Project 1 (*Due: 19 November*)
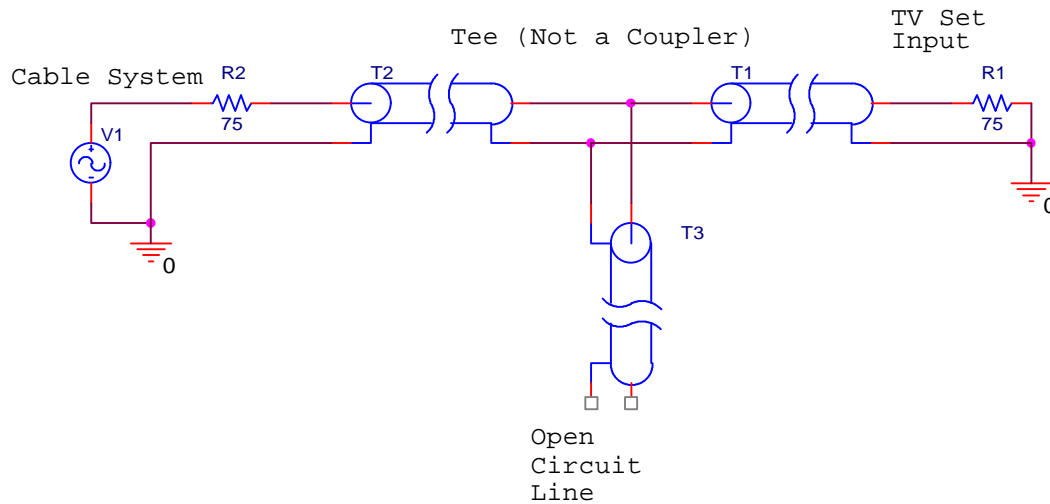
Cable TV Station Blocker

Some Comments

For this project, students can work in groups of two to four. No reports will be accepted from single students.

Introduction (4 pts): Introduce and describe the goals of the project.

The purpose of this project is to build a simple device that blocks the signal from a particular cable TV channel while leaving the other channels with sufficient signal to be viewable. No active or lumped circuit elements will be used for this purpose. Rather, this will be accomplished by adding a stub-type tuner to the cable that brings the signal to the TV. List at least three educational goals for this project. That is, <u>list at least three topics you might encounter in practical electromagnetics that play a significant role in this project. Be specific, indicating where in the textbook or other course reference materials these topics are discussed</u>.

Initial Design (8 pts): Describe your initial project design, how it works, how you came up with this particular design, and discuss potential problems. This last item is very important.

The basic principle of this signal blocker is relatively simple. The CATV cable (T2 in the figure above) is interrupted with a Tee coupler to which is connected a short piece of cable (T3 above) with nothing connected to it (open circuited line). The input impedance of this extra piece of cable adds in parallel to the input impedance of the cable that runs from the Tee to the TV set (T1 above). Assuming that the cable is properly matched to the TV, the input impedance of the cable connected to the TV (T1) will be equal to the characteristic impedance of the cable. In this case, the impedance of the cable and the TV is 75 ohms. Since the input impedance of any cable (Z_{in}) is a function of the electrical length of the cable (through the terms like $\tan \boldsymbol{b}d$ where d is the

length), the Z_{in} of the open-circuited cable (T3) will change with frequency. If the length of this cable is properly selected, the signal from one CATV channel will be reflected from the Tee while the signals from other channels will not be reflected. A crude explanation of how this can work can be made by looking just at two frequencies where Z_{in} is either very small or very large.

For example, assume that the extra piece of cable has a length = d. Also, assume that it is insulated with polyethylene $\mathbf{e}_r$ = 2.26. Then the velocity of propagation on the line is v = 2 x 10^8 m/s. In the simulation of this line, one can either reduce the expression for Z_{in} for an open circuit or just use a very large value for Z_L. To be as general as possible, choose the latter approach. Then $Z_{in} = Z_o \dfrac{Z_L + jZ_o \tan \mathbf{b}d}{Z_o + jZ_L \tan \mathbf{b}d} \approx -jZ_o \cot \mathbf{b}d$. When this is very large (cot$\mathbf{b}d \circledR \yen$), adding it in parallel to the cable will have no effect. When this is very small (cot$\mathbf{b}d \circledR 0$), adding it in parallel to the cable will look like a short circuit and which is as large an impedance mismatch as can be obtained.

Describe the basic design. Draw a picture if your artistic skills are up to it. When you have a description of your design, show it or email it to a TA or to Prof. Connor. It is very important that you understand the basic principles before you proceed with the rest of the project. Also, be sure that you identify at least two potential problems. Remember that you will probably be basing your design on an ideal lossless model of transmission lines. Anything that deviates from such an ideal can cause a problem.

