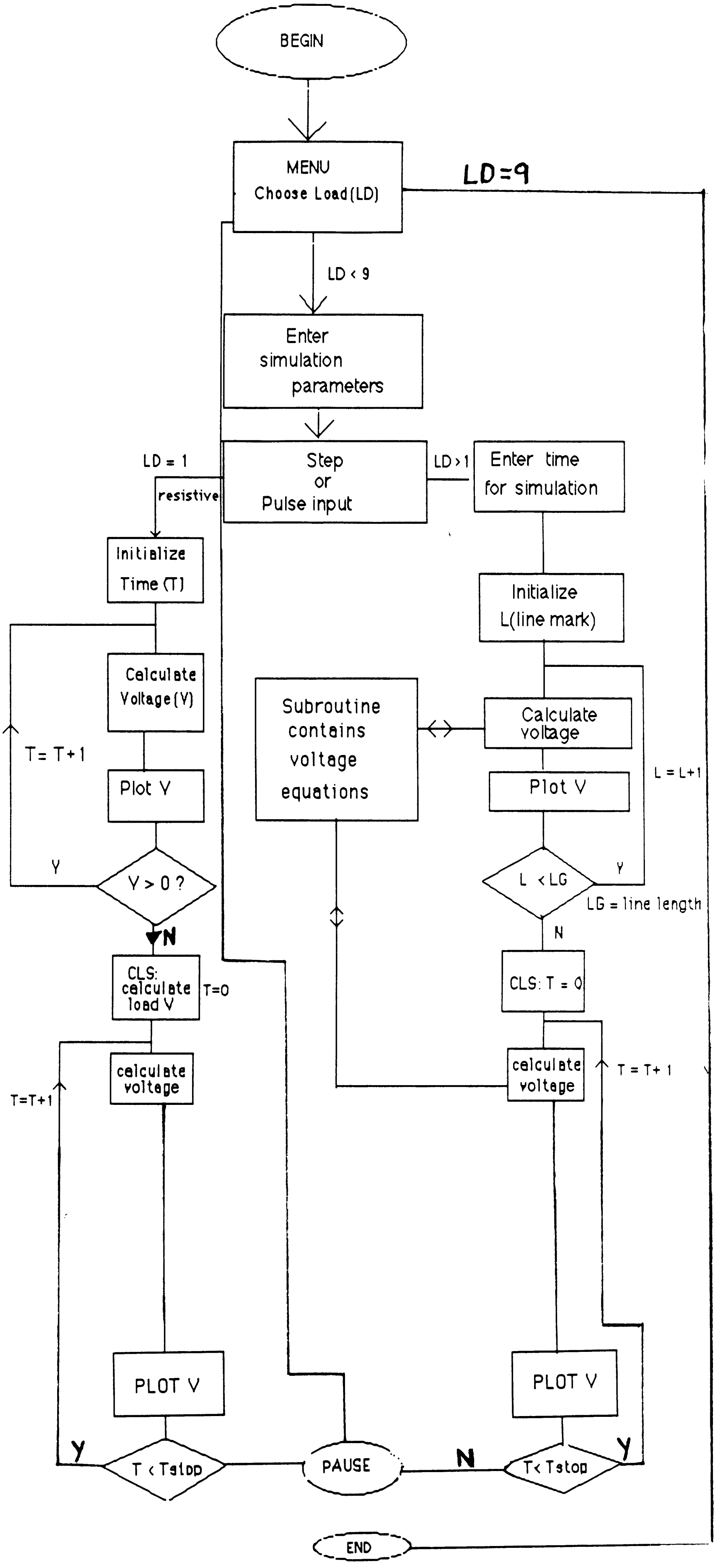
While preparing this package two principles were kept in mind.

1. To make the program as versatile as possible.

2. To make it as simple to use as possible.

The versatility of the program lies in its organization. As shown in the flow chart, the program will follow the same path with the specific relationships governing each type of load in a subroutine. Therefore, if a new type of loading is desired to be considered, it can be added easily. The equations for new terminations can be included in the subroutine with very few other additions to the program.

The package is written in such a way that anyone familiar with transmission line theory can run it without the use of this literature. The program displays comments and calculations on the screen to help the user choose parameters and make decisions. Errors on input data will not cause the program to fail, but will result in a prompt and message to the user. Circuit diagrams and labeling make the graphs and plots self explanatory.


BEGIN
MENU
Choose Load(LD)
LD=9
LD < 9
Enter simulation parameters
Step or Pulse input
LD = 1
resistive
LD > 1
Enter time for simulation
Initialize Time (T)
Calculate Voltage (V)
T= T+1
Plot V
Y
V > 0 ?
N
CLS: calculate load V
T=0
calculate voltage
T=T+1
PLOT V
Y
T < Tstop
PAUSE
Initialize L(line mark)
Subroutine contains voltage equations
Calculate voltage
Plot V
L = L+1
L < LG
Y
LG = line length
N
CLS: T = 0
calculate voltage
T = T+ 1
PLOT V
N
T< Tstop
Y
END

B. **User's Guide**

The following sections explain important aspects of running the program. For questions on the theory behind it refer to appendix A. Appendix B contains guidelines for choosing program parameters and help in troubleshooting.

The Main Menu

Upon entering the program the user sees the following screen.

MENU

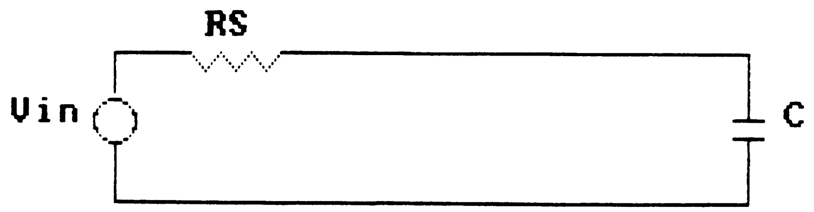
Choose the line loading

1) Resistive Load
2) Capacitive Load
3) Inducative Load
4) Parallel LC Load
5) Parallel RLC Load
6) Series RLC Load

9) Exit Quickline

Enter Choice

The user may enter the desired load. Nine exits the program. Next, the program displays a picture of the chosen configuration and asks for confirmation. Also the program gives a choice of pulse (P) or step(s) excitation and the user has to respond accordingly.




```
Is This The desired configuration(Y/N)?

Do you want to excite the line with a
pulse(p), or a  step(s)?
```

At this point the program automatically decides what parameters are needed for the specified load and asks for them. (See appendix B-choosing Program parameters). Exit from the program is possible at any time.

Resistive Load Simulation*

The resistive load simulation differs from all others. It displays moving steps (pulses) and follows these steps (pulses) until steady state. As seen in the flow chart the voltages are calculated until the reflected step (pulse) decays to zero. Then the load voltage is displayed as a function of time. This is the only simulation which allows an unmatched source resistance; all other assume that the source resistance matches the characteristic impedance of the line.

Other Simulations (C,L,LC,RLC)

For the more complex simulations the program calculates the time a step or pulse transits the line in and displays it. It then asks for the time at which the user wishes to see the line voltage. This time can take any value from 0 to twice the transit time as shown below.

