

$$2.2) R = 4.0 \, \Omega/m, G = 0.02 \, S/m, L = 0.5 \, \mu H/m, C = 200 \, pF/m$$

$$f = 800 \, MHz, l = 30 \, cm$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = 0.54 + j 50.268 \, m^{-1}$$

$$Z_0 = \sqrt{(R + j\omega L)/(G + j\omega C)} = 49.99 + j 0.46 \, \Omega$$

$$\text{attenuation} = 20 \log_{10}(e^{\gamma l}) = 20 \log_{10}(e^{(0.54)(0.3)}) = 1.4 \, dB$$

$$\text{Lossless: } R = G = 0$$

$$\beta = \omega \sqrt{LC} = 50.27 \, rad/m$$

$$Z_0 = \sqrt{L/C} = 50.0 \, \Omega$$

$$2.3) a = \frac{0.91 \, mm}{2}, b = \frac{3.02 \, mm}{2}, f = 10^9 \, Hz$$

$$L = \frac{\mu_0}{2\pi} \ln\left(\frac{b}{a}\right) = 2.4 \times 10^{-7} \, H/m, C = \frac{2\pi\epsilon_0\epsilon_r}{\ln(b/a)} = 9.64 \times 10^{-11} \, F/m$$

$$R_s = \sqrt{\frac{\omega\mu}{2\sigma}} = 0.00825 \, \Omega, R = \frac{R_s}{2\pi} \left(\frac{1}{a} + \frac{1}{b}\right) = 3.76 \frac{\Omega}{m}, G = \frac{2\pi\omega\epsilon_0\epsilon_r \tan\delta}{\ln(b/a)} = 2.42 \times 10^{-4} \frac{S}{m}$$

since $\frac{G}{\omega C} \ll 1$ and $\frac{R}{\omega L} \ll 1$ can make low-loss approximation.

$$Z_0 = \sqrt{L/C} = 49.9 \, \Omega, \alpha \approx \frac{1}{2} \left(\frac{R}{Z_0} + G Z_0 \right) = 0.044 \, np/m = 0.38 \, dB/m$$

Manufacturers Specs: Attenuation @ 1000 MHz = 12 dB/100 ft = 39.27 dB/100 m = 0.393 dB/m

$$Z_0 = 50 \, \Omega$$

Difference due to braided outer conductor.

2.4)

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%% Constants
a = 0.91/2000;
b = 3.02/2000;

sigma = 5.813*10^7;
mu0 = 4*pi*10^-7;
epsilon0 = 8.85*10^-12;
er = 2.1;
d = 0.0004;

%inner radius
%outer radius

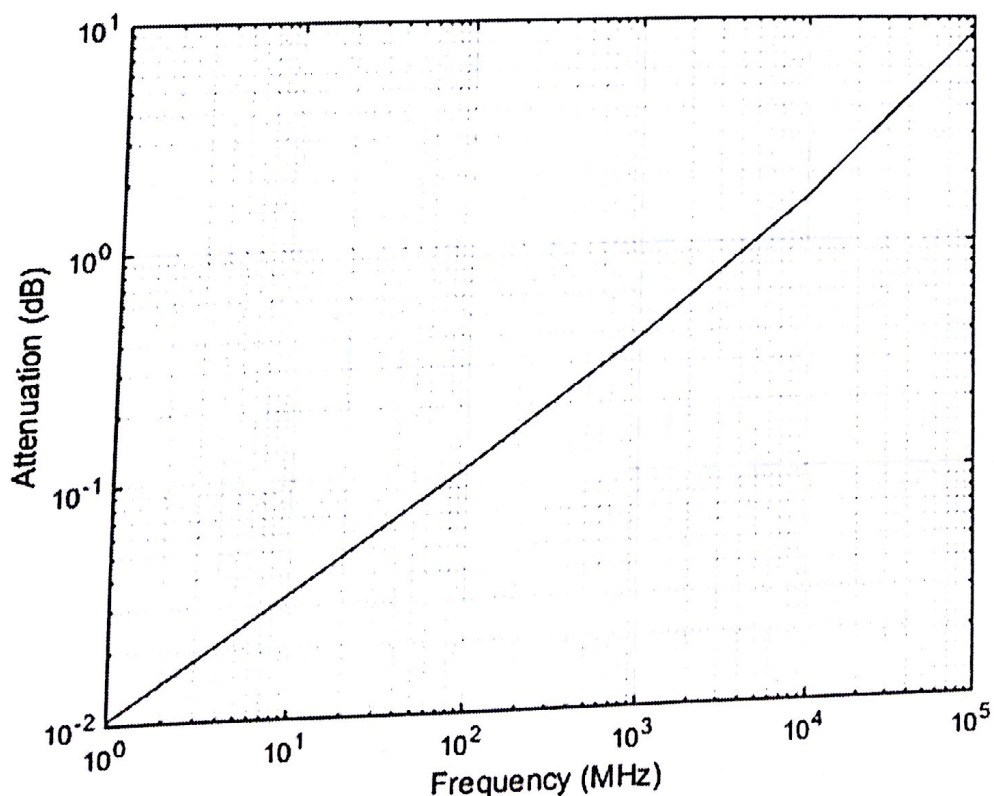
%copper conductivity
%vacuum permeability
%vacuum permittivity
%relative permittivity

