ECE ECE145A (undergrad) and ECE218A (graduate)

Mid-Term Exam. November 9, 2021

Do not open exam until instructed to.

Open notes, open books, etc.

You have 1 hour and 15 minutes.

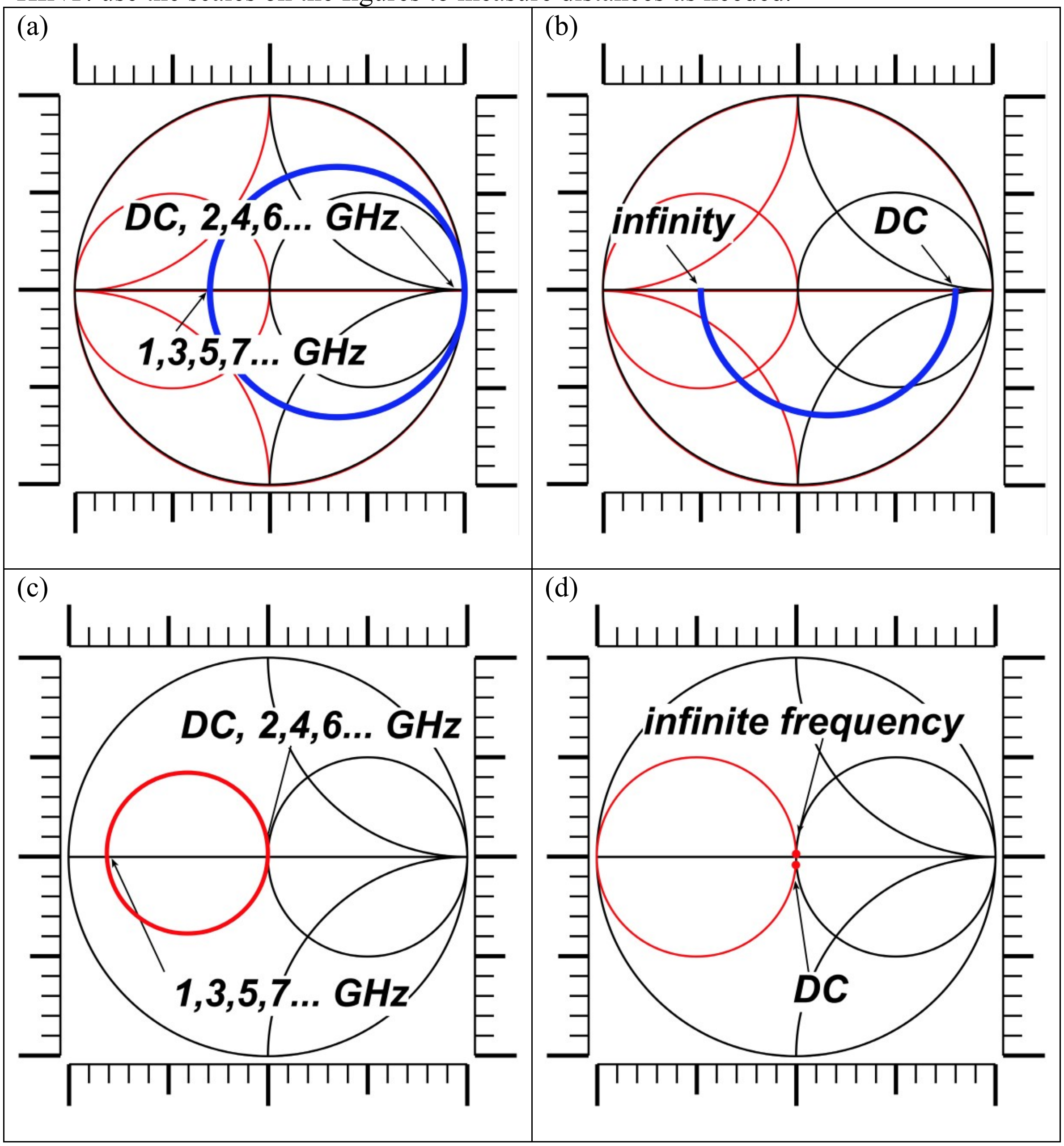
Use any and all reasonable approximations (5% accuracy is fine.) , ***AFTER STATING THEM.***

Problem	Points Received	Points Possible
1		15
2a		10
2b		7
2c		8
2d (218 only)		10 (218A only)
3a		5
3b		7.5
3c (218 only)		5 (218A only)
3d		7.5
4		15
5a		5
5b (218 only)		10
5c		10 (218A only)
6		10
total		100 (145), 125 (218A)

Name: solution

Problem 1, 15 points
The Smith Chart and Frequency-Dependent Impedances.

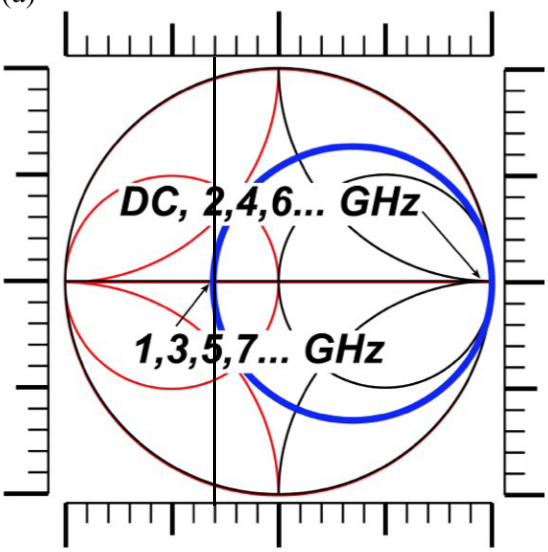
HINT: use the scales on the figures to measure distances as needed.



$@1\,\text{GHz},\ Z = 50\Omega \cdot \frac{1-0.3}{1+0.3} = 50\Omega \cdot \frac{0.7}{1.3} = \frac{35}{13}\Omega$

3pts

(a)



unfortunately, my mistake

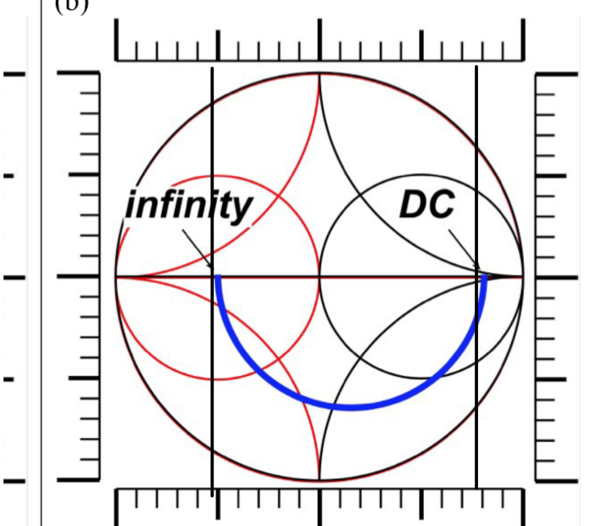
$\frac{35}{13}\Omega$

was not given as solution choice.

