Laboratory Manual
for
Principles of Electronics:
Analog and Digital

1. INTRODUCTION

These introductory notes describe the laboratory equipment and some general procedures to be followed on all of the exercises.

2. EQUIPMENT

The major pieces of lab equipment at each station are:

1. Signal Generator (B & K 0.1 Hz - 1 MHz Function Generator)
2. Enhanced Breadboard (Proto-Board PB-503)
3. Dual Trace Oscilloscope (B & K Model 1479 BP or equivalent)

The model B & K function generator produces sine, triangle, and square wave signals with a 600W output impedance. It also has a TTL output.

This Proto-Board unit is available from Global Specialties and includes + 5 V, +15 V, and -15 V power supplies, an uncalibrated 0.1 Hz - 100 kHz function generator, coax to breadboard connectors, push buttons, switches, potentiometers, LEDs, and a number of other features.

This B & K scope is a dual trace unit with the ability to add or subtract the A and B inputs.

Each lab-station has a wire stripper and the lab is stocked with #22 gauge solid wire in several colors. The lab is also stocked with resistors and capacitors in a limited number of values.

Resistors

39, 51, 100, 200, 510, 1 k, 2 k, 5.1 k,
10 k, 20 k, 51 k, 100 k , 300 k, 510 k,
820 k, 1 M, 10 M

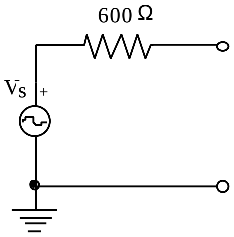
Capacitors

100 pF, 300 pF, 1000 pF, 0.01 µF,
0.1 µF, 0.47 µF, 1 µF*, 10 µF*
* Polarized

3. GENERAL PROCEDURES

Many of the laboratory exercises have sections that should be performed before you come to lab. They are indicated by this type style. Typically, these sections will ask you to develop certain equations specific to the lab or to complete some aspect of circuit design. Your time in lab will be much better spent if you come prepared, and in some cases there will not be time to perform this work during the lab period.

The following measurement techniques and procedures are common to several of the lab exercises and are grouped here to avoid repetition.



3.1. Function Generator Model.

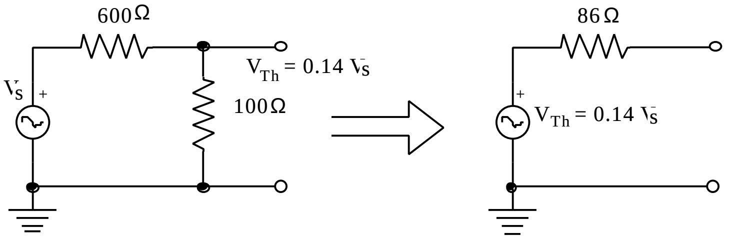
For the analysis of laboratory circuits you can model the function generator as a Thevenin's equivalent circuit consisting of an ideal signal source and a 600 Ω resistor as shown.

Note that the amplitude of the ideal source is the amplitude you measure at the output of the function generator before it is loaded by attachment to your laboratory circuit. This ideal signal at the Thevenin source remains unchanged even though the function generator output may appear smaller or distorted as a result of being connected to a laboratory circuit.

3.2. Reducing the Output Impedance of Function Generator.

For some of the lab exercises it is desirable to reduce the function generator's output impedance by placing a 100 Ω resistor across its output terminals. The following figure shows the schematic and equivalent circuits for this modification.

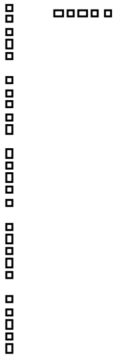
Note that the effect is to reduce both the output impedance and the amplitude of the equivalent ideal source.