*Note - All simulations are lossless

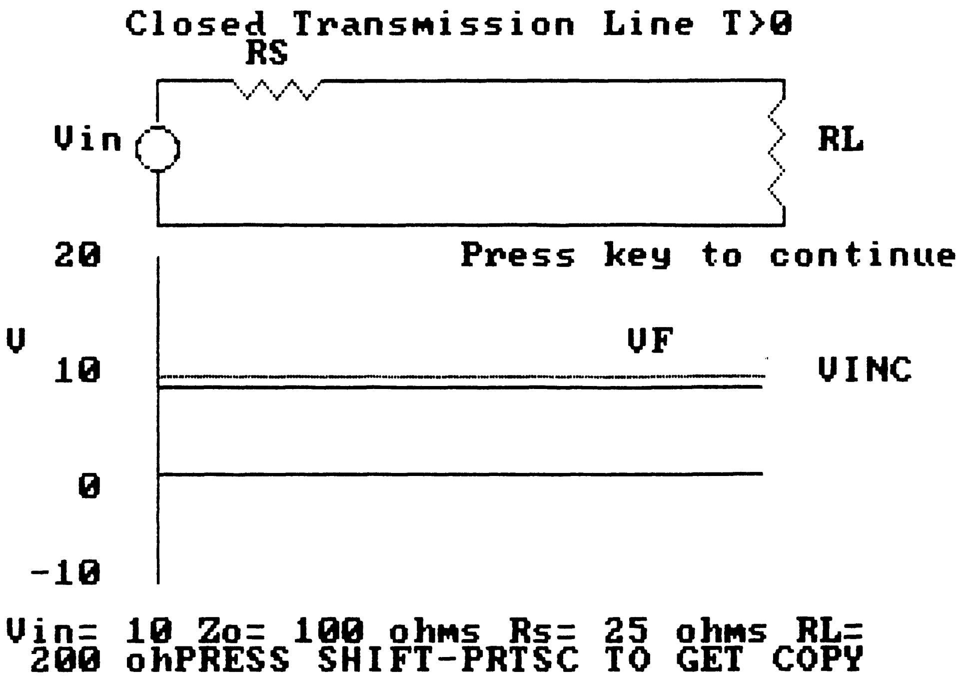
```
The pulse can travel from end to end of
the line in T1= 3.333333 ns

 At what time in nanoseconds do you want
 to see the line voltage(ENTER 0 -2XT1)?
 █
```

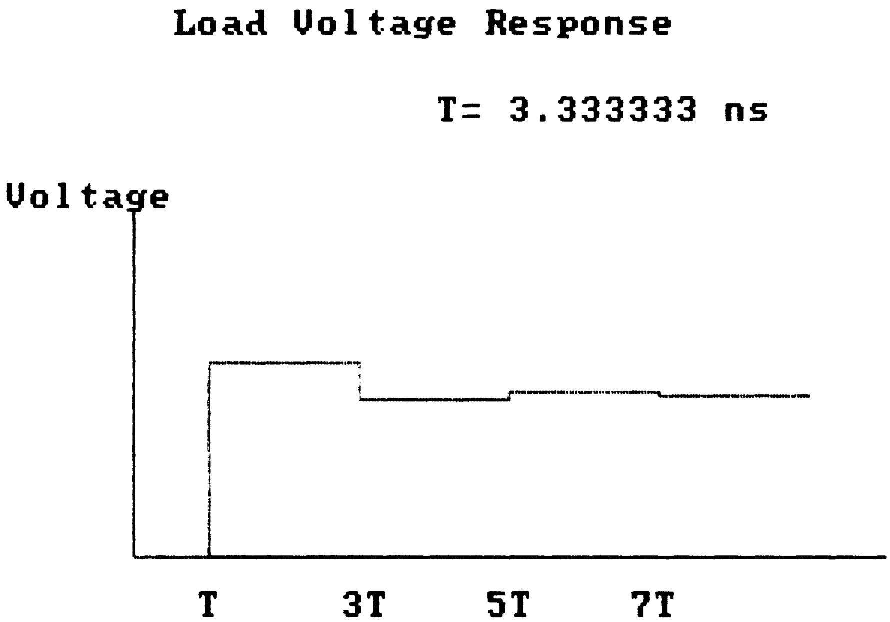
Upon entering the time, the line voltage is displayed. By entering a prompt the user can see the load voltage. In all simulations, the program automatically adjusts the voltage scales by the given input voltage.

Printing

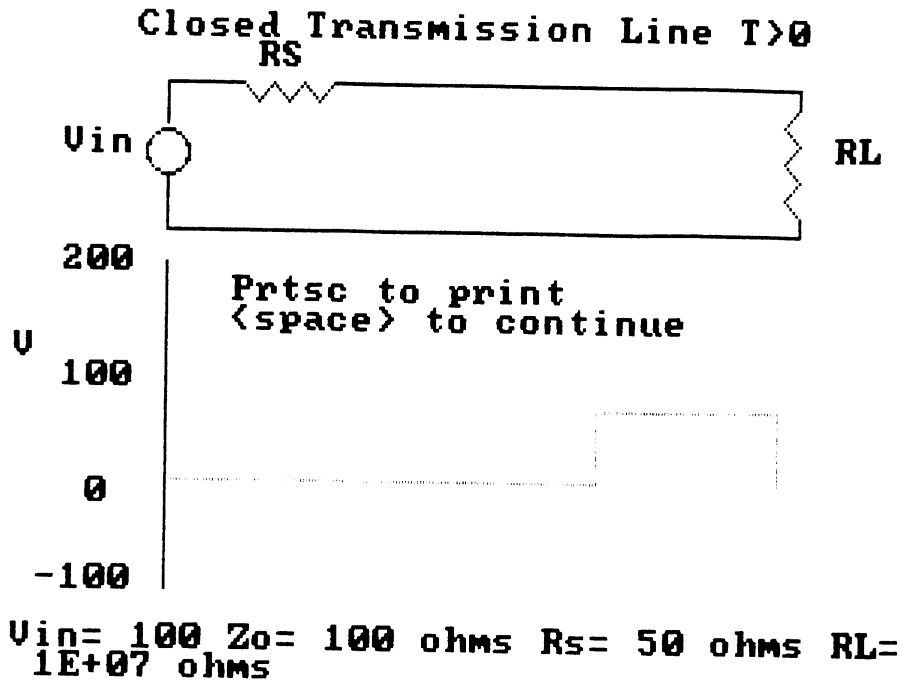
Messages are often displayed on the screen for copying to a printer. These can be treated as reminders. Actually, the user can print the screen at any time by punching shift-Prtsc. The program waits until printing is complete.