(c)

asure distances as needed.

(b)



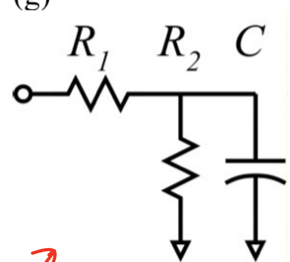
(d)

at DC, $Z = 50\Omega \frac{1+0.8}{1-0.8} = 50\Omega \frac{1.8}{0.2}$

$\Rightarrow 450\Omega$

$@\infty\,\text{Hz},\ Z = 50\Omega \cdot \frac{1-0.5}{1+0.5} = 16.7\Omega$

(g)

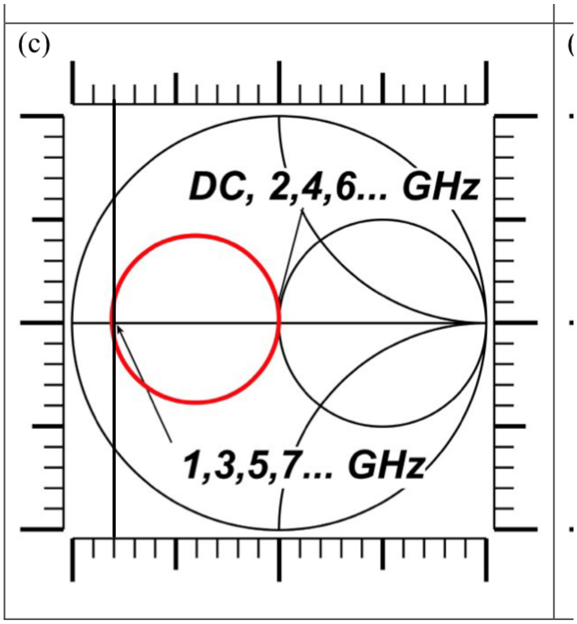


2pt

$R_1 = 16.7\Omega$ 1pt

$R_2 = 450 - 16.7\Omega$

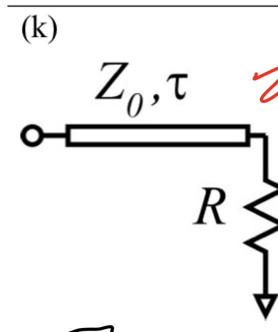
$\Rightarrow 433.3\Omega$ 1pt



$@ 1\,\text{GHz},\ Z = 50\Omega \dfrac{1-0.8}{1+0.8} = 50\Omega \dfrac{2}{18}$

$= \dfrac{50}{9}\Omega$

$@ \text{DC},\ Z = 50\Omega$



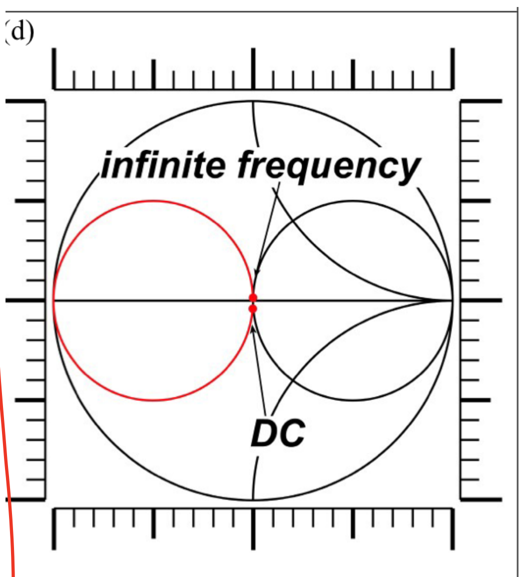
2pt

50Ω

$Z_0 = \sqrt{50\Omega \cdot \dfrac{50\Omega}{9}} = \dfrac{50}{3}\Omega$ 1pt

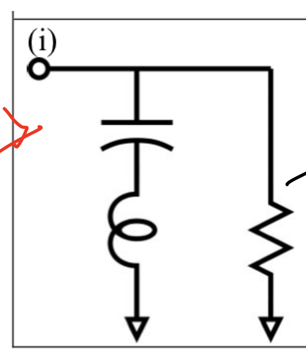
$\tau = 0.25\ \text{ns}$ ($\lambda/4$ @ 1 GHz)

1pt



50Ω @ DC and $f \to \infty$

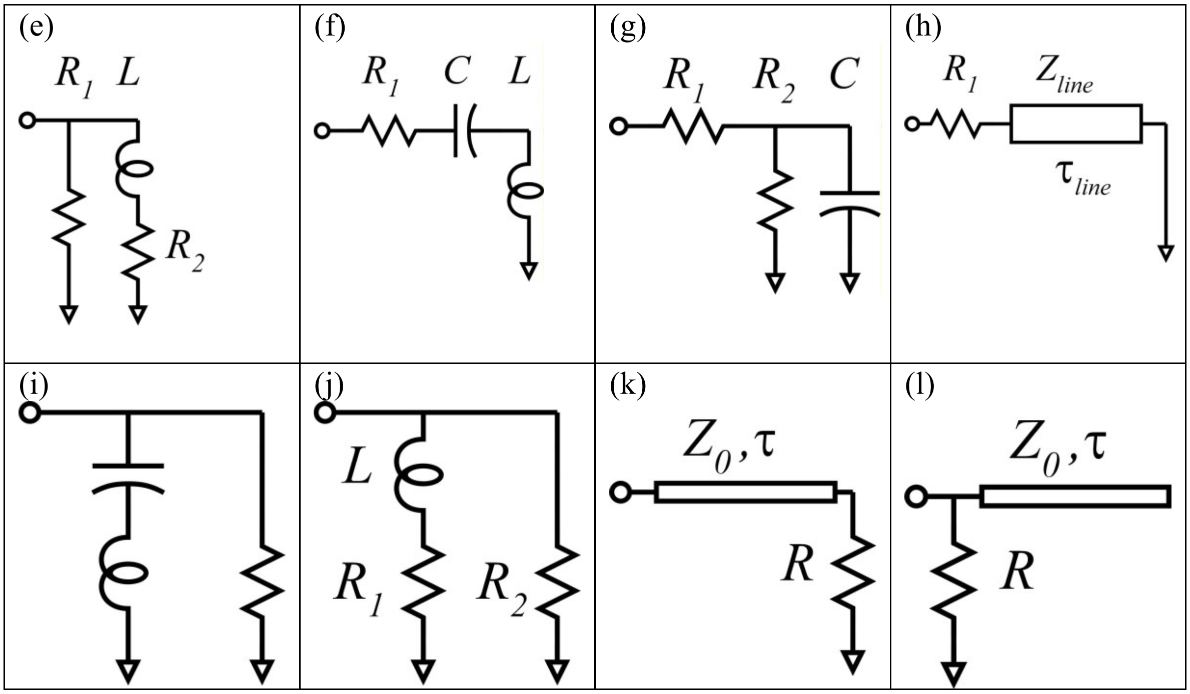
short ckt @ resonance.