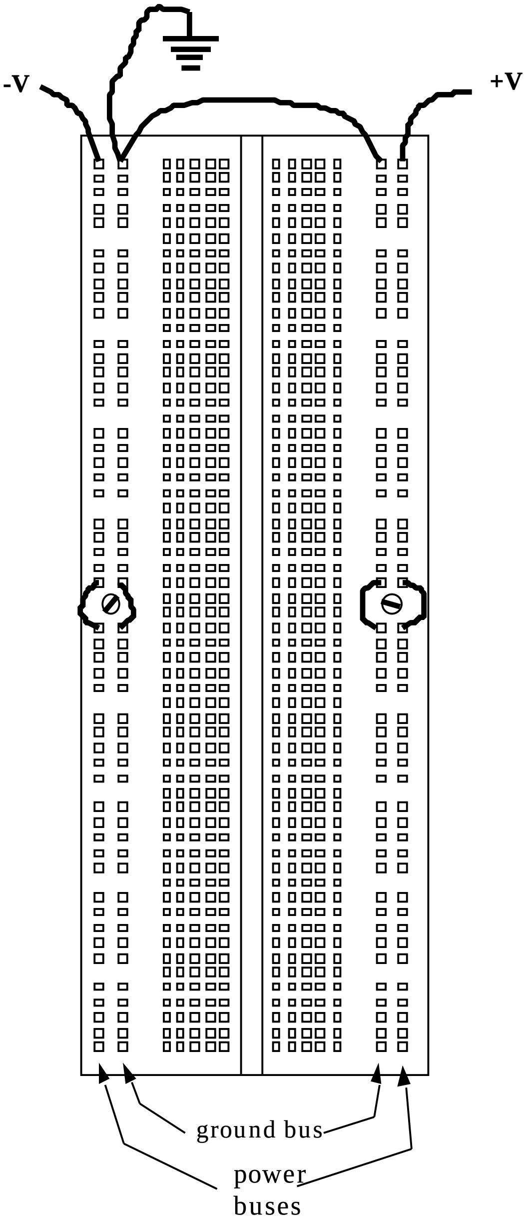
3.3. Breadboard Connections.

One of the more common breadboard blocks is shown at the far right. Each hole in the plastic block contains a springy metal clamp designed to accept the wire leads of common circuit elements or #22 or #24 gauge solid wire.

The holes are interconnected inside the block in one of the two patterns shown at the left of this text. There are no other hidden connections. On the block, each of the 5-hole horizontal patterns can be used as a circuit node for up to five wires. Along the edges of the breadboard block the vertical 5-hole patterns are not isolated but are internally connected to form 25-node structures as shown on the left of this text. There are eight of these on the block to the right.



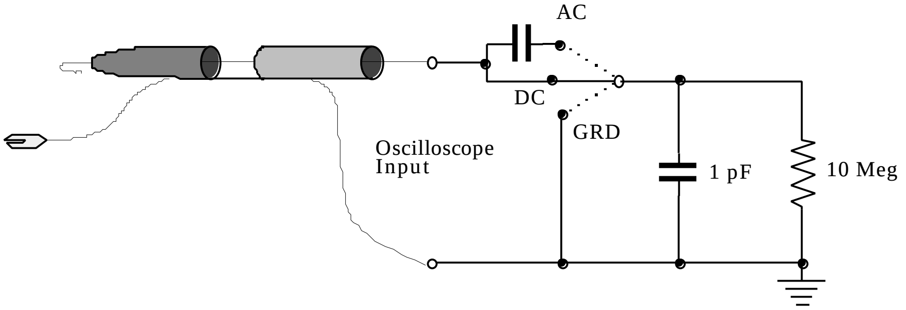
It is recommended that the eight 25-hole strips be connected with four short jumpers as shown at the right to form four long bus lines. For passive circuits without power connections, the inner two strips can be used for the common bus and should be connected to ground at one point. When power is required for a circuit, its common (or return) should be wired to the inner bus strips as shown and its plus and/or minus power should be wired to the outer strips. The polarity shown here is a match to our most common DIP (Dual Inline Package) components when their pin one is positioned at the upper left. Individual power and common connections to the circuit are then made to the buses and not directly to the power supply.



To avoid damage to the equipment, do not make the +V and -V power connections until they are explicitly required by a lab. Once these connections have been made, be extra careful when making connections to the breadboard. It is very easy to damage circuit elements and the power supplies with incorrect power connections. Except for the connections to the plus and minus voltages, this wiring can be left in place from lab to lab.

3.4. Model for Oscilloscope Input.

On most oscilloscopes, each input channel will have a three position switch labeled AC, GND, and DC. The DC position shown in the figure is preferred since it is able to passes both DC and AC signals to the display. The AC position is used to observe a small AC signal on a large DC offset, and the GND position is useful for establishing the zero voltage position on the display.



The oscilloscope is normally used with a 10X probe that reduces the input signal by a factor of 10 while increasing the effective input impedance of the instrument by the same factor. This increase in impedance is particularly important at frequencies above 100 kHz or when large resistors are present in the test circuit. Used with a 10X probe the effective input impedance of most oscilloscopes can be represented by a 1 pF capacitor in parallel with a 10 MΩ resistor as shown in the figure. If a 1X probe or a direct connection to the oscilloscope is used, these change to 10 pF and 1 MΩ.