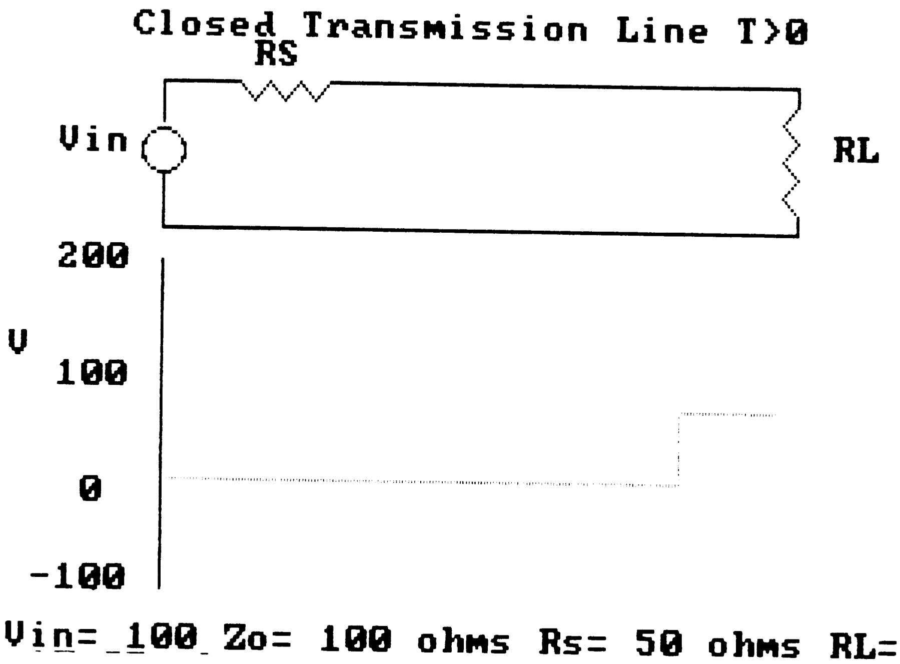
Example Output Displays



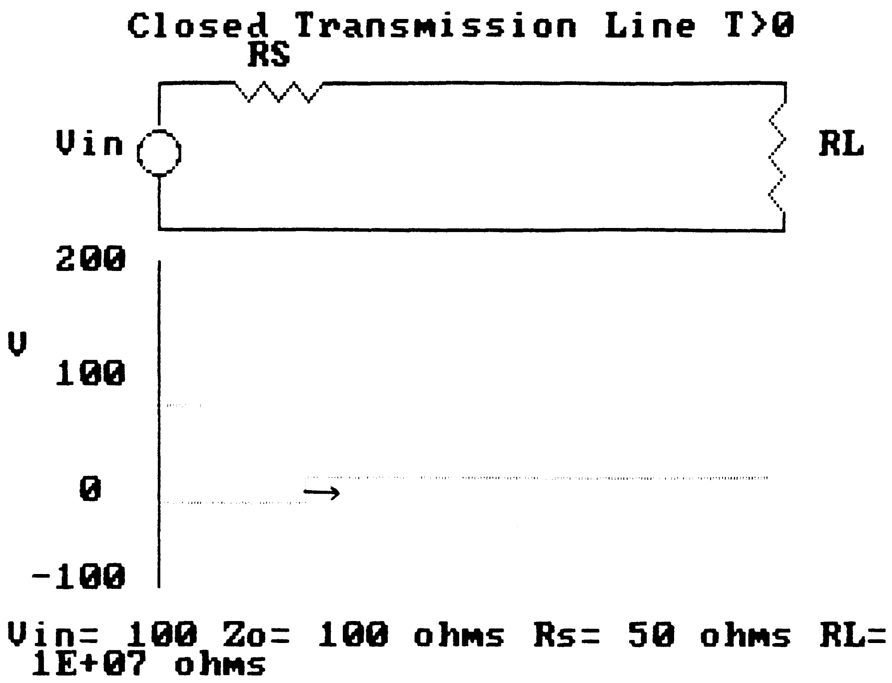


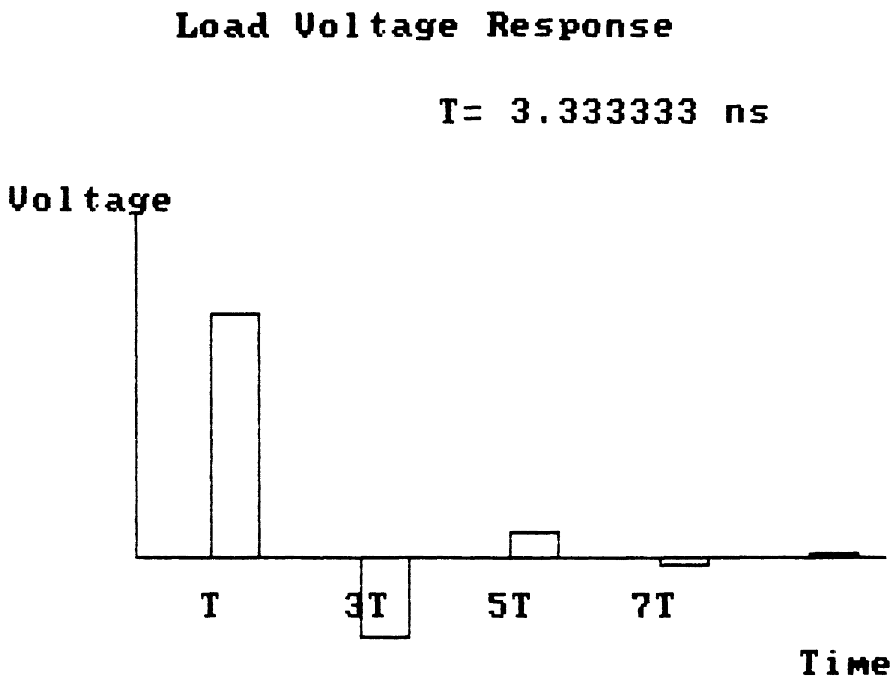
Voltage Step Applied on a Transmission Line Terminated on a Resistive Load