The simplest implementation of the blocker is made using the following parts. First, a CATV splitter is purchased. Such a device is used to connect two TV sets to one cable line. This reduces the power to each set, of course, but the source and the TV sets are all properly matched. The splitter uses a transformer and/or discrete components to make the impedance looking into any of its three connections equal to 75ohms. This is not the device we need. Rather we need a Tee. Remove the cover of the splitter and then all of the discrete components. Connect the input and the two outputs directly together to form the same kind of Tee we use in the studio with the 50ohm cables. Next, purchase two short CATV cables with connectors on each end. Disconnect the TV set from its cable. Insert the Tee we made with the splitter. Connect one of the new short cables to one of the outputs of the Tee. Connect the other end of this cable to the TV set. The picture should look as good as before. Then connect the second new cable to the other output of our Tee. Depending on the length of this second cable, the station being watched will look the same or have a much weaker signal. The length of this second cable can be shortened (we do not need the connector on the open end) to block a particular channel, once we have analyzed the system and determined the correct length.

Problems – Real cables have some loss. Thus, their ability to block a channel might not be as good as our lossless line analysis might suggest. Also, the Tee may very likely be adding some additional capacitance to the location where the three cables come together. It is also difficult to determine the effective length of the cables when we have

to account for the connectors. Therefore, it is usually best to field fit the cable length, by cutting it a bit long, testing it, and then cutting again and again until the desired channel is blocked.

Analysis (8 pts): Discuss why your initial design should work and support your discussion with calculations, graphs, simulations, reference materials and/or common sense reasoning.

Write out the equations that describe how this channel blocker works. Select a length for the open-circuited cable. Determine the voltage and power transfer function for the complete system. Use Maple or Matlab to solve the equations for the entire range of frequencies of the CATV channels received in the Albany-Schenectady-Troy area.

The input impedance of an open circuited cable is

$$Z_{in} = Z_o \frac{Z_L + jZ_o \tan \boldsymbol{b}d}{Z_o + jZ_L \tan \boldsymbol{b}d} \approx -jZ_o \cot \boldsymbol{b}d \ \text{ while the input impedance of a matched cable is}$$

$Z_{in} = Z_o$. *Ideally, at the location of the Tee, these two impedances will add in parallel. Since this is a parallel combination, it is easier to add them as admittances. $Y_{in}=1/Z_{in}$ and $Y_{in}=1/Z_o$, respectively.*

Information on the Standard Cable-TV Frequencies can be found at
http://www.info2000.net/~aloomis/catv.html