2pt

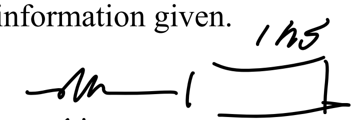
2pt

50Ω


(e)
R1 L
R2
(f)
R1 C L
(g)
R1 R2 C
(h)
R1 Zline
τline
(i)
(j)
L
R1 R2
(k)
Z0, τ
R
(l)
Z0, τ
R

.

First match each Smith Chart with each circuit. ***Then determine as many component values as is possible*** (RLC values, transmission line delays and characteristic impedances)...note that some values cannot be determined with the information given. The charts all use 50 Ohm normalization:



Smith chart (a). Circuit= J . solution not given
Component values: __________ , __________ , 35/.3 Ω ,

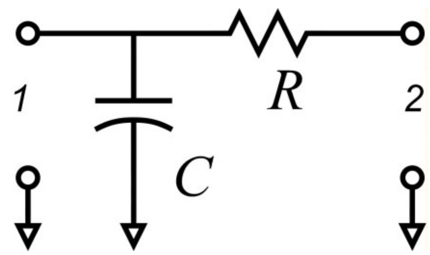
Smith chart (b). Circuit= G .
Component values: R1 = 16.7 Ω , R2 = 433.3 Ω ,

Smith chart (c). Circuit= K .
Component values: R = 50 Ω , $Z_0 = \frac{50}{3}$ Ω , τ = 0.25 ns.

Smith chart (d). Circuit= L .
Component values: R = 50 Ω , __________ , __________ ,

Problem 2, 25 points (ece145A), 35 points (ece218A)
2-port parameters and Transistor models

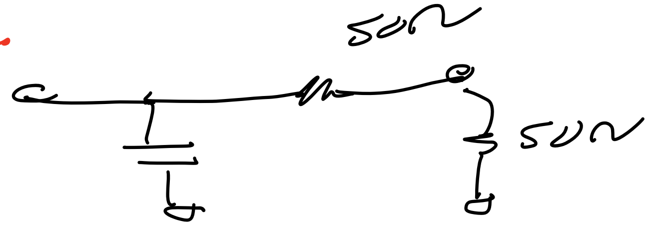
Part a, 10 points
For the network at the right, give the numerical values of S21 and S11. The reference Zo is 50 Ohms. The signal frequency is 1GHz, R=50Ohms, and C=3.18pF.



$$\text{at } f = 1\text{GHz}, \ \frac{1}{j\omega C} = -j\frac{1}{2\pi \cdot 1\text{GHz} \cdot 3.18\text{pF}} = -j\,50\Omega \ ; \ \omega C = 1/Z_0$$

S_{11}

2pt



$$Y_{in}\Big|_{Z_0 = Z_L} = \frac{1}{2Z_0} + j\omega C$$

2pt

$$S_{11} = \frac{Z_{in}/Z_0 - 1}{Z_{in}/Z_0 + 1}\Bigg|_{Z_L = Z_0} = \frac{1 - Y_{in}Z_0}{1 + Y_{in}Z_0}$$

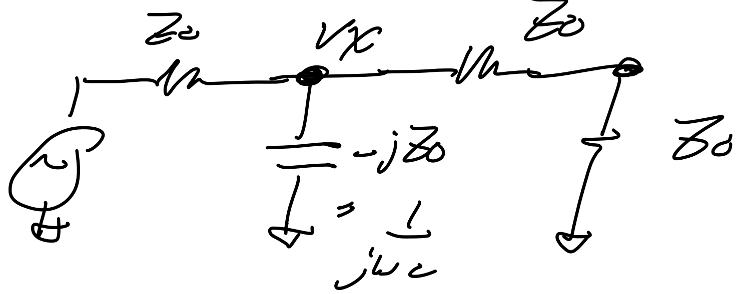
1pt

$$= \frac{1 - (1/2 + j\omega C Z_0)}{1 + (1/2 + j\omega C Z_0)}$$

$$= \frac{1/2 + j}{3/2 + j} \ ; \quad \|S_{11}\| = \sqrt{\frac{1 + 1/4}{1 + 9/4}} \approx 0.62$$

$$\angle S_{11} = \text{atan}(2) - \text{atan}(2/3) = 30^\circ$$

S_{21}



2pt

$$S_{21} = \left.\frac{2V_0}{V_{gen}}\right|_{Z_L = Z_0 = Z_g} = 2\frac{V_x}{V_{gen}} = \frac{2 Z_0 \,\|\, (-jZ_0)}{2Z_0 \,\|\, (-jZ_0) + Z_0}$$

2pt

$$= \frac{\dfrac{2Z_0(-jZ_0)}{2Z_0 + jZ_0}}{Z_0 + \dfrac{2Z_0(-jZ_0)}{2Z_0 + jZ_0}}$$

1pt.

