STANDING WAVES

Objective: To demonstrate the effect of different types of termination.

a) Line terminated in characteristics impedance (Matched termination)

b) Line terminated in short

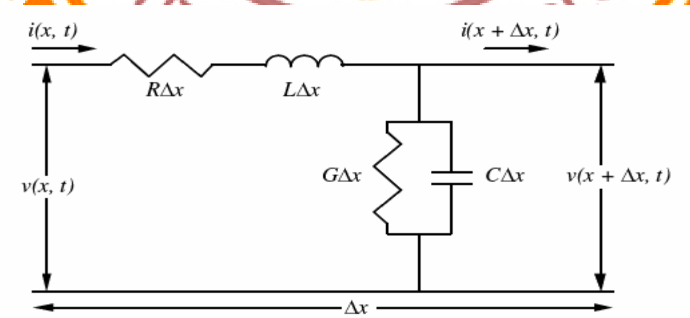
c) Line terminated in an open

List of Equipment:

1. Transmission Line Demonstrator (TLD)
2. Sine-wave generator
3. Load
4. Oscilloscope (CRO)

Theory:

In the microwave frequency region, power is considered to be in electric and magnetic fields that are guided from place to place by some physical structure. Any physical structure that will guide an electromagnetic wave place to place is called a ***Transmission Line.*** At low frequencies, the circuit elements are lumped since voltage and current waves affect the entire circuit at the same time. At microwave frequencies the circuit must be broken down into unit sections within which the circuit elements are considered to be lumped.



Distributed Element Model of a Transmission Line

Figure 1

L, R are the distributed inductance and resistance (per unit length) of the conductor.

C, G are the distributed capacitance and conductance (per unit length) of the dielectric between the conductors.

Relation between instantaneous voltage v and current i at any point along the line

$$\frac{\partial i}{\partial x} = -Gv - C\frac{\partial v}{\partial t} \tag{1}$$

$$\frac{\partial v}{\partial x} = -Ri - L\frac{\partial i}{\partial t} \tag{2}$$

phasors of voltage V and current I

$$\frac{\partial V}{\partial x} = -(R + j\omega L)I \tag{3}$$

$$\frac{\partial I}{\partial x} = -(G + j\omega C)V \tag{4}$$

The propagation constant, γ is a complex number and given by

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{5}$$

$$= \alpha + j\beta \tag{6}$$

α is the attenuation constant, β is the phase constant.

The general solutions of the second-order, linear differential equation for V, I are:

$$V = V^{+}e^{-\gamma x} + V^{-}e^{+\gamma x} \tag{7}$$

$$I = I^{+}e^{-\gamma x} + I^{-}e^{+\gamma x} \tag{8}$$

V^{+}, V^{-}, I^{+}, I^{-} are constants (complex phasors). The terms containing $e^{-\gamma x}$ represent waves travelling in +z direction, terms containing $e^{+\gamma x}$ represent waves travelling in -z direction. Since

$$e^{-\gamma x} = e^{-\alpha x}\, e^{-j\beta x} \tag{9}$$

α determines the attenuation along the line, and β determines the phase shift along the line. Characteristics impedance Z_0 is given by

$$\frac{V^{+}}{I^{+}} = Z_0 \qquad \frac{V^{-}}{I^{-}} = -Z_0 \tag{10}$$

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{11}$$

Consider a transmission line of length l terminated by an arbitrary impedance Z_L. At the load z = 0, the voltage and current phasors can be written as:

$$V(0) = V^{+} + V^{-} \tag{12}$$

$$I(0) = \frac{1}{Z_0}(V^{+} + V^{-}) \tag{13}$$

Load impedance Z_L=V(0)/I(0), so we can express the ratio of the backward to forward voltages as:

$$\Gamma_L = \frac{V^-}{V^+} = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{14}$$

Γ_L is called the load reflection coefficient if we consider V^+ as the incident wave and V^- as the reflected wave.

Line terminated in its characteristic impedance: If the end of the transmission line is terminated in a resistor equal in value to the characteristic impedance of the line as calculated by eqn 14, then the voltage and current are compatible. All the power sent down the line is absorbed at the termination and no reflections occur.

Line terminated in a short: When the end of the transmission line is terminated in a short (R_L = 0), the voltage at the short must be equal to the product of the current and the resistance. The value of reflection coefficient is -1 as calculated by eqn 14 and standing wave will be formed.

Line terminated in an open: When the line is terminated in an open, the resistance between the open ends of the line must be infinite. Thus the current at the open end is zero. The value of reflection coefficient is 1 as calculated by eqn 14 and standing wave will be obtained.

Procedure:

Initial Control Settings

1. Use Hold/ run button to 'run'.
2. Change the electrical length by using the control to 8L.
3. Attenuation should be minimum.
4. The generator frequency should be set, preferably on a range allowing continuous variation between 0.5 and 2 Hz.

Pulse Propagation

1. Operate the switch for 'step input to A' briefly: the switch should be released after light has appeared in the second column.
2. A pulse, two columns wide, will then travel to the B end of the line and disappear.

Line terminated in its Characteristic Impedance

1. Terminate the line with 600 ohm terminator which is equivalent to its characterstics impedance (as shown in fig 2).
2. Now operate the 'step input to A' switch until the second column of the display lights, sending a short pulse along the line.
3. Note that the pulse is absorbed in this termination. Because characteristic impedance absorb the whole energy of the wave and no reflection is there. Hence no standing wave will form.