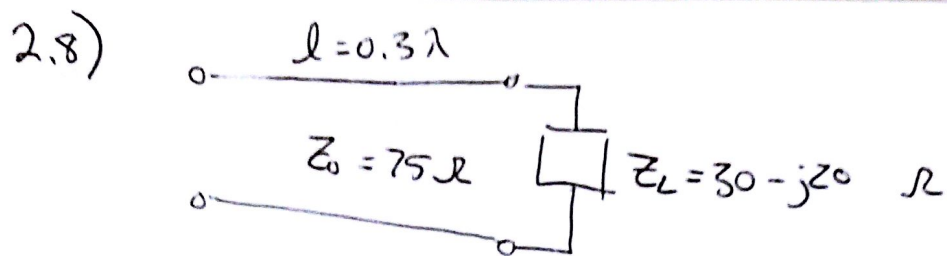
%%
f = 1e6:1e6:1e11;
w = 2*pi*f;

L = 2.4e-7;
C = 9.64e-11;
Rs = sqrt(w*mu0/(2*sigma));
R = Rs/(2*pi) * (1/a + 1/b);
G = 2*pi*2*pi*f*er*epsilon0*tan(d) / log(b/a);
G1=(2*pi*2*pi*f*2.1*epsilon0*tan(.0004))/log(b/a);

Z0 = sqrt(L/C);
alpha_np = 1/2 * (R/Z0 + G1*Z0);
alpha_dB = 8.686 * alpha_np;

figure()
loglog(f/1e6,alpha_dB)
xlabel('Frequency (MHz)');
ylabel('Attenuation (dB)');
grid on
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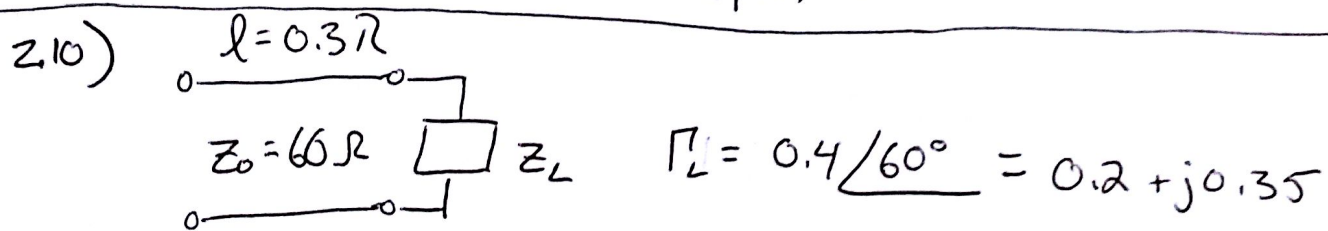
$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} = -0.38 - j0.26$$

$$SWR = \frac{1 + |\Gamma_L|}{1 - |\Gamma_L|} = 2.71$$

$$\beta l = \frac{2\pi}{\lambda} (0.3\lambda) = 0.6\pi$$

$$\Gamma_{in} = \Gamma(l) = \Gamma_L e^{-2j\beta l} = 0.46 - j0.013$$

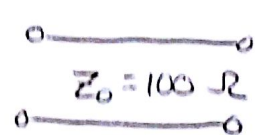
$$Z_{in} = Z_0 \left[\frac{Z_L + j Z_0 \tan(\beta l)}{Z_0 + j Z_L \tan(\beta l)} \right] = 203 - j5.2 \Omega$$



