

Experiment 4

The oscilloscope and RC filters

The objective of this experiment is to familiarize the student with the workstation equipment to be used throughout the course. Some simple experiments/measurements will be conducted to facilitate the practical use of this equipment.

4.1 Workstation equipment

Digital oscilloscope

An oscilloscope displays on a two-dimensional grid the variation in voltage (y) with time (x) of one or more input signals. A digital scope includes a lot of features intended to make the measurement and analysis of these signals easy.

The basic controls are grouped into the following functional blocks:

1. the **VERTICAL** controls set the voltage gain and input coupling for each channel. Select a channel by pressing the **CH1** or **CH2** keys, then use the **VOLTS/DIV** knob to adjust the vertical resolution, or gain, of the waveform. The voltage gain *per grid division* is shown on the bottom of the display. You can use the grid to make approximate measurements or preferably, use the framing cursors. Press the **CURSOR** button, followed by the **X-Y** button to display two horizontal cursors in the same colour as the selected channel. Select a cursor **Y1** or **Y2** and position it with the **VARIABLE** knob; their values and difference **Y1Y2** are shown to the right.

By default, the display gain occurs about the ground level ($V=0$) of the signal. You can zoom in on any part of the waveform by setting the **Expand** menu selection to **center**; the zoom then occurs about the vertical center of the display. As you change the gain setting, you will likely need to re-center the region of interest using the vertical position knob.

The coupling selection allows the input channel to be grounded (displaying a flat line at $V=0$), to view the input signal as it is (**DC**) or view it with the DC component removed (**AC**). The **AC** setting can be used to focus on a small varying signal when it is offset by a larger DC voltage.

The **MATH** button provides ways to add, subtract, and multiply together the instantaneous voltages of the two channels. A Fast Fourier Transform (**FFT**) can also be applied to an input signal. In this mode, the signal x -axis is calibrated in units of frequency (**Hz**) rather than time (**s**) and the scope displays the amplitude-frequency relationship, or frequency spectrum, of the signal.

2. the **HORIZONTAL** controls similarly set and adjust the common time scale for the two input channels. Again, you can use the cursors to take measurements. By selecting the **XY** mode, **CH2** (y) is displayed as a function of **CH1** (x). This mode is used to measure phase or voltage-current relationships between two signals;

- the **TRIGGER** controls set the starting position (level) and direction (slope) of a signal relative to the centre of the display x-axis. The trigger source can be either CH1, CH2, the 60Hz Line input to the scope, or some **External** input connected to the **EXT TRIG** connector. The voltage level is set with the **LEVEL** knob and is monitored by an arrow on the right edge of the display. The trigger slope can be set to \uparrow (positive) or \downarrow (negative). The trigger coupling functions as outlined above. The **SINGLE** capture mode causes the scope to wait for and record a single screen and then stop; this is useful when monitoring non-periodic events.

As with all things, familiarity comes with practice. Try out the various settings, some functions you will use all the time, others rarely. If the signal disappears, press the **Autoset** button. To restore the default settings, turn the scope off and then back on.

Digital multimeter

Use this instrument to precisely measure the basic electrical quantities such as DC and AC voltage and current, and resistance. In the AC domain, the peak, average, and RMS values of a signal can be measured.

Waveform generator

A waveform (or function) generator is used to provide a precise, adjustable signal to an electronic circuit. Typical waveforms include sine, triangle, ramp and square/pulse. These various signals vary in harmonic content, from the pure sinusoid to the others that contain various mixtures of sinusoidal overtones. The rapid transition of the pulse waveform can be used clock digital circuits or to excite analog circuits into a state of self-oscillation.

Basic controls allow the adjustment of amplitude, frequency, pulse width, and the application of a DC offset voltage to the signal that appears at the *output* BNC connector of the FG. The amplitude and frequency of the signal can also be modulated, or varied in some way. A typical modulation used for testing the response of electronic circuits is a frequency sweep.

The *Sync* BNC connector provides a 0-5V square wave at the frequency set by the FG. This signal can be used as a clock in digital circuits or to synchronize (phase lock) external devices to the FG signal.

Note that some of the function generators have an *output* switch that enables the FG output; be sure to turn it on otherwise no signal will appear at the output BNC connector.

Precision power supply

This device approximates an ideal voltage source. The output is regulated so that the voltage will not vary with changes in output current of up to 1A. The output can also be current limited so that a test circuit will not draw excessive amounts of current if defective or if there is a short circuit. The output voltage and current can be monitored and the maximum current can be set.

This device provides three voltage outputs adjustable in steps of 0.1mV and 1mA. This voltage resolution allows the power supply to be used as a precision voltage reference.

