

$$T_{line} = 75 \Omega = Z_0$$

$$C' = 138 \text{ pF/m}$$

$$l = 2.5 \text{ m}$$

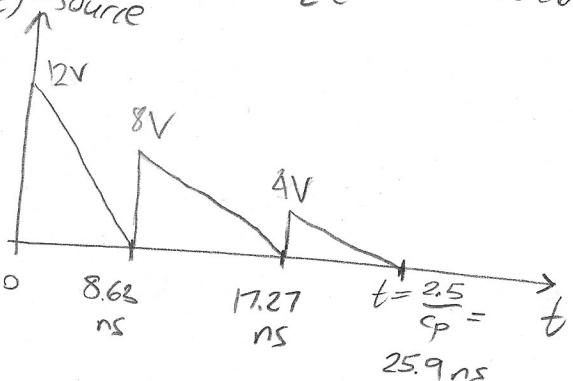
a) What voltage waveform is needed @ the input?

$$Z_0 = \sqrt{\frac{L'}{C'}} \quad 75 = \sqrt{\frac{L'}{138 \times 10^{-12}}} \Rightarrow L' = 776 \text{ nH/m}$$

Assuming

$$\text{source impedance } R_s = Z_0$$

$$c_p (\text{phase velocity}) = \sqrt{\frac{1}{L' C'}} = 96.6 \times 10^6 \text{ m/s}$$



b) At what time does the entire message appear on the line?

$$t_{msg} = \frac{l}{c_p} = \frac{2.5}{96.6 \times 10^6} \approx 26 \text{ ns}$$

c) How much energy is stored on the line @ this point?

$$E_c = \frac{1}{2} C V^2 \quad E_l = \frac{1}{2} L I^2$$

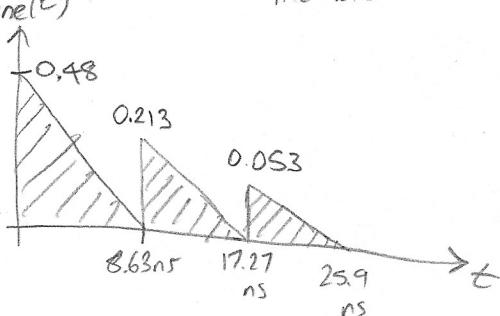
$$P_{line}(t) = V_{line}(t)^2 / Z_0 \quad P_{line}(t) \quad E_{line} = P_{line} \cdot \Delta t$$

$$E_{line} = \int_0^{t=t_{msg}} P_{line}(t) dt$$

$$E_{line} = \frac{1}{2} (8.63)(0.48)$$

$$+ \frac{1}{2} (8.63)(0.213)$$

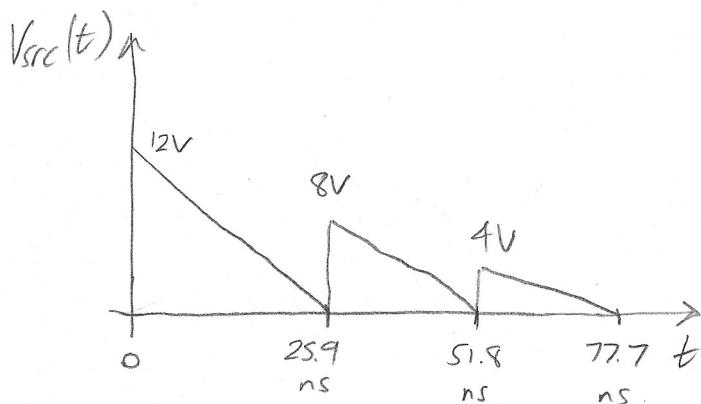
$$+ \frac{1}{2} (8.63)(0.053) = 3.22 \text{ J}$$



d) Slow down the message by 3x. What is the new time-domain waveform? Specify  $Z_L$ .