$$A) Z_L = Z_0 \frac{1 + \Gamma_L}{1 - \Gamma_L} = 60 \frac{1.2 + j0.35}{0.8 - j0.35} = 66.3 + j54.7 \Omega$$

$$B) \Gamma_{in} = \Gamma_L e^{-2j\beta l} = 0.4 \angle 60^\circ - 216^\circ = 0.4 \angle -156^\circ$$

$$C) Z_{in} = Z_0 \left[\frac{Z_L + j Z_0 \tan(\beta l)}{Z_0 + j Z_L \tan(\beta l)} \right] = 26.7 - j10.3$$

2.11)  $Z_0 = 100 \Omega$ $\epsilon_r = 1.65$, $f = 2.5 \text{ GHz}$

Cap: $Z_{in} = \frac{-j}{\omega C} = -j 12.73 \Omega$, $C = 5 \text{ pF}$
 $Z_{oc} = -j Z_0 \tan(\beta l) = -j 12.73 \Omega$

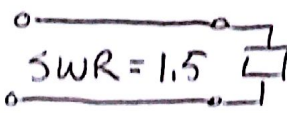
$\Rightarrow \tan(\beta l) = 7.86 \Rightarrow \beta l = 82.75^\circ$

$R_0 = \frac{c}{f} = 0.12$, $\beta = \frac{2\pi \sqrt{\epsilon_r}}{\lambda_0} = \frac{3854^\circ}{\text{m}} \Rightarrow l = 0.0215 \text{ m}$

Ind: $Z_{in} = j\omega L = j 78.5 \Omega$, $L = 5 \text{ nH}$

$Z_{oc} = -j Z_0 \tan(\beta l)$

$\Rightarrow \tan(\beta l) = -1.27 \Rightarrow \beta l = 128.1 \Rightarrow l = 0.0332 \text{ m}$

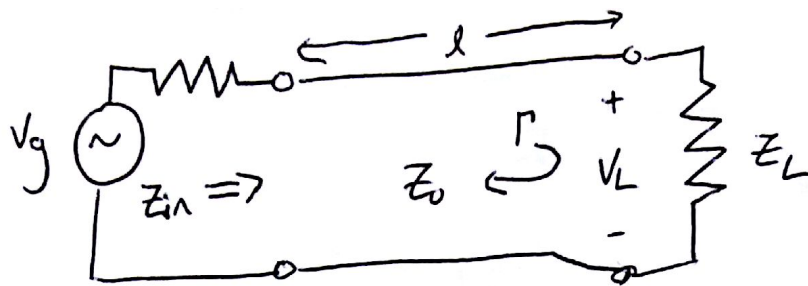
2.12)  $SWR = 1.5$, $Z_L = 100 \Omega$

$|\Gamma| = \frac{SWR - 1}{SWR + 1} = 0.2 = \left| \frac{Z_L - Z_0}{Z_L + Z_0} \right| = \left| \frac{100 - Z_0}{100 + Z_0} \right|$

case 1: $\frac{100 - Z_0}{100 + Z_0} = 0.2 \Rightarrow Z_0 = 66.7 \Omega$

case 2: $\frac{100 - Z_0}{100 + Z_0} = -0.2 \Rightarrow Z_0 = 150 \Omega$

2.16)



$$V_g = 15 \text{ V rms}, Z_g = 75 \Omega, Z_0 = 75 \Omega, Z_L = 60 - j40 \Omega$$

$$l = 0.7 \lambda$$

A)

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{-15 - j40}{135 - j40} = -0.021 - j0.302$$

Based on

$$P_L = P_{inc} (1 - |\Gamma|^2)$$

Only for lossless lines.

$$P_L = \frac{V_g^2}{4} \frac{1 - |\Gamma|^2}{Z_0} = 0.681 \text{ W}$$

B)

$$Z_{in} = \frac{Z_0 (Z_L + jZ_0 \tan(\beta l))}{Z_0 + jZ_L \tan(\beta l)} = 48.2 + j27.2 \Omega$$

