Fundamentals of Electromagnetics for Wireless Applications

Final Project by Mason Nixon

ELEC 3320 MATLAB Project
Due 12/7/09 F

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You are expected to develop your own MATLAB code for this project. Teamwork is unacceptable.

If a constant $|\Gamma_L|$ circle for transmission line terminated in a mismatched load is drawn on a Smith chart, it will intersect the $1 \pm jx$ circle at two points. Thus, there are two fundamental solutions to a stub matching problem. The magnitude of the reflection coefficient $|\Gamma|$ looking into the matching network will ideally be zero at the design frequency. Your task is to plot and compare $|\Gamma|$ vs. frequency for the two fundamental matching networks realized in microstrip. Your microstrip substrate has perfect conductors sandwiching a lossless dielectric.

Given:

Substrate relative permittivity ε_r = 2.0

Substrate height h = 30 mils

Characteristic impedance Z_o = 50 Ω

Load impedance Z_L = 80 + j40 Ω

Type of shunt stub: short

Design frequency: 2 GHz

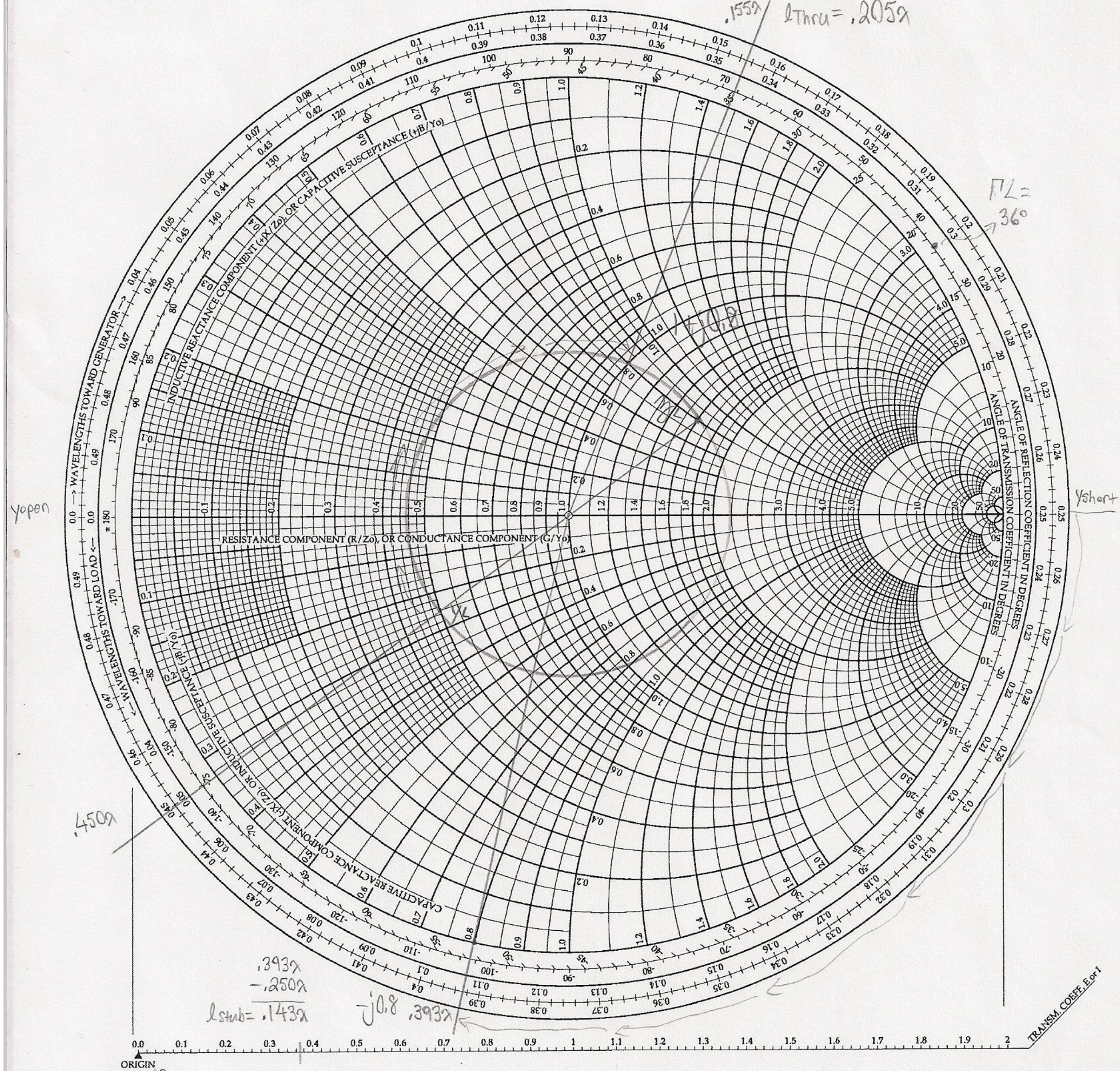
Frequency range for plot: 1 – 3 GHz

Note that you can solve for the matching network in terms of wavelength, but to find the actual lengths you must design 50 Ω microstrip for your given circuit board material and determine guide wavelength at your design frequency.

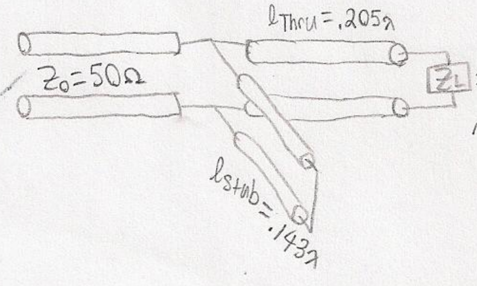
1st solution

$1+j.8$

$$
\begin{array}{r}
.500\lambda \\
-\ .450\lambda \\
+\ .155\lambda \\
\hline
\ell_{Thru} = .205\lambda
\end{array}
$$