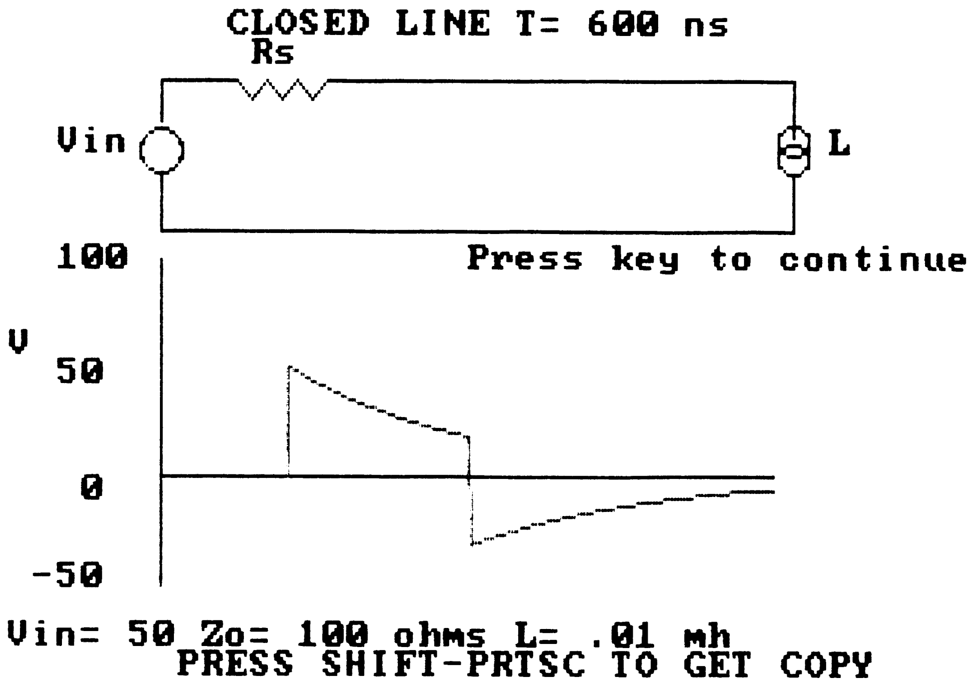


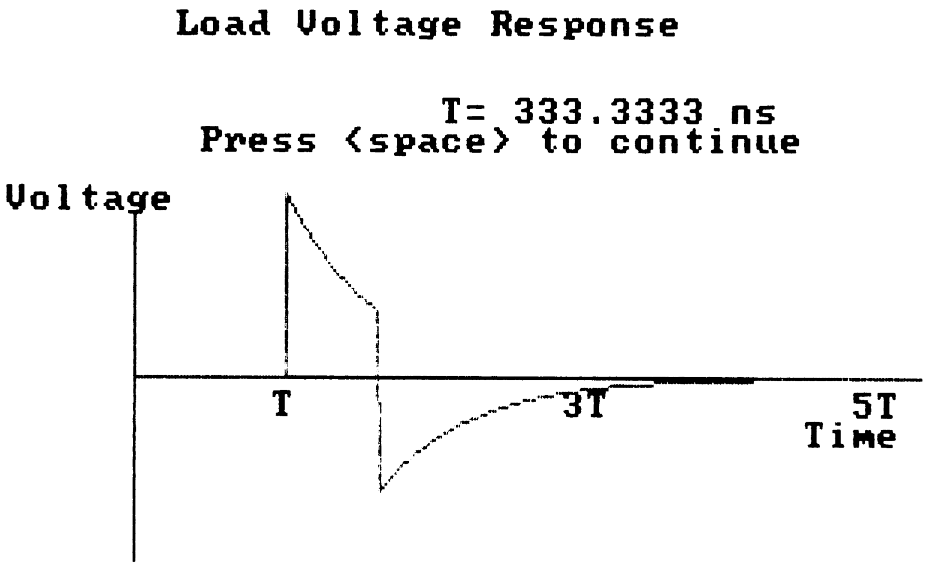
Pulse Reflecting of Load



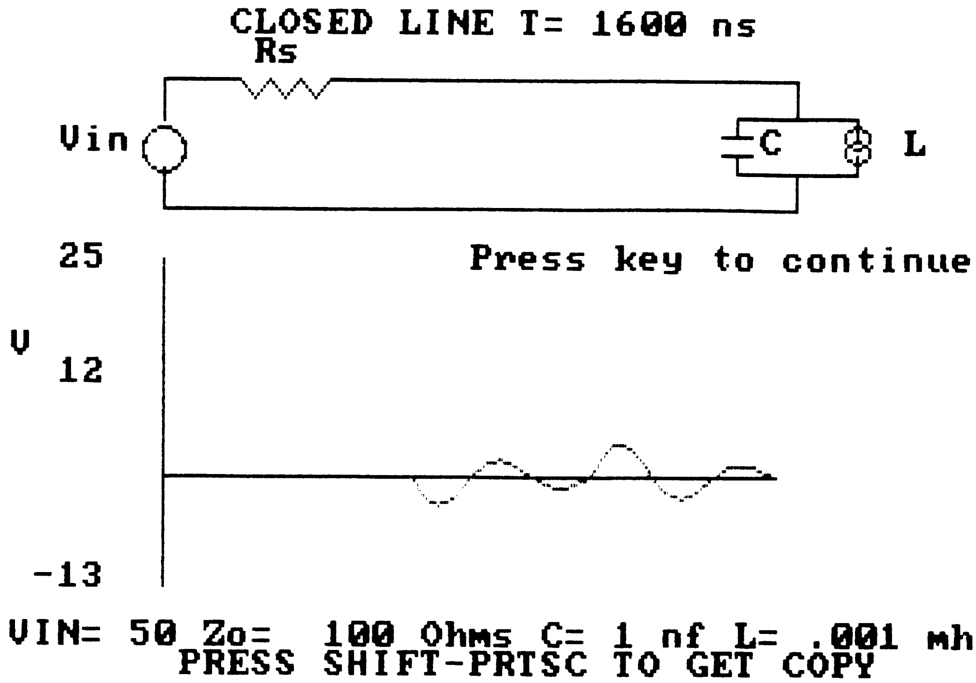


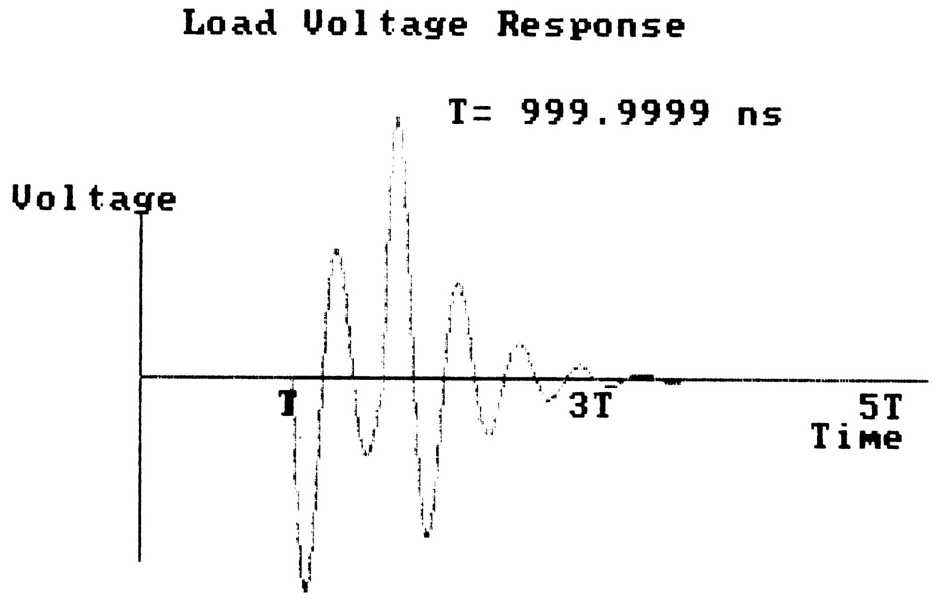
