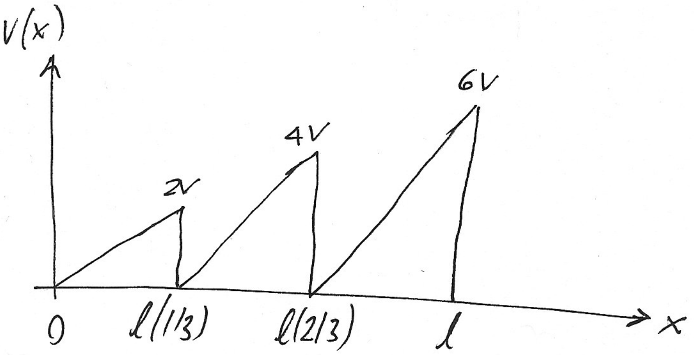
#1)

Tline: $75\Omega = Z_0$

$c' = 138 pF/m$

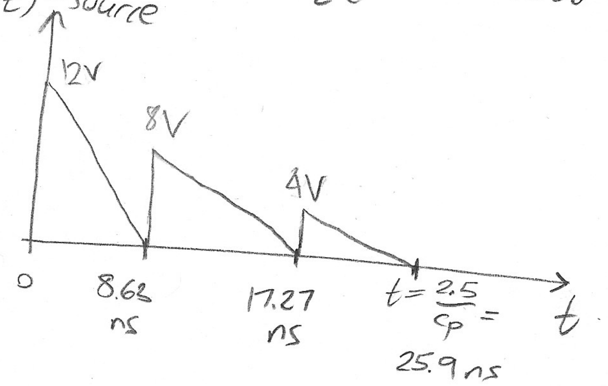
$l = 2.5 m$



a) What voltage waveform is needed @ the input? Assuming source impedance. $R_s = Z_0$

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

C_p (phase velocity) $= \sqrt{\frac{1}{L'C'}} = 96.6e6\ m/s$



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

$t_{msg} = \frac{l}{C_p} = \frac{2.5}{96.6e6} \approx \boxed{26\ ns}$

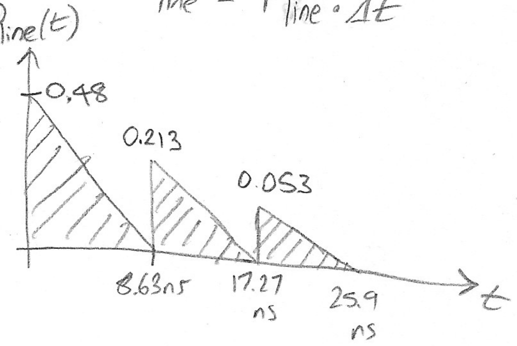
c) How much energy is stored on the line @ this point?