$\Gamma = .37e^{j36°}$



$Z_L = 80 + j40\Omega$

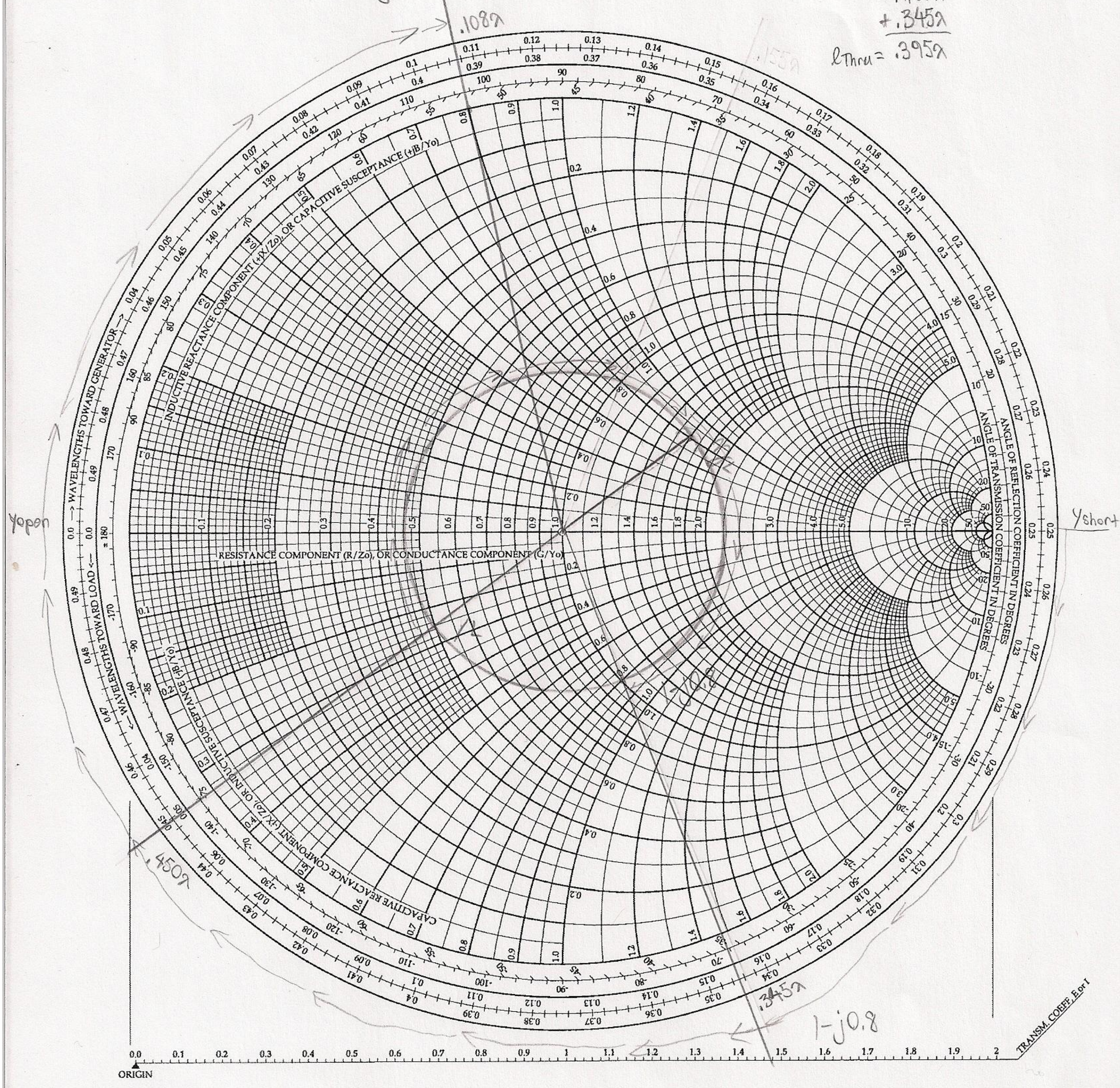
$z_L = \frac{Z_L}{Z_0} = 1.6 + j0.8$

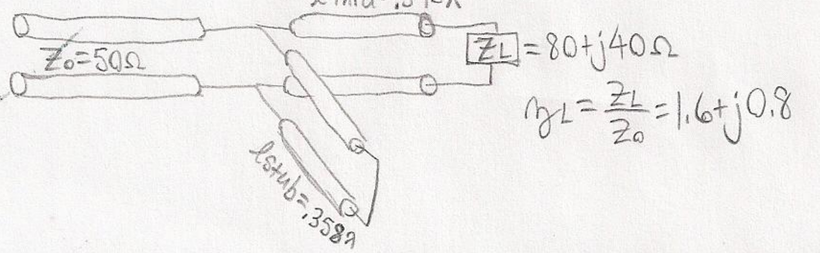
$y_L = 0.5 - j.25$

2nd solution

$$\begin{array}{r} .500\lambda \\ -.250\lambda \\ +.108\lambda \\ \hline l_{stub} = .358\lambda \end{array}$$

$$\begin{array}{r} .500\lambda \\ -.450\lambda \\ +.345\lambda \\ \hline l_{Thru} = .395\lambda \end{array}$$