Connecting instruments

Always connect external devices such as meters, scopes, and function generators using the banana

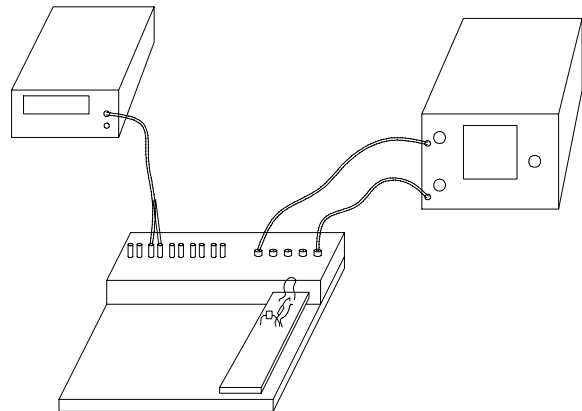


Figure 4.1: The proper breadboarding technique

plug (black and red pairs) and BNC (coaxial) connectors near the top of the breadboard workstation. These contact points are available on the breadboard and can be accessed using jumper wires.

- ⓘ Turn on the instruments. Note that for the best measurement accuracy, electronic measuring devices should be given time to warm up and equilibrate to operating temperature, typically around 30 minutes, hence you should power-up your workstation at the start of the lab session. At the end of the lab, power-down all equipment and disconnect from the AC outlets any devices that you may have plugged in.
- ⓘ With appropriate (BNC-terminated) cables, connect the output of the function generator (FG) and then the Channel 1 (CH1) input on the oscilloscope to the workstation. Insert a breadboard into the workstation, then insert a short jumper wire on the breadboard to complete the signal path between FG and scope.

Connecting the scope channels CH1 and CH2 to the corresponding BNC1 and BNC2 on the breadboard will make it easier for you to remember the location of the signal connections.

- ⓘ Set the FG to output a sine wave of 1 KHz frequency and 1 V amplitude. On the scope, turn off CH2 by toggling the CH2 button until the blue trace disappears. Turn on CH1 and set the gain to 500 mV/DIV, the timebase to 500 us/DIV and the coupling to DC.

Be sure that the *Voltage* is set to 1X; if not, turn the *variable* knob to make it so.

- ⓘ The zero voltage level of the signal is given by the position of the symbol 1> on the left side of the screen. You can temporarily ground the signal so it collapses to a horizontal line by setting the coupling to *ground*.

Rotate the knob above the CH1 button to set the trace vertical position at 0 V; the current position appears on the bottom left corner of the display while the knob is being turned.

- ⓘ Press the *Trigger, menu* button and check that the trigger source is set to CH1, then with the **LEVEL** knob adjust the trigger level to 0V.

- ⓘ You can capture the current oscilloscope screen by typing `GDS-1102A.tcl` in the terminal window; this application makes a USB connection to the scope and displays a virtual scope screen that can be saved for inclusion in your report by pressing the *Hardcopy* button.

You can place a shortcut to this application on your desktop by right-clicking the desktop background, then clicking on **Create Launcher**. Enter a meaningful name and in the command box enter `/usr/local/bin/GDS-1102A.tcl`. If you wish, double-click on **Icon** to select an icon from those available. Click **Create** and you are done!

Similarly, you can create a shortcut to the **Screenshot** application by following the same procedure and entering `xfce4-screenshooter`.

- ⓘ Use the cursors to measure the amplitude and period of the signal. Tabulate all your data. Estimate the measurement errors by determining the cursor step sizes at the current display settings and apply these uncertainties to the measured values.
- ⓘ Vary the gain and timebase of the displayed signal and repeat the above procedure. Note how the choice of scale affects the measurement error. How should you scale the signal in order to minimize the measurement error?
- ⓘ Press the **Autoset** button to have the scope set the display parameters. Do the settings selected by the scope yield the best resolution for the input signal? Explain.

- ? Vary the scope trigger level. How does the waveform change? What happens when the trigger level exceeds the range of the signal? Change the trigger slope. What effect does this have on the waveform? Use screen captures to describe the function of these trigger controls.

4.2 Exponential decay in an RC circuit

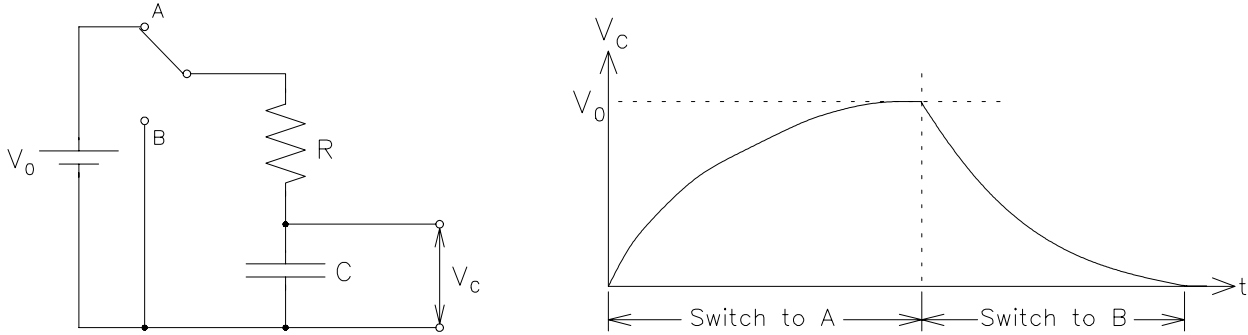


Figure 4.2: Time dependence of V_C

Consider the battery-driven RC circuit on the left. Initially, the capacitor is uncharged, so $V_C = 0$. When the switch is first turned to position A, the current I has the initial value:

