RF and Microwave Transmission Lines

ELEC 2230

Section 4

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Reflections on a transmission line

A practical transmission line will never be perfectly uniform, nor always be terminated in its characteristic impedance.

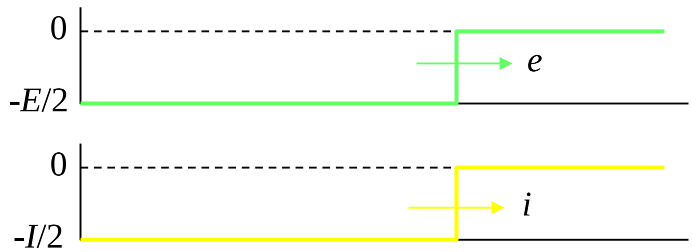
When the line is not terminated in Z_0 the incident energy is not absorbed but is returned along the only path available - the transmission line.

We'll start by looking at the behaviour of a d.c. pulse at the open circuit end of a transmission line.

Reflection of a d.c. pulse at an open circuit

Assumptions:

- **Lossless line**
- **Matched source (hence $E/2$ appears across line)**
- **Termination perfect open circuit ($Z_L = \infty$)**



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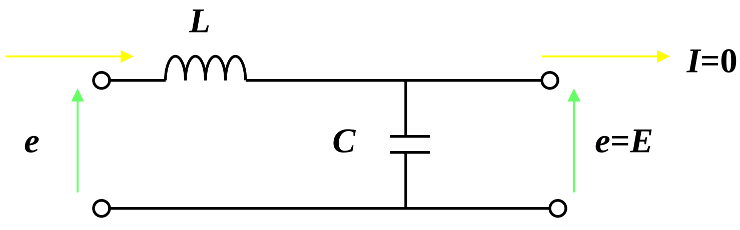
Reflection of a d.c. pulse at an open circuit

When the last C is charged to $E/2$, no voltage across L, hence current flow stops, magnetic field in last L collapses resulting in more current to charge last C. Since energy in magnetic field equals energy in C, the voltage across C doubles.



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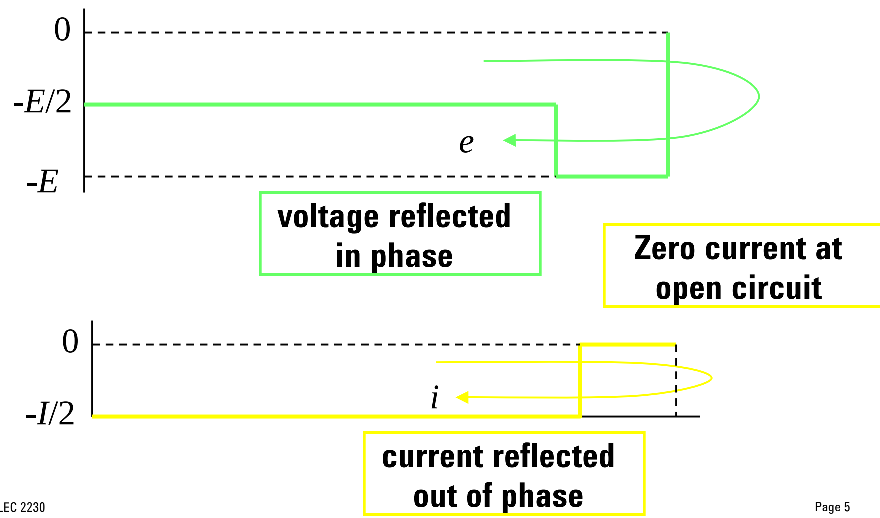
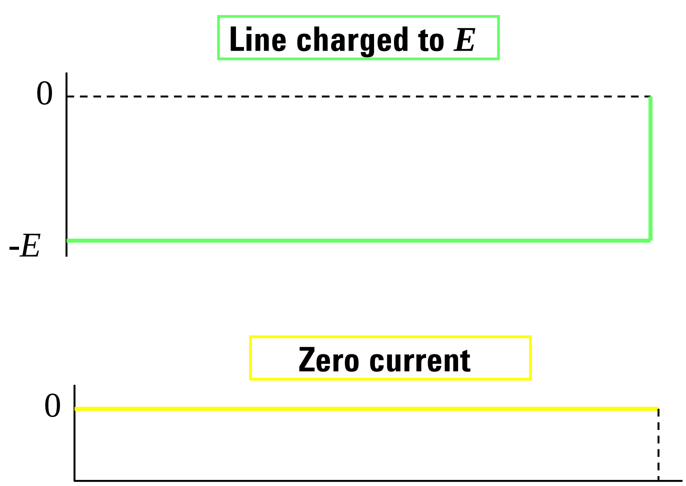
Reflection of a d.c. pulse at an open circuit