3.5. Time Constant Measurement.

On occasion you will also be asked to measure the time constant t of a falling or rising exponential signal defined either by $e^{-t/\tau}$ or by $(1-e^{-t/\tau})$. Since at the time $t = \tau$ these time varying factors take on the respective values $e^{-1} = 0.4$ and $(1-e^{-1}) = 0.6$, the experimental method is to find the point in time where the signal amplitude has either fallen to 0.4 of its initial value or has risen to 0.6 of its final value. Reading this time from the oscilloscope display gives you the time constant.

3.6. Frequency Measurement.

You can measure the frequency of a signal from your function generator either by reading the dial and range setting directly or by measuring the signal period using your oscilloscope. The oscilloscope is likely give the more accurate result and can also be used with signals that do not originate with the function generator, but the procedure is more complicated since you actually measure a length and must know the time base setting of the horizontal sweep to be able to convert to period and frequency. Since there are occasions when you must use the oscilloscope to determine a frequency, check the two procedures against each other with a simple sine wave to be sure you know how to use the oscilloscope. Whenever you use the oscilloscope for this purpose, be sure that the continuously variable knob on the time base is in its calibrate position.

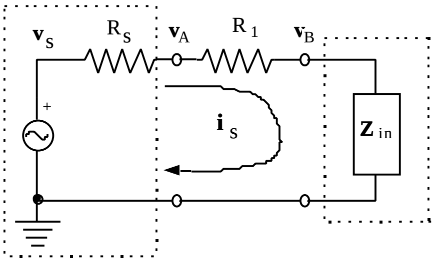
3.7. Phase Angle Measurement.

To measure the phase angle between two signals, first display the input or reference signal on the A channel and the phase shifted signal on the B channel. Adjust you function generator to give a sine wave signal of the desired frequency and amplitude, then configure the time base controls on the oscilloscope so that it is triggering on the rising edge of the A-channel signal.

Note the time interval selector knob on your oscilloscope. It should be near the trigger controls.. In the center of this control is a small knob that provides a continuous adjustment of the time interval. Use these controls in combination until you have one cycle of your A-channel sine wave displayed in exactly four large (1 cm) intervals on your screen. The horizontal position control will allow you to center the wave so that its zero crossings match the centimeter grid lines. It is now easy to read off the phase shift of the B-channel wave since each 1 cm interval now corresponds to 90° or $\pi/2$ radians. If the B-channel sine wave is shifted to the right (later time) it is said to lag behind the A-channel signal. When you complete this measurement, return the continuous control to its calibrated position (fully clockwise).

3.8. Input Impedance Measurement.

To measure the input impedance of a circuit you need to determine both the voltage applied across the input terminals $\mathbf{v}_B$ and the loop current $\mathbf{i}_S$ circulating in the input loop. A typical situation is shown below where $\mathbf{v}_B$ is the applied voltage and is the loop current.



The voltage $\mathbf{v}_B$ can be measured directly using your oscilloscope but $\mathbf{i}_S$ must be derived from $(\mathbf{v}_A - \mathbf{v}_B)/R_1$. This procedure is straightforward for the case where $\mathbf{Z}_{in}$ is a resistance because the voltages and currents are then all in phase and the problem reduces to the simple voltage divider of Chapter 1.

More generally the absolute value of $\mathbf{Z}_{in}$ must be measured using the equation

$$|\mathbf{Z}_{\text{in}}| = R_1 \frac{|\mathbf{v}_B|}{|\mathbf{v}_A - \mathbf{v}_B|}.$$

This denominator can be measured directly if your scope has the ability to subtract two signals: in that case the magnitude of the difference is just the amplitude of the subtracted signal. Note however that $|\mathbf{v}_A - \mathbf{v}_B|$ is not the same as $|\mathbf{v}_A| - |\mathbf{v}_B|$. An easier method is to choose a value for R_1 so that $|\mathbf{v}_A| >> |\mathbf{v}_B|$: in that case we can neglect $\mathbf{v}_B$ compared to $\mathbf{v}_A$ and have

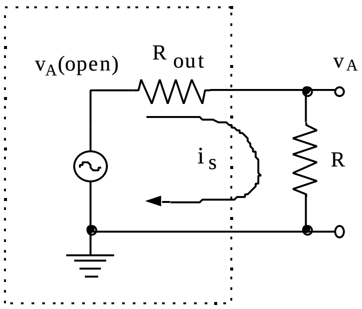
$$|\mathbf{Z}_{\text{in}}| = R_1 \frac{|\mathbf{v}_B|}{|\mathbf{v}_A|} = \frac{R_1}{|\mathbf{v}_A|} |\mathbf{v}_B|,$$

showing that with the proper procedure $|\mathbf{Z}_{in}|$ will be simply proportional to the directly measurable $|\mathbf{v}_B|$.