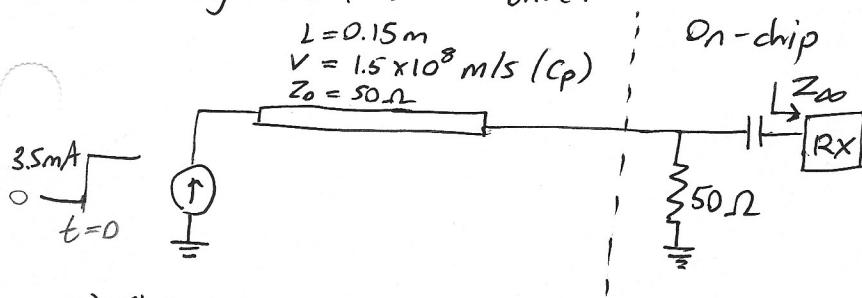
Choose  $Z_i = Z_o = 75\Omega$  to not worry about load reflections.

New time-domain waveform sent by source.

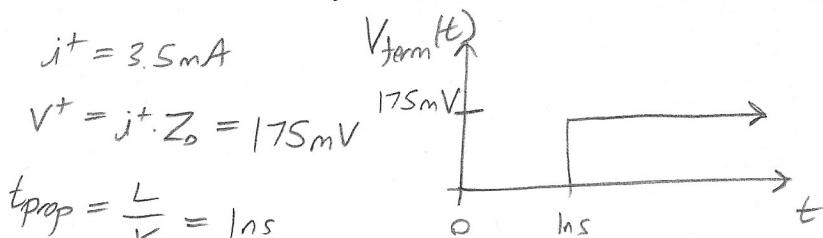


Since impedances match, the voltage driven by the source is the same as what it sees (due to no load reflections).

#2) Single-ended LVDS driver.



a) Plot time domain voltage waveform @  $50\Omega$  termination. Assume the line is discharged @  $t = 0$ .

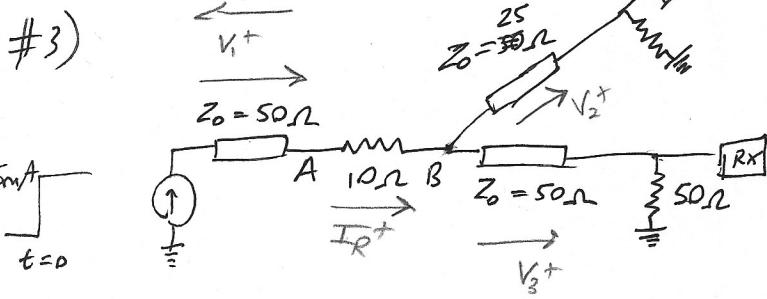


b) w/  $Z_0 = 60\Omega$ , find voltage @ termination at  $t = \infty$ .

@  $t = \infty$ , the line is a short.  $\boxed{V_{\text{term}} = 3.5 \text{ mA} \cdot 60 \Omega = 0.21 \text{ V}}$

c) RX input bias voltage = 1V. If max RX input is 1.2V, what's the max  $Z_0$  deviation from  $50\Omega$ ?  
 RX Nominal Voltage =  $1V + 3.5 \text{ mA} \cdot 50 \Omega = 1.175 \text{ V}$

$$1V + 3.5 \text{ mA} \cdot Z_0 = 1.2V \Rightarrow \boxed{Z_0^{\max} = 57\Omega}$$



$$L = 0.15\text{m} \Rightarrow t_{\text{prop}} = 1\text{ns}$$

$$v = 1.5 \times 10^8 \text{ m/s}$$

a) Find magnitudes of  $V^+$  &  $V^-$  @ A and B @  $t = 1.5\text{ns}$ .