$$I_0 = \frac{V_0 - V_C}{R} = \frac{V_0}{R} \quad (4.1)$$

As the current brings charge to the capacitor, the voltage V_C increases up to its maximum value $V_C = V_0$, at which point the current reduces to zero:

$$I = \frac{V_0 - V_C}{R} = \frac{V_0 - V_0}{R} = 0. \quad (4.2)$$

To analyze the circuit at intermediate times, we apply KVL:

$$V_0 - RI - V_C = 0, \quad (4.3)$$

which for this circuit translates into a differential equation, since

$$V_C = \frac{1}{C} \int I(t') dt'. \quad (4.4)$$

Substituting equation (4.4) into equation (4.3) and differentiating once gives

$$\frac{1}{C}I + R \frac{dI}{dt} = 0, \quad (4.5)$$

or

$$\frac{dI}{dt} + \frac{1}{RC}I = 0. \quad (4.6)$$

The solution to this differential equation (4.6) is

$$I = I_0 e^{-t/\tau}. \quad (4.7)$$

where $\tau = RC$ is the characteristic time constant, and I_0 is the constant of integration whose value is determined from the initial conditions, as in Equation (4.1). For the voltage across the capacitor,

$$V_C = V_0 - IR = V_0 - \frac{V_0}{R} e^{-t/\tau} R = V_0(1 - e^{-t/\tau}) \quad (4.8)$$

If the switch is now turned to position B, the battery is eliminated from the circuit and the capacitor discharges through the resistor. The direction of I is reversed, but it has the same exponential time dependence

$$I = -I_0 e^{-t/\tau}. \quad (4.9)$$

where $I_0 = V_0/R$ as before. Again, the time dependence of V_C is also exponential:

$$V_C = -IR = V_0 e^{-t/\tau} \quad (4.10)$$

Equations (4.8) and (4.10) are summarized in Figure 4.2.

4.3 Measuring transients in an RC circuit

Additional components required

- one 10 k Ω resistor
- one 0.01 μ F capacitor

Often, the time constant, $\tau = RC$, of the transient is so short that it is impossible to move a mechanical switch, or to measure the voltage using a voltmeter, fast enough to see the exponential decay. Instead, one can use a square-wave output of a function generator (FG) and an oscilloscope, to monitor both V_{in} and V_{out} , as in Figure 4.3. **Note** that in the above circuit, all the BNC ground connections are already made by the protoboard; only the capacitor needs to be grounded.

- ⓘ Construct the circuit of Figure 4.3 with $R = 10\text{ k}\Omega$ and $C = 0.01\mu\text{F}$, using the proper breadboarding technique. Drive it with a 1 KHz square wave of 5 Vpp (peak-to-peak). Adjust the DC offset voltage on the FG so that the signal toggles between 0 V and 5 V. Obtain a stable trace and record a graph of the voltage as a function of time on both channels of the scope, for one full period of the square wave.

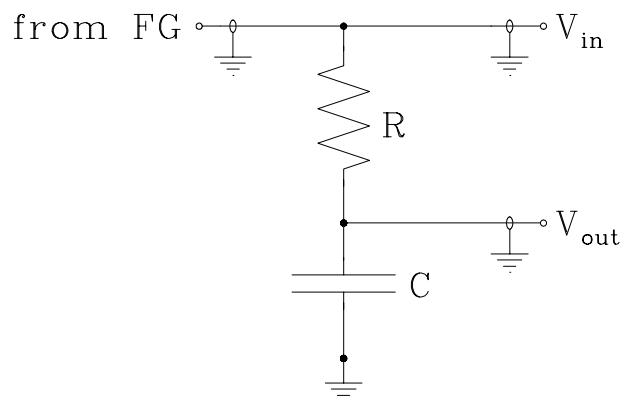


Figure 4.3: Transients measurement setup

- ⓘ Adjust the function generator and gain and timing controls of the oscilloscope as necessary to best measure the exponential fall of the voltage. Determine the time constant of the circuit by using the cursors to select two points on the decay curve that satisfy the voltage change with time equation used in the previous lab. Include error estimates for all your measurements and results. You can jog the cursors to determine the measurement step size and thus the scale error.
- ⓘ Determine the relationship between signal period and RC time constant necessary for the output signal to behave as an integrator. Use a series of frequencies starting at 1-KHz and scope screen captures to show how this integrator behaviour emerges.
- ⓘ Interchange C and R and repeat the time constant measurement.
- ⓘ Determine the necessary condition to have the circuit acts as a differentiator. Follow the above steps to show how this behaviour emerges.
- ❓ Discuss your results and compare with theory.