$Z_L = 80 + j40\,\Omega$

$z_L = \frac{Z_L}{Z_o} = 1.6 + j0.8$

MATLAB code:

```
%   Microstrip Design
%
%     Problem statement: If a constant |ΓL| circle for transmission line
%     terminated in a mismatched load id drawn on a Smith Chart, it will
%     intersect the 1 ± jx circle at two points. Thus, there are two
%     fundamental solutions to a stub matching problem. The magnitude of the
%     reflection coefficient |Γ| looking into the matching network will
%     ideally be zero at the design frequency. Your task is to plot and
%     compare |Γ| Vs. frequency for the two fundamental matching networks
%     realized in Microstrip. Your Microstrip substrate has perfect
%     conductors sandwiching a lossless dielectric.
%
%     The following program determines the Microstrip design parameters and
%     also solves for and plots the reflection coefficient looking into the
%     matching network vs. frequency.
%
%   Nixon, 12/02/09
%
%   Variables:
%   w           line width
%   h           substrate thickness
%   er          substrate relative permittivity
%   eeff        effective relative permittivity
%   up          propagation velocity (m/s)
%   Zo          characteristic impedance (ohms)
%   ZL          load impedance (ohms)
%   A,B         calculation variables
%   smallratio  calc variable
%   bigratio    calc variable
%   lamdaG      guide wavelength (m)
%   beta        (rad/m)
%   lthru1&2m   Through length of T-line (m)
%   lstub1&2m   Stub length of T-line (m)
%   Zthru1&2    The input impedance of the through line of solution 1&2
%   Zstub1&2    The input impedance of the stub line of solution 1&2
%   Ztot1&2     The parallel combination of the input impedances of the
%               through line and stub line for solutions 1&2
%   Ref1&2      The reflection coefficents of soltuion 1&2
%
clc         %clears the command window
clear       %clears variables

%Define constants and given values
c=3e8;
Zo=50;
ZL=80+i*40;
h=30; %in mils
er=2.0;
f=(1e9:.01e9:3e9); %Range of frequencies to plot in GHz
fd=2e9; %The design frequency in GHz

%T-line lengths in terms of guide wavelength calculated from Smith Chart
lthru1=(.206);
```

```
lstub1=(.143);
lthru2=(.395);
lstub2=(.358);

%Perform Microstrip Calculations
%Borrowed with permission from Dr. Stu Wentworth
A=(Zo/60)*sqrt((er+1)/2)+((er-1)/(er+1))*(0.23+0.11/er);
B=377*pi/(2*Zo*sqrt(er));
smallratio=8*exp(A)/(exp(2*A)-2);
bigratio=(2/pi)*(B-1-log(2*B-1)+((er-1)/(2*er))*(log(B-1)+0.39-0.61/er));
if smallratio<=2
    w=smallratio*h;
end
if bigratio>=2
    w=bigratio*h;
end

eeff=((er+1)/2)+(er-1)/(2*sqrt(1+12*h/w));
up=2.998e8/sqrt(eeff);

%Reflection Coefficient
lamdaG=(c/(fd*sqrt(eeff)));
beta=((2.*pi.*f)./c).*sqrt(eeff);
lthru1m=(lthru1*lamdaG);
lstub1m=(lstub1*lamdaG);
lthru2m=(lthru2*lamdaG);
lstub2m=(lstub2*lamdaG);

%Display results
disp('Microstrip dimensions:')
disp(['w = ' num2str(w) ' mils'])
disp(['h = ' num2str(h) ' mils'])
disp(['lthru1 = ' num2str(lthru1m/25.4e-6) ' mils'])
disp(['lstub1 = ' num2str(lstub1m/25.4e-6) ' mils'])
disp(['lthru2 = ' num2str(lthru2m/25.4e-6) ' mils'])
disp(['lstub2 = ' num2str(lstub2m/25.4e-6) ' mils'])

Zthru1=(Zo.*((ZL+i.*Zo.*tan(beta.*lthru1m))./(Zo+i.*ZL.*tan(beta.*lthru1m))))
;
Zstub1=(i.*Zo.*tan(beta.*lstub1m));
Zthru2=(Zo.*((ZL+i.*Zo.*tan(beta.*lthru2m))./(Zo+i.*ZL.*tan(beta.*lthru2m))))
;
Zstub2=(i.*Zo.*tan(beta.*lstub2m));

Ztot1=((Zthru1.*Zstub1)./(Zthru1+Zstub1));
Ztot2=((Zthru2.*Zstub2)./(Zthru2+Zstub2));

Ref1=abs((Ztot1-Zo)./(Ztot1+Zo));
Ref2=abs((Ztot2-Zo)./(Ztot2+Zo));

plot(f,Ref1,'-+',f,Ref2,'-*')
legend('Solution #1','Solution #2','Location','SouthEast')
title('Reflection Coefficient Vs. Frequency (GHz)')
xlabel('Frequency (GHz)')
ylabel('Reflection Coefficient')
grid on
```