@  $t = 1\text{ns}$ ,  $175\text{mV}$  @ A =  $V_1^+$

$$V_1^- = V_1^+ \cdot \Gamma @ A = V_1^+ \cdot \frac{(25/50) - 50}{(25/50) + 50}$$

$$I_R^+ = \frac{V_1^+ - V_1^-}{Z_0} = \frac{175}{50} + \frac{53}{50} = 4.56\text{mA}$$

$$V_2^+ = V_3^+ = V_1^+ + V_1^- - 10I_R^+ = 77.4\text{mV}$$

@  $t = 1.5\text{ns}$ ,

$$V @ A = 175\text{mV} - 53\text{mV} = 122\text{mV}$$

$$V^+ @ B = 77.4\text{mV}$$

b) @  $t = 3.5\text{ns}$

@  $2\text{ns}$ ,  $V_1^-$  launches  $V_{1b}^+ = V_1^- = -53\text{mV}$

$$V_2^+ \text{ launches } V_2^- = \frac{50-25}{50+25} \cdot (-77.4\text{mV}) = 25.8\text{mV}$$

$V_2^+$  is terminated & doesn't reflect

@  $3\text{ns}$   $V_{1b}^+$  launches  $V_{2b}^+ = V_{3b}^+ = V_{1b}^+ + V_1^- - 10I_{Rb}^+ = -23.4\text{mV}$

$$V_{1b}^- = V_{1b}^+ \cdot \Gamma = 16\text{mV} \quad I_{Rb}^+ = \frac{V_{1b}^+ - V_{1b}^-}{Z_0} = -1.38\text{mA}$$

$$V_2^- \text{ launches } V_{2c}^+ = V_2^- \cdot \frac{60/150 - 25}{60/150 + 25} = 1\text{mV}$$

$$I_R^- = \frac{25.8 - 1}{25} \cdot \frac{50}{110} = 0.48\text{mA}$$

$$V_{1c}^- = V_2^- + V_{2c}^+ - 10I_R^- = 22\text{mV}$$

$V @ A$

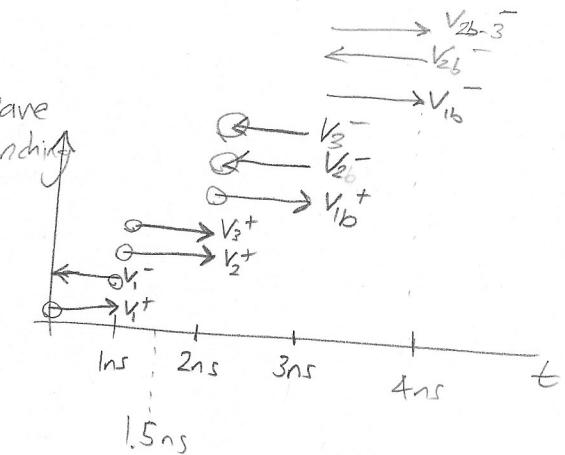
$$V^+ = V_1^+ + V_{1b}^+ = 122\text{mV}$$

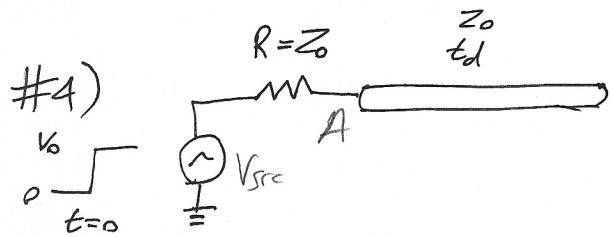
$$V^- = V_1^- + V_{1b}^- + V_{1c}^- = -15\text{mV}$$