Reflection of a d.c. pulse at an open circuit

Steady state



Reflection of a d.c. pulse at an open circuit

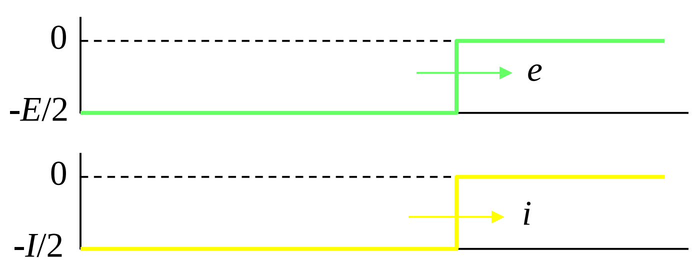
Voltage is reflected without change in polarity, amplitude or shape

Current is reflected with opposite polarity and without change in amplitude or shape

Reflection of a d.c. pulse at a short circuit

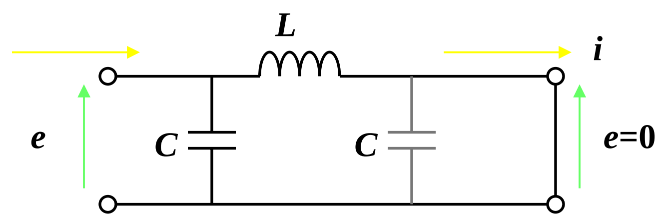
Assumptions:

- **Lossless line**
- **Matched source (hence $E/2$ appears across line)**
- **Termination perfect open circuit (Z_L = 0)**

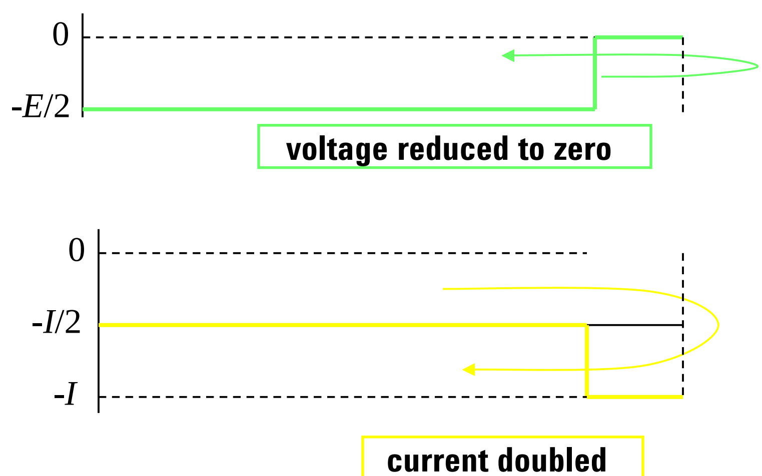


Reflection of a d.c. pulse at a short circuit

There is no last *C* to be charged, so current through last *L* produces voltage of opposite polarity. When the magnetic field in last *L* collapses, current flows into *C* in the opposite direction resulting in *C* discharging to zero. With no voltage to support the current through the next-to-last *L*, this discharges the next-to-last *C*.



Reflection of a d.c. pulse at an open circuit

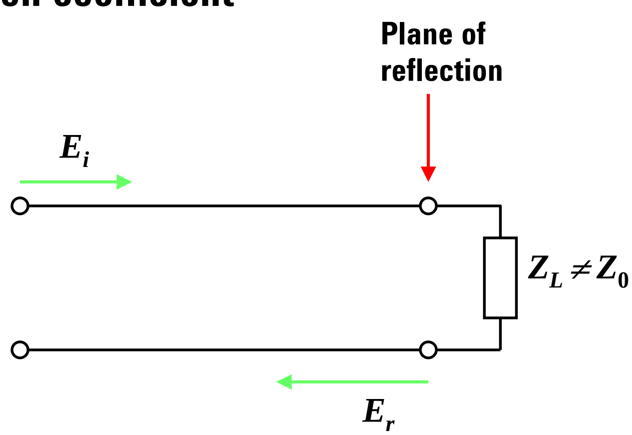


Reflection of a d.c. pulse at an open circuit

Voltage is reflected with opposite polarity and without change in amplitude or shape

Current is reflected without change in polarity, amplitude or shape

Reflection coefficient



$$\frac{E_r}{E_i} = \Gamma$$

Reflection coefficient

The reflection coefficient Γ is a vector (magnitude and phase)

Incident and reflected waves travel on the transmission line in opposite directions

The magnitude depends only on how much the terminating impedance is mismatched

Relative phases are dependent on the terminating impedance and the distance from the termination to the point of measurement