$E_c = \frac{1}{2}CV^2$ $\quad E_L = \frac{1}{2}LI^2$

$E_{line} = P_{line} \cdot \Delta t$

$P_{line}(t) = V_{line}(t)^2 / Z_0$

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



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

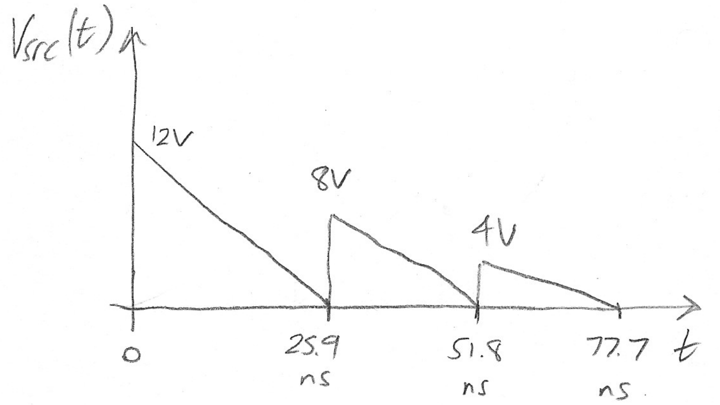
$+ \frac{1}{2}(8.63)(0.213)$

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

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

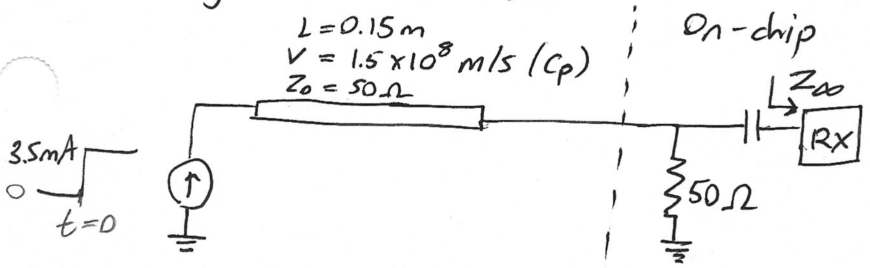
Choose $Z_L = Z_0 = 75\Omega$ to not worry about load reflections.

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.

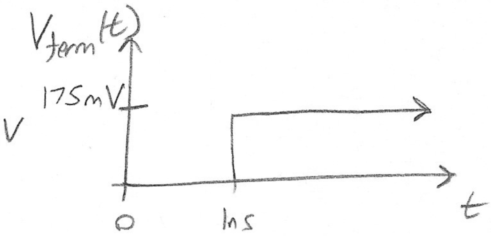


a) Plot time domain voltage waveform @ 50Ω termination. Assume the line is discharged @ $t=0$.

$i^+ = 3.5mA$

$V^+ = i^+ \cdot Z_0 = 175mV$

$t_{prop} = \frac{L}{v} = 1ns$



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

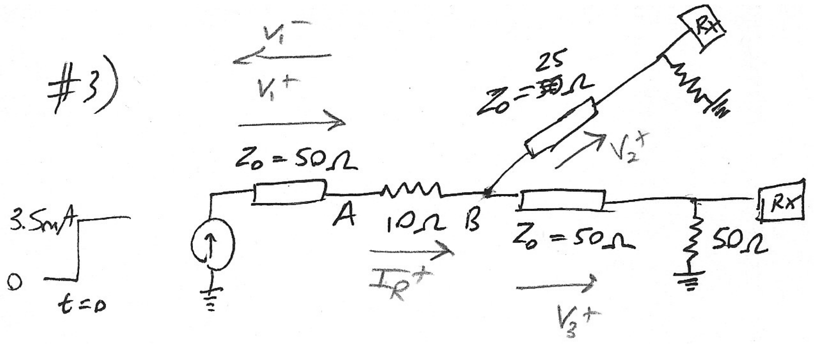
@ $t=\infty$, the tline is a short. $\boxed{V_{term} = 3.5mA \cdot 60\Omega = 0.210V}$

c) RX input bias voltage = 1V. If max RX input is 1.2V, what's the max Z_0 deviation from 50Ω?

RX Nominal Voltage $= 1V + 3.5mA \cdot 50\Omega = 1.175V$

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

#3)



$L = 0.15m \Rightarrow t_{prop} = 1ns$
$v = 1.5\times10^8 m/s$

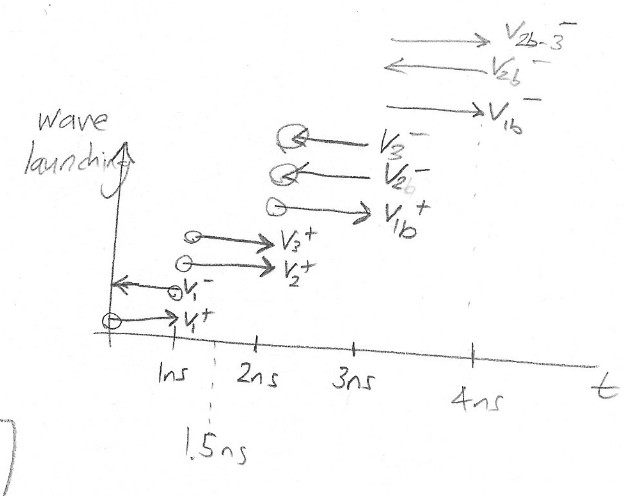
a) Find magnitudes of V^+ & V^- @ A and B @ t = 1.5ns.