$V @ B$

$$V^+ = V_2^+ + V_{2b}^+ + V_{2c}^+ = 53\text{mV}$$

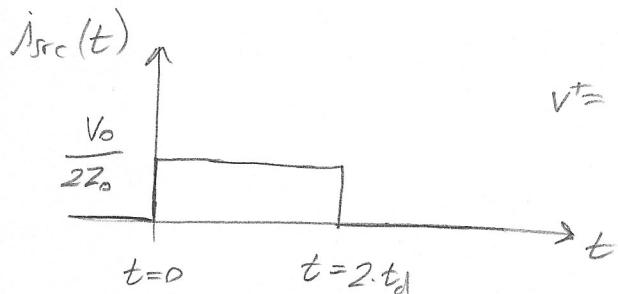
$$V^- = V_2^- = 25.8\text{mV}$$





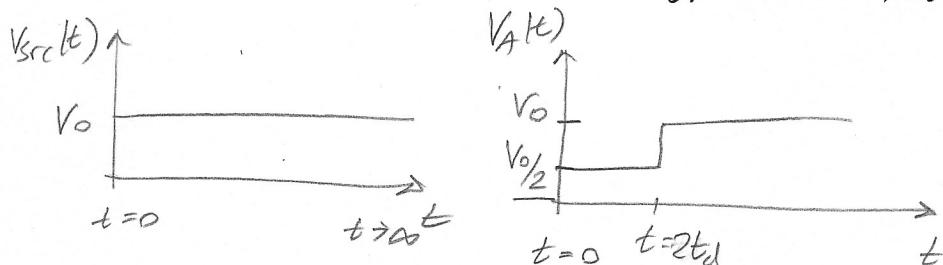
A step voltage source is connected to a line.

- a) Draw time domain response of current flowing thru voltage source.



$$V^+ = V_o \cdot \frac{1}{2} \quad i^+ = \frac{V^+}{Z_0} = \frac{V_o}{2Z_0}$$

- b) Use T-D response to find total energy delivered by voltage source & total energy consumed on resistor. What is the energy stored on line @  $t = \infty$ .



$$E_{src} = V_o \cdot \frac{V_o}{2Z_0} \cdot 2t_d = \boxed{\frac{V_o^2 t_d}{Z_0} \text{ delivered by source}}$$

$$E_{res, dissipated} = \frac{V_o}{2} \cdot \frac{V_o}{2Z_0} \cdot 2t_d = \frac{V_o^2 t_d}{2Z_0} = \boxed{\frac{1}{2} E_{src} \text{ dissipated on resistor}}$$

@  $t = \infty$ , line charged to  $V_o$  & no current flows.

$$E_c = \frac{1}{2} CV^2 = \frac{1}{2} C V_o^2$$

$$C = C' \cdot l = \frac{1}{Z_0 \cdot V} \cdot V t_d = \frac{t_d}{Z_0}$$

$$\rightarrow E_c = \boxed{\frac{1}{2} \frac{t_d}{Z_0} V_o^2} \text{ stored on line}$$

- c) Express the total cap of the line by  $Z_0$  &  $t_d$ .  $E_c + E_{res} = E_{src}$  ✓ good!

$$C = C' \cdot l = \boxed{\frac{t_d}{Z_0}}$$

$$V = \sqrt{\frac{1}{L'C'}} \quad Z_0 = \sqrt{\frac{L'}{C'}}$$

$$t_d \cdot V = l$$

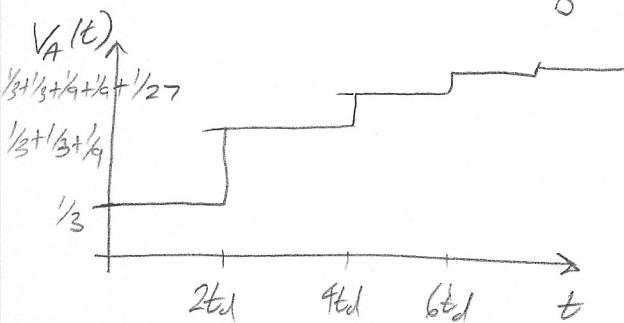
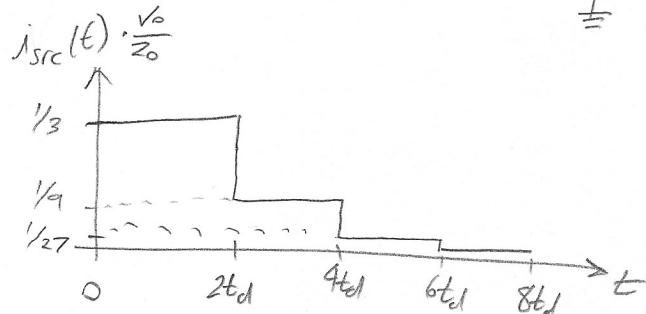
d) Repeat a) & b) w/ source resistance =  $2Z_0$ .