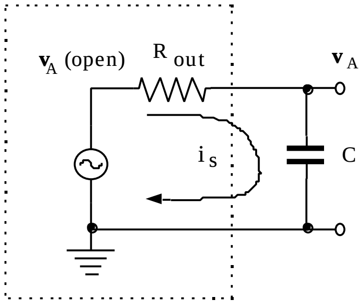
3.9. Output Impedance Measurement.

In most cases a resistive output impedance can be measured by first measuring the open circuit voltage at point A, identified as $\mathbf{v}_A$(open) in the following figure, then adding a load resistor to produce a voltage divider as shown in the figure. An often convenient procedure is to adjust R until $|\mathbf{v}_A|$ is one-half of $|\mathbf{v}_A(\text{open})|$, the condition that occurs when R_{out} is equal to R.

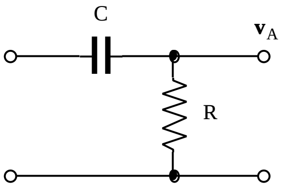
It is sometimes necessary and often more convenient to use a capacitive load instead of R. A capacitance is convenient since its impedance can be varied by the simple process of changing the frequency of the driving signal, thus making a ohmmeter unnecessary. A capacitive load must be used when measuring the output impedance of an active circuit where the addition of the DC current path through R would alter the operation of the circuit. This situation will arise in these labs only when dealing with single transistor circuits. In these cases it is necessary to use a loading capacitor instead of a resistor. The method is shown in the following figure.



This method is complicated by the fact that $\mathbf{v}_A$ and $\mathbf{v}_A$(open) are not in phase when the load is reactive. Because $\mathbf{v}_A$(open) is not available for measurement when C is connected, we cannot measure the voltage drop across R_{out} directly. However the circuit is just a single-pole low-pass filter, and using the methods of Chapter 3 it is easy to show that $|\mathbf{Z}_C| = R_{out}$ when $|\mathbf{v}_A| = 0.707|\mathbf{v}_A(\text{open})|$.



It is also possible to retain the use of a resistive load and still avoid the DC current problem by attaching a large capacitor in series with the output before the load resistor is attached. The added components are indicated at the right. This procedure has the advantage of avoiding the complicating phase shift if care is taken to make all impedance measurements at a frequency f that is much greater than the $(2\pi R_t C)^{-1}$ corner frequency of the high pass filter resulting from C and $R_t = R_{out} + R$.



Output impedances that contain reactive elements are best measured by one of the resistive methods, but care must still be taken to distinguish between measured signal amplitudes $|\mathbf{v}|$ and the complex representations that appear in the basic equations. Generally, the best method is to treat the loaded circuit as a filter following the methods of Chapter 3. The location of resonant frequencies and single-term approximation lines in appropriate frequency domains will usually yield the fundamental elements of any impedance.

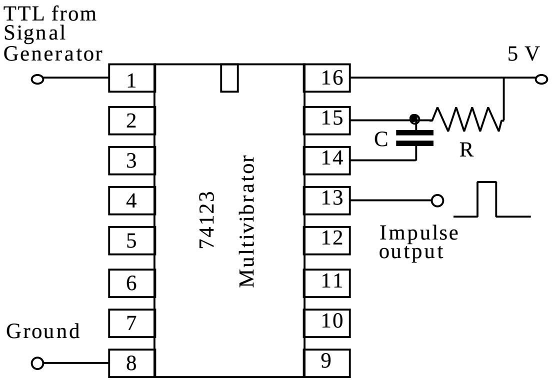
3.10. Measuring a 0 to 3 dB/Octave Corner Frequency

The corner frequency between a flat single-term approximation and one with a 3 dB/octave slope occurs at the frequency ω_c where $|\mathbf{H}(j\omega_c)| = 0.707|\mathbf{H}|$ with $|\mathbf{H}|$ being the asymptotic value of the transfer function in the flat region. If the input signal $\mathbf{v}_A$ does not change with frequency, then H is just proportional to the observed output signal $\mathbf{v}_B$. The corner frequency is then easily found on an oscilloscope by adjusting the gain controls so that $\mathbf{v}_B$ in the flat region has a peak-to-peak amplitude of 6 large divisions. This particular type of corner frequency can then be found by locating the frequency where the peak-to-peak amplitude drops to 0.707 × 6 4 divisions.

