Clicker lecture 2 of Topic 1: Transmission line theory and waveguides

Jan 17, 2019

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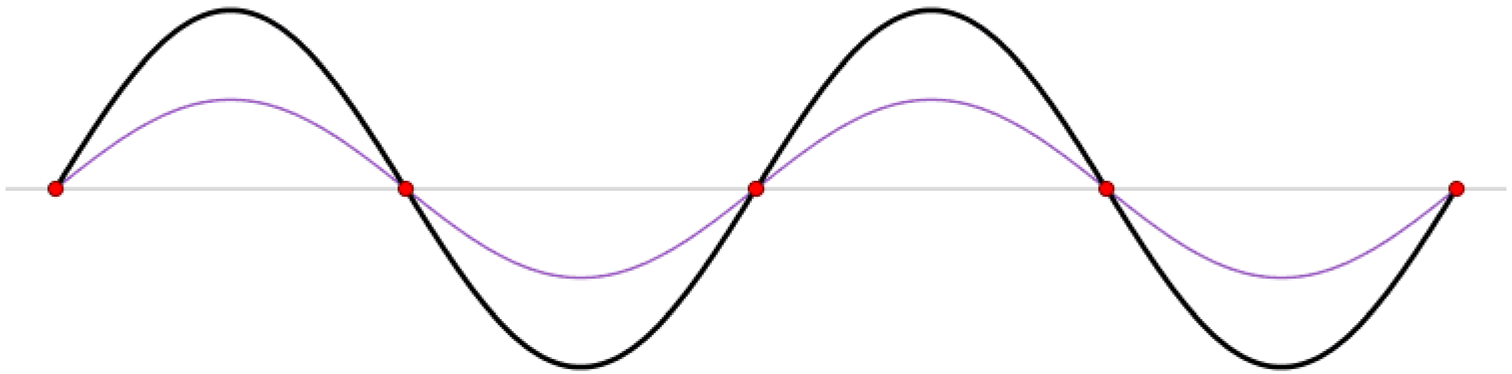
Standing wave in time domain

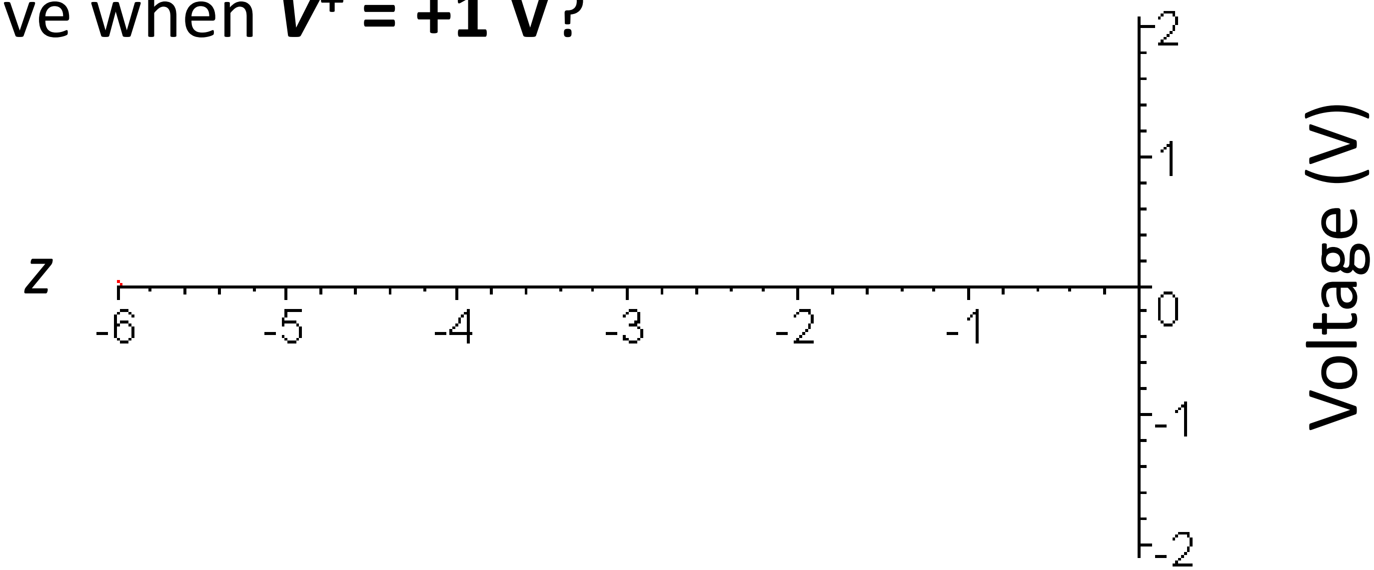


$$V(z) = V^+ e^{-j\beta z} + V^- e^{+j\beta z}$$

- Blue curve = ?
- Red curve = ?
- Black curve = ?
- Red dots = ?
- The part between the red dots = ?

- Animation Source: https://commons.wikimedia.org/wiki/File:Standing_wave.gif

Q1a. What is the voltage amplitude ***V*****-** of the **reverse** voltage wave when ***V*****+ = +1 V**?