@t=1ns, 175mV @ A = V_1^+

$V_1^- = V_1^+ \cdot \Gamma(@A) = V_1^+ \cdot \dfrac{(25\|50) - 50}{(25\|50) + 50} = -53mV$

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

$V_2^+ = V_3^+ = V_1^+ + V_1^- - 10 I_R^+ = 77.4mV$



@t=1.5ns, $\boxed{\begin{aligned} V @ A &= \underset{V_A^+}{175mV} - \underset{V_A^-}{53mV} = 122mV \\ V^+ @ B &= 77.4mV \end{aligned}}$

b) @ t=3.5ns

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

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

V_3^+ is terminated & doesn't reflect

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

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

V_2^- launches $V_{2c}^+ = V_2^- \cdot \dfrac{60\|50 - 25}{60\|50 + 25} = 1mV$

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

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

V @ A

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

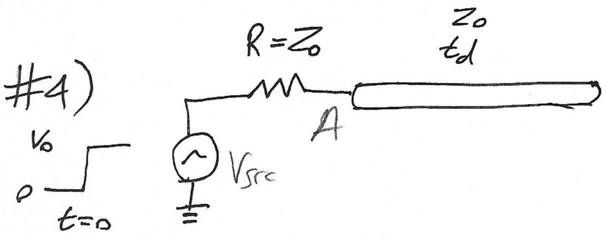
$V^- = V_1^- + V_{1b}^- + V_{1c}^- = -15mV$

V @ B

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

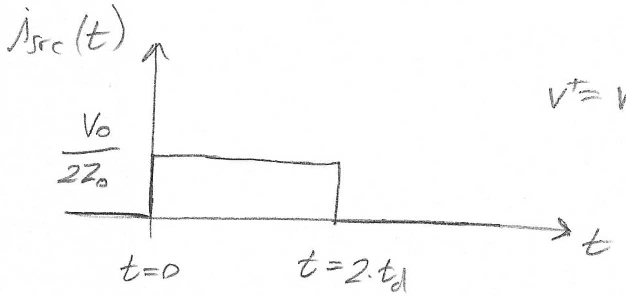
$V^- = V_2^- = 25.8mV$

#4)



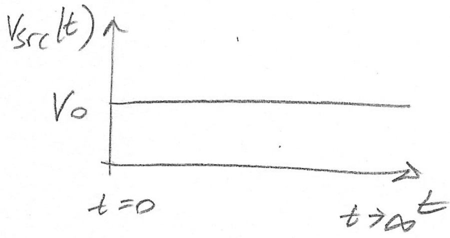
A step voltage source is connected to a tline.

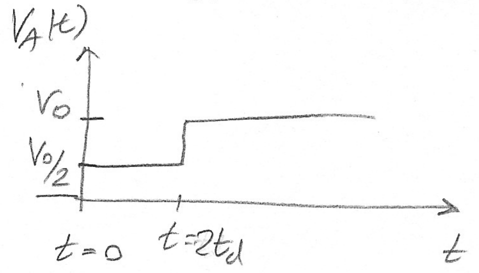
a) Draw time domain response of current flowing thru voltage source.



$v^+ = V_o \cdot \frac{1}{2} \quad i^+ = \frac{v^+}{Z_o} = \frac{V_o}{2Z_o}$

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





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

$E_{res,dissapated} = \frac{V_o}{2} \cdot \frac{V_o}{2Z_o} \cdot 2t_d = \frac{V_o^2 t_d}{2Z_o} = \boxed{\frac{1}{2} E_{src}}$ dissappated on resistor

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

$E_c = \frac{1}{2}CV^2 = \frac{1}{2}CV_o^2$

$C = C' \cdot l = \frac{1}{Z_o \cdot v} \cdot v t_d = \frac{t_d}{Z_o}$ $\rightarrow E_c = \boxed{\frac{1}{2}\frac{t_d}{Z_o} V_o^2}$ stored on tline

$E_c + E_{res} = E_{src}$ ✓ good!

c) Express the total cap of the tline by Zo & td.