Pulse Reflecting at Generator



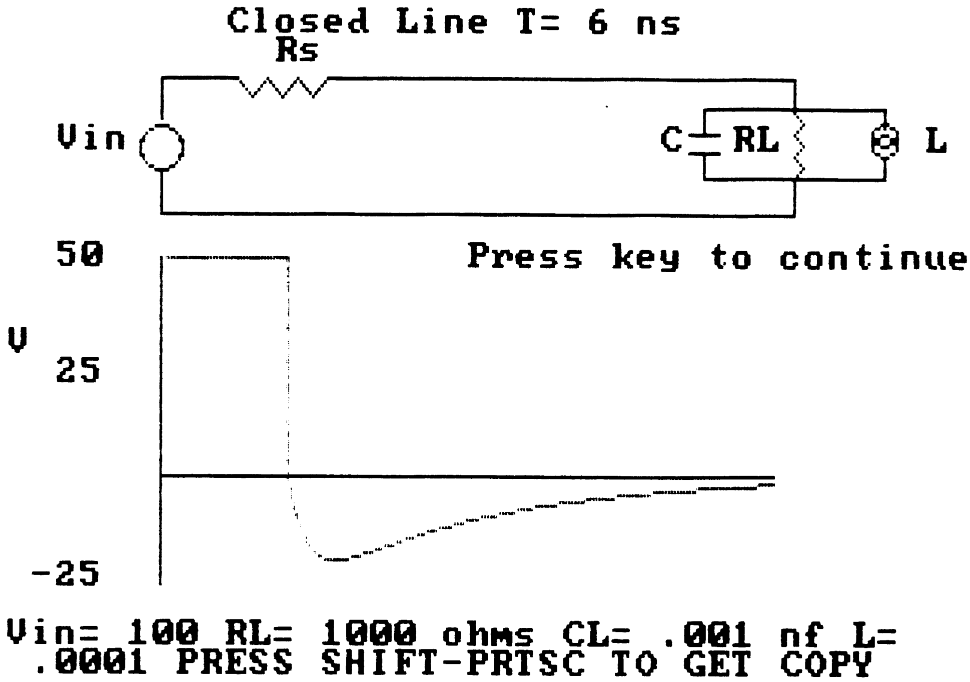


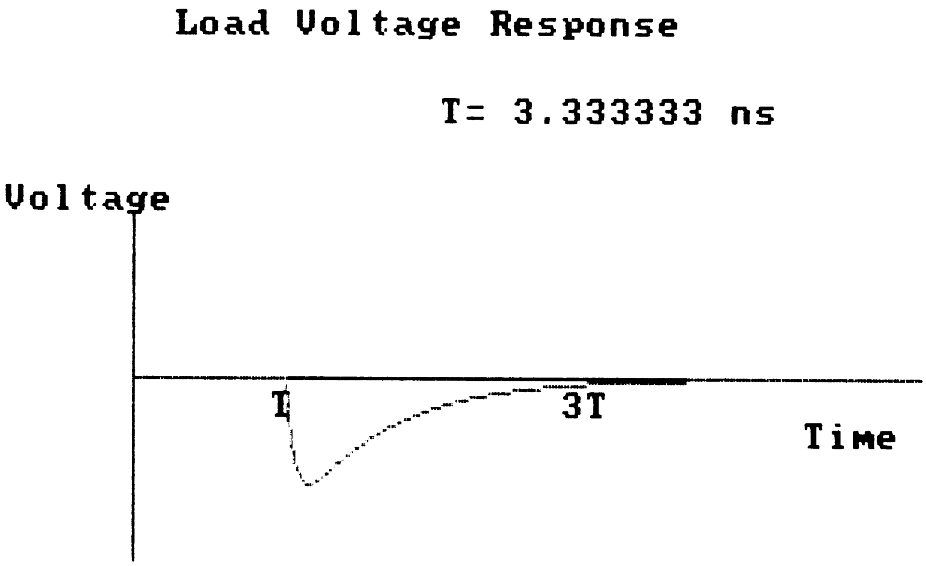
Voltage Pulse Applied to Inductively Loaded Line