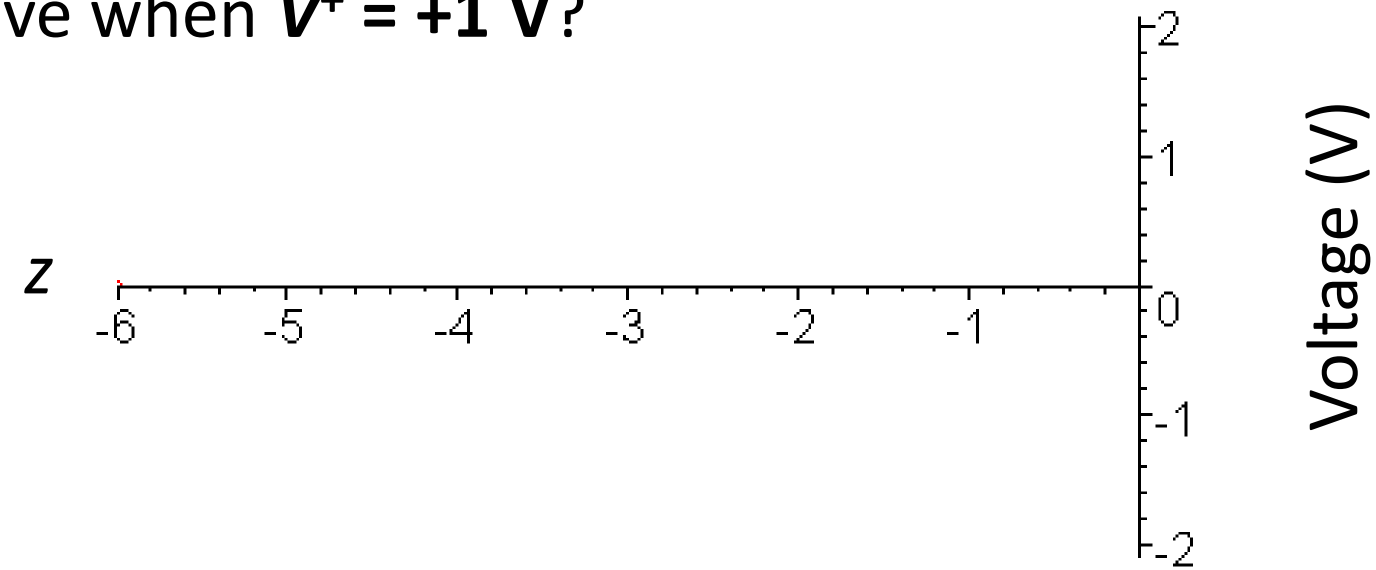
1. V- = -2 V
2. V- = -1 V
3. V- = 0 V
4. V- = +1 V
5. V- = +2 V
6. I don't know

$\boxed{+1\text{ V}}$

$$V(z) = V^+ e^{-j\beta z} + V^- e^{+j\beta z}$$

$$I(z) = \frac{V^+}{Z_0} e^{-j\beta z} - \frac{V^+}{Z_0} e^{+j\beta z}$$

Q1b. What is the voltage amplitude ***V*⁻** of the **reverse** voltage wave when ***V*⁺ = +1 V**?



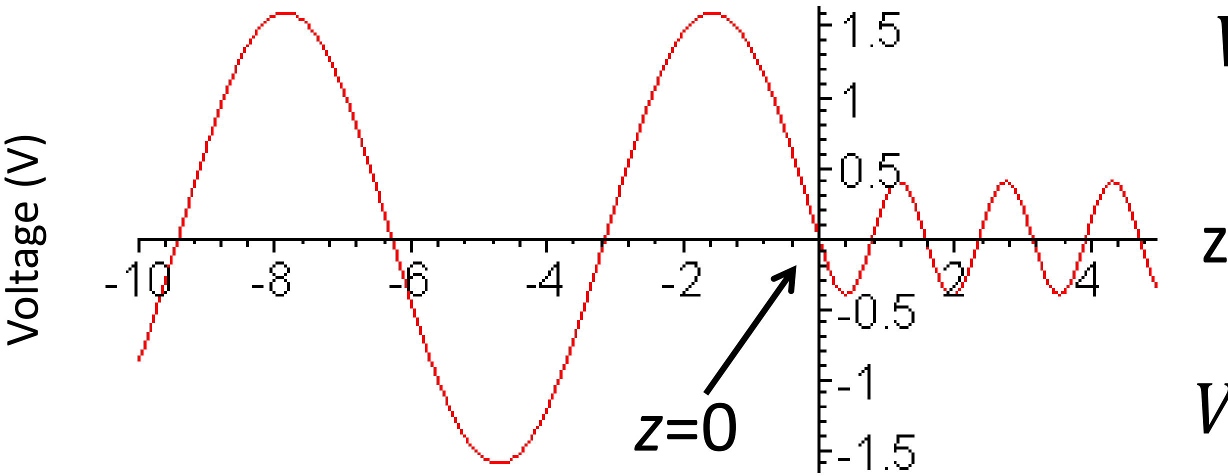
1. $V^- = -2$ V
2. $V^- = -1$ V
3. $V^- = 0$ V
4. $V^- = +1$ V
5. $V^- = +2$ V

$\boxed{+1 \text{ V}}$

$$V(z) = V^+ e^{-j\beta z} + V^- e^{+j\beta z}$$

$$I(z) = \frac{V^+}{Z_0} e^{-j\beta z} - \frac{V^+}{Z_0} e^{+j\beta z}$$

Q2a. What kind of wave in the region z < 0? (choose one!)