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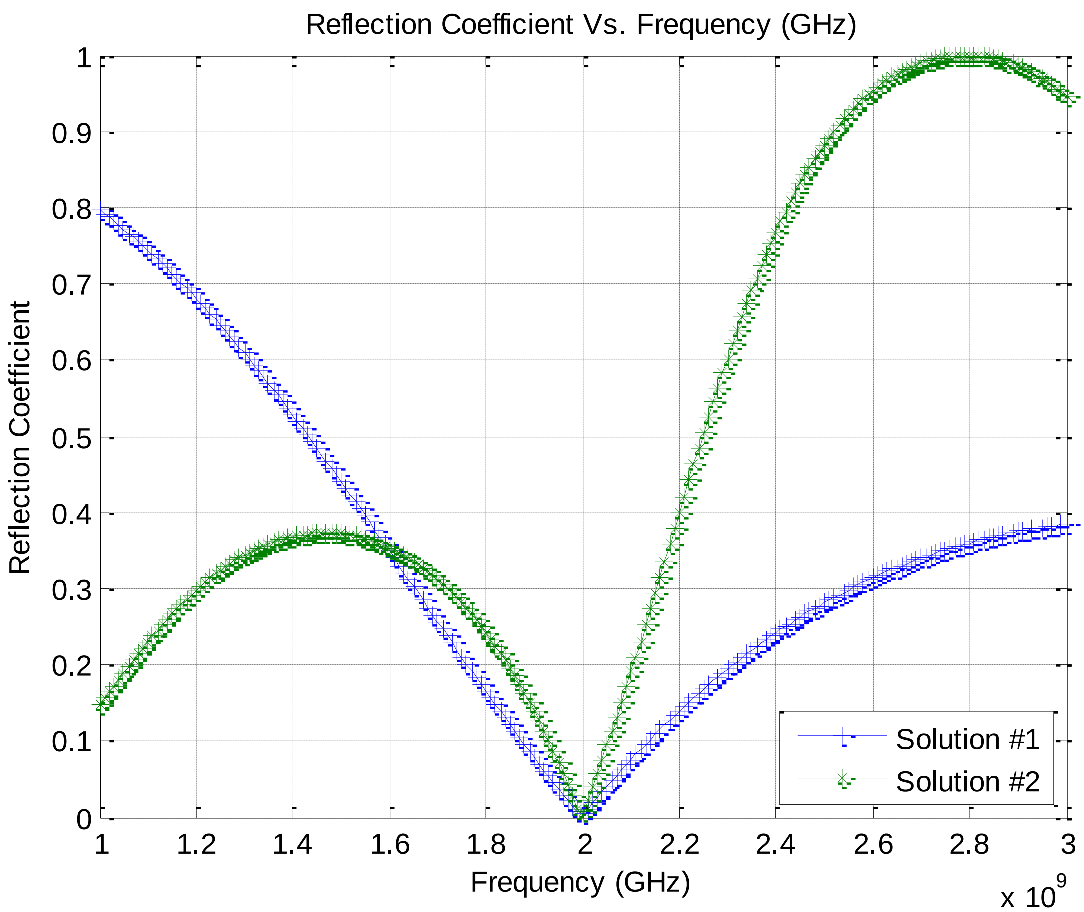
MATLAB output:

```
Microstrip dimensions:
w = 98.1435 mils
h = 30 mils
lthru1 = 924.5355 mils
lstub1 = 641.7892 mils
lthru2 = 1772.7744 mils
lstub2 = 1606.7171 mils
>>
```