Cable TV frequencies run from about 50MHz to 650MHz, according to the reference above. The following Matlab m-file was written to analyze the blocker design. In this program, the frequency f is specified as a vector covering the entire range of CATV frequencies. Then Z_o and Z_L (called Zl in the program) are given and $\boldsymbol{b}$ is determined for each frequency from the propagation velocity v. Next, the input impedance of the open circuit line is determined at each of the frequencies. So far we have three vectors of equal length – f, $\boldsymbol{b}$, and Z_{in}. Next, the parallel combination of the two impedances is determined. This combination (Ztotal) is now the load seen by the original CATV cable. The reflection coefficient on the original cable is then determined from $\Gamma = \dfrac{Ztotal - Zo}{Ztotal + Zo}$, where we have used Ref instead of $\boldsymbol{G}$ due to Matlab limitations. The transmission coefficient is then determined from $\boldsymbol{t} = 1 + \boldsymbol{G}$ or Trans = 1+Ref in Matlab. The transmission coefficient tells us what transmits past the Tee into the TV set. We then plot the real and imaginary parts of each of these terms along with their magnitude. It is the magnitude that is of the most interest. The output plots from this program for d=.25m are shown after the program listing.

```
% Program for modeling a CATV channel blocker
% K. A. Connor 10 November 1999

f=[5:.01:65]*1e7;
Zo=75; d=.224; beta=2*pi*f/2e8;Zl=1e8;
```

```
% Input impedance of the open circuit line

Zin=Zo.*(Zl+j.*Zo.*tan(beta.*d))./(Zo+j.*Zl.*tan(beta.*d));

% Combination of Zin and Zo

Ztotal=1./(1./Zin+1./Zo);

% Reflection Coefficient

Ref=(Ztotal-Zo)./(Ztotal+Zo);

% Transmission Coefficient

Trans=1+Ref;

%Plotting Results

plot(f,real(Zin),f,imag(Zin),f,abs(Zin));
title('Input Impedance of Open Line');xlabel('Frequency');grid;figure;

plot(f,real(Ref),f,imag(Ref),f,abs(Ref));
title('Reflection Coefficient');xlabel('Frequency');grid;figure;

plot(f,real(Trans),f,imag(Trans),f,abs(Trans));
title('Transmission Coefficient');xlabel('Frequency');grid;
```
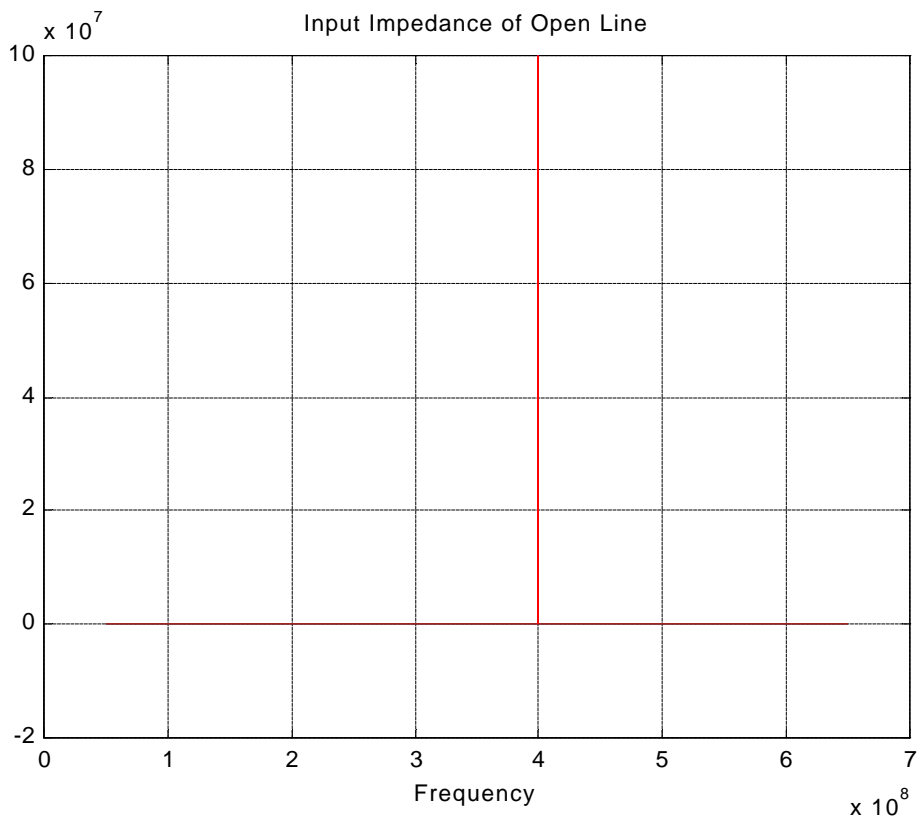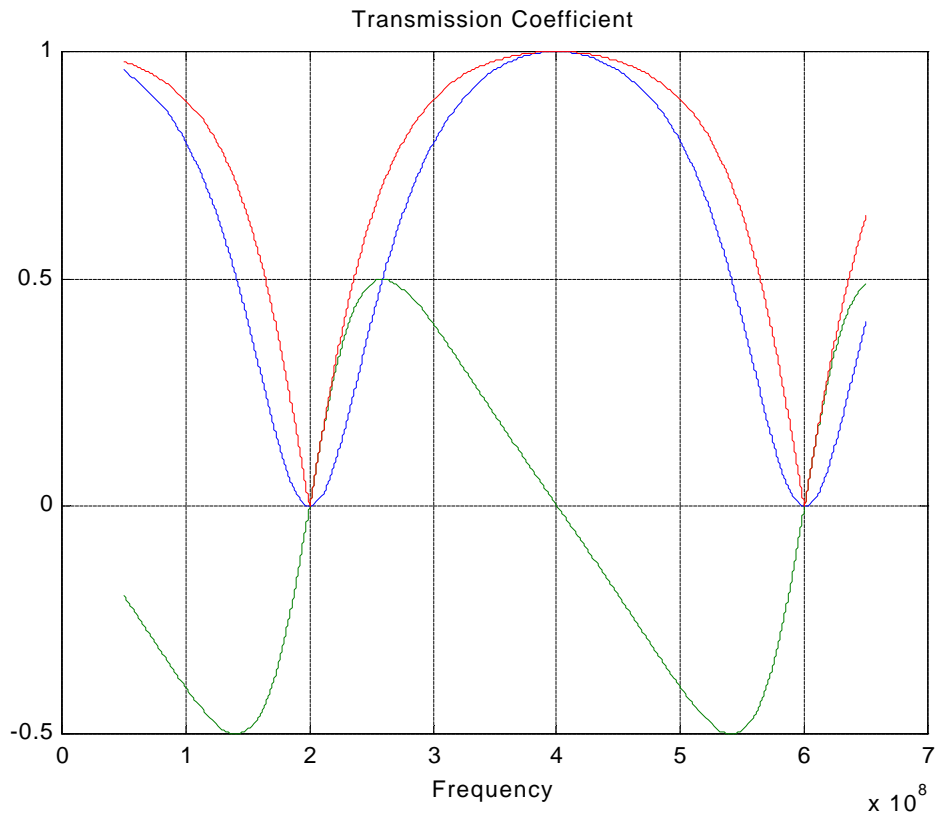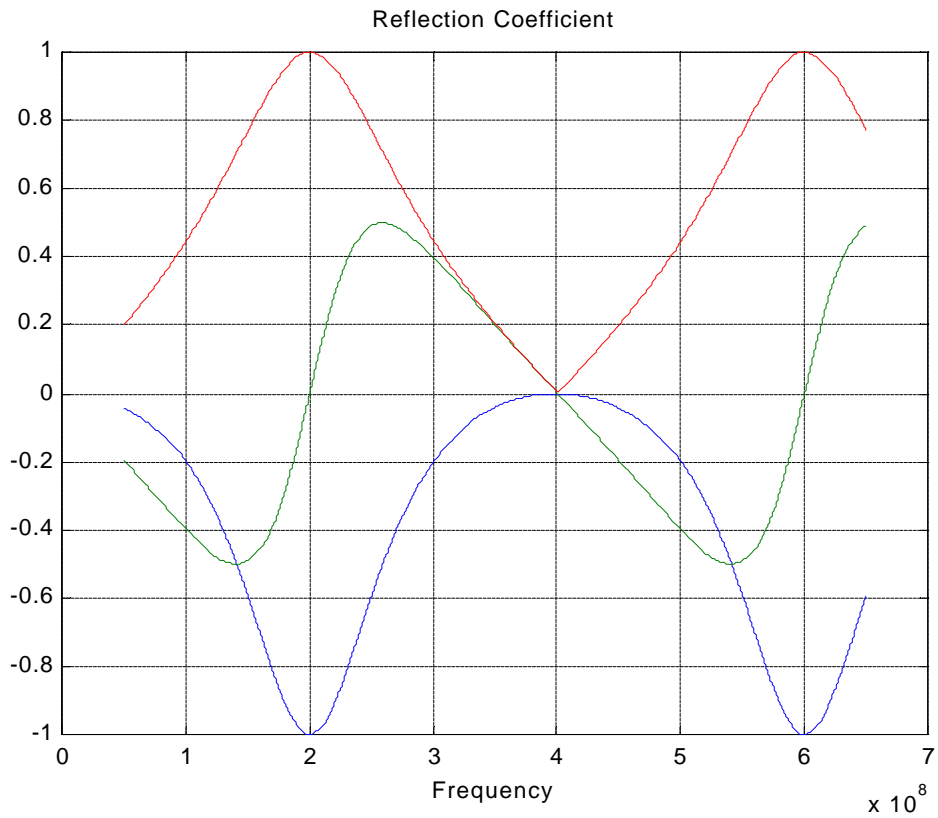
Output Plots