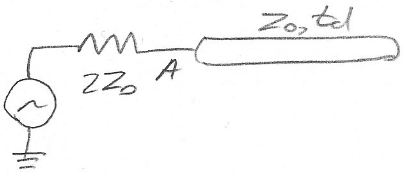
$C = C' \cdot l = \boxed{\frac{t_d}{Z_o}}$

$v = \sqrt{\frac{1}{L'C'}} \quad Z_o = \sqrt{\frac{L'}{C'}}$

$t_d \cdot v = l$

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

$\Gamma_2 = 1 \qquad \Gamma_s = \frac{R_s - Z_0}{R_s + Z_0} = \frac{Z_0}{3Z_0} = \frac{1}{3}$

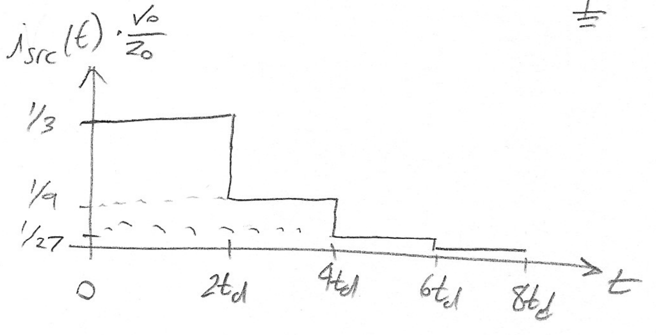


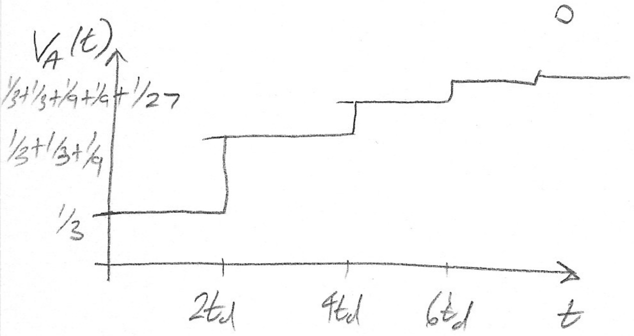
$V_1^+ = \frac{Z_0}{Z_0 + R_s} \cdot V_0 = \frac{1}{3} V_0 \qquad i_1^+ = \frac{V_1^+}{Z_0} = \frac{1}{3}\left(\frac{V_0}{Z_0}\right)$

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

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

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





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

$= \frac{V_0^2 \cdot 2t_d}{Z_0} \underbrace{\sum_{i=1}^{\infty} \frac{1}{3^i}}_{1/2} = \boxed{\frac{V_0^2 \cdot t_d}{Z_0} \text{ delivered by source}}$

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

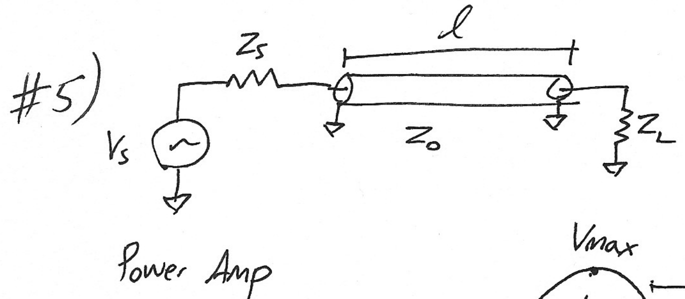
$E_{res} = (V_0 - V_A) \cdot 2t_d \cdot i_{src}$

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

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

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

#5)



