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Radio Frequency Circuits Laboratory

Excercise 5
Simulation of Long Lines with *Travis* Software

Aim of the exercise

The aim of this exercise is to examine the electromagnetic wave propagation in the transmission lines using TRAVIS software. You should also become acquainted with the basic rules for designing different types of the transmission lines and analyzing their transmission properties for different kinds of impedance loads.

Transmission lines – background information

Transmission line consists of two parallel conductors held apart at a fixed distance by insulators or by insulation. It is used to transfer electrical energy, e.g. output rf energy. The types of transmission lines used for transmitting rf signals are presented in figure 3. The dielectric material is marked in green. It is a mechanical component of the transmission line and has influence on the line's electrical properties.
Transmission line can be approximated by a distributed-parameter network provided the length of the transmission line is comparable with the wavelength of the transmitted signal through this line. The conductors of such transmission line can be characterized by: distributed resistance (Ω/m), distributed inductance (H/m) and distributed capacitance (F/m). In low frequencies (hundred of hertz) the reactance of the transmission line can be omitted. However, as the frequency increases, the reactance values must be taken into consideration. Moreover, the time needed for the transmitted wave to reach the end of the line increases and becomes the large part of the input signal period (the propagation time can be longer than the signal's period).
The transmission line with distributed parameters is called the *long line*. This name is related to the wave character of the electromagnetic phenomena which must be included when describing the propagation of the signal in the transmission line. For the frequency of few GHz the wavelength is equal to several centimeters, therefore the length of the transmission line is given in units of the transmitted signal wavelength.
One of the most important parameters characterizing the electrical properties of a transmission lines *characteristic impedance*. Assuming the distributed resistance of the line is much smaller than the reactance of the line, the characteristic impedance is given by the formula:

$$Z_0 = \sqrt{\frac{L}{C}} \qquad [\Omega]$$

where:
L – unit inductance of the transmission line;
C – unit capacitance of the transmission line;

Inductance L and capacitance C can be measured directly. The ratio of L to C is comparable to the load resistance of the line necessary to avoid the reflections of the wave transmitted through the line. If this condition is not fulfilled, the mismatching impedance can cause the generation of unwanted currents and voltages traveling along the transmission line in both directions. These currents and voltages can cause power losses and distortions of the transmitted signal.

In practice three kinds of losses may occur in transmission lines for rf signals (even if we have the impedance matching):

- losses in the conductor resulting in heat generation from current flow;
- losses in the dielectric resulting in heating the isolator;
- radiation and induction losses resulting from transmitting power from the line to the neighboring cables, or power radiated to the environment.

As a result the transmitted signal is suppressed. The suppression determines the power loss in the transmission line and is measured in dB per unit length.

<u>TRAVIS – quick start</u>

TRAVIS is an electronic circuit simulation program designed to allow visualization of propagating waveforms as they travel along the transmission lines. It works in Windows environment and allows full flexibility and ease in creating analyses that contain the transmission lines of interest.

1. Start TRAVIS.
2. Pull down the "File" menu and select "Open Project". The Open File dialog box appears. Select the file "example1.pro" and click the "OK" button. The scheme of the electrical circuit will appear in the Main Circuit Window. The circuit consists of transient voltage source V1 of the pulse shape, transmission line T1 with characteristic impedance Z_0=50Ω connected in series with resistor R1=25Ω. The load impedance for this circuit is the resistor R2=1kΩ. The voltage on the resistor R2 is the input signal for the circuit.