Reflection Coefficient

Transmission Coefficient

Note that, for this choice of length, the blocked frequencies are at 200MHz and 600MHz.

Basic Performance (4 pts): To test out your designs, you must identify one channel that will be blocked by your first choice of cable length.

CATV Channel _____   **Length** _____   **Witnessed** _____

Implementation (7 pts) -- Discuss what problems were encountered during the implementation of your project and how you solved them. Include advice you would offer to someone who wished to avoid these problems in the future.
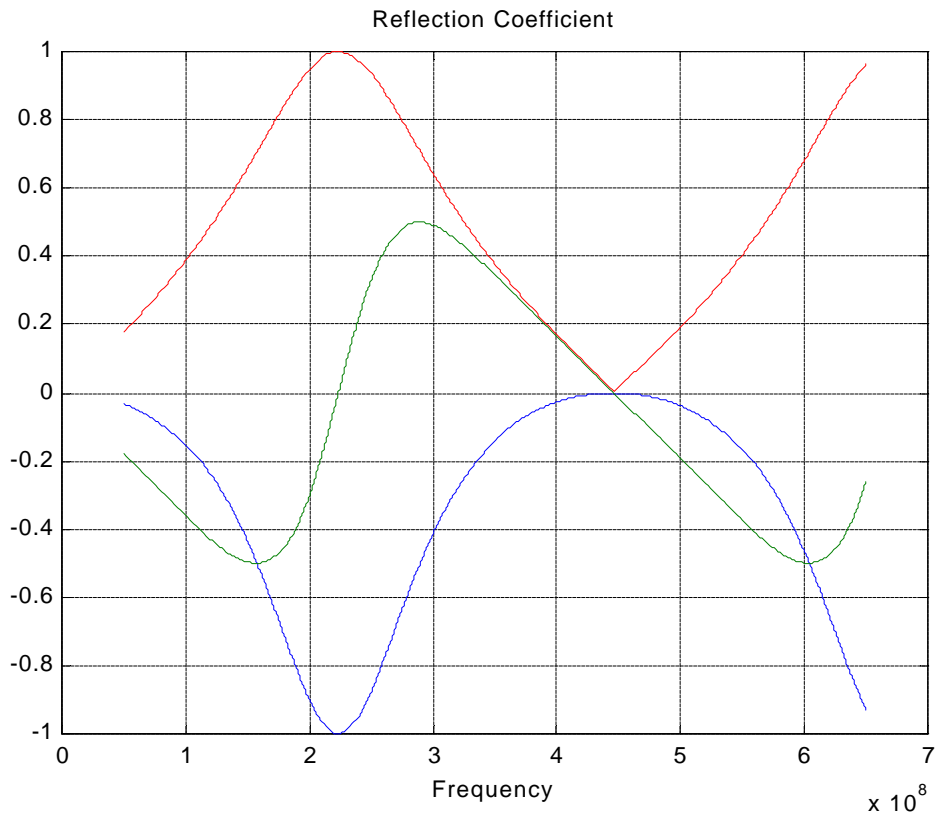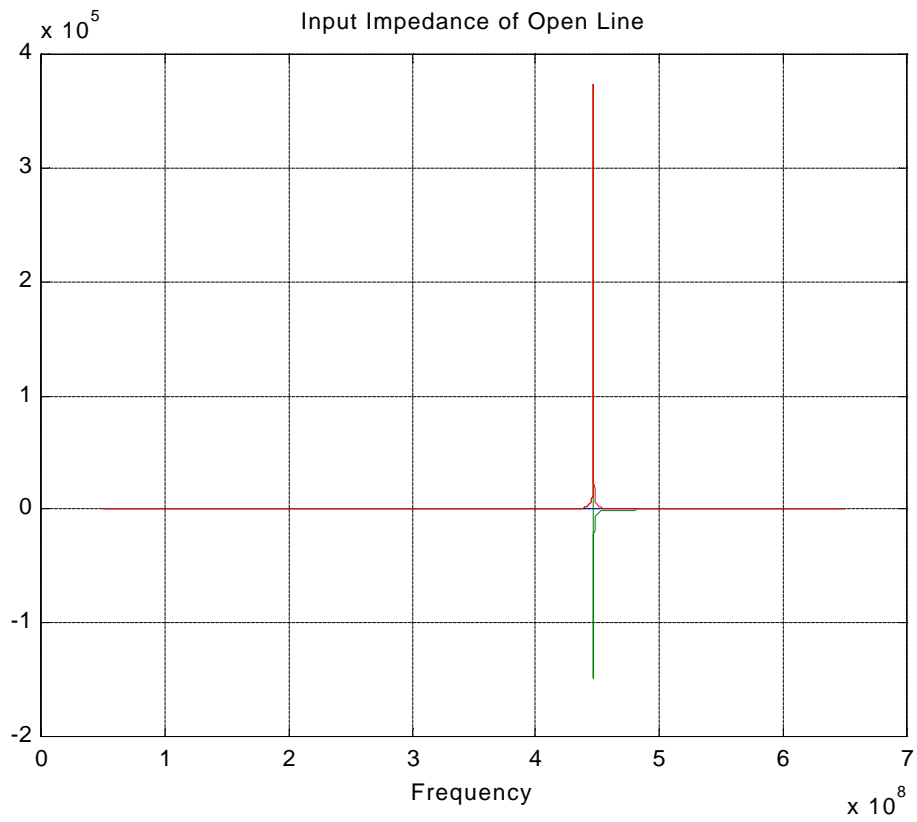

Describe your problems and be as helpful to others as possible.