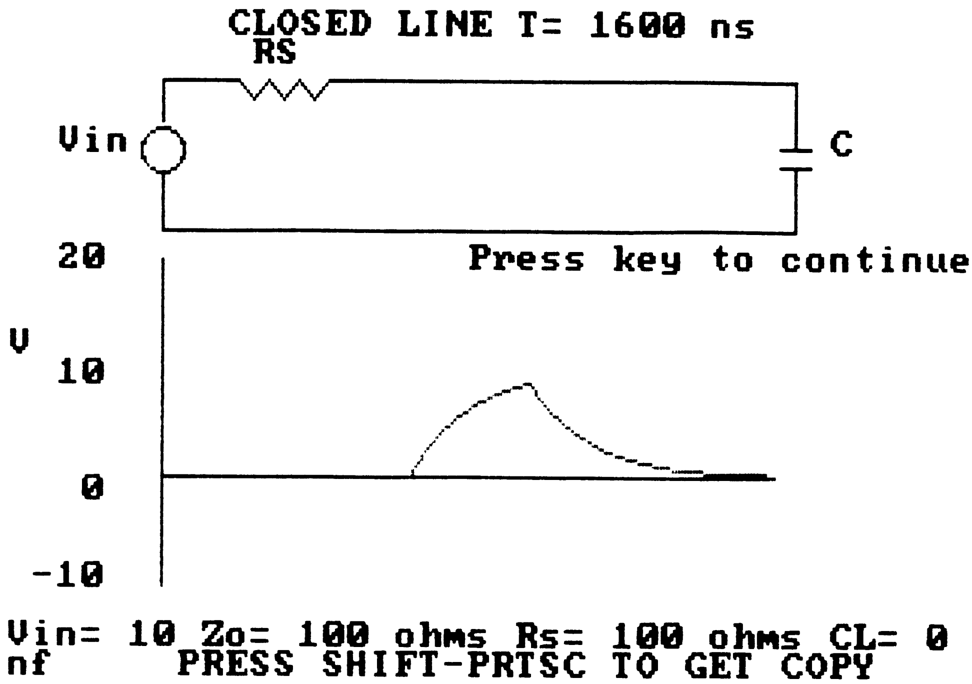


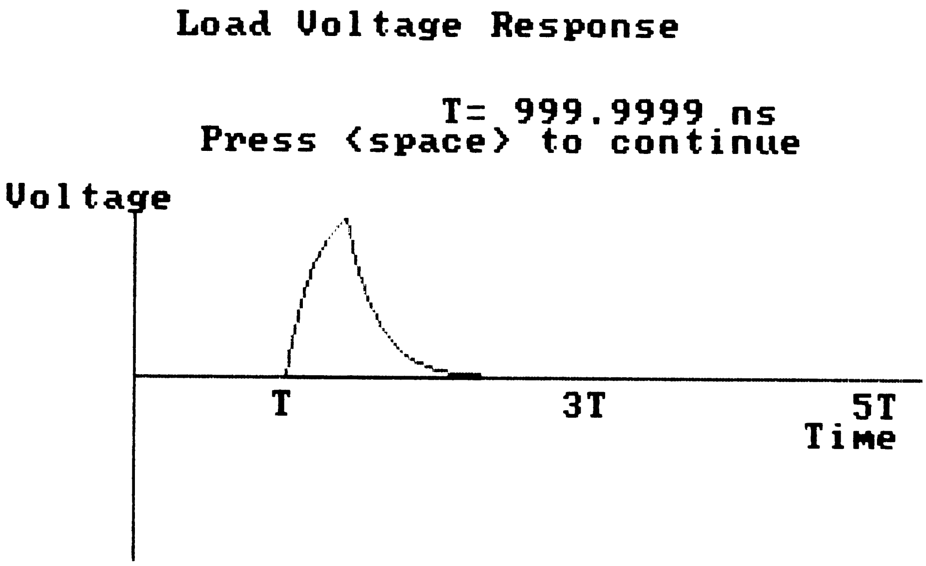
Voltage Pulse Applied to LC Loaded Line



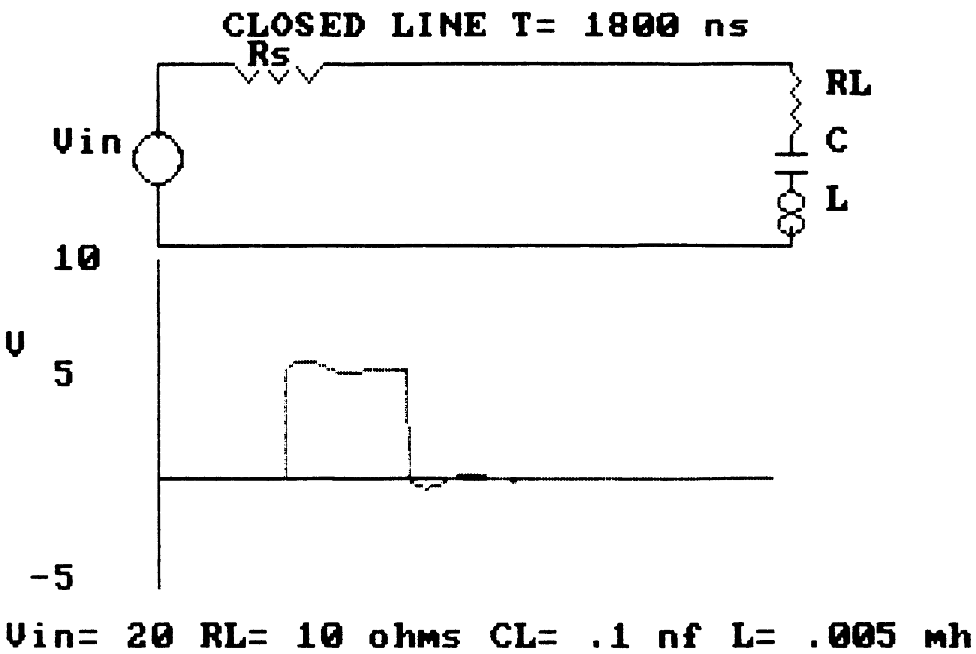


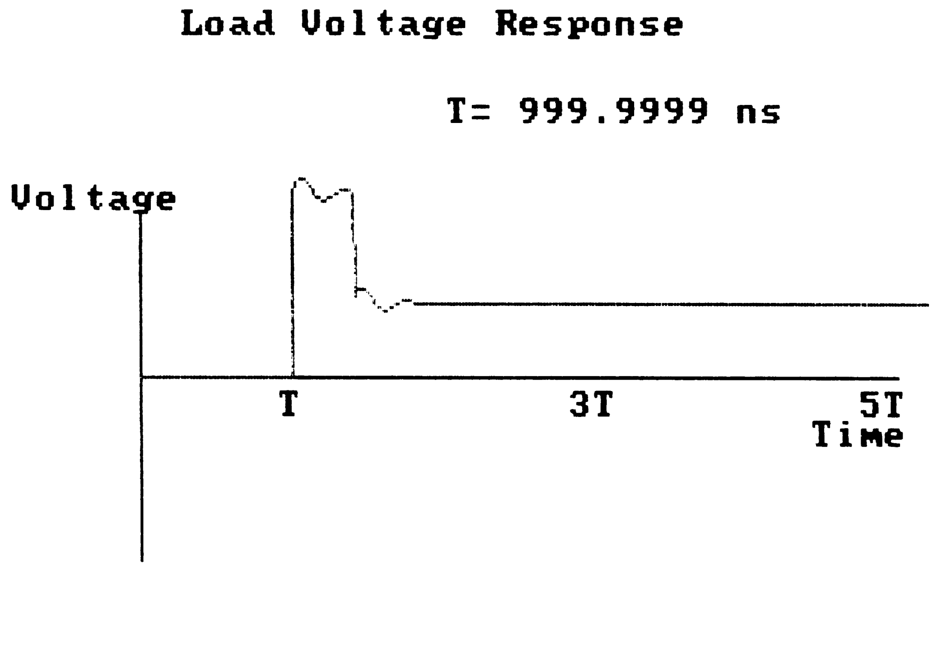
Voltage Step Applied to a RLC Parallel Loaded Transmission Line





Voltage Pulse Applied to a Capacitely Loaded Line





RLC Series Configuration with Applied Voltage Step

APPENDIX A-THEORY

In developing this program all Transmission lines are considered lossless, and the velocity of propagation is equal to the speed of light. For the resistive load case the source resistance can be chosen different from the characteristic impedance of the line; for all other cases, the source resistance is assumed to match the line.

1) Incident Voltage

When a step or pulse is transmitted on a transmission line the incident voltage is given by the voltage divider between the source resistance and the characteristic impedance of the line.

$$V_{inc} = V_{in} \left(\frac{Z_0}{Z_0 + R_s} \right)$$

2) Resistive Load

When the incident pulse reaches the load a portion is reflected back towards the generator given by the equation.

$$V_R = \rho V_{inc} \text{ where } \rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

The resistively loaded case may have an unmatched source resistance. Then, the reflected voltage from the source will be.

$$V_{Rg} = \rho_g V_R \text{ where } \rho_g = \frac{R_s - Z_0}{R_s + Z_0}$$

3) **Capacitive Load**

The reflected voltage from a capacitive load is.

$$V_R = V_{inc} \left(1 - 2 \exp(-t/CZ_0)\right)$$

and the load voltage is:

$$V_L = V_{inc} + V_R = 2 V_{inc}\left(1 - \exp(-t/CZ_0)\right)$$

4) **Inductive Load**

The reflected voltage is:

$$V_R = V_{inc} \left(-1 + 2 \exp(-tZ_0/L)\right)$$

and the load voltage is

$$V_L = V_{inc} + V_R = 2 \exp(-tZ_0/L)$$

5) **LC Parallel Load**

$$V_R = V_{inc} \left\{-1- \frac{\exp(-t/2Z_0C)}{\sqrt{\frac{4Z_0^2C}{L} -1}} \sin\left(\sqrt{\frac{4Z_0^2C}{L} -1} \; \frac{t}{2Z_0C}\right)\right\}$$

if

$$2Z_0\sqrt{C/L} \geq 1$$

or

$$V_R = V_{inc}\left\{-1-\frac{1}{\sqrt{1-\frac{4Z_0^2C}{L}}}\ \sinh\left(\sqrt{1-\frac{4Z_0^2C}{L}}\ \frac{t}{2Z_0C}\right)\right\}$$

$$2Z_0\sqrt{C/L} \leq 1$$

<u>RLC Load</u>

$$V_R(t) = V_{inc}\cdot u(t)\left\{-1-\left(\frac{R}{Z_0+R}\right)\frac{\exp\left(-\frac{1}{2CR}\,\frac{Z_0+R}{Z_0}\,t\right)}{\sqrt{\frac{4CR^2}{L}\left(\frac{Z_0}{Z_0+R}\right)^2-1}}\right.$$