3.11. Constructing an Impulse Generator.

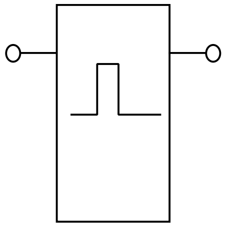
The TTL multivibrator chip 74123 makes a convenient impulse source. Build the source with your breadboard power switched off. Locate the chip near the +5 V power source on your breadboard. You can orient the chip by the notch in the middle of one end, by a dot near pin 1, or by the writing on the top oriented as indicated.

Use special care to align the 16 pins with the holes when inserting the chip into the breadboard and always use a tool to extract the chip from the breadboard (A small screwdriver used as a pry bar under the ends works well.). **Fingers alone almost always bend pins** when the chip finally breaks free of the breadboard!



Before beginning construction, be sure the signal generator is in the TTL position. Leave it there whenever it is connected to this chip. With the power to the breadboard switched off, select or cut and strip the necessary wire and make the connections shown on the figure, beginning with the power and ground pins. A 0.1 μF capacitor and a 2 kΩ resistor will give a 56 ms wide output pulse; the width is proportional to the *RC* product. Apply a 500 Hz TTL signal from your signal generator and verify that you get the expected output. You will find it easiest to display the input signal on the A channel, adjust the scope to trigger on the rising edge of this square wave, then use the dual trace feature to also display the 74123 output on the B channel; remember that it will be very narrow!

The previous 74123 pin-out figure is for construction purposes only and should not be reproduced on a schematic. A convenient schematic symbol for a multivibrator (or one-shot) is simply a rectangle surrounding the text "OS" or a pulse wave form as shown here.



3.12. Working with Digital Circuits.

The following are some general rules that should be followed when working with digital circuits.

3.12.1. Use of breadboard:

Most TTL chips have power (labeled VCC) and ground pins on opposite diagonal corners. When laying out a circuit on the breadboard, produce a +5 V power bus down one side of the breadboard and a ground bus on the other, then orient the chips so that the power pin is on the same side as the power bus. Depending on the orientation of your breadboard, the top or right side works best for the +5 V bus. Build this bus first and if other voltages are present be especially careful to avoid accidental contact. TTL chips are instantly destroyed by voltages in excess of 7 V.

3.12.2. Handling of chips:

Be sure that the pins are straight before inserting a chip into the breadboard; the more pins there are the harder this is to accomplish without bending a pin. Use needle nose pliers or a pin straightener to repair any damage. Chips with many pins are most often damaged when removing them from the breadboard! **Never** attempt to remove a chip using arm muscle because the pins will almost always be bent. The best method of removal is with a special extraction tool or a small pry bar such as a small screwdriver applied alternately to either end. If no tool is available then brace your hand on the breadboard and remove the chip with finger muscles alone.

3.12.3. Schematic drawing:

A proper digital schematic shows the logic function, not the physical layout of the circuit. Use individual logic symbols, not DIP outlines such as those given in the back of the text. Locate specific chips by a letter-number grid on the breadboard, with each logic function on the schematic labeled with its grid position, and each input and output labeled with the pin number from the DIP pin-out diagrams.

Wherever possible, logic functions should be arranged so that signals on the schematic flow from left to right and top to bottom. If the circuit is complex, do not try to show all connections as point-to-point wires: rather assign names to signals and break the schematic into smaller logical sections, using named signals for inputs and outputs. When several pages are necessary, it is helpful to annotate input signals with their page of origin.

3.12.4. Unused inputs:

A disconnected TTL input pin is a true input. Good design practice would not leave any input pins disconnected, but it is acceptable to do so in this lab.

3.12.5. Output pins:

With the exception of 3-state devices, the output of a TTL element may only be connected to another output if one or both are of the open collector type. The outputs of 3-state devices may be connected only if control logic exists to guarantee that only one output driver is enabled at a time, leaving the other drivers in their high output-impedance third state.