Laboratory 1: Review of Passive Networks

Laboratory Exercises

INTRODUCTION

Objectives

This lab is intended to help you review basic circuit construction and measurement techniques, and to review basic passive circuit concepts by demonstrating the "anti-loading" function of oscilloscope probes, all while introducing you to the lab equipment.

Summary of Procedures

(i) Determine the properties of a simple lowpass network by measuring its step response and frequency response.

(ii) Construct a simple oscilloscope probe to study its operation and demonstrate the need for compensation.

Materials Required

- AD2 USB Oscilloscope
- BNC Adapter Board
- Digital Multimeter
- Breadboard
- Assorted Resistors and Capacitors

PROCEDURE

As you work through this lab, be sure to look at the *Results Sheet for Laboratory Exercises* to make sure you are obtaining enough data to answer all of its questions.

1. Setting Up the Analog Discovery 2 USB Oscilloscope

Before you can begin building and measuring circuits, you must familiarize yourself with the lab equipment. To set up the AD2 USB Oscilloscope, first make sure you have downloaded the accompanying Waveforms software (https://store.digilentinc.com/waveforms-download-only/) and that the software successfully recognizes the AD2 when connected to your computer via USB. If Waveforms cannot detect the AD2, you will get an error message and the software will close.

Next, connect the BNC adapter board to the AD2 making sure that the text on the printed circuit board (PCB) is facing up. You can then connect the wire assembly to the other side of the BNC adapter board. The adapter board has four BNC connectors: two oscilloscope channels—designated CH1 and CH2 on the PCB—and two arbitrary waveform generator outputs—

designated W1 and W2 on the PCB. There are also four jumpers, each consisting of a three-pin header and a blue two-pin jumper. Each jumper has two settings which are labeled accordingly on the PCB: AC or DC coupling for the oscilloscope channels; and 0 or 50 Ω source impedance for the AWG outputs. Take care to use the correct BNC connections and jumper settings depending on your specific application.

2. Compensating the Oscilloscope Probe

After organizing the required equipment, the first step in any lab is to COMPENSATE THE OSCILLOSCOPE PROBE. You can easily compensate the probe as follows:

(a) Connect the BNC terminated end of the oscilloscope probe to either oscilloscope channel (CH1 or CH2) on the BNC adapter board. Find the red switch on the other end of the oscilloscope probe and make sure it is in the 10X position. Connect either non-oscilloscope probe BNC cable to either AWG output (W1 or W2) on the BNC adapter board.

(b) Connect the hook lead of the oscilloscope probe to the red clip lead on the BNC cable connected to the AWG output. Connect the black ground clip on the oscilloscope probe to the black clip lead on the BNC cable connected to the AWG output. This can either be done directly, or by using a male pin header.

(c) Set the oscilloscope channel's jumper to DC coupling mode and the AWG output's jumper to 0 Ω source impedance.

(d) Create a new Wavegen tool instance in Waveforms and set the AWG to output a 1 kHz, 1 V amplitude square wave with 0 V of DC offset.

(e) Create a new Scope tool instance in Waveforms and make sure that the attenuation for the channel you are using is set to 10X by clicking the gear icon next to the channel name on the right-hand side of the Waveforms window. Click the run button and adjust the voltage and time scales until approximately two periods of the compensation waveform are clearly visible. If needed adjust the trigger level to stabilize the display.

(f) Using the adjustment tool included with the BNC oscilloscope probes gently adjust the compensation control on the probe tip while observing the image displayed on the screen. This tool looks like a small black plastic screwdriver and fits into the hole located near the BNC termination on the probe. Continue to adjust the probe until the square wave has as "flat a top" as possible, as seen on the far right of Fig. L1.1.