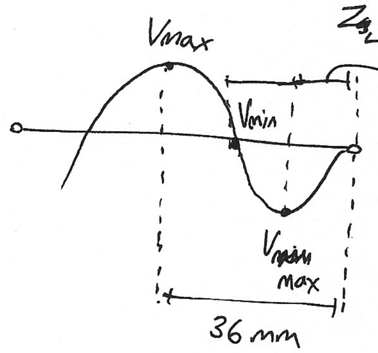
$Z_o = 50\,\Omega$

$\varepsilon_r = 4$

$l = 21.875$ cm

$Z_L = ?$ unknown

$C_p = \frac{c_o}{\sqrt{4}} = 1.5\times10^{8}$ m/s



SWR = 3

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

$\rho(z) = \rho_L e^{2jkz}$

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

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

$\lambda = 125$mm $\Rightarrow 0.125$ m

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

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

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

$1+|\rho_L| = 3 - 3|\rho_L|$

$4|\rho_L| = 2$

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

The min swing happens @ $z = -4.75$mm

$|V^+||1-\rho_L e^{2j\beta z}|\Big|_{z=-4.75mm} = \text{min.}$

$\rho_L e^{-2j\beta z} = -|\rho_L|$

$\rho_L = -|\rho_L| e^{j2\beta x} = -0.5 + 1.89e{-9}j$

$\rho_L = \frac{Z_L - Z_o}{Z_L + Z_o}$

$\rho_L Z_L + \rho_L Z_o = Z_L - Z_o$

$Z_L(\rho_L - 1) = Z_o(-1-\rho_L)$

$Z_L = \frac{Z_o(-1-\rho_L)}{\rho_L - 1}$

$= \boxed{16.66\,\Omega + 8.4e{-8}j}$

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

@ $Z_L = \frac{v(0)}{i(0)} = \frac{V^+ + V^-}{\frac{V^+}{Z_o} - \frac{V^-}{Z_o}} = Z_o \frac{1+\frac{V^-}{V^+}}{1-\frac{V^-}{V^+}} = \boxed{\frac{1+\rho_L}{1-\rho_L} Z_o = Z_L}$

$v(z) = V_o^+[e^{-j\beta z} + \Gamma_L e^{+j\beta z}]$

$i(z) = \frac{V_o^+}{Z_o}[e^{-j\beta z} - \Gamma_L e^{+j\beta z}]$

$\frac{V_o^-}{V_o^+} = \frac{Z_L - Z_o}{Z_L + Z_o}$ B.C.

d) What are the boundary conds @ the source? Assume $Z_s = 5\,\Omega$ (leave symbolic).

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

$V_s = V_o^+[e^{+j\beta l} + \Gamma_L e^{-j\beta l}] + Z_s \cdot \frac{V_o^+}{Z_o}[e^{+j\beta l} - \Gamma_L e^{-j\beta l}]$

$V_o^+ = V_s e^{-j\beta l} \frac{Z_o}{Z_o(1+\Gamma_L e^{-2j\beta l}) + Z_s(1-\Gamma_L e^{-2j\beta l})}$

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 + 50Ω comparison.

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

$I(-l) \Rightarrow 15.4$mA

$= \boxed{111.7\text{mW}}$

$P_{eff} \approx \frac{P_{load}}{P_{src}} = \boxed{29.3\%}$

part g) ↑

g) All calcs are valid except power. Assume line loss of 0.1dB/cm.

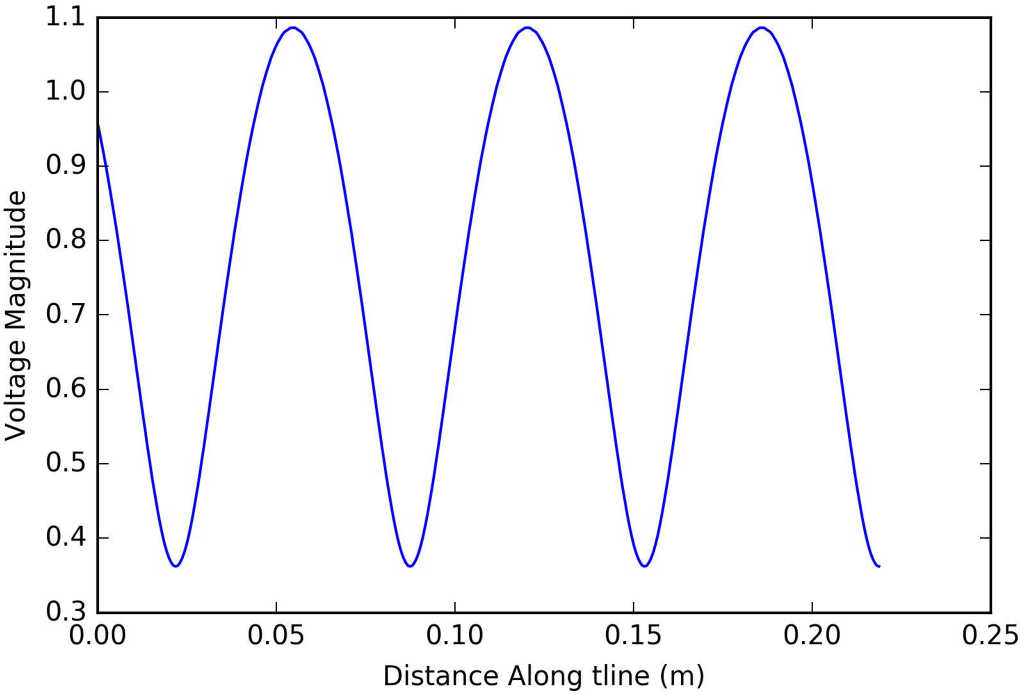
P_{src} is identical.