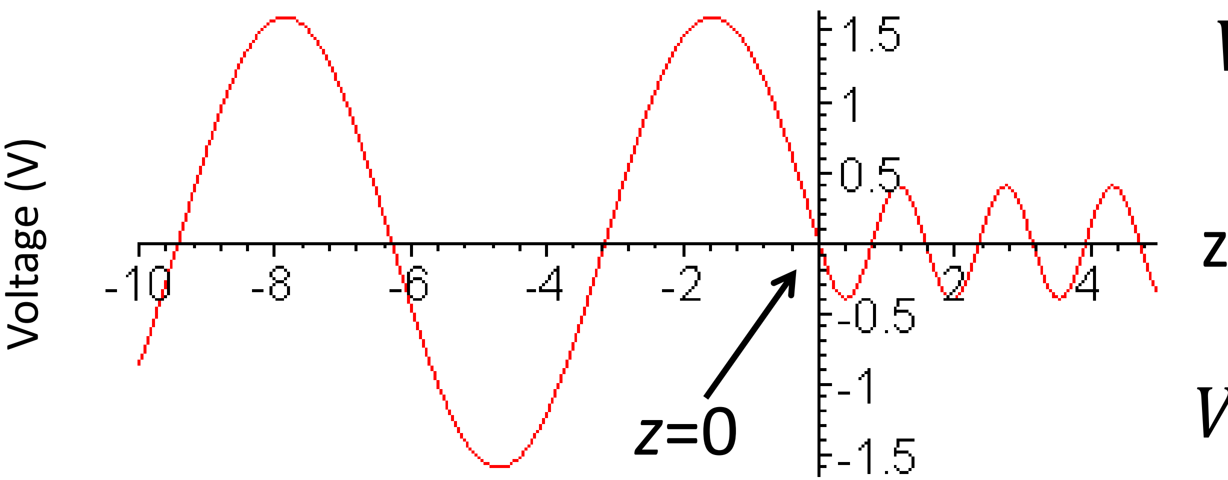
$$V(z \leq 0) = V^{+}e^{-j\beta z} + V^{-}e^{+j\beta z}$$

$$V(z > 0) = V^{T}e^{-j\beta z}$$

transmitted voltage

1. A pure forward (to positive z) propagating wave – i.e., $V^{-} = 0$.
2. A pure reverse (to negative z) propageting wave – i.e., $V^{+} = 0$.
3. A pure standing wave – i.e., $|U^{+}| = |U^{-}|$.
4. A partial standing wave with a net power flow forward (to positive z) – i.e., $|U^{+}| > |U^{-}|$.
5. Transmitted wave through the interface at z = 0.
6. I don't know

Q2b. What kind of wave in the region z < 0? (choose one!)



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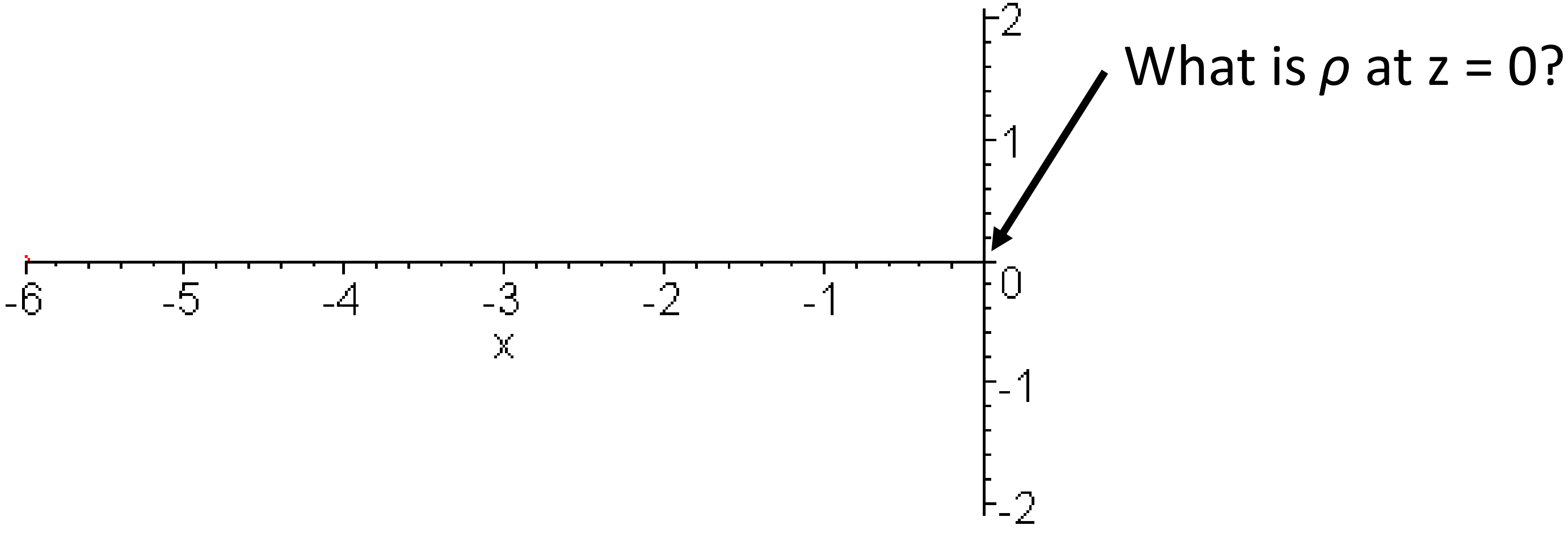
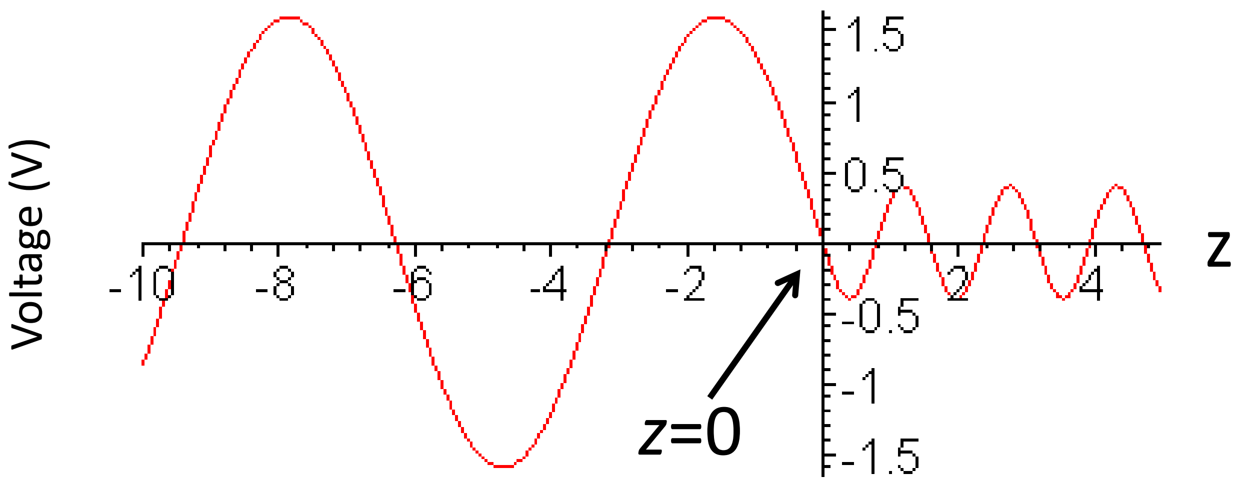
Voltage reflection coefficient ρ