$$= \frac{2Z_0(-jZ_0)}{-2Z_0(jZ_0) + Z_0(2Z_0 + jZ_0)}$$

$$= \frac{-2j}{-2j + 2 + j} = \frac{-2j}{2 - j}$$

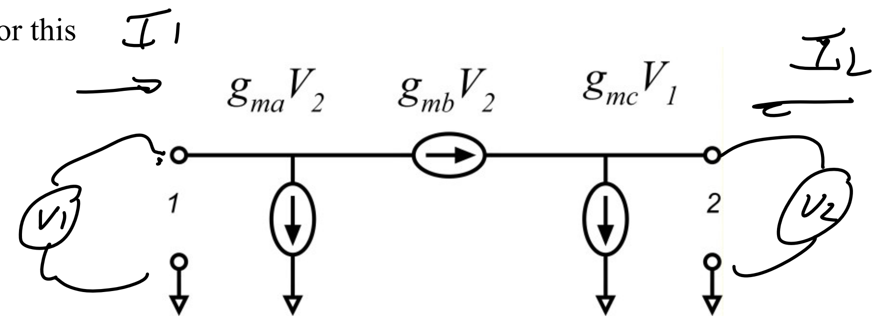
$$\| S_{21} \| = \sqrt{\frac{4}{5}} = 0.894$$

$$\angle S_{21} = -90^\circ + \operatorname{atan}(1/2) = -90^\circ + 26.6^\circ$$

$$= -63.4^\circ$$

Part b, 7 points

Compute the four Y parameters for this network



$$I_1 = (0\cdot)V_1 + (g_{ma} + g_{mb})V_2$$

$$I_2 = (g_{mc})V_1 + (-g_{mb})V_2$$

$$Y_{11} = 0\,S$$

$$Y_{12} = g_{ma} + g_{mb}$$

$$Y_{21} = g_{mc}$$

$$Y_{22} = -g_{mb}$$

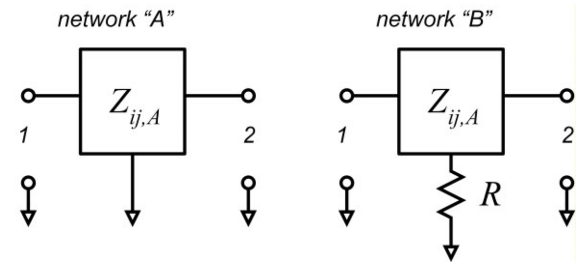
1.75pts each

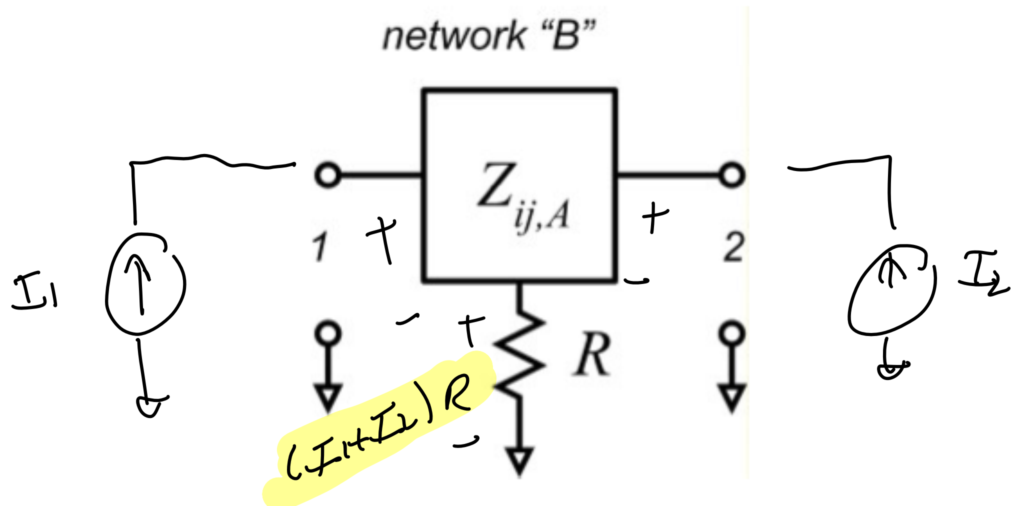
Part c, 8 points

Network "A" has

$$Z_A = \begin{bmatrix} Z_{11,A} & Z_{12A} \\ Z_{21,A} & Z_{22,A} \end{bmatrix}$$

Compute the Z parameters for network "B"





2 we have $\begin{bmatrix} V_a \\ V_b \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$

2 and
$$V_1 = V_a + (I_1+I_2)R$$
$$V_2 = V_b + (I_1+I_2)R$$

so

2 $Z_{ijB} = Z_{ijB} + R$

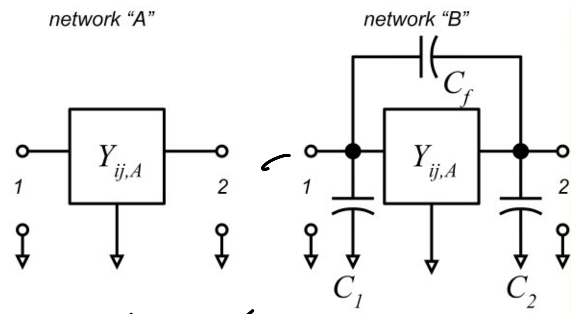
2 $$Z_{ijB} = \begin{bmatrix} Z_{11A}+R & Z_{12A}+R \\ Z_{21a}+R & Z_{22A}+R \end{bmatrix}$$

Part d, ***ECE218A students only*** 10 points

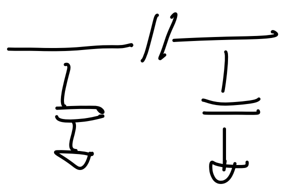
Network "A" has

$$Y_A = \begin{bmatrix} Y_{11,A} & Y_{12A} \\ Y_{21,A} & Y_{22,A} \end{bmatrix}$$

Compute the Y parameters for network "B"



4



This network has

$$Y = \begin{bmatrix} j\omega C_1 + j\omega C_f & -j\omega C_f \\ -j\omega C_f & j\omega C_f + j\omega C_2 \end{bmatrix}$$

3

The Y parameters of network B is the sum of this and network A.

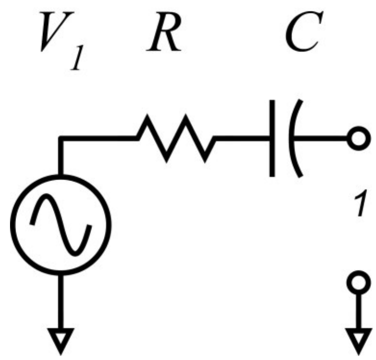
3

$$Y_{ij,B} = \begin{bmatrix} Y_{11A} + j\omega C_1 + j\omega C_f & Y_{12A} - j\omega C_f \\ Y_{21A} - j\omega C_f & Y_{22A} + j\omega C_f + j\omega C_2 \end{bmatrix}$$

Problem 3, 20 points (ECE145A), 25 points (ECE 218A)
Available source power relationships, lumped/distributed relationships.