Final Design (8 pts) – Select a particular channel to be blocked and one that is not to be blocked. This channel must be different than the one you used above. Show that the new design works with experimental data from your hardware and simulations or paper-and-pencil analysis. Include schematics. To demonstrate your design you must either build a CATV channel blocker (which will be tested by a member of the course staff) or use your model on an equivalent experiment that can be done in the studio. Since the function generator is limited to 15MHz, use a range of frequencies that is equivalent to the CATV frequencies you analyzed. That is, the maximum and minimum frequencies should be in the same ratio as the CATV frequencies. The latter choice is simpler to do since you do not need to build anything. To build the former, you will have to provide your own Tee, which can be made from a coupler by removing the lumped circuit elements and by wiring together the three connectors.
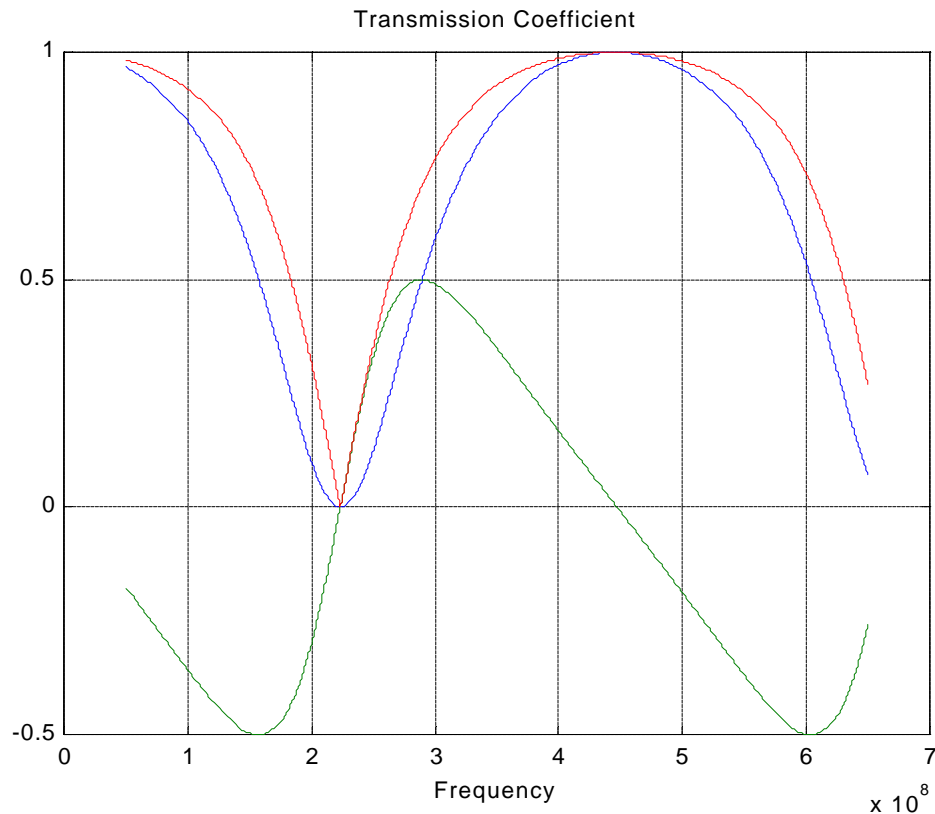

CATV Channel _____   **Length** _____   **Witnessed** _____

(This is for the design, not the test of the hardware.)

Input Impedance of Open Line

Reflection Coefficient

Transmission Coefficient

which blocks the particular frequency of 223.2MHz.

Performance (7 pts) – Build and test your design or do an equivalent experiment in the studio.

 CATV Channel _____   **Length** _____   **Witnessed** _____
This is for the test of a CATV channel blocker.

For the equivalent test in the studio, <u>describe the method you used to take the data and discuss the features of the data you have obtained. For example, explain the voltage levels observed. Be sure that you explain why the measurements you have made demonstrate that your model is sufficient to build an actual channel blocker.</u> <u>Have your experimental data signed by a TA or instructor.</u>
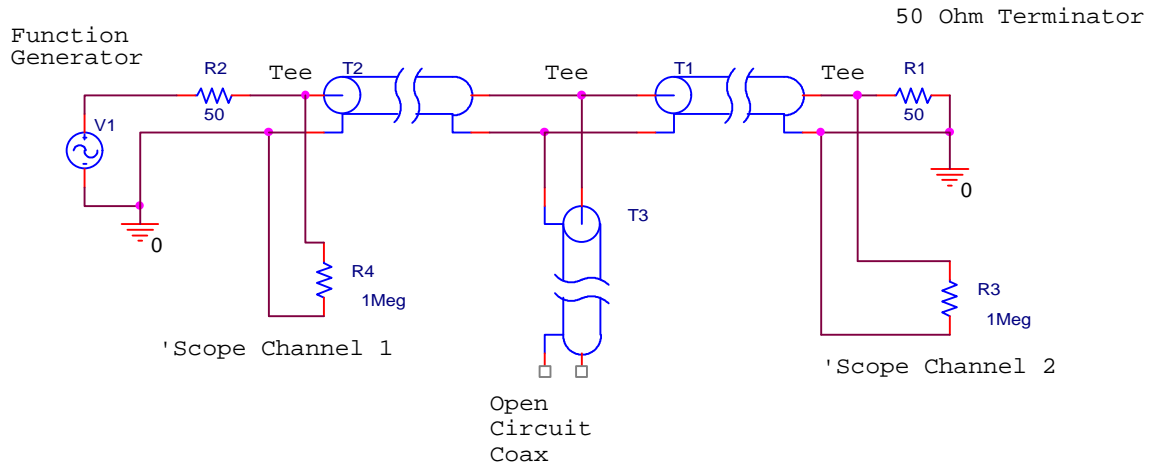
The equipment in the studio differs from the CATV test in frequency range (0-15 MHz is possible using the function generator) and cable characteristic impedance (Z_o=50ohms). Set up the configuration shown below using three pieces of coax from the cable box. Connect to Tees as shown. Measure the length of the open circuit cable. If it is not at least 4 meters long, add another piece of cable using a Tee to increase the total length. Measure the length of this cable combination. Input this length into the equations used to model the blocker, using 50 ohms for Z_o. The modified code and the results of such analysis follow.