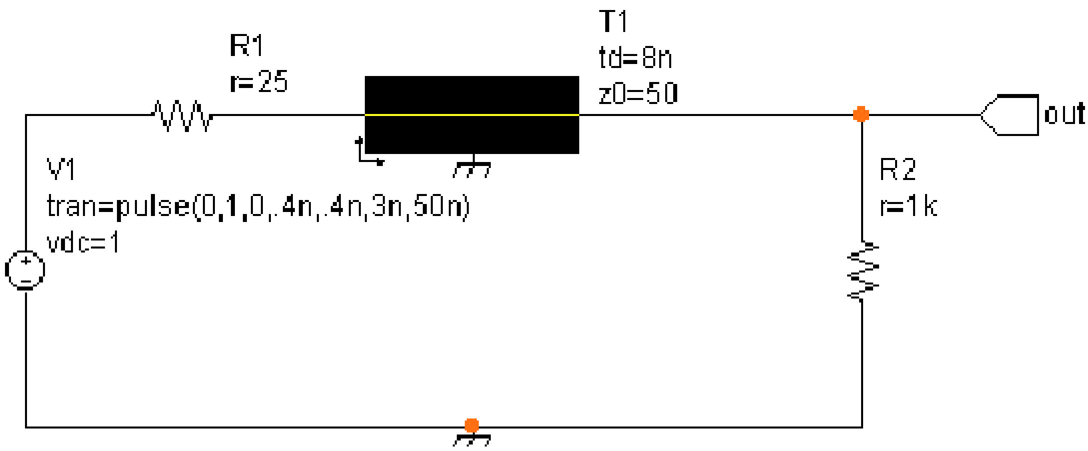

Figure 1 Electrical circuit containing the transmission line.

Description of the transient pulse voltage source: "tran=pulse(iv,pv,td,tr,tf,pd,T)" where:
iv – initial value;
pv – pulsed value;
td – delay time;
tr – rise time;
tf – fall time;
pd – pulse duration;
T – period;
Graphical transient pulse definition is presented in figure 2.

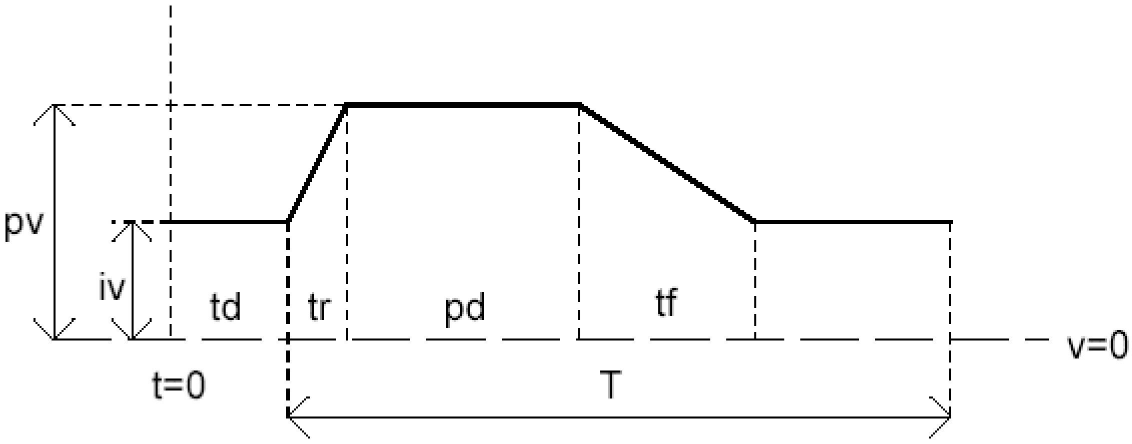

Figure 2 Transient Pulse Definition.

Transmission line parameters: “td” – propagation length, which specifies the length of the transmission line in seconds (must be greater than zero); “Z_0” – characteristic impedance of the transmission line in ohms (must be greater than zero).