Based on

$$P_L = P_{in} = |I_{in}|^2 R_{in}$$

Only for lossless lines.

$$P_L = \left| \frac{V_g}{Z_g + Z_{in}} \right|^2 \text{Re}\{Z_{in}\} = 0.681 \text{ W}$$

C)

$$V(z) = V^+ (e^{-j\beta z} + \Gamma e^{j\beta z}) \Rightarrow V_L = V(0) = (1 + \Gamma) V^+, V^+ = \frac{V_g}{2} = 7.5 \text{ V}$$

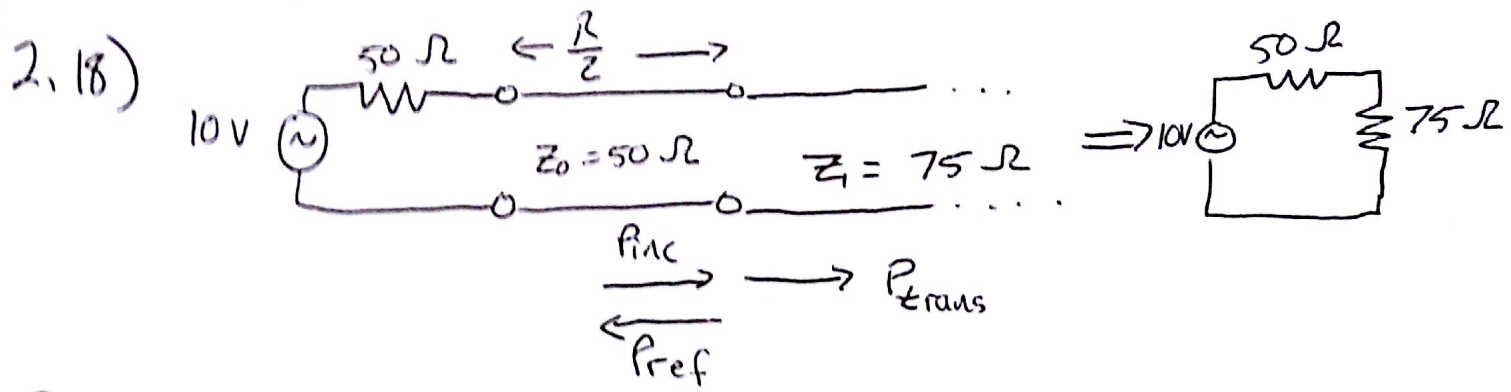
$$V_L = 7.34 - j2.27 = 7.68 \angle -17^\circ$$

Based on

$$P_L = |I_L|^2 R_L$$

Works on lossy lines

$$P_L = \left| \frac{V_L}{Z_L} \right|^2 \text{Re}\{Z_L\} = 0.681 \text{ W}$$



$$P_{trans} = \frac{1}{2} (75) \left(\frac{10}{50+75} \right)^2 = 0.24 \text{ W}$$

$$P_{inc} = \frac{1}{2} (50) \left(\frac{10}{50+50} \right)^2 = 0.25 \text{ W}$$

$$P_{ref} = P_{inc} \left| \Gamma \right|^2 = 0.25 \left| \frac{75-50}{75+50} \right|^2 = 0.01 \text{ W}$$

$$P_{inc} = P_{trans} + P_{ref}$$

$$\text{Power from source} = \frac{1}{2} (50+75) \left(\frac{10}{50+75} \right)^2 = 0.4 \text{ W}$$

$$\text{Power}_{50 \Omega} = \frac{1}{2} 50 \left(\frac{10}{50+75} \right)^2 = 0.16 \text{ W} \leftarrow \text{power dissipated in } 50 \Omega \text{ resistor}$$

$$P_{source} = P_{50 \Omega} + P_{trans}$$

2.20

$Z_0 = 50 \Omega$, $Z_L = 60 + j50 \Omega$, $l = 0.4 \lambda$, $\Gamma = 1.2 j 1.0$