50 Ohm Terminator

Function
Generator

R2   Tee   T2   Tee   T1   Tee   R1
50   50

V1

0

R4
1Meg

'Scope Channel 1

T3

0

R3
1Meg

'Scope Channel 2

Open
Circuit
Coax

```
% K. A. Connor 10 November 1999

f=[1.5:.01:15]*1e6;
Zo=50% Program for modeling a CATV channel blocker
; d=5; beta=2*pi*f/2e8;Zl=1e8;

% Input impedance of the open circuit line

Zin=Zo.*(Zl+j.*Zo.*tan(beta.*d))./(Zo+j.*Zl.*tan(beta.*d));

% Combination of Zin and Zo

Ztotal=1./(1./Zin+1./Zo);

% Reflection Coefficient

Ref=(Ztotal-Zo)./(Ztotal+Zo);

% Transmission Coefficient

Trans=1+Ref;

%Plotting Results

plot(f,real(Zin),f,imag(Zin),f,abs(Zin));
title('Input Impedance of Open Line');xlabel('Frequency');grid;figure;

plot(f,real(Ref),f,imag(Ref),f,abs(Ref));
title('Reflection Coefficient');xlabel('Frequency');grid;figure;

plot(f,real(Trans),f,imag(Trans),f,abs(Trans));
title('Transmission Coefficient');xlabel('Frequency');grid;
```
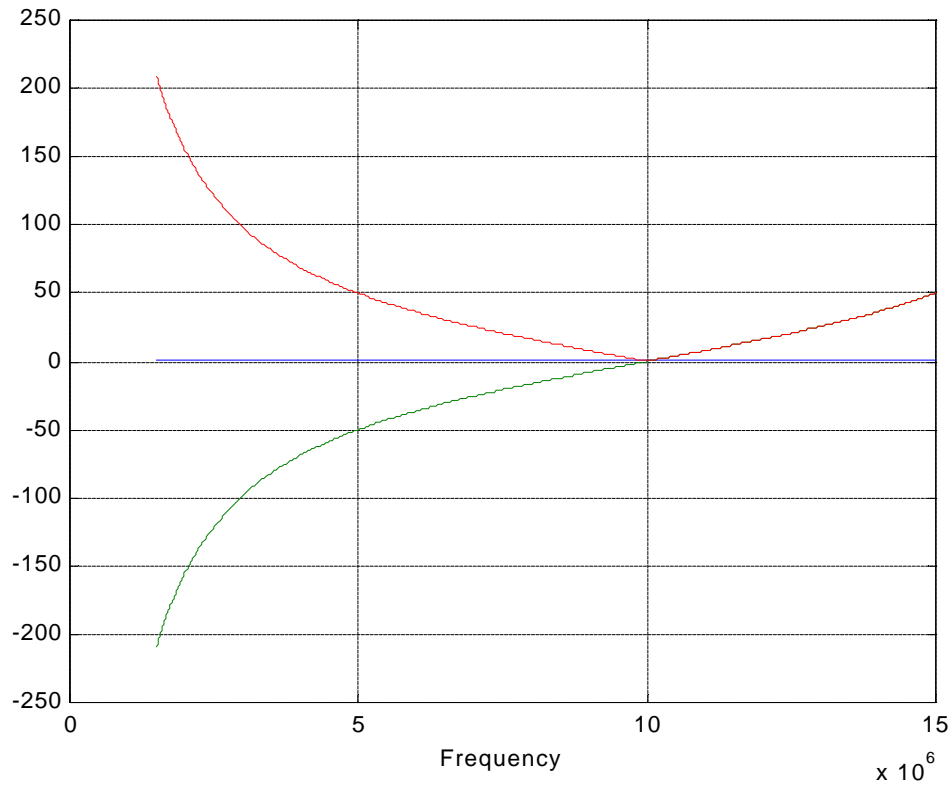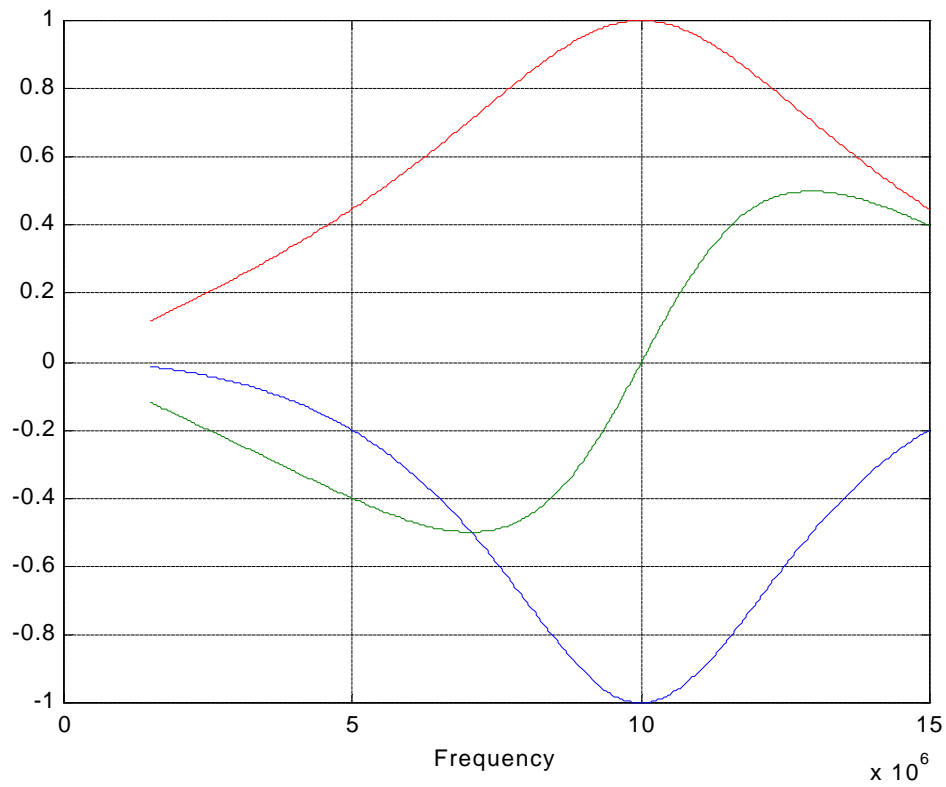