$$V_1^+ = \frac{Z_0}{Z_0 + R_S} \cdot V_0 = \frac{1}{3} V_0, \quad i_1^+ = \frac{V_1^+}{Z_0} = \frac{1}{3} \left( \frac{V_0}{Z_0} \right)$$

$$V_1^- = \frac{1}{3} V_0$$

$$V_2^+ = \frac{1}{9} V_0 = V_2^-$$

$$V_3^+ = \frac{1}{27} V_0$$



$$E_{src} = V_0 \cdot \frac{V_0}{3Z_0} \cdot 2t_d + V_0 \cdot \frac{V_0}{9Z_0} \cdot 2t_d + \dots$$

$$= \frac{V_0^2 \cdot 2t_d}{Z_0} \sum_{i=1}^{\infty} \frac{1}{3^i}$$

$\boxed{\frac{V_0^2 \cdot t_d}{Z_0}}$  delivered by source

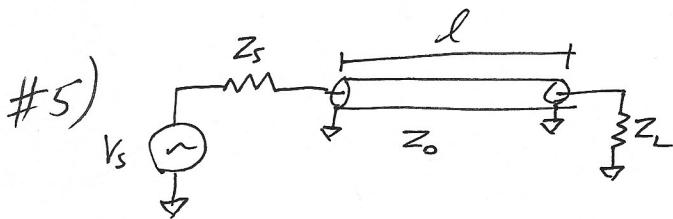
$E_{res} = \frac{1}{2} E_{src}$   $\star$  still true

$$E_{res} = (V_0 - V_A) \cdot 2t_d \cdot i_{src}$$

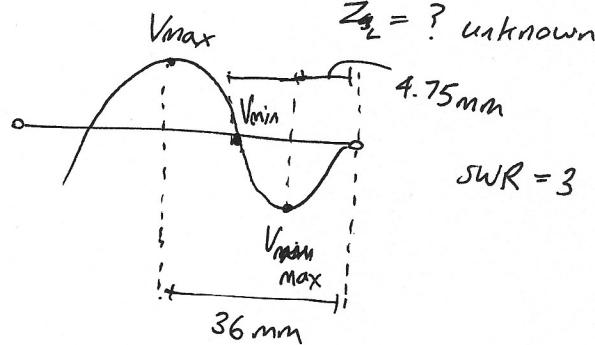
e) Energy stored on line @  $t = \infty$ .

Same strategy... @  $t = \infty$  line is charged to  $V_0$

$E_c = \boxed{\frac{1}{2} \frac{t_d}{Z_0} V_0^2 = E_{line}}$



Power Amp



a) Operating freq of power amp? Assume  $Z_s = Z_0$ .

$$f(z) = f_L e^{jkz}$$

$$2kz = \pi$$

$$\lambda = \frac{2\pi}{k} = \beta$$

$$\Rightarrow z = \frac{\pi}{2k} = \frac{\lambda}{4} = \text{dist. bet. max & min points}$$

$$\lambda = 125 \text{ mm} \Rightarrow 0.125 \text{ m}$$

$$\lambda \cdot f = c_p \Rightarrow f = 1.2 \text{ GHz}$$

b) What is the load (antenna) impedance @ the freq?

$$\text{SWR} = \frac{1+|P_L|}{1-|P_L|} = 3$$

$$1+|P_L| = 3 - 3|P_L|$$

$$4|P_L| = 2$$

$$|P_L| = \frac{1}{2}$$

The min swing happens @  $z = -4.75 \text{ mm}$

$$|V| = \left| V_L e^{-2jBz} \right| \quad z = -4.75 \text{ mm} = \text{min.}$$

$$V_L e^{-2jBz} = -|P_L|$$

$$V_L = -|P_L| e^{j2Bx} = -0.5 + 1.89e^{-9j}$$

$$c_p = \frac{c_0}{\sqrt{4}} = 1.5 \times 10^8 \text{ m/s}$$

g) All calcs are valid except power. Assume line loss of  $0.1 \text{ dB/cm}$ .