The Complete Smith Chart

Black Magic Design

$Y_L = 0.49 - j0.41$

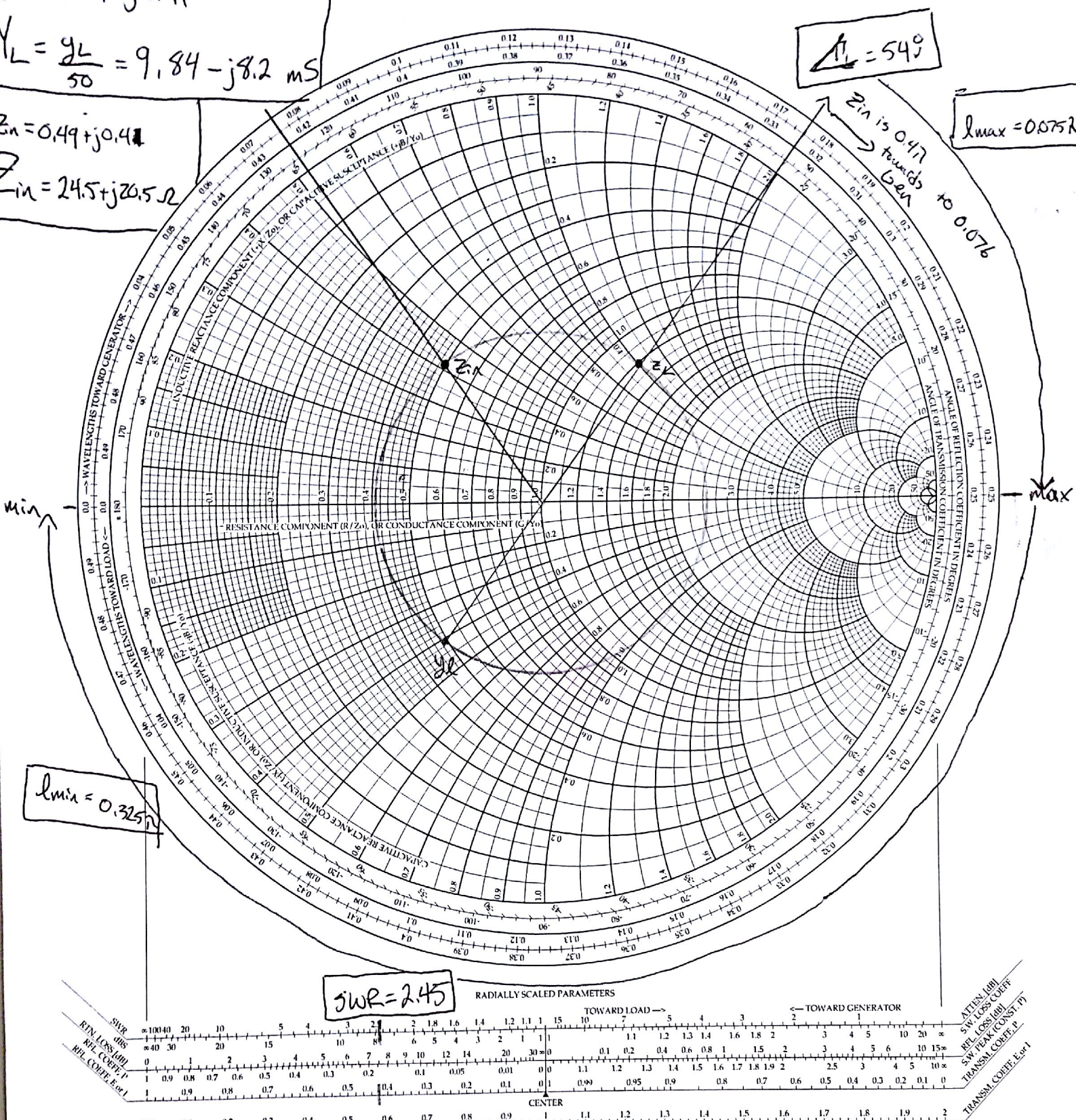
$Y_L = \frac{Y_L}{50} = 9.84 - j8.2 \text{ mS}$

$Z_L = 0.49 + j0.41$

$Z_{in} = 24.5 + j20.5 \Omega$

$\angle \Gamma = 54^\circ$

$l_{max} = 0.075 \lambda$



$SWR = 2.45$

$|\Gamma| = 0.42$