Voltage reflection coeffficient ρ definition (remember!):

$$\rho = \frac{\text{reflected voltage at } z = 0}{\text{forward voltage at } z = 0} = \frac{V^{-}e^{+j\beta\cdot 0}}{V^{+}e^{+j\beta\cdot 0}} = \frac{V^{-}}{V^{+}}$$

Q3a. U^{+} = 1 V. What is the voltage reflection coefficient ρ at z = 0?



1. $\rho = 0$
2. $\rho = -1$
3. $\rho = 1$
4. $0 < \rho < 1$
5. $-1 < \rho < 0$
6. I don't know

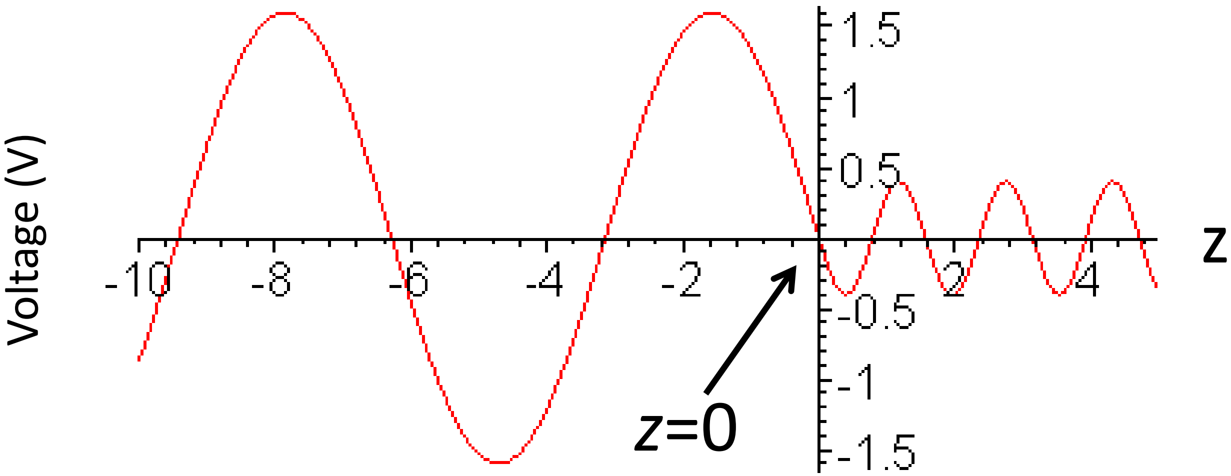
$\boxed{+1\text{ V}}$

$$V(z \leq 0) = V^{+}e^{-j\beta z} + V^{-}e^{+j\beta z}$$

$$V(z > 0) = V^{T}e^{-j\beta z}$$

$\boxed{+0.5\text{ V}}$

Q3b. U^+ = 1 V. What is the voltage reflection coefficient ρ at z = 0?



1. $\rho = 0$
2. $\rho = -1$
3. $\rho = 1$
4. $0 < \rho < 1$
5. $\boxed{-1 < \rho < 0}$

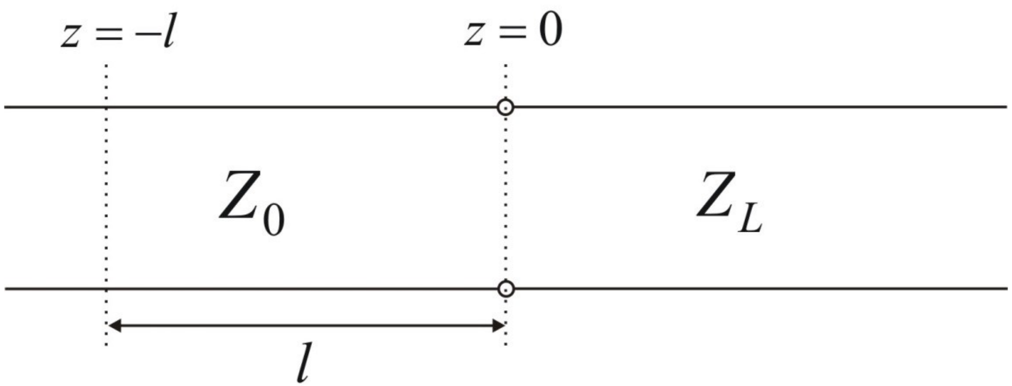
$\boxed{+1\text{ V}}$

$$V(z \leq 0) = V^+ e^{-j\beta z} + V^- e^{+j\beta z}$$

$$V(z > 0) = V^T e^{-j\beta z}$$

$\boxed{+0.5\text{ V}}$

Voltage reflection ρ and transmission τ coefficients



Z_L is the characteristic impedance when z > 0.

