1   Lab Introduction

In this lab we are examining loading behavior of cabling by engaging with a brain teaser: can you figure out the contents of the mystery box using only a BNC cable and an oscilloscope probe? The learning goals are listed below.

1. Deal with Thevenin models in a pracitcal context.

2. Be convinced of the virtue of oscilloscope probes by observing loading effects of different cables.

3. Refamiliarize yourself with the oscilloscope by making a Bode Plot.

2   Compare the 10X Scope Probe to a BNC Cable

Text Reference: Horowitz and Hill pp1045 to1049, Lab Manual Ref: Hays and Horowitz PP 62, 63
    Capacitive loading is always a consideration when measuring high frequency circuits because capacitance in your cabling can steal your signal from your load. In this section, we are going to measure the capacitance and resistance of oscilloscoope probes and BNC cables in order to build models of them. Probes are two-port devices, so measuring their "impedance" is actually a misnomer, but you are going to be instructed to take measurements in this section whcih allow you to build models of probes for which input and output impedance are fairly readily defined.

1. Make a series of measurements to characterize the impedance of a "BNC Probe."

   (a) Use the RLC meter to measure the resistances and capacitances of the following configu-
       rations of a BNC (coaxial) cable which is terminated with a pair of hooks or gator clips
       but no load impedance. We will refer to this cable (with its termination) as your "BNC
       Probe."

       i. The resistance between the signal terminal at one end of the wire and the other end
       ii. The capacitance between the signal terminal and the shield
       iii. The resistance between the signal terminal and the shield

   (b) Consider your measurements and draw a circuit model that is suitable for your BNC
       probe (hint: this model should be really simple)

   (c) Look at the face of the oscilloscope to determine the input resistance and capacitance of
       each channel. (The resistance and capacitance are in parallel from the input to ground.)

   (d) Draw a Thevenin model that represents the BNC probe connected to an oscilloscope. We
       will call this model the "Combined BNC model". Instead of using a single impedance like
       a normal Thevenin model, represent the input impedance of the combined BNC model
       using an input resistance in parallel with an input capacitance. When finding the input
       resistance and capacitance, you may calculate resistance in a low frequency limit and
       capacitance in a high frequency limit. Consider whether it's important to include small
       resistances, or if you can omit them.

   Required Data: Model of the BNC probe with numerical values. Input resistance and
   capacitance of BNC probe when connected to scope.

2. Make a series of measurements to characterize the impedance of a 10x oscilloscope probe and
   build a model of the probe.

   (a) A model of a 10x oscilloscope probe is pictured in Figure 1. Use the RLC meter to
       measure the resistances and capacitances in this model. The settings of the RLC meter
       matter when taking these measurements (they basically didn't for the simpler BNC cable).
       Do you want a high or low probe frequency when measuring resistance? How about
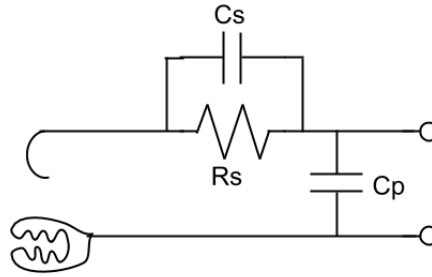   capacitance?

Figure 1: A schematic model of a 10x oscilloscope probe.

(b) Draw a Thevenin model that represents the 10x probe connected to an oscilloscope. We
    will call this the "Combined 10x model". Instead of using a single impedance like a normal
    Thevenin model, represent the input impedance of the combined 10x model using an input
    resistance in parallel with an input capacitance. When finding the input resistance and
    capacitance, you may calculate resistance in a low frequency limit and capacitance in a
    high frequency limit.

(c) What is the DC gain of a 10x oscilloscope probe? What is the high frequency gain of a
    10x oscilloscope probe?

Required Data: Model of the 10x probe with numerical values. Input resistance and capacitance of 10x probe when connected to scope. Discussion of low and high frequency gain of 10x probe.

3. Make another series of measurements to examine the loading of the two types of probes when
   the source impedance is increased. Start by adding a 10 kΩ resistor in series with the output
   of your function generator.

   (a) Find the output impedance of the function generator before the 10kΩ resistor is added.

   (b) Calculate the corner frequency of the two Bode plots representing each probe type con-
       nected to a function generator with a 10 kΩ source impedance. Using the proper models
       will make this calculation easier, so think about which of the models we've made are the
       best for this job.

   (c) Verify the -3 dB corner of each probe type on the oscilloscope by making a Bode plot for
       each. Explain any differences from your estimated value.

   Required Data: Output impedance of function generator before 10kΩ resistor is added.
   Analytical caluclations of corner frequency for each probe type. Bode plot with annotated
   corner frequency for each probe type.

3   Figure Out the Thevenin Impedances of the Mystery Box

You will now use the probes you have characterized to load a mystery box and determine its secrets.
The mystery box should be modeled as a single function generator connected to two outputs, A and
B, by output impedances Z_A and Z_B. This model is pictured in Figure 2.

You may assume Z_A is either purely resistive or purely reactive. You may assume the same for
Z_B. Note that Z_A being reactive doesn't imply Z_B is reactive and vice-versa. In general, Thevenin
models may have an arbitrary impedance $Z_{th} = R + jX$, but we're working with the simpler, purely
real and purely imaginary cases in this lab.

1. Observe the outputs of a mystery box with the 10x and BNC probes. We only have six mystery
   boxes, so we need to share them. Plan your measurements carefully and execute them quickly.
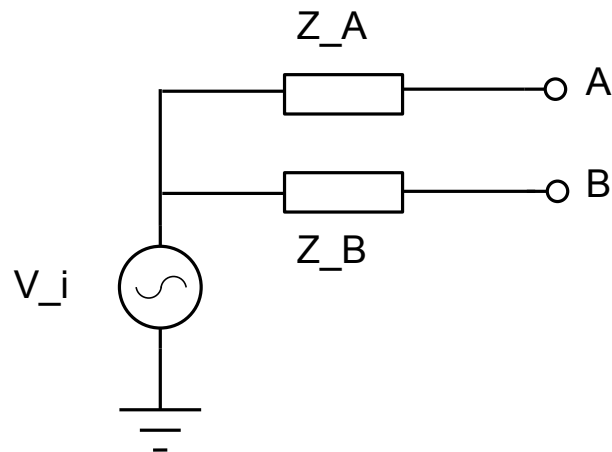   Do all of your measurements on the same mystery box.

Figure 2: A schematic model of the mystery box.

2. Determine the Thevinin equivalent circuit of the function generator for outputs A and B using the information obtained from your two probes. Show your calculations. Simplifying your circuit before analyzing it may make your life easier. For instance, if a component is in parallel with something that has a much lower impedance, then you might consider removing it from your schematic before doing analysis. Document all such assumptions. If you make the right set of assumptions and look for the right set of features, these calculations are straightforward, so think about circuits twice and calculate once.

3. Sketch the wave generated by the mystery box's function generator before it is loaded. Include axis labels that specify the voltage and duration of wave features.

Required Data: Thevenin equivalent impedances Z_A and Z_B. Calcuations used to find them. Sketch of wave generated by mystery box.