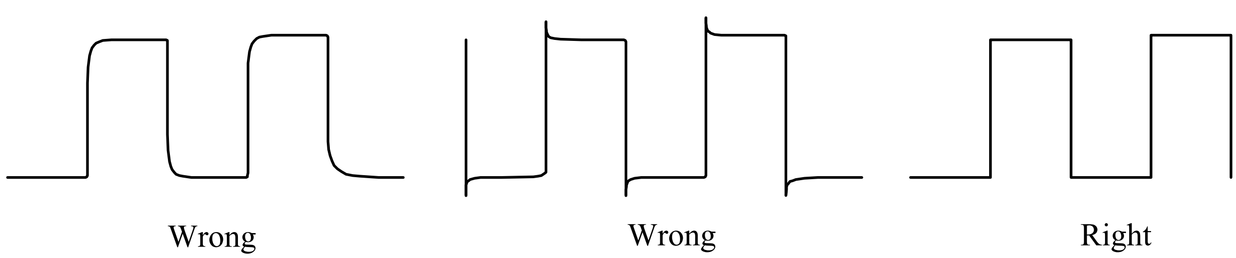

Figure L1.1

3. Finite Instrumentation Impedance

Measure the low frequency output impedance of the AD2's arbitrary waveform generator. Do this by hooking the output of the generator to a test resistor R_{test} of value from 50 Ω to 100 Ω to ground, as shown in Fig. L1.2. Before measuring this impedance, be sure to set the AWG output's jumper to the 50 Ω source impedance.

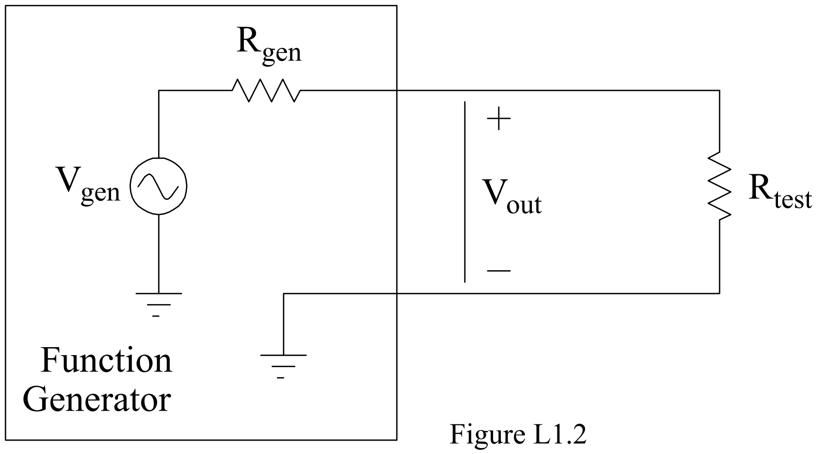

Figure L1.2

In this configuration, the voltage V_{out} indicated in Fig. L1.2 takes the form

$$V_{out} = \frac{R_{test}}{R_{test}+R_{gen}} \times V_{gen}.$$

Thus, with knowledge of V_{gen} and with measurements of the resistor R_{test} and the voltage V_{out}, one can compute R_{gen}.

(a) Choose a test resistor R_{test} with value between 50 Ω and 100 Ω and hook up the circuit shown in Fig. L1.2. Make sure you measure and record the exact value of the chosen resistor using the DMM. Set the function generator to output a sinusoidal waveform with a reasonable choice of amplitude (e.g., 1V) and a frequency of 10 kHz or lower. Measure the amplitude of V_{out} using your oscilloscope (with a properly compensated probe).

(b) Compute the value of R_{gen}.

4. A Simple Lowpass Network

Build the simple lowpass filter shown in Fig. L1.3 below. Be sure to follow the construction suggestions described in Section 2.1 of the Laboratory Instruction Manual. Also, make sure you measure and record your actual component values.

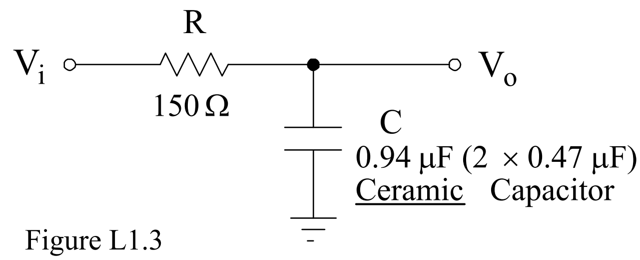

Figure L1.3

(a) Using the function generator to produce a 100 Hz square wave, measure the rise time t_r of the lowpass filter (use the *X* & *Y* cursors on the oscilloscope; do not use the predefined Measurement function). Compute the value of τ from t_r.