At z =0, the voltage and current must be **continuous**!

$$\rho = \frac{V^-}{V^+}$$

$$V(z=0) = V^+e^{-j\beta\cdot 0} + V^-e^{+j\beta\cdot 0} = V^Te^{-j\beta\cdot 0}$$

Transmission Coefficient:

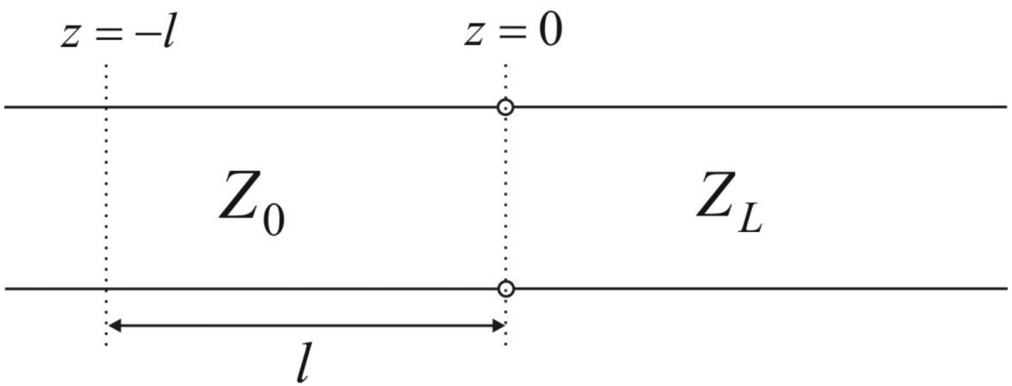
$$\tau = \frac{V^T}{V^+}$$

$$I(z=0) = \frac{V^+}{Z_0}e^{-j\beta\cdot 0} - \frac{V^-}{Z_0}e^{+j\beta\cdot 0} = \frac{V^T}{Z_L}e^{-j\beta\cdot 0}$$

$\rho = ???$

$\tau = ???$

Voltage reflection ρ and transmission τ coefficients



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At z =0, the voltage and current must be **continuous**!

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$$V(z=0) = V^+ e^{-j\beta\cdot 0} + V^- e^{+j\beta\cdot 0} = V^T e^{-j\beta\cdot 0}$$

$$I(z=0) = \frac{V^+}{Z_0} e^{-j\beta\cdot 0} - \frac{V^-}{Z_0} e^{+j\beta\cdot 0} = \frac{V^T}{Z_L} e^{-j\beta\cdot 0}$$

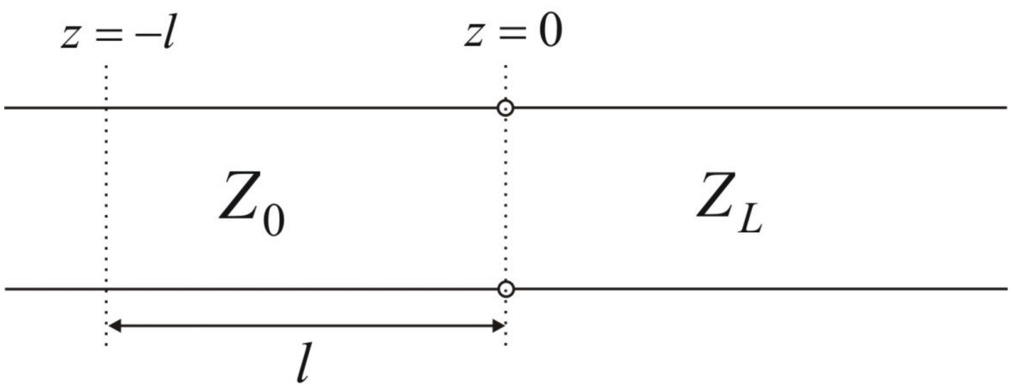
Transmission coefficient

$$\tau = \frac{V^T}{V^+}$$

$$\Rightarrow \quad \rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$\tau = 1 + \rho$$

Q4a: $\boldsymbol{\rho}$ **= -0.5** and $\boldsymbol{V^+}$ **= 1** V. What is the **maximum** voltage (absolute value) of the standing wave in z ≤ 0?