$P_{src}$  is identical.

$$P_{load}' = P_{load} - 21.875 \text{ dB}$$

$$= P_{load} (0.0806)$$

$$= 2.636 \text{ mW}$$

$$\text{Eff} = \frac{P_{load}}{P_{src}} = 2.4\%$$

$$f_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$f_L Z_0 + f_L Z_0 = Z_L - Z_0$$

$$Z_L (f_L - 1) = Z_0 (-1 - f_L)$$

$$Z_L = \frac{Z_0 (-1 - f_L)}{f_L - 1}$$

$$= 16.66 \Omega + 8.4e-8j$$

$$v(z) = V_o^+ [e^{-jBz} + R_L e^{jBz}]$$

$$v(z) = \frac{V_o^+}{Z_0} [e^{-jBz} + R_L e^{jBz}]$$

$$\frac{V_o^-}{V_o^+} = \frac{Z_L - Z_0}{Z_L + Z_0} B \Pi$$

c) In SCS, what are the boundary conditions @ the load?

$$@ Z_L = \frac{V(0)}{i(0)} = \frac{V^+ + V^-}{I^+ - I^-} \quad Z_0 = \frac{Z_0 \frac{1 + \frac{V^-}{V^+}}{1 - \frac{V^-}{V^+}}}{1 - \frac{V^-}{V^+}} = \frac{1 + P_L}{1 - P_L} \quad Z_0 = Z_L$$

d) What are the boundaryconds @ the source? Assume  $Z_s = 5 \Omega$  (leave symbolic).  $v(z) = \frac{V_o^+}{Z_0} [e^{-jBz} + R_L e^{jBz}]$

$$V_s = V(z = -l) + Z_s \cdot I(z = -l)$$

$$V_s = V_o^+ [e^{jB(-l)} + R_L e^{-jB(-l)}] + Z_s \cdot \frac{V_o^+}{Z_0} [e^{jB(-l)} - R_L e^{-jB(-l)}]$$

$$V_o^+ = V_s e^{-jB(-l)} \quad Z_0 = \frac{Z_0 (1 + R_L e^{-2jB(-l)}) + Z_s (1 - R_L e^{-2jB(-l)})}{Z_0 (1 + R_L e^{-2jB(-l)}) - Z_s (1 - R_L e^{-2jB(-l)})}$$

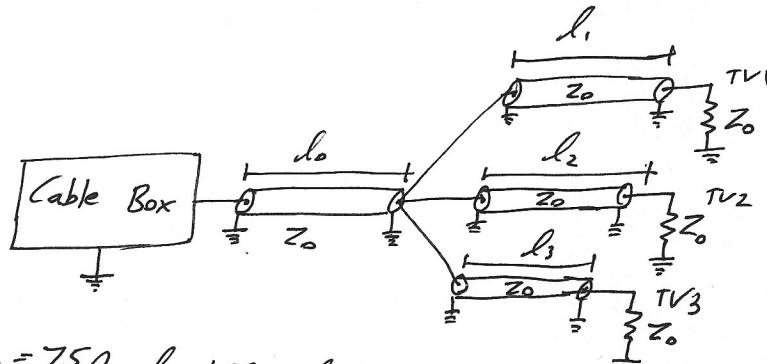
e) Find voltage waveform along the line & plot magnitude. Use Python. Attached.

f)  $V_s$  has a 10V swing. What is  $P_{src}$  &  $P_{load}$ ? Efficiency +  $50 \Omega$  comparison.