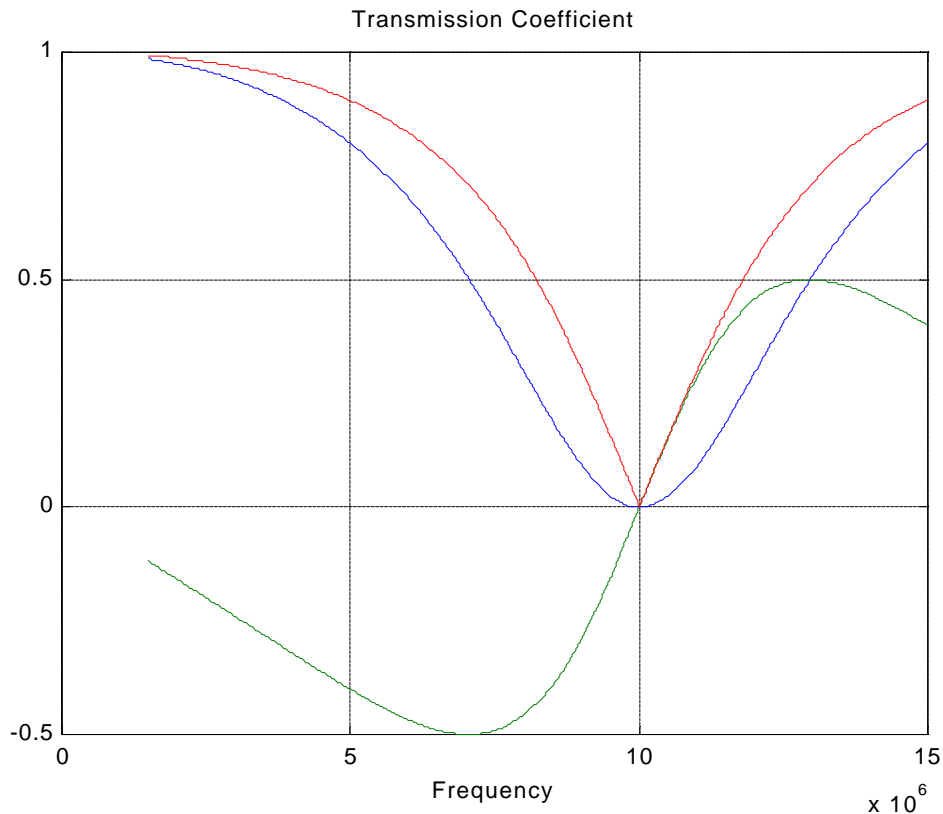## Input Impedance of Open Line

Reflection Coefficient

Transmission Coefficient

*Note that this combination of cables (d=5meters) blocks frequencies around 10MHz.
Manually change the frequency of the function generator while observing both the input
and output to the cables as indicated. A very small output voltage (relative to the input)
should be observed around 10MHz, if the experiment is set up correctly.*

Personal Responsibilities (2 pts) -- A short paragraph should be written describing what
each group member did to develop and implement the final design.

Creativity (0-5 pts) – Any exceptionally creative approaches to implementation, analysis
and/or design will be rewarded with up to 5 additional points.

*Please note that this category is reserved for **exceptionally creative** work.*

Appendix (2 pts): Include any background materials you used in the preparation of your
design.