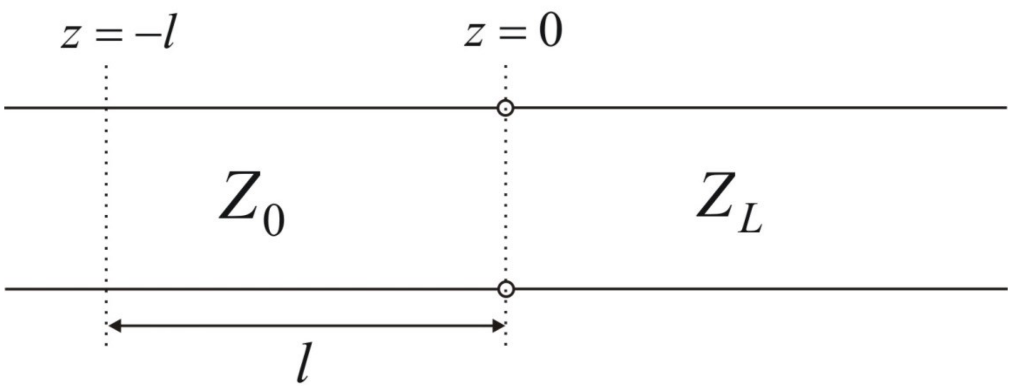
$$V(z \leq 0) = V^+ e^{-j\beta z} + V^- e^{+j\beta z}$$

$$V(z > 0) = V^T e^{-j\beta z}$$

$V^+ = 1$ V, $\rho = -0.5$
$V^T = 0.5$ V

1. 0.5 V
2. 1 V
3. 1.5 V
4. 2.0 V
5. 2.5 V
6. I don't know

Q4b: **ρ = -0.5** and **V^+ = 1** V. What is the **maximum** voltage (absolute value) of the standing wave in z ≤ 0?

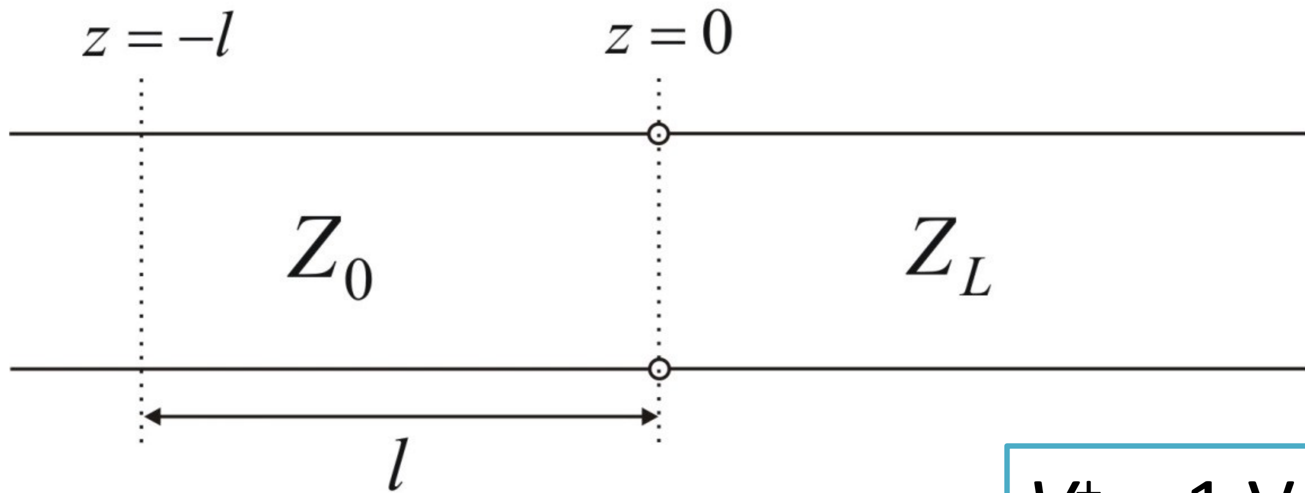


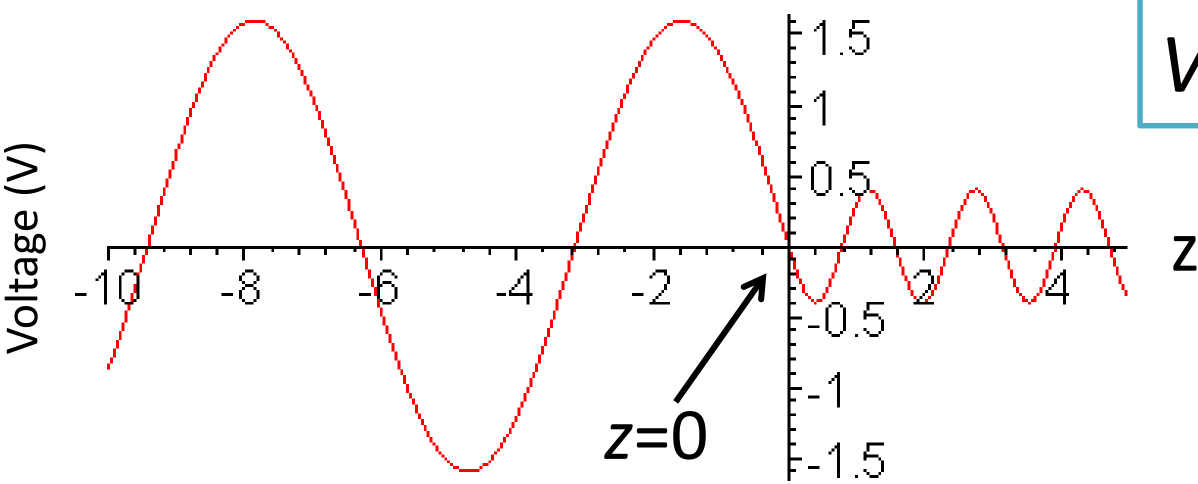
$$V(z \leq 0) = V^+ e^{-j\beta z} + V^- e^{+j\beta z}$$