3. Pull down the “analysis” menu and select “Run Transient Analysis”. The analysis Status dialog box pops up showing the progress of the analysis. When the analysis is complete, click “OK” button.
4. Position the mouse pointer over the wire connecting to the right-hand side of the transmission line in the circuit (it has the node marker “out” attached to it). Push down left mouse button. A small menu pops up; select “v(out)” and release the mouse button. A transient plot pops up with the voltage waveform from that wire. Notice how distorted the waveform looks due to reflections on the transmission line ($R2 \neq Z_0$).
5. Pull down the “See Results” menu and select “stick All Plots on Top”. This will cause the plot to stick on the top of the schematic. Pull down the “See Results” menu again and select “Use Active Plot” and “Stick All Plots on Top”. This will cause any more waveforms that you plot to be sent to the waveform plot that is already open.
6. Move and resize the plot window so that it does not obscure the circuit in the circuit window. Pull down “See Results” menu and select “Animate Transient Animation Plots”. The Animation Control dialog box pops up. Press “Play” button in the Animation Control dialog box. The voltage waveform within the transmission line starts animating. Also notice that an “X” marker is moving along the waveform in the plot window corresponding to voltage versus time on that node. When you are finished looking at the animation results, close the Animation Control dialog box by clicking the “Done” button.
7. Position the mouse pointer over the circuit window and click the right mouse button until the status text in the upper left corner of the circuit window says “Edit Circuit” (this mode allows for changing the values characterizing any component of the circuit).
8. Position the mouse pointer over the resistor “R2” in the circuit and click the left mouse button. The Edit Component dialog box pops up for the resistor.
9. In the parameter field, the resistor parameters are listed, among them “r=1k”. Change this to “r=50” and click the “OK” button of the dialog box. This will properly terminate the transmission line.
10. Repeat steps 3 and 4. Now there are two waveforms in the plot.

11. Pull down the “See results” menu and select “Animate Transient Animation Plots”. The Animation Control dialog box pops up. Press the play” button again. Now notice that the waveform has no reflections ($R2=Z_0$).

Examined circuit can be extended using commands form the “Place” menu. You will find there the list of primitive components that can be placed in the circuit: wire, resistor, capacitor, inductor, voltage source, current source, transmission line, etc.
You can delete any of the components by selecting “Cut Whatever is Touched” from the “Edit” menu. In order to undo an action, select the “Undo” item from the same “Edit” menu.
To save current project to disc, select the “Save project” (without changing the project’s name) of the “Save Project as” item (when you want to change the project’s name) from the “File” menu.

Designing the transmission line

TRAVIS contains a Transmission Line Designer tool that allows you to see a graphical representation of a transmission line’s cross section. The Transmission Line Designer also features the ability to calculate any transmission line parameter given the others. Four different types of transmission lines are supported: microstrip, stripline, coaxial and twin lead. They are presented in figure 3. Table 1 contains characteristic impedance equations for different types of transmission lines.