$$\left.\sin\left(\frac{t}{2CR}\left(\frac{Z_0+R}{Z_0}\right)\sqrt{\frac{4CR^2}{L}\left(\frac{Z_0}{Z_0+R}\right)^2-1}\right)\right\}$$

if

$$\frac{2RZ_0}{Z_0+R}\sqrt{C/L} \geq 1$$

or

$$V_R(t) = V_{inc}\,u(t)\left\{-1-\left(\frac{R}{Z_0+R}\right)\frac{\exp\left(-\frac{1}{2CR}\,\frac{Z_0+R}{Z_0}\,t\right)}{\sqrt{1-\frac{4CR^2}{L}\left(\frac{Z_0}{Z_0+R}\right)^2}}\right.$$

$$\left.\sinh\left(\frac{t}{2CR}\left(\frac{Z_0+R}{Z_0}\right)\sqrt{1-\frac{4CR^2}{L}\left(\frac{Z_0}{Z_0+R}\right)^2}\right)\right\}$$

$$\frac{2RZ_0}{Z_0+R}\sqrt{C/L} \leq 1$$

Series RLC

$$V_R(t) = u(t)V_{inc} \left\{ 1 + \left(\frac{Z_0}{Z_0 + R} \right) \frac{\exp\left(\frac{-Z_0 + R}{2L} t \right)}{\sqrt{\frac{4L}{C(Z_0 + R)^2} - 1}} \sin\left(\frac{Z_0 + R}{2L} t \sqrt{\frac{4L}{C(Z_0 + R)^2} - 1} \right) \right\}$$

if $\frac{2}{Z_0 + R} \sqrt{L/C} > 1$

or

$$V_R(t) = u(t)V_{inc} \left\{ 1 + \left(\frac{Z_0}{Z_0 + R} \right) \frac{\exp\left(\frac{-Z_0 + R}{2L} t \right)}{\sqrt{1 - \frac{4L}{C(Z_0 + R)^2}}} \sinh\left(\frac{Z_0 + R}{2L} t \sqrt{1 - \frac{4L}{C(Z_0 + R)^2}} \right) \right\}$$

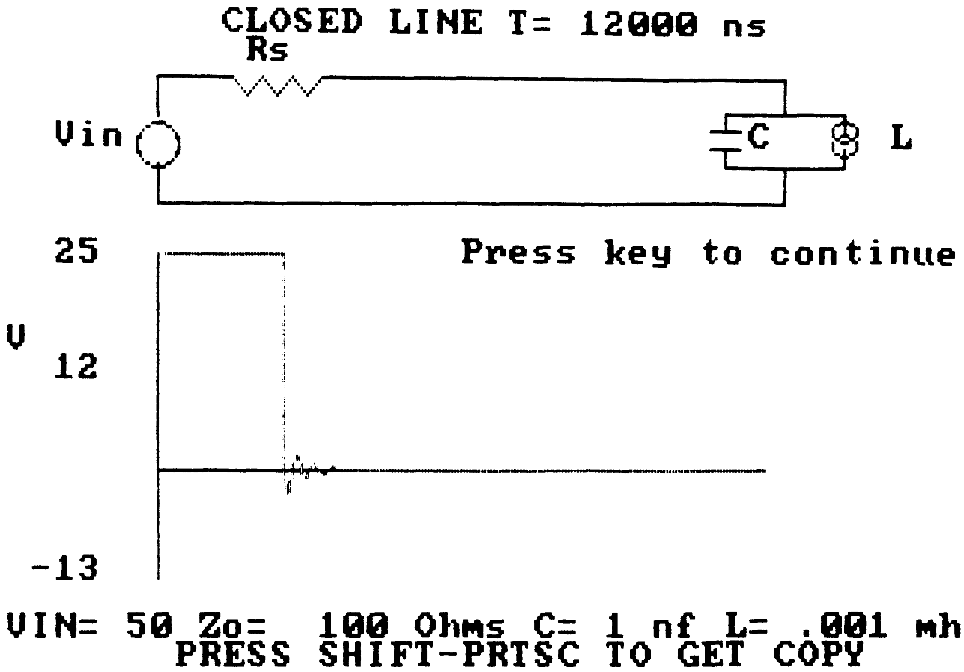
if $\frac{2}{Z_0 + R} \sqrt{L/C} < 1$

Responses to pulses

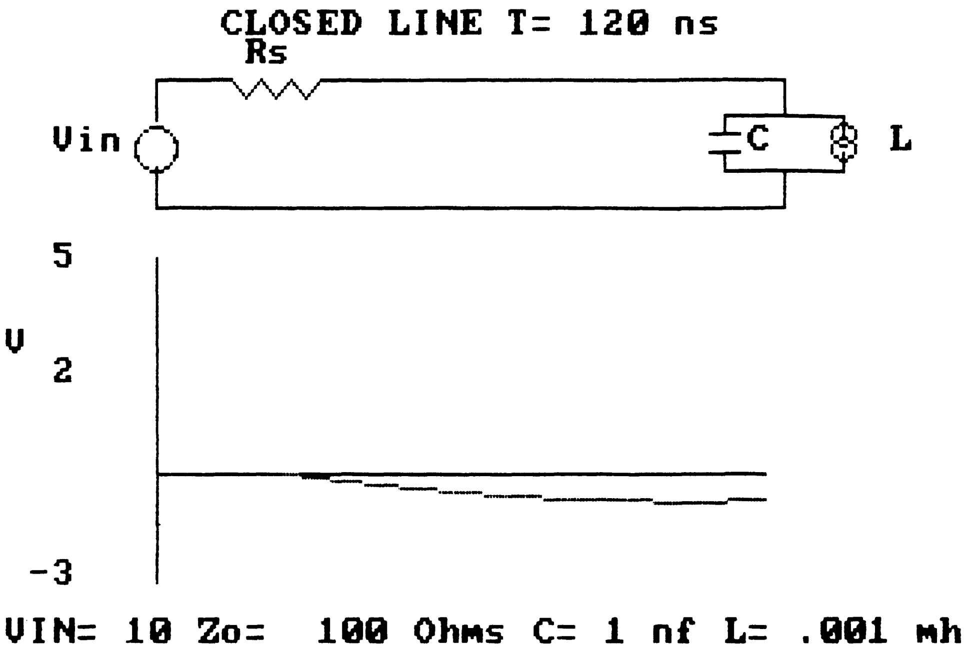
assume u(t)V(t) is any of the responses to a step above. The response to a pulse is:

$$V_R(t) = u(t)V(t) - u(t-\tau)V(t-\tau)$$

where τ is the pulse width of the incident pulse.


CLOSED LINE T= 12000 ns
Rs
Vin
C
L
25
Press key to continue
V
12
-13
VIN= 50 Zo= 100 Ohms C= 1 nf L= .001 mh
PRESS SHIFT-PRTSC TO GET COPY

A.1


CLOSED LINE T= 120 ns
Rs
Vin
C
L
5
V
2
-3
VIN= 10 Zo= 100 Ohms C= 1 nf L= .001 mh

A.2

APPENDIX B - CHOOSING PROGRAM PARAMETERS AND TROUBLESHOOTING.