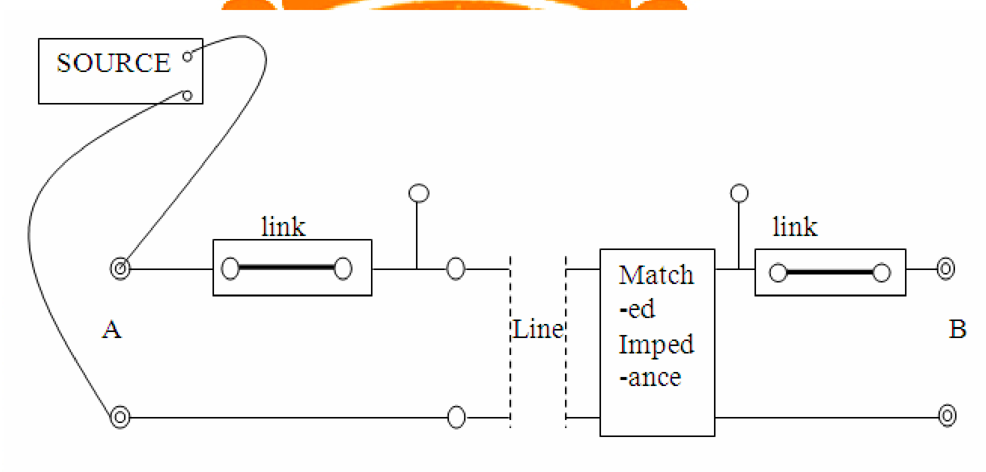


Figure 2. The line terminated in its characteristics impedance

Line terminated in open

1. Do not terminate the line with any kind of loads. Keep it open as shown in fig 3.
2. Operate the step input switch in the direction to A, just long enough to light up the second column of the display, and then release it. This will generate a reflected wave and thus standing wave pattern will form.

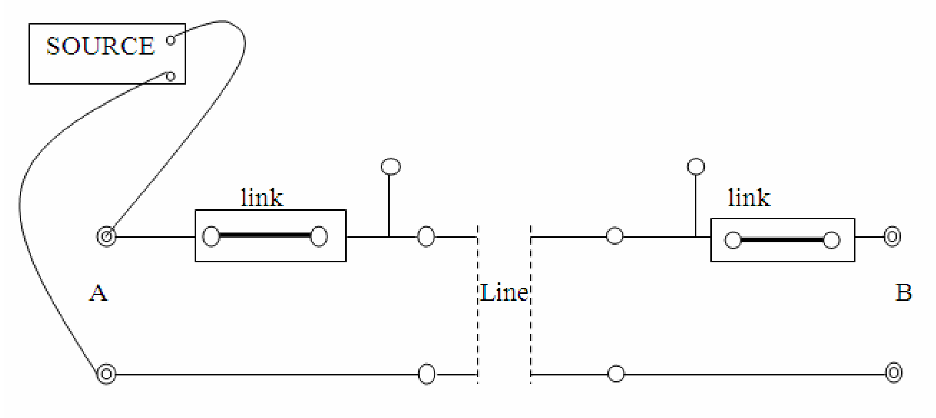


Figure 3. The line terminated in an open

Line terminated in short

1. Put a short in the other end of line as shown in fig 4.
2. Operate the step input switch in the direction to A, just long enough to light up the second column of the display, and then release it. The reflected current wave will interfere with forward current wave and form standing wave pattern.

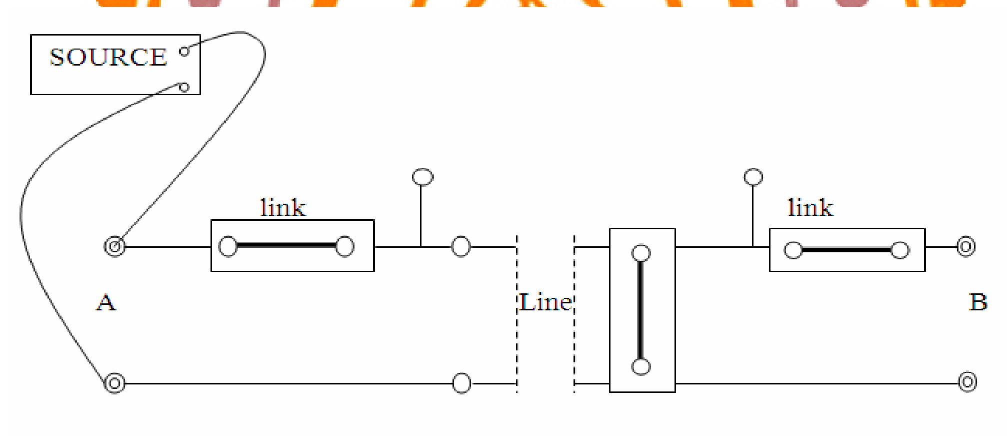


Figure 4. The line terminated in a short

Discussions:

1. What will happen if we apply a load different form matched?
2. Why the reflections occur if the line is terminated in an open?
3. How do you explain the maximum amplitude in terms of the reflection coefficient found previously?

References:

1. E.C. Jordan and K.G.Balmain, ‘Electromagnetic wave Radiating Systems’ 1968.
2. A.W. Cross, ‘Experimental Microwaves’, 1977.
3. Mathew N. O. Sadiku, “Elements of Electromagnetics”, Oxford University Press, 2001.