Part a, 5 points
Vs is 2V RMS at 1GHz
Rs is 5 Ohms, C is 1.59 pF.

At 2GHz, what is the available signal power ? Draw the circuit diagram of a load network, with element values specified, that would, when connected to the source, absorb this amount of power from the generator



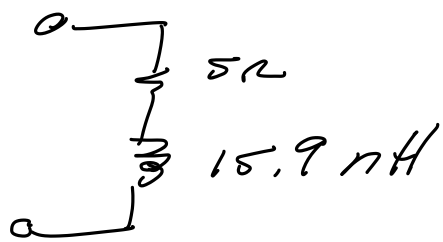
1 $1/j\omega C = -j100\Omega$

1 $P_{AVG} = \dfrac{(2V)^2}{4(5\Omega)} = \dfrac{4V^2}{4\cdot 5\Omega} = \dfrac{1}{5}W = 0.2W$

1 $Z_{L,opt} = Z_{gen}^{*} = 5\Omega + j100\Omega = 5 + j\omega L$

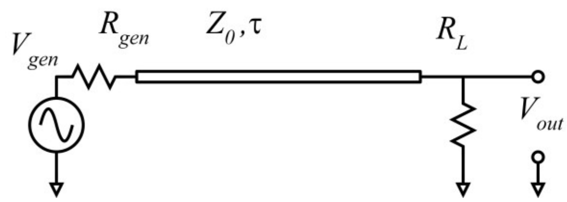
1 $L = \dfrac{100\Omega}{2\pi(1\,GHz)} = 15.9\,nH$

1



Part b, 7.5 points

In the network to the right, Rgen=RL=10 Million Ohms, the transmission, line has a 50 Ohm characteristics impedance, a length of 1 meter, and a velocity of $2 \cdot 10^8$ meters/second.



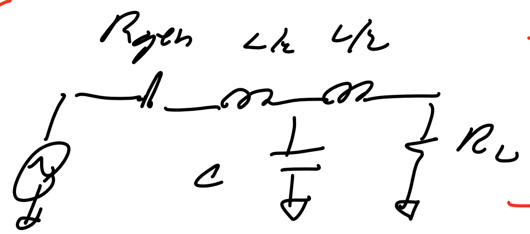
As frequency is increased from a few Hz into the MHz range, the magnitude of Vout/Vgen is observed to decrease.

Approximately at what frequency is Vout/Vgen at -3dB relative to its DC value?

$$\tau = \frac{1\,m}{2\cdot 10^8\,m/s} = \underline{5\,ns}$$ 1/2

If we use a T equivalent model;

1



$L = \tau Z_0 = 5ns \cdot 50\Omega = 250\,nH$ 1

$C = \tau / Z_0 = \frac{5ns}{50\Omega} = 100pF$ 1

Then

1 $\tau_{RC} = C \cdot R_L \| R_{gen} = 100pF \cdot 5M\Omega = 500 \cdot 10^{-6}$ sec $= 0.5ms$

much larger than τ. 1/2

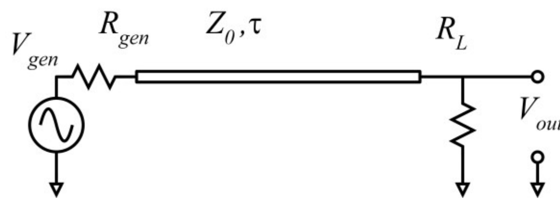
1 $\tau_{LR} = L/(R_{gen} + R_L) = 250nH/20M\Omega = 12.5 \cdot 10^{-15}$ sec

much smaller than τ. 1/2

1 So, we see an RC roll-off (3dB frequency) of $f_{3dB} \cong \frac{1}{2\pi\tau_{RC}} = \frac{0.159}{0.5ms} = 318Hz$.

Part c, 5 points (218A only)

In the network to the right, Rgen=RL=10 Million Ohms, the transmission, line has a 50 Ohm characteristics impedance, a length of 1 meter, and a velocity of $2 \cdot 10^8$ meters/second.



If the frequency is further increased, Vout will again increase. At what frequencies will Vout/Vgen be a maximum, and what value will Vout/Vgen then be ?

whenever the line is an even # of half-wavelengths, Zin of the line will be R_L, we will deliver (Vgen/2) to the input impedance of R_L, hence Vout must also be Vgen/2

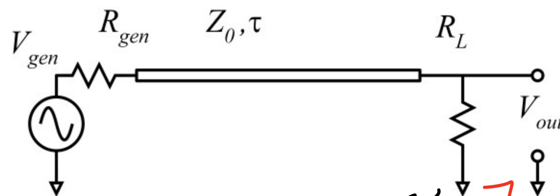
line is 5ns → one wavelength @ 200MHz

so @ N·100MHz (N = an integer)

Vout/Vgen is the DC value.

Part d, 7.5 points

In the network to the right, Rgen=RL=0.1 Ohms, the transmission, line has a 50 Ohm characteristics impedance, a length of 1 meter, and a velocity of $2 \cdot 10^{8}$ meters/second.



$L = 250nH$

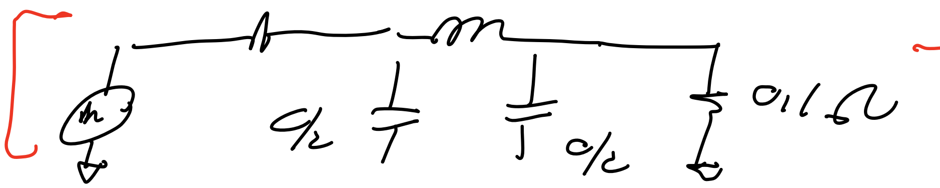
$C = 100pF$

from before (part b)

As frequency is increased from a few Hz into the MHz range, the magnitude of Vout/Vgen is observed to decrease.

L

Approximately at what frequency is Vout/Vgen at -3dB relative to its DC value? 0.1Ω



2 $\tau_{L/R} = \dfrac{250nH}{0.2\Omega} = 1250\,ns = 1.25\mu s \gg \tau$ 1/4

1 $\tau_{RC} = 100pF \cdot 0.05\Omega$ = very small $\ll \tau$ 1/4

2 $f_{3dB} = \dfrac{1}{2\pi\,\tau_{L/R}} = 127\,kHz$

Problem 4, 15 points
Impedance-matching exercise.