A degree of care must be taken in the choice of program parameters to give meaningful results. Due to the limits of the program's graphics, the student is advised to do some preparation. Reasonable guidlines are given below. This section will conclude with some suggestions on troubleshooting confusing results.

1) **Resistive Load**

The simple resistive load can be simulated with no preparation. Some easily remembered guidlines are:

a) Never use a pulse longer than the time it takes to traverse the line.

$$PW < Length/3 \times 10^8$$

b) For larger incident voltages make $Z_0 > R_S$.

2) **Capacitive Load**

Make the time constant $1/Z_0C$ comparable to the time a pulse traverses the line in

$$Z_0C \sim L/3 \times 10^8 \text{ m/s.}$$

For example with $Z_0 = 100\ \Omega$

$$C \sim {}^{L(meters)}/_{3} \times 10^{10}$$

3) **Inductive Load**

As above, make the time constant Z_0/L comparable to the transit time.

$$L(INC)/Z_0 \sim L^{(m)}/3 \times 10^8 m/s$$

Again with $Z_0 = 100$.

$$L(INC) \sim L^{(meter)}/3 \times 10^6$$

4) **LC Load**

The quantatity $2Z_0C$ should be comparable to the time it takes to reverse the line.

And:

$$\cdot\, 1 < \frac{4Z_0^2C}{L} < 10$$

With $Z_0 = 100$

$$C \sim L(m)/6 \times 10^{10} \text{ and } L \sim C \cdot 4 \times 10^4$$

5) **Parallel RLC**

In this case, $2CR_L \times \frac{Z_0}{Z_0 + R_L}$ should be comparable to the transit time of the line.

and:

$$.1 < \frac{4CR_L^2}{L} \left(\frac{Z_0}{Z_0 + R_L} \right)^2 < 10$$

if $Z_0 = R_L \sim 100\ \Omega$

Then

$$C \sim \frac{L(\text{meters})}{3 \times 10^{10}}$$

$$L \cong C \times 1 \times 10^4$$

Series RLC

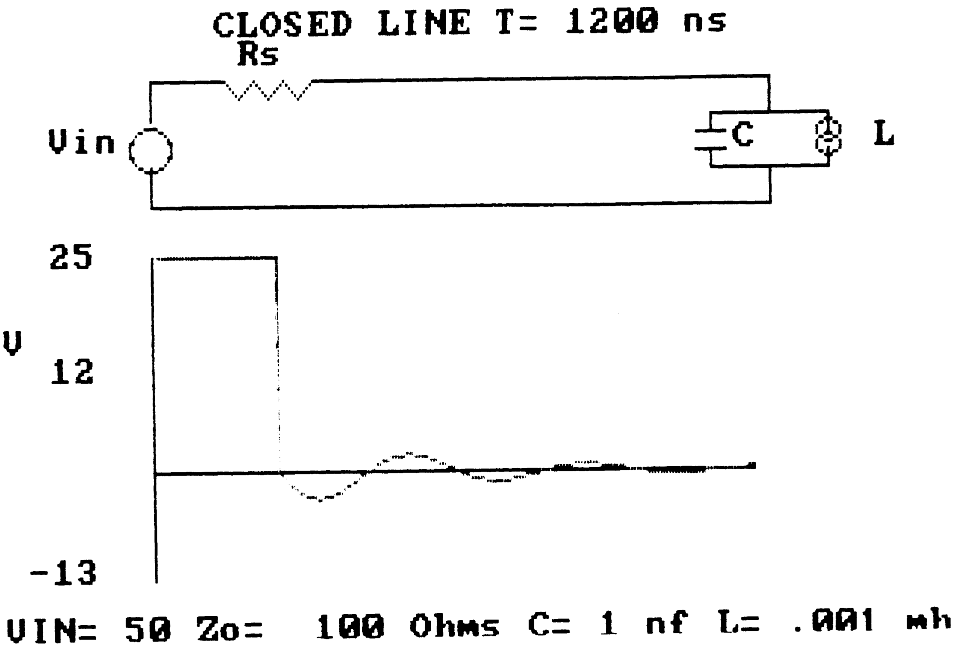
For this load, $2L/(Z_0+R_L)$ should be chosen comparable to the transit time of the line, and:

$$.1 < \frac{4L}{C(Z_0 + R_L)^2} < 10$$

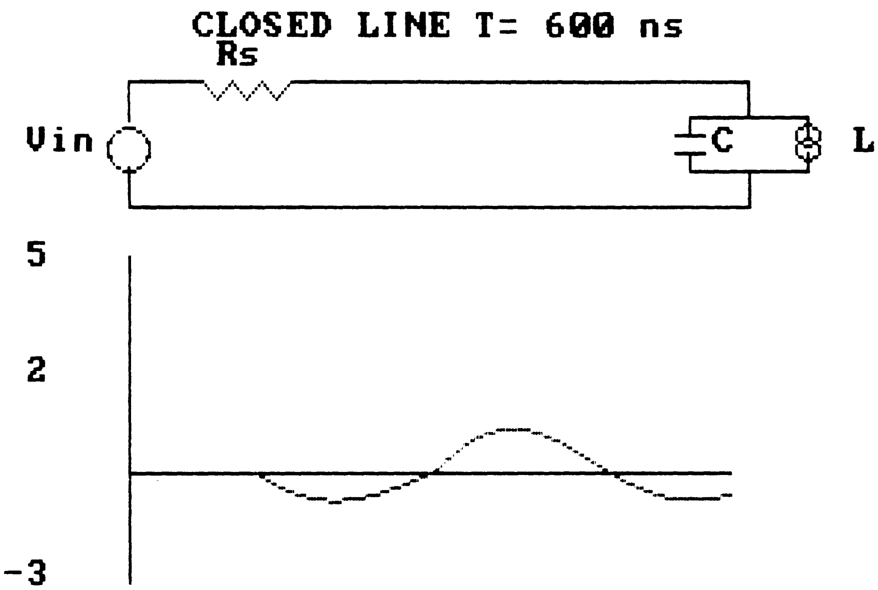
If $Z_0 = R_L \sim 100\ \Omega$

$$L(\text{INC}) = \frac{L(\text{meters})}{3 \times 10^6}$$

$$C \sim L \times 10^{-4}$$


CLOSED LINE T= 1200 ns
Rs
Vin
C
L
25
V
12
-13
VIN= 50 Zo= 100 Ohms C= 1 nf L= .001 mh

B.1


CLOSED LINE T= 600 ns
Rs
Vin
C
L
5
V
2
-3

B.2

TROUBLESHOOTING

1) If a very large source resistance is used with a open or shorted load, the simulation may run for a very long time. If this occurs you can CTRL-Break and then rerun the program.

2) If in a simulation (L,C,LC,RLC) too long a line is used for the other parameters diagram A.1 may result.

To correct simply rerun again with a shorter line and do not change other parameters as shown in B.1.

3) If too short a line is used A.2 may result. Rerun again with a longer line and do not change other parameters (B.2).