Reflection coefficient

Absolute value of reflection coefficient

$$\left|\frac{E_r}{E_i}\right| = |\Gamma| = \rho$$

Used as figure of merit for termination

Will always be <1 for passive termination

Standing waves

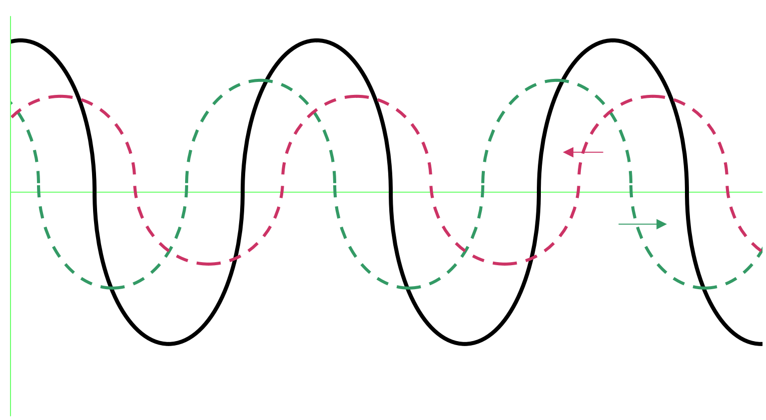
Two waves of the same amplitude and frequency travelling in opposite directions on a transmission line will alternately add and subtract, resulting in a standing wave

The maximum and minimum voltage points do not shift with time (*cf* travelling waves)

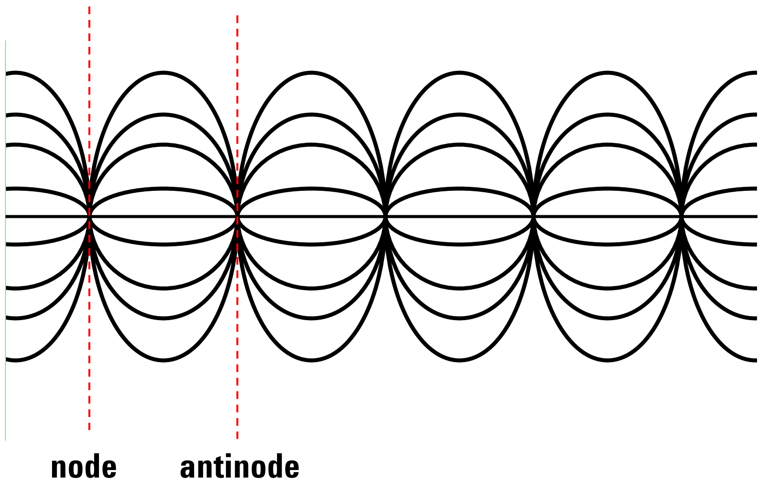
Nodes = positions of zero crossings
Antinodes = positions of maxima

Waves with same frequency (wavelength) but not necessarily same amplitude for a standing-wave pattern

Formation of standing waves

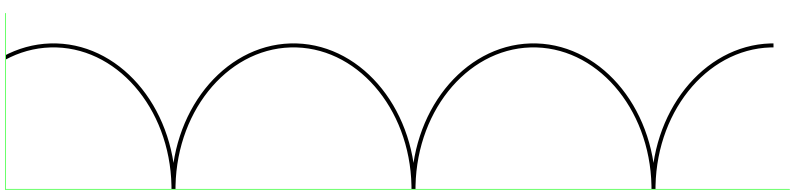


Formation of standing waves

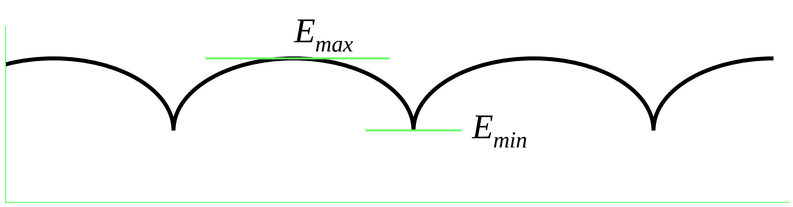


Detected standing wave pattern

Total reflection



partial reflection



Standing wave ratio

$$\text{VSWR} = \sigma = \frac{E_{\max}}{E_{\min}}$$

with

$$E_{\max} = |E_i| + |E_r|$$

$$E_{\min} = |E_i| - |E_r|$$

Standing wave ratio

$$\text{VSWR} = \sigma = \frac{E_{\max}}{E_{\min}} = \frac{|E_i| + |E_r|}{|E_i| - |E_r|}$$

$$\sigma = \frac{1 + \dfrac{|E_r|}{|E_i|}}{1 - \dfrac{|E_r|}{|E_i|}} \qquad \sigma = \frac{1+\rho}{1-\rho}$$

VSWR

$$\sigma = \frac{1+\rho}{1-\rho}$$

$$\rho = \frac{\sigma - 1}{\sigma + 1}$$

Other useful relations

Power standing-wave ratio

$$\mathrm{PSWR} = \sigma^2$$

SWR (dB)

$$\mathrm{SWR(dB)} = 20\log_{10}\sigma$$

Return loss (dB)

$$\text{Return loss(dB)} = -20\log_{10}\rho$$

Mismatch loss

How many decibels less than the incident voltage are absorbed by the termination?

e.g. Because of mismatch, how much less power is radiated from an antenna than available at the port of the antenna.

$$\text{Mismatch loss(dB)} = -10\log_{10}\left(1-\rho^2\right)$$