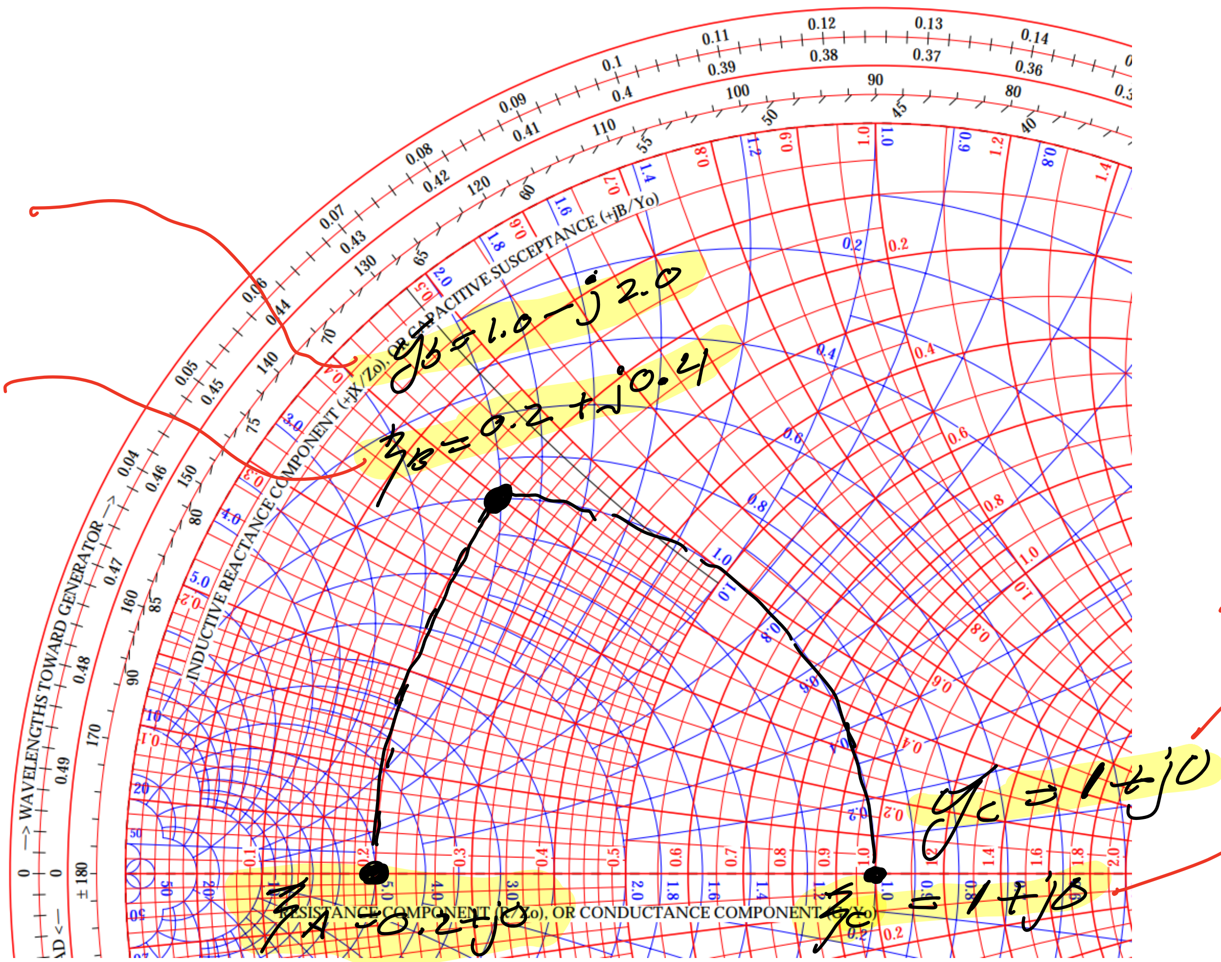
At 1GHz signal frequency, an antenna has an input impedance of 10+j0 Ohms. Design a matching network, using a series inductor and a shunt capacitor, which matches this impedance to 50 Ohms.

Give all element values. Either use a separate impedance-admittance chart , or use the attached one below..

1 $Z_A = 10 + j0$

$z_A = 0.2 + j0$

50 Ω chart



2 A → B add series element of

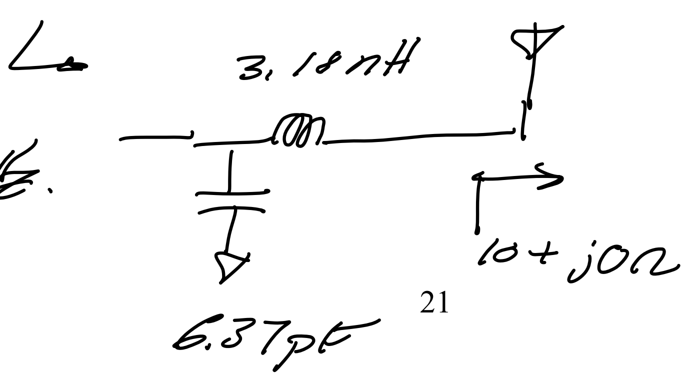
$\Delta x = \frac{\omega L}{Z_0} = 0.4 \rightarrow L = \frac{0.4 \cdot 50\Omega}{2\pi(1GHz)} = 3.18\ nH$

2 B → C adds parallel element of

$\Delta b = \omega C Z_0 = 2.0 \rightarrow C = \frac{2.0}{50\Omega\, 2\pi(1GHz)} = 6.37pF$

2 50Ω

@ 1GHz.



Problem 5, 15 points (ece145A), 25 points (218A)
Transmission-line properties.

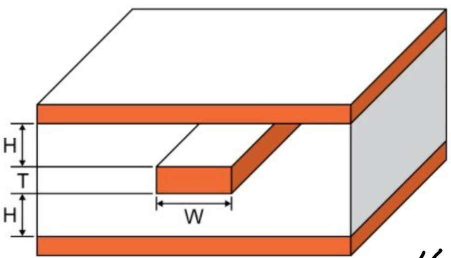
Part a, 5 points

Stripline is like microstrip, except that it has a dielectric layer, and a ground above the signal conductor as well as below it. If T is small, The characteristic impedance is, very approximately

$Z_0 = (\mu_0 / \varepsilon_r \varepsilon_0)^{1/2} H / (4H + 2W)$ ← Suspect!! Formula.

where $(\mu_0 / \varepsilon_0) = 377\Omega$, and ε_r is the insulator dielectric constant.