$$V(z > 0) = V^T e^{-j\beta z}$$

$\boxed{V^+ = 1 \text{ V}, \rho = -0.5 \quad V^T = 0.5 \text{ V}}$

1. 0.5 V
2. 1 V
3. $\boxed{1.5 \text{ V}}$
4. 2.0 V
5. 2.5 V
6. I don't know





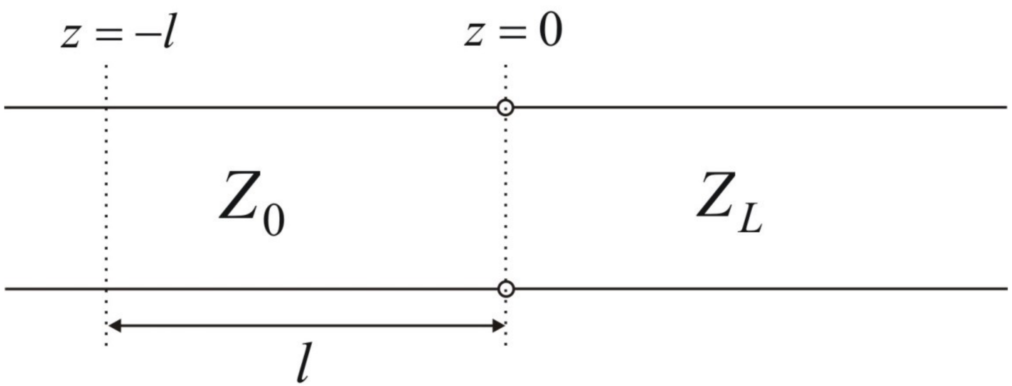
$V^+ = 1$ V, $\rho = -0.5$

$V^T = 0.5$ V

$$V(z \leq 0) = 1\ \mathrm{V} \cdot e^{-j\beta z} - 0.5\ \mathrm{V} \cdot e^{+j\beta z}$$

$$V(z > 0) = 0.5\ \mathrm{V} \cdot e^{-j\beta z}$$

Standing wave along a transmission line (z ≤ 0)



$$\boxed{\rho = \frac{Z_L - Z_0}{Z_L + Z_0}}$$

$$\boxed{\tau = 1 + \rho}$$

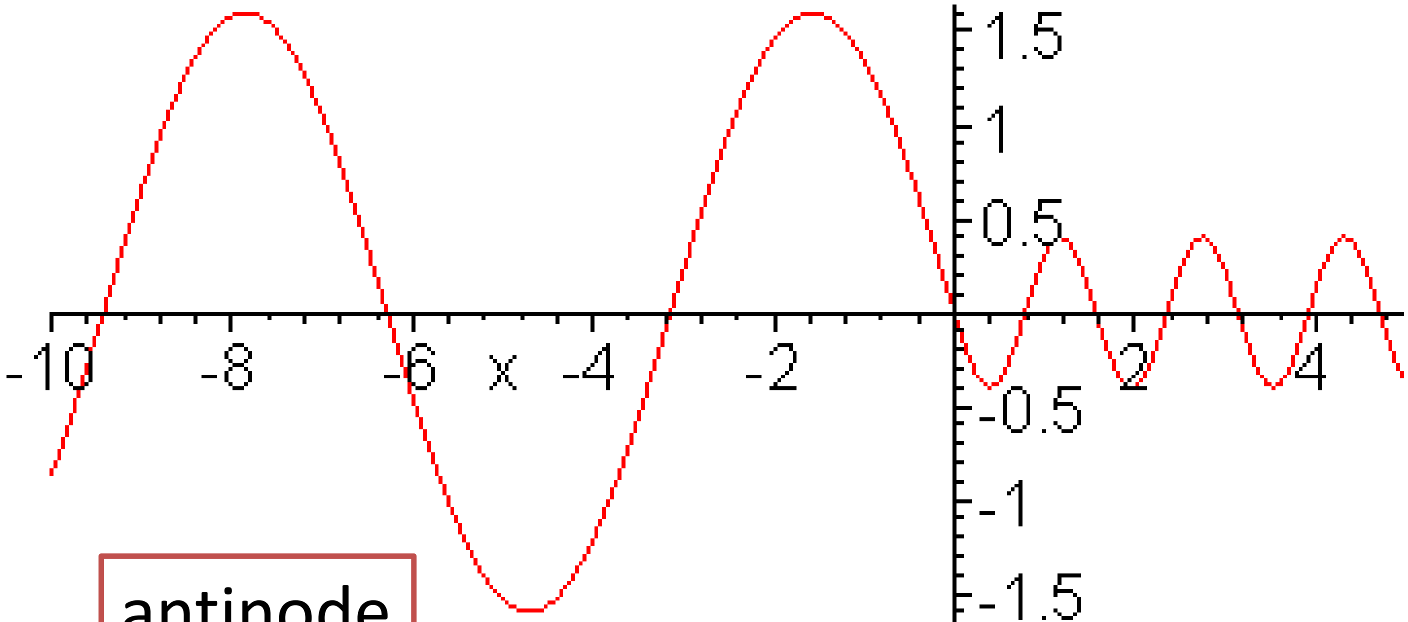
$$V(z) = V^+ e^{-j\beta\cdot z} + V^- e^{+j\beta\cdot z} = V^+\, e^{-j\beta\cdot z}\left(1 + \rho\cdot e^{+j2\beta z}\right)$$

$$I(z) = \frac{V^+}{Z_0} e^{-j\beta\cdot z} - \frac{V^-}{Z_0} e^{+j\beta\cdot z} = \frac{V^+}{Z_0} e^{-j\beta\cdot z}\left(1 - \rho\cdot e^{+j2\beta z}\right)$$

absolute values / envelope curves of the standing wave:

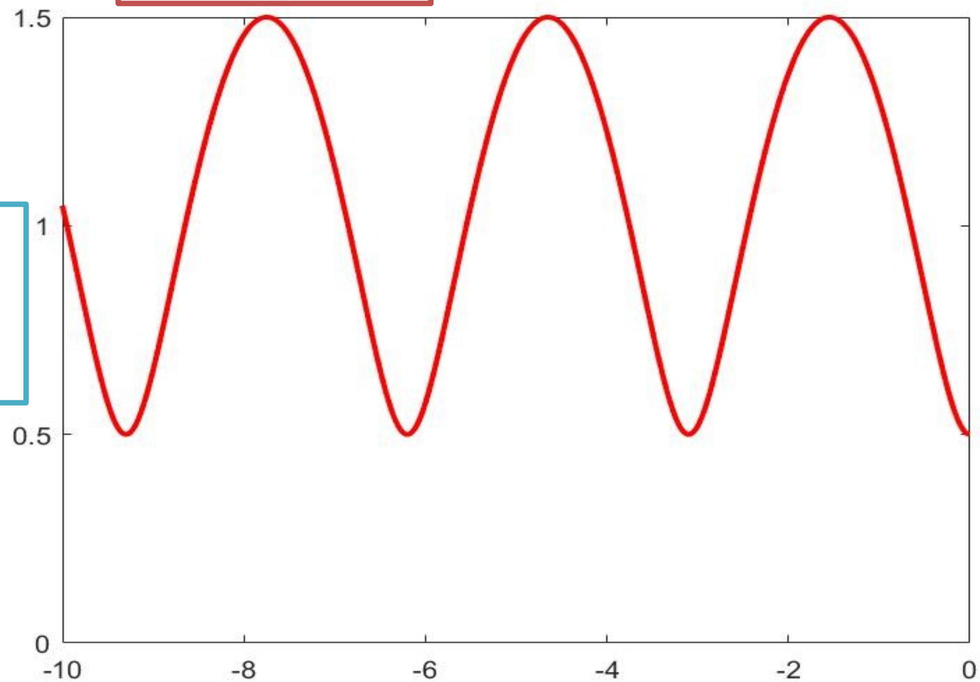
$$|V(z)| = V^+\left|1 + \rho\cdot e^{+j2\beta z}\right| \qquad |I(z)| = \frac{V^+}{Z_0}\left|1 - \rho\cdot e^{+j2\beta z}\right|$$

Time domain voltage $V(z,t)$



antinode

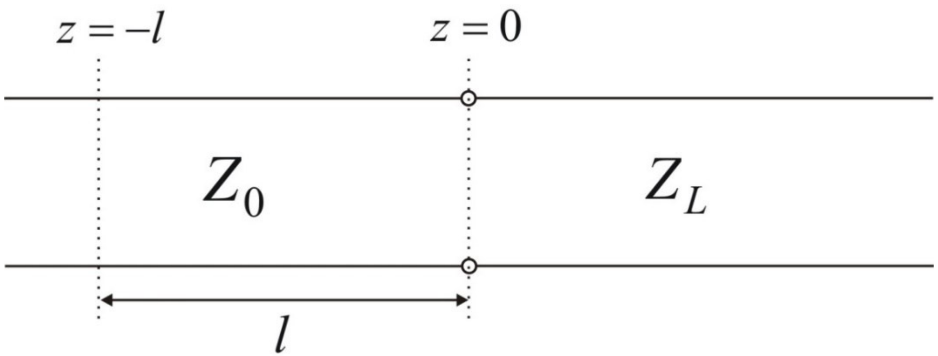
envelope $|V(z)|_{\max}$



voltage standing wave ratio:

VSWR = 1.5/0.5
= 3

Q5a: Which of the statements is **incorrect**?



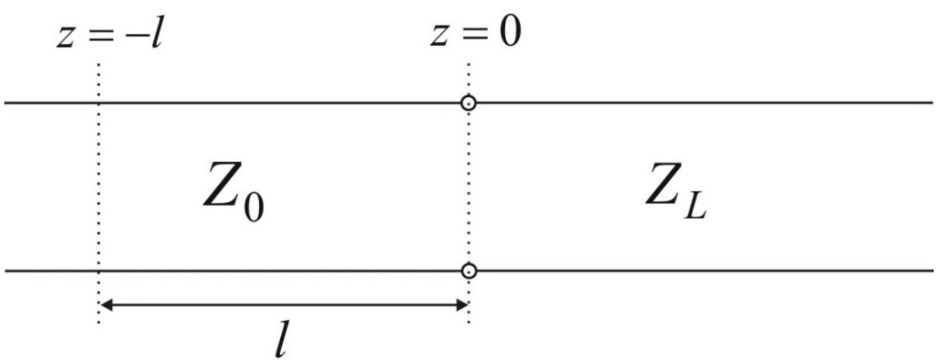
$$|V(z)| = V^{+}\left|1+\rho\cdot e^{+j2\beta z}\right|$$

$$|I(z)| = \frac{V^{+}}{Z_0}\left|1-\rho\cdot e^{+j2\beta z}\right|$$

In the antinode (voltage maximum) of the standing wave…

1. electrical breakdown is possible in high-power applications.
2. the current has the maximum too.
3. the impedance - defined as $Z(z) = V(z)/I(z)$ - has the maximum.
4. in the time domain the voltage oscillates between maximum positive and minimum negative voltage values
5. the distance to the next voltage maximum is **half** wavelength, λ/2
6. I don’t know

Q5b: Which of the statements is **incorrect**?



$$|V(z)| = V^+ \left|1 + \rho \cdot e^{+j2\beta z}\right|$$

$$|I(z)| = \frac{V^+}{Z_0}\left|1 - \rho \cdot e^{+j2\beta z}\right|$$

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