Experiment 1: Circuits

Naim Ayat

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David Bauer

Lab Partners: Danielle Collado, Andrew Yama

1.4.1 Worksheet

1. Oscilloscope
    (a) The measured amplitude of the scope's calibration signal peak-to-peak is $20.0V$ at the default setting of $10\times$ attenuation. Therefore, at $1\times$ attenuation, the amplitude is $2.00V$.
    (b) As measured by eye, the rise time of the calibration signal is approximately $700\mu s$. The scope's rise time function generates inconsistent results, a sample of which is: $\{710\mu s, 792\mu s, 764\mu s, 722\mu s, 749\mu s\}$. The mean $\bar{x}$, or best value, of this set is $747\mu s$. Where $N = 5$, the statistical uncertainty can be determined with the following formula:

$$\delta x = \frac{\sigma_x}{\sqrt{N}} = \frac{1}{\sqrt{N}}\sqrt{\frac{1}{\sqrt{N-1}}\sum_{i=1}^{N}(x_i - \bar{x})^2}. \tag{1}$$

    This gives $\delta x = \pm 14.7\mu s$. Thus, the rise time is $747\mu s \pm 14.7\mu s$.
    (c) The uncertainty in the $\approx 0V$ signal from the pre-triggered portion is approximately $\pm 2.00mV$.
2. Potentiometer and myDAQ
    (a) To derive an expression for V_{out} on the potentiometer wiper as a function of V_{in}, R_1, and R_2, first note that all potential difference entering the loop will eventually be dropped. Hence, V_{in} must equal the current I multiplied by the sum of the resistors. Moreover, the initial voltage drop caused by R_1 leaves V_{out} to equal I multiplied by R_2. Thus, the following equations hold:

$$V_{in} = IR_1 + IR_2 \text{ and} \tag{2}$$

$$V_{out} = IR_2. \tag{3}$$

    Now, equation (2) may be rewritten in terms of V_{out}, I, and R_1:

$$V_{in} = IR_1 + V_{out} \text{ and} \tag{4}$$

$$V_{out} = V_{in} - IR_1. \tag{5}$$

    Solving equation (2) for I gives:

$$I = \frac{V_{in}}{R_1 + R_2}. \tag{6}$$

Finally, by substituting the right-hand side of equation (6) for I in equation (5), it follows that:

$$V_{out} = V_{in} - \frac{V_{in}R_1}{R_1+R_2}. \tag{7}$$

(b) The voltage applied across the potentiometer is approximately $5.00V$.

(c) The apparent functional form of the potentiometer's output voltage as a function of the turning angle θ is of standard linear form:

$$V_{out} = m\theta + b. \tag{8}$$

In theory, there is no V_{out} when $\theta = 0$, so the y-intercept b in equation (8) is equal to 0. Therefore, the linear model can be simplified to:

$$V_{out} = m\theta. \tag{9}$$

(d) The potentiometer is ohmic. This conclusion is supported by equations (2) and (3), which both indicate that current and potential difference are directly proportional to one another. Specifically, equations (2) and (3) are of the form $V = IR$, the mathematical definition of Ohm's law.

3. Magnetic Levitator

(a) The equilibrium position of the bolt assembly (measured to the top of the uppermost magnet) is approximately $2.80cm$ below the coil, as determined by a millimeter ruler. Note that there is a $\pm 0.05cm$ margin of uncertainty associated this method of measurement, as given by:

$$\delta x = \pm \frac{resolution}{2}. \tag{10}$$

(b) This equilibrium is unstable – that is, whenever the magnet is disturbed at equilibrium, it will stray further from its initial position rather than returning to it. If the magnet is positioned below the coil at a distance greater than $2.80cm$, it drops to the ground. Conversely, if the magnet is positioned below the coil at a distance less than $2.80cm$, it sticks to the coil.

(c) Both the front- and rear-facing cameras of Samsung Galaxy S7 and S8 cell phones are sensitive to IR light.

1.4.2 Presentation Report

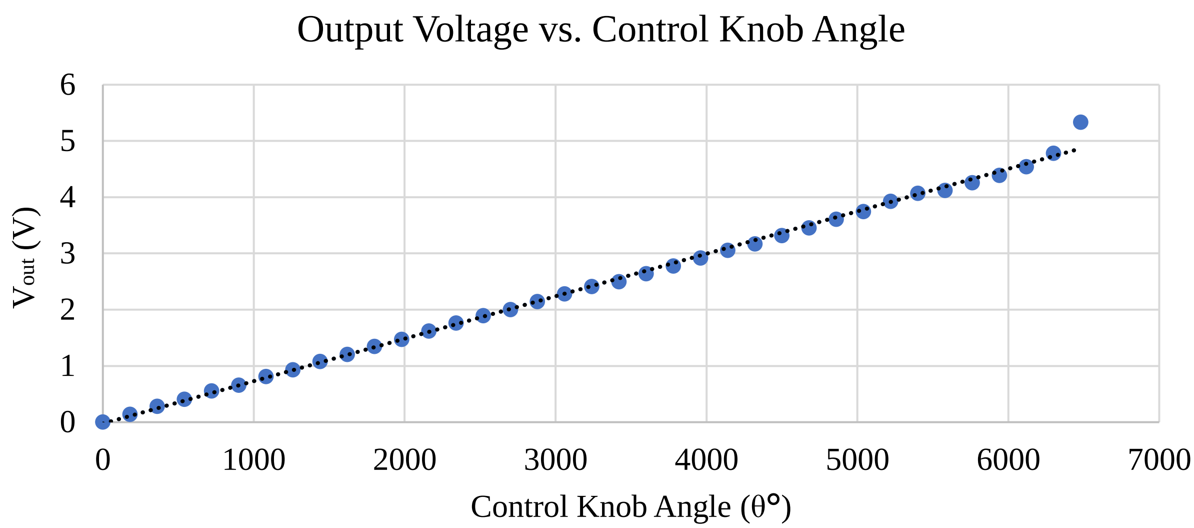

Figure 1: A linear regression superimposed on a plot of output voltage (V_{out}) vs. control knob angle (θ) on a linear taper potentiometer. Data points represent output voltage as observed in the UCLA Physics 4BL Windows application and measured by myDAQ. There is one data point per 180° increment on the y-axis. The regression line has a coefficient of determination $R^2 = 0.996$. The y-intercept and slope for equation (8) are $b = (-0.0284 \pm 0.0302)V$ and $m = (7.55 * 10^{-4} \pm 7.93) * 10^{-6} \frac{V}{deg}$, respectively. The complete regression formula is therefore $V_{out} = (7.55 * 10^{-4} \pm 7.93) * 10^{-6}\theta \frac{V}{deg} + (-0.0284 \pm 0.0302)V$.

By analyzing V_{out} data with respect to the control knob angle, it is possible to conclude that the potentiometer adheres to Ohm's law. By definition of a linear taper potentiometer (and as demonstrated by Fig. 1), V_{out} is directly proportional to the knob angle. This relationship suggests that V_{out} must also be directly proportional to R_2, as presented in equation (3). Also notable is the fact that the linear regression model has a y-intercept of $b = (-0.0284 \pm 0.0302)V$, which is relatively close to the expected value $0V$ after adjusting for human and instrument error. This expectation follows from equations (3) and (4); when the potentiometer is set to $\theta = 0°$, R_2 is also 0Ω since the two variables are linearly proportional. Hence, all the resistance in the potentiometer must come from R_1 in this case. Moreover, the slope $m = (7.55 * 