The velocity is $v = c / \varepsilon_r^{1/2}$, where c is the speed of light.



probably $\frac{H}{2H+2W}$ is closer

Suppose that the dielectric is Isola Astra, a commercial high-frequency printed circuit boar material which has ε_r=3.00, and that H is 75 micrometers.

For 50 Ohms characteristic impedance, what must be the conductor width W ? What is the wave velocity on the transmission line ?

If the conductor is 1 cm long ,what is the total line capacitance and inductance ?

$$Z_0 \cong \frac{377\Omega}{\sqrt{3}} \frac{H}{4H+2W} = 50\Omega$$

$$\frac{4H+2W}{H} = 4 + \frac{2W}{H} = \frac{377\Omega}{50\Omega}\frac{1}{\sqrt{3}} = 4.353$$

1

$$\frac{2W}{H} = 0.353 \rightarrow \frac{W}{H} = 0.1766 \rightarrow W = 13.2\mu m$$

1

$$v = \frac{3 \cdot 10^8}{\sqrt{3}} m/s = 1.73 \cdot 10^8 m/s.$$

1

$$\ell = 1cm = 10^{-2} m; \; \tau = 10^{-2} m / 1.73 \cdot 10^8 m/s = 57.7 ps$$

1

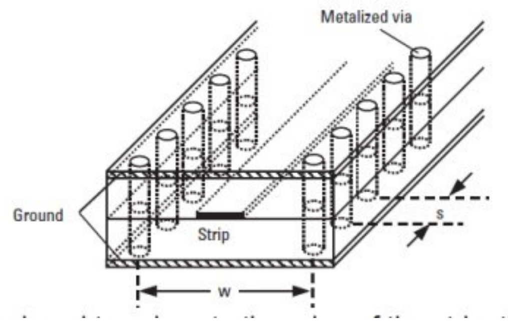
$$C = \tau / Z_0 = 57.7ps / 50\Omega = 1.15 pF$$

1

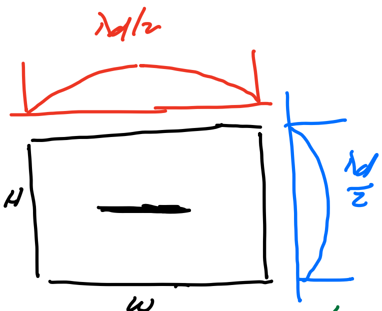
$$L = \tau Z_0 = 57.7ps \cdot 50\Omega = 2.89 nH.$$

Part b, 10 points (ece218A only)

Stripline is used with rows of closely-spaced vias between the top and bottom ground planes. These not only keep the two ground planes at the same potential, but also keep the stripline field confined to the region enclosed by the vias; the signal cannot radiate into the surrounding dielectric. Can you (1) estimate maximum allowable values of dielectric thickness H for a given signal frequency, and the maximum lateral distance W between vias ? (Assume S is so small as to be able to treat the row of vias as a continuous metal conductor.)



cross-section :



5 the enclosed cavity can support higher-order modes when either 2H or W is $\lambda_d/2$

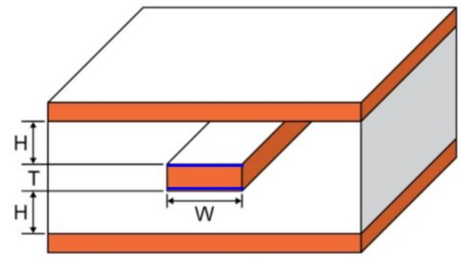
3 $\lambda_d/2 = \frac{c}{\sqrt{\epsilon_r}\, f}\,\frac{1}{2}$ where c is the speed of light.

1 maximum $H = \frac{1}{4}\frac{c}{\sqrt{\epsilon_r}\, f}$

1 maximum $W = \frac{1}{2}\frac{c}{\sqrt{\epsilon_r}}\, f$

Part c, 10 points

Let us now estimate skin-effect losses, including for simplicity only skin loss on the signal conductor, not the ground plane. In stripline, the current flows equally on both the top and bottom of the signal conductor, with skin depth $\delta = \sqrt{2/\omega\mu\sigma}$:, equal to 0.2 micrometers in gold at 100GHz. The conductivity of Gold is 4.11×10^{7} S/m. At 100GHz, how much loss would the line have, in dB, if 1cm long ?



$w = 13\,\mu m.$

2

$$\frac{R_{skin}}{length} = \frac{1}{2\cdot w\cdot \delta\cdot \sigma} = \frac{1}{2\,(13\mu m)(0.2\mu m)\,4.11\cdot 10^{7}\,S/m}$$

1

$$= 4.68\,k\Omega/m$$

2

$$\boxed{\alpha = \frac{R_{skin}}{Z_0\ell}} = \frac{4.68\,k\Omega/m}{50\Omega} = 93.6\,\frac{1}{meter}$$

2 3dB loss $\rightarrow e^{-\alpha\ell} = 1/\sqrt{2}$

1 $\alpha\ell = \ln\sqrt{2} = \underline{0.35}$

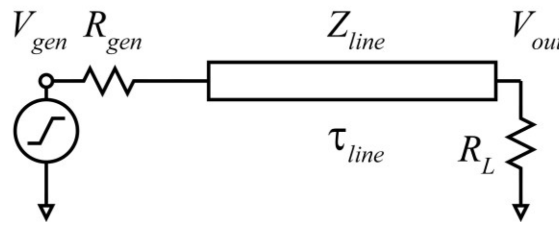
1 $\ell = \dfrac{0.35}{93.6\ {}^{1}/meter} = \underline{3.7\,mm}$