$$P_{src} = \frac{10 \cdot I(-l)}{\sqrt{2}} \quad P_{src,dis} = Z_s \cdot I(-l) \quad P_{load} = P_{src} - P_{res} = I(-l) \left( \frac{10}{\sqrt{2}} - 5 \right) = 32.7 \text{ mW}$$

$$\text{Eff} \approx \frac{P_{load}}{P_{src}} = 29.3\% \quad \text{part g) } \uparrow$$

#6)



$$Z_0 = 75\Omega, l_0 = 1.22m, l_1 = 2.59m, l_2 = 11.23m, l_3 = 33.85m$$

$$\rho_L = 1 \times 10^8 \text{ m/s}$$

a) TV is tuned to Ch. 14 ~ 473 MHz, what's the impedance seen by the cable box?

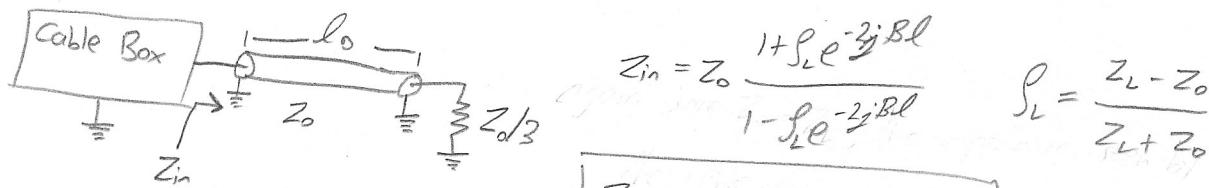
For a lossless line  $Z_{in}(l) = Z_0 \cdot \frac{Z_L + jZ_0 \tan(\beta l)}{Z_0 + jZ_L \tan(\beta l)}$

$$\text{Where } \beta = \frac{2\pi}{\lambda} \text{ and } \lambda_0 = \frac{c}{f} = \frac{1 \times 10^8}{473 \times 10^6} = 0.2142 \text{ m}$$

$$\beta = 29.7195$$

$$Z_{in}(fl_1) = Z_0 = Z_{in}(-l_2) = Z_{in}(-l_3) \text{ b/c } Z_L = Z_0$$

$$\text{Then we can model: } \beta l = \frac{2\pi}{\lambda} \cdot 5.772$$



b) Cable Box puts out -30 dBm power. How much reaches each TV?

$$\text{dBm} = 10 \log \left( \frac{P_{\text{avg}}}{1 \text{ mW}} \right)$$

$$-30 \text{ dBm} = 1 \text{ mW}, 10^{-30/10} = 0.001 \text{ mW}$$

$$10 \log \left( \frac{0.0003}{1 \text{ mW}} \right) = -34.77 \text{ dBm}$$

c) Perf gets worse when TV3 is unplugged, why? How much power reaches TV2/3.

$$l_1 = 2.59m = 12.25\lambda = N + \frac{\lambda}{4}$$

↑  
some integer

So  $l_1$  looks like an AC short (impedance inverter).

d) Does adding a series R to  $l_1, l_2, l_3$  help? What impedance is seen by the cable box? How much power reaches the TVs?

$$Z_{in} = Z_0 \cdot \frac{1 + \rho_L e^{-2j\beta l_1}}{1 - \rho_L e^{-2j\beta l_1}} \quad \rho_L = \frac{Z_L - Z_0}{Z_L + Z_0} \quad \text{Power} = -35 \text{ dBm} \left( \frac{Z_0}{Z_0 + R} \right) = \frac{1}{3} (-35 \text{ dBm}) = -39.5 \text{ dBm}$$

$$Z_L = \frac{Z_0 + R}{3} \Rightarrow \frac{Z_L - Z_0}{Z_L + Z_0} = 0 \quad (Z_L = Z_0)$$

$$3Z_0 = Z_0 + R \rightarrow \text{if } R \text{ is properly chosen, the cable box should see an impedance of } Z_0.$$