(b) Measure t_r of the generator while it is not hooked up to your circuit (again, use the *X* & *Y* cursors on the oscilloscope; do not use the predefined Measurement function). You may find it useful to adjust the frequency of the function generator to make this measurement.

(c) Take frequency response data sufficient to construct a Bode plot of both the gain and phase of the network. You should take this data using the oscilloscope with the input signal displayed on one channel and the output on the other.

5. A Prototype Oscilloscope Probe

As discussed in Part 3 of the *Preliminary Exercises*, attenuating oscilloscope probes can increase measurement accuracy by minimizing the loading effects of the oscilloscope input capacitance on the circuit under test.

Earlier, in Part 2 of the *Preliminary Exercises*, you showed that although a simple voltage divider did minimize the loading on the circuit under test, it also slowed the response of the oscilloscope probe. You then showed in Part 3 of the *Preliminary Exercises* that the addition of a compensation capacitor (C_1 in Fig. PL1.3) to the simple voltage divider can significantly "speed up" the response. Indeed, by adding the capacitor C_1, one can theoretically compensate perfectly for the "slowing" effects of C_2 and obtain an ideal step response.

To ensure we are all working with correct formulas (i.e., in case your *Preliminary Exercises* answers were not correct), let us derive the appropriate formulas here. This time, however, instead of using nodal analysis, as was done for the *Preliminary Exercises*, let's use some intuition to arrive at the same result, but with a simpler approach. We start by first recognizing that for perfect compensation, the initial (t = 0+) voltage across R_2 must equal the final voltage ($t = \infty$). For this to be true, the following relation must hold: (refer to Fig. PL1.3 for variable definitions)

$$\frac{R_2}{R_1+R_2} = \frac{C_1}{C_1+C_2}.$$

Thus, for compensation, we must have

$$C_1 = \frac{R_2C_2}{R_1} \qquad \text{or} \qquad R_1 = \frac{R_2C_2}{C_1}.$$

In practice, the required value of C_1 is so critical that its value must be determined experimentally, as is done when compensating an oscilloscope probe.

The above derivation (as well as the one in the *Preliminary Exercises*) implicitly assumes a source impedance of zero. An analysis with finite source impedance would show that perfect compensation is no longer possible. However, as you will soon demonstrate, significant improvement in rise time over the uncompensated case is still attainable.

Because of the above finite source impedance problems, a handful of real oscilloscope probes actually use a more complicated circuit than indicated in Fig. PL1.3. The majority of probe circuits, however, do use the circuit topology of Fig. PL1.3. In particular, high speed (>200 MHz) probes are often designed exactly like the one you will now evaluate.

Construct the prototype oscilloscope probe shown in Fig. L1.4 below. In a real probe, the capacitance C_2 represents the parasitic capacitance associated with the probe cable. Compensation of a real oscilloscope probe normally comes about through adjustment of the compensating capacitor C_1. In this lab, for ease of construction, we are using a potentiometer to adjust R_1, rather than C_1. The resistive voltage divider then provides the required probe attenuation.