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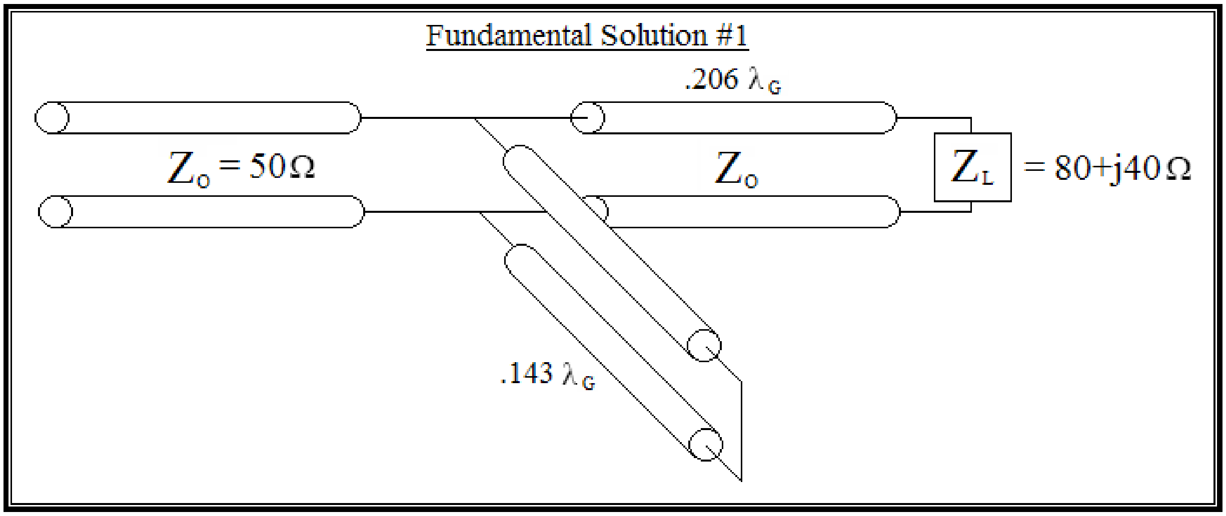
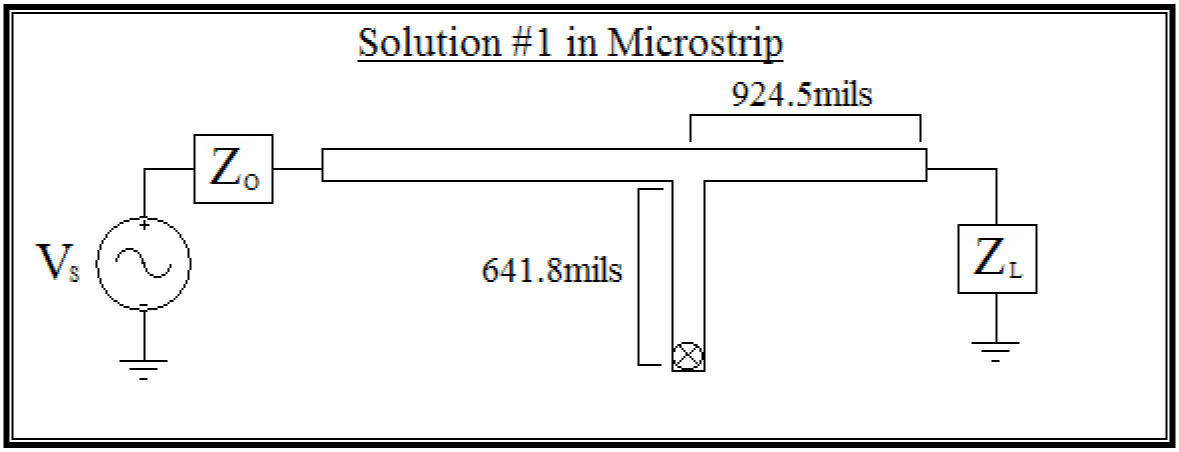
Designs Realized in Microstrip





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Designs Realized in Microstrip