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

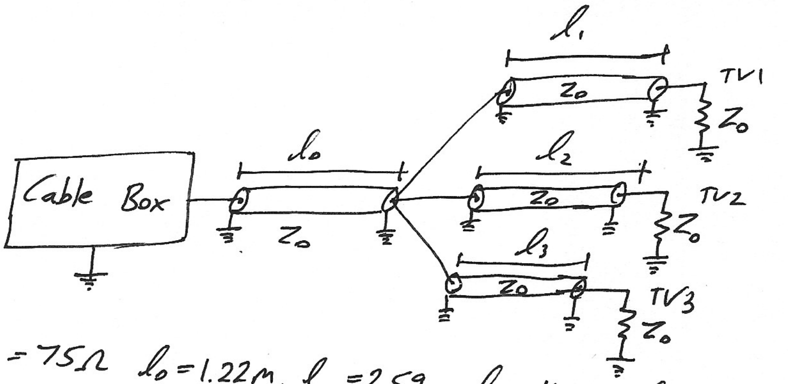
$= P_{load}(0.0806)$

$= \boxed{2.636\text{mW}}$

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


Voltage Magnitude
Distance Along tline (m)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.00
0.05
0.10
0.15
0.20
0.25

#6)



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

$C_p = 1\times10^8 m/s$

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

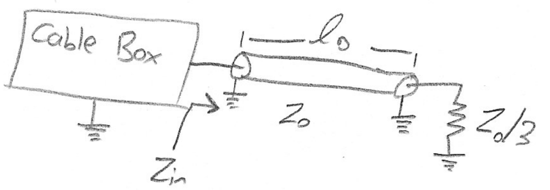
For a lossless line $Z_{in}(l) = Z_0 \cdot \frac{Z_L + jZ_0\tan(\beta l)}{Z_0 + jZ_L\tan(\beta l)}$ $\quad l_0 = 5.77\lambda$

where $\beta = \frac{2\pi}{\lambda}$ and $\lambda_0 = \frac{C_p}{f} = \frac{1\times10^8}{473e6} = 0.2114m$

$\beta = 29.7195$

$Z_{in}(-l_1) = Z_0 = Z_{in}(-l_2) = Z_{in}(-l_3)$ b/c $Z_L = Z_0$. $\quad \beta l = \frac{2\pi}{\lambda}\cdot 5.77\lambda$

Then we can model:



$Z_{in} = Z_0 \frac{1+\rho_L e^{-2j\beta l}}{1-\rho_L e^{-2j\beta l}}$ $\quad \rho_L = \frac{Z_L - Z_0}{Z_L + Z_0}$

$\boxed{Z_{in} = 200 - 66.3j\ \Omega}$

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

$dBm = 10\cdot\log_{10}(P_{mW}/1mW)$

$-30\,dBm = 1mW\cdot 10^{-30/10} = 0.001\,mW$ $\quad 10\cdot\log_{10}\left(\frac{0.000\bar{3}}{1mW}\right) = \boxed{-34.77dBm}$

c) Perf gets worse when TV1 is unplugged, why? How much power reaches TV2/3.

$l_1 = 2.59m = 12.25\lambda = \underbrace{N}_{\text{some integer}} + \frac{\lambda}{4}$ $\quad$ So l_1 looks like an AC short (impedance inverter).

No real power is allowed to go to TV 2/3 as a result.

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?

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

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

$3Z_0 = Z_0 + R$

$\boxed{2Z_0 = R}$ → if R is properly chosen, the cable box should see an impedance of Z_0.