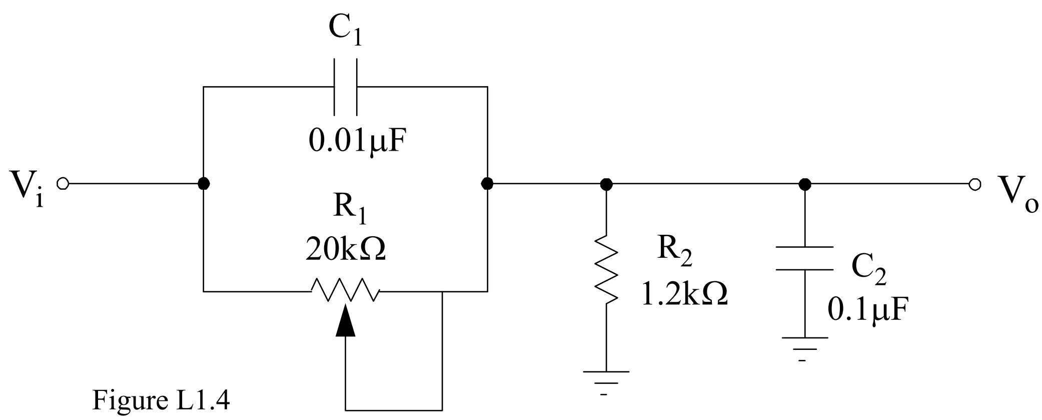

Figure L1.4

(a) Temporarily remove C_1 and set R_1 to 10 kΩ. Note that now the network condenses to the simple lowpass filter of Fig. PL1.2. Using a square wave, repetitively display the step response on the oscilloscope. Using a step response measurement, determine t_r, again using the cursors rather than the Measurement function.

(b) Using the variable resistor setup for R_1, compensate your prototype oscilloscope probe by adjusting the potentiometer and watching the shape of the waveform. After compensation, measure C_1, C_2, R_1, and R_2, and verify the formulas derived above. Measure the rise time of the voltage step at both the input and the output (V_i and V_o) of the network. Measure the time required for the output of the prototype oscilloscope probe to settle to its final value, defined as $V_{o,final} = V_o$ @ $(t = \infty) \pm 1\%$.

Laboratory 1: Review of Passive Networks

Results Sheet for Laboratory Exercises

NAME: ________________________________ **LAB SECTION:** _____

3. Finite Instrumentation Impedance

(a) R_{test} = ________________________

V_{out} = ________________________

(b) R_{gen} = ________________________

4. A Simple Lowpass Network

(a) Filter Rise Time t_r= ___________________________ (attach oscilloscope plot)

Value of τ computed from measured rise time ___________________________

(b) Rise Time of Generator = _________________________ (attach oscilloscope plot)

Is the rise time of the generator small enough to be ignored? Justify by computing the predicted error resulting from an assumption that the generator output is an ideal step; i.e., compute the theoretical rise time for the lowpass filter circuit using your measured values of R and C and assuming an ideal step input (but don't neglect the R_S of the generator), then calculate the percent error between the measured and theoretical rise times.

Value of τ predicted from the component values _________________________
(and assuming an ideal step input)

% error between measured and computed τ's from (a) and (b) above ______________

Explain any discrepancies between the computed and measured values of τ.

(c) Using a semi-log scale, construct and attach the Bode plot of the lowpass filter. (The gain and phase should be on separate axes.) How many points did you use? _______. Attach annotated oscilloscope plots showing measurement of both gain and phase at the 3dB point.

Assuming that you know a given circuit has a single pole, and that you can make qualitative observations over a very broad frequency range, how many quantitative data points are required to construct the asymptotic Bode plot? ______________

From the Bode plot, or otherwise, determine the cut-off frequency of the lowpass filter ______________________. Does this value agree with the value of τ measured above? Explain.

5. A Prototype Oscilloscope Probe

(a) Rise Time t_r = ____________________________ (without C_1; attach annotated oscilloscope plot)

Predicted Rise Time Using Circuit Analysis = ____________________________

(b) After compensation:

C_1 = _________________________

C_2 = _________________________

R_1 = ___________________________

R_2 = ___________________________

Rise Time at Input = __________________________ (attach annotated oscilloscope plot with scale magnified to accurately show t_r)

Rise Time at Output = _________________________ (attach annotated oscilloscope plot with scale magnified to accurately show t_r)

After compensation, is the output voltage a reasonable representation of the input voltage? Do you need to take the actual oscilloscope probe characteristics into account in your discussion? Justify.

How long did the prototype oscilloscope probe take to reach its final value? _______________

How long would the prototype probe have taken without compensation? __________________

Comment on the need for compensation and its benefits.