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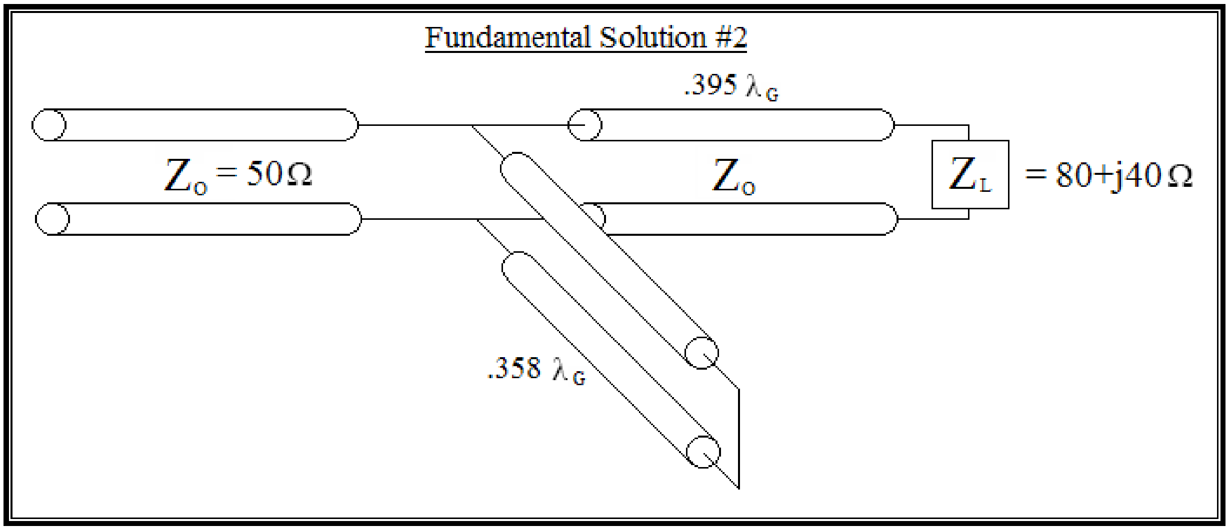

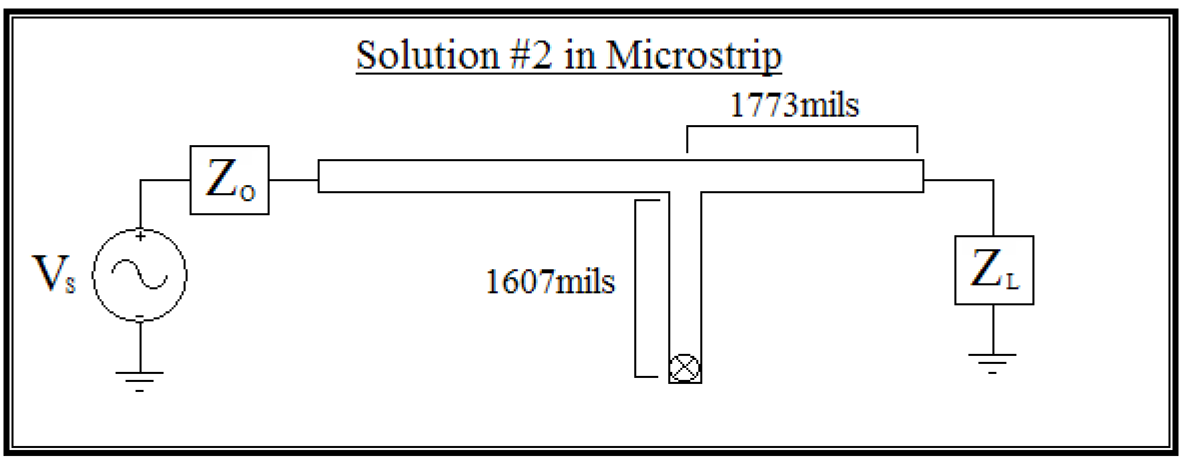

Discussion

So, not surprisingly, the network seems to work for the given design frequency of 2GHz – that is, there is little to no reflection at the design frequency. The first solution seems to have the advantage of, not only having smaller stub and through-line lengths (i.e. less board space), but also seems to have a much broader bandwidth close to the design frequency.

I decided to plot out a little wider than the requested frequency range to observe the behavior of each solution and got an interesting result (Seen below). When the reflection coefficient is plotted versus frequency from 1 MHz to 5 GHz the second solution shows some interesting symmetry and also another frequency with little to no reflection at around 3.6GHz. I am not sure what this comes from, but it does demonstrate an advantage to the second solution over the first.