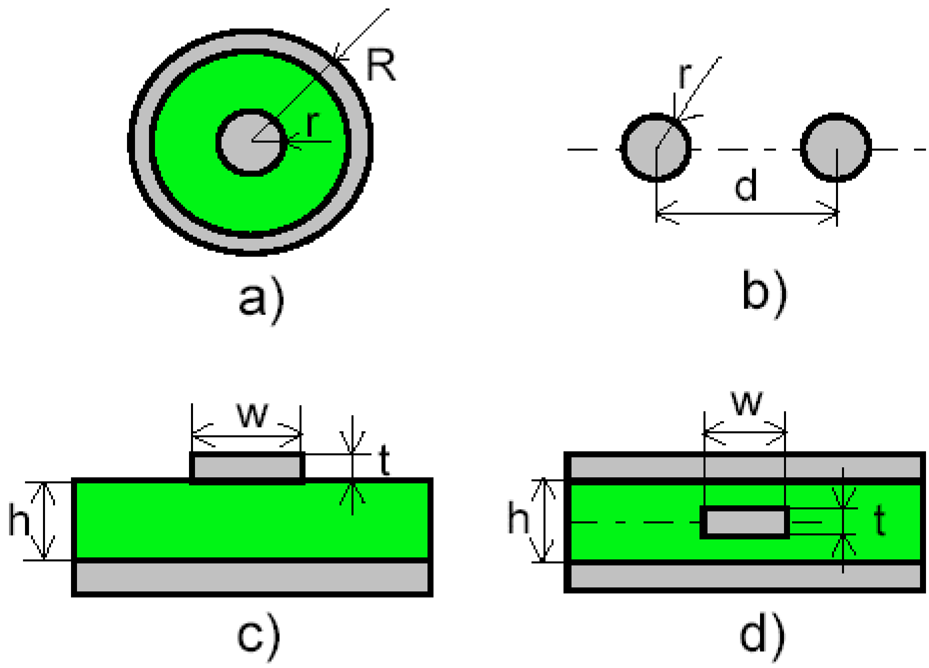

Figure 3 Cross sections of diffenert types of transmission lines: a) coaxial cable, b) twin lead line, c) microstrip line, d) stripline.

Table 1

Type of the transmission line	Characteristic impedance equation $Z_0[\Omega]$	Approximation conditions
Coaxial	$60\ln\frac{R}{r}$	-
Twin lead	$120\ln\frac{d}{r}$	$\frac{d}{r} > 5$
Microstrip	$120\pi\frac{\frac{h}{w}}{1+\frac{2h}{\pi w}\left(1+\ln\frac{\pi w}{h}\right)}$	$t << w$
Stripline	$60\pi\ln\frac{2h}{\sqrt{\pi w t}}$	$\frac{w}{h-t} < 0{,}4$

Let us examine the parameters of the transmission line form project “example1.pro”.

1. Load “example1.pro”
2. Select ”Transmission Line Info” item from the “Edit” menu. The status text will display “Click t-line for T-line Designer”. While in this mode, click left mouse button over the transmission line whose cross section you want to examine.

The “Transmissionline Designer” window, containing the cross section of the transmission line and its dimensions, is displayed. In our case the transmission line is of the coaxial type. The dimensions are given in units defined in the “Length Units” filed (mils=0.001inch, 1 inch≈25.4mm). At the top of the window is the characteristic impedance (Z_0) and a message display. Note that the Z_0 displayed hare correctly corresponds to the cross section drawing only after performing a calculation by selecting one of the items from the “Calculate” menu (except for the “Plot” item).
Transmission line dimensions can be edited by clicking on the picture of the transmission line. A dialog box will pop up with the parameters that can be edited (figure 4).

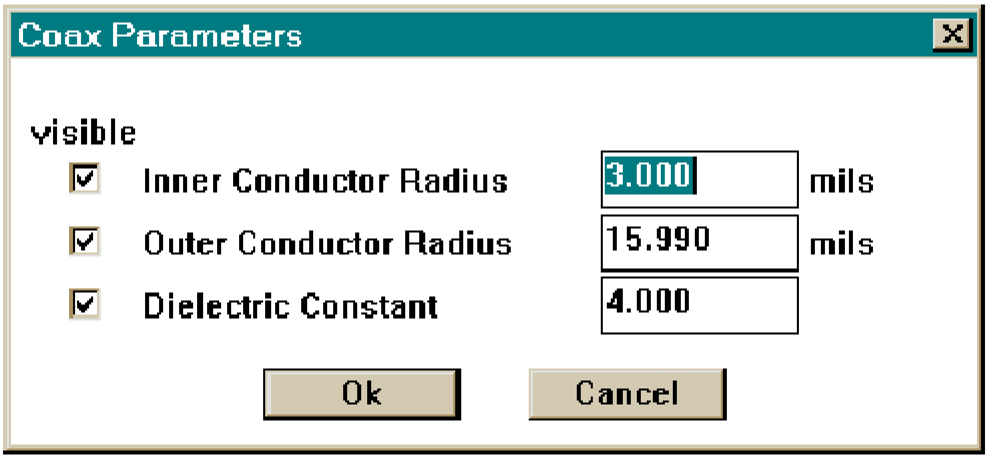

Figure 4 Coaxial Parameter dialog box

For defined dimensions of the transmission line, the characteristic impedance will be calculated when “Z_0” item is selected from the “Calculate” menu. Similarly, changing the Z_0 value (e.g. 75Ω), you can calculate the corresponding values of remaining three parameters, e.g. relative dielectric constant of the insulator by selecting “er” item from the “Calculate” menu.