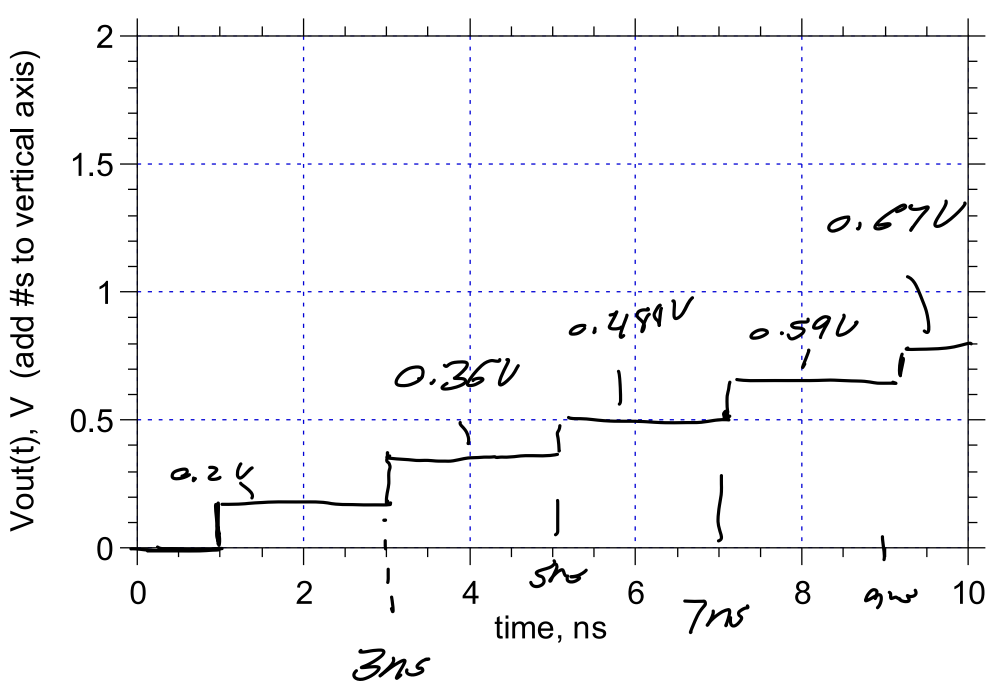
Problem 6, 10 points
Transmission lines in the time domain.
Vgen is a 1V step-function occurring at t=0 seconds. Zline is 50 Ohms. τ_{line} is 1 ns.

RL is (50/9) Ohms
Rgen is 0 Ohms.

Plot Vout (t) on the graph below.

Does the step response of the line appear inductive, capacitive, both, or neither ?





answers come from next page...

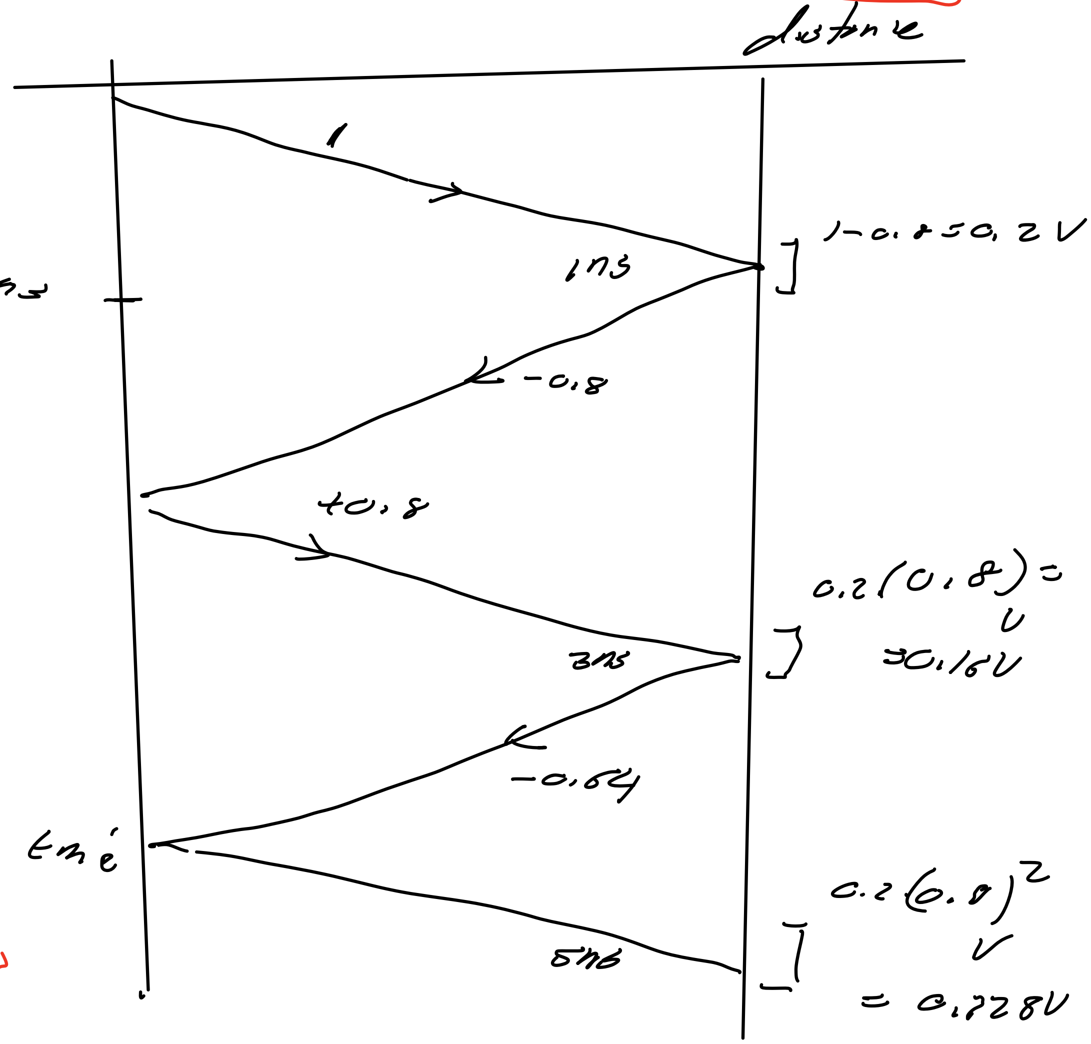
$\Gamma_S = -1$ 1/2 , $\Gamma_L = \frac{1/9 - 1}{1/9 + 1} = \frac{-8/9}{10/9} = \frac{-8}{10}$

1 $= -0.8$

$\Gamma_S \Gamma_L = 0.8$

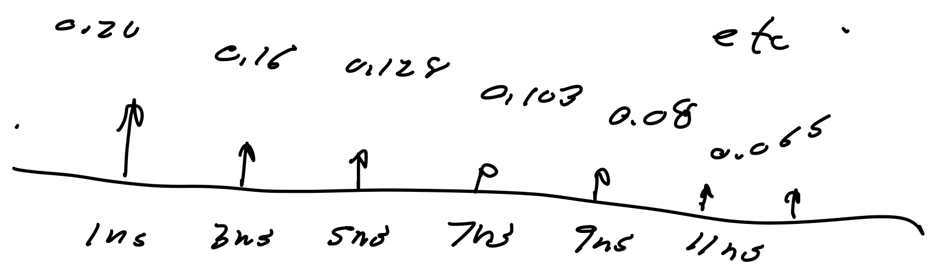
1/2 $T_S = 1$

3



2.5

Impulse response is:



step Response is:

2.5