To make a plot of one transmission line parameter versus another (with the other parameters held constant), select the “Plot” menu item from the “Calculate” menu. A dialog box pops up with three regions. The top two regions are Horizontal Axis and Vertical Axis. In the bottom region (Horizontal Axis Limits) you choose the range of the horizontal axis variable and the number of points to calculate within the range. Clicking the “Run Plot” button causes a plot window to pop up with the information requested.

Measurement procedure

I. Designing different types of transmission lines

1. You are given the stripline (fig. 3d) with the following parameters: height of the insulator h=13.8mils, relative dielectric constant of the insulator er=4.0F/m, thickness of the conductor t=3.0 mils. Using TRAVIS software find the width of the conductor (w=?) such that the characteristic impedance of the transmission line is equal to Z_0=50Ω. Plot the dependence of the characteristic impedance versus the width of the conductor using appropriate TRAVIS tools.

2. You are given the coaxial transmission line (fig. 3a) with the following parameters: characteristic impedance Z_0=50Ω, and the diameter of the outer conductor 2R=13.8 mils. What is the dielectric constant of the of the insulator used in this transmission line? What should be the value of the dielectric constant for the same dimensions of this transmission line to get the characteristic impedance equal to Z_0=75Ω? Plot the dependence of the characteristic impedance versus the geometric parameters of the transmission line using appropriate TRAVIS tools.

3. Compare the characteristic impedance values for all four types of the transmission line from fig. 3 calculated from the equations given in Table I, and values of Z_0 obtained using TRAVIS software, provided that the air is the insulator.

II. Examining the transmission line for different impedance loads.

Using TRAVIS software, design the electrical circuits presented in figures 5, 6 and 7. The transmission line is of the coaxial type, the characteristic impedance Z_0=50Ω, and the delay time td=250ns. The load is:

a) mismatching resistance (fig. 5)
b) capacitive load (fig. 6)
c) inductive load (fig. 7)

Design the electrical circuits with transmission line:

d) ended with open-circuit
e) ended with short-circuit
f) matching resistance load

For all cases perform the simulation of the propagating waveforms as they travel along the transmission line using TRAVIS software. Observe the input and output voltage waveform. In the report include the printouts of the obtained plots and explain their shape.

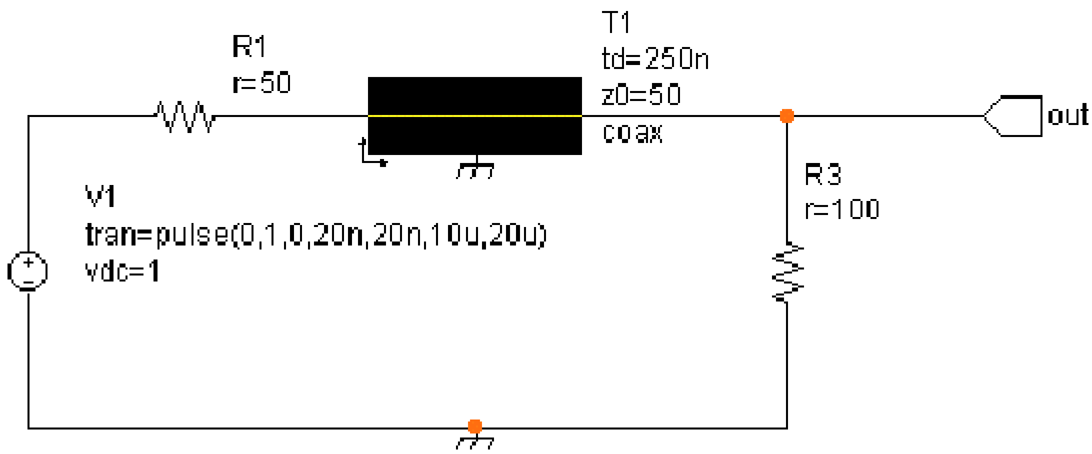

Figure 5 Transmission line with mismatching resistive load.

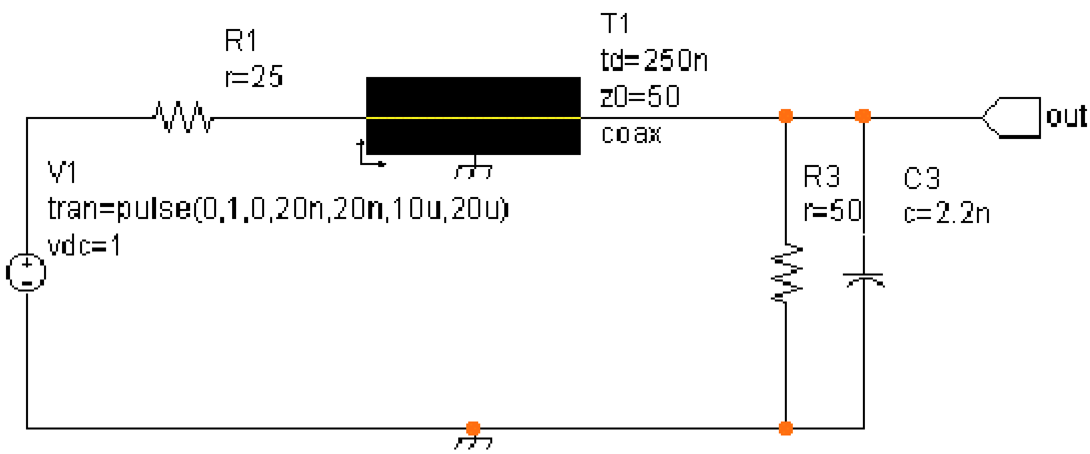

Figure 6 Transmission line with capacitive load.

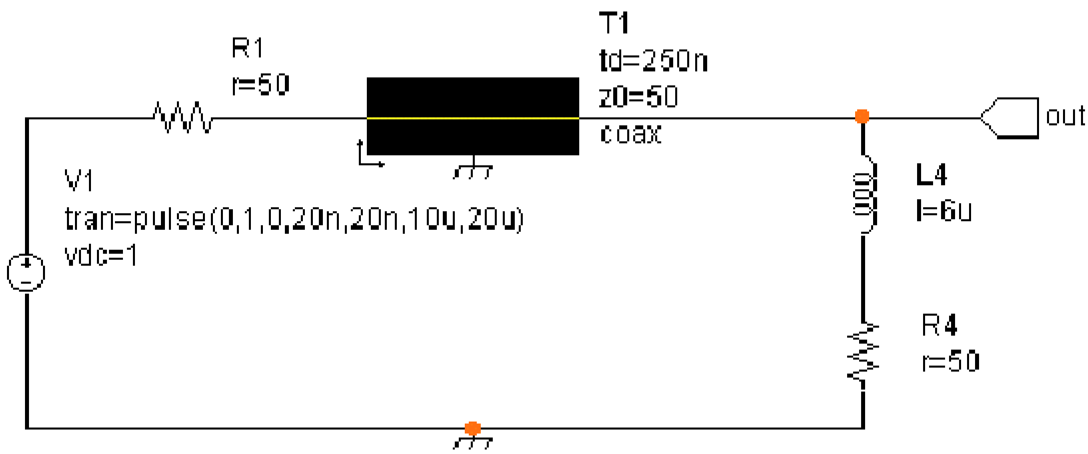

Figure 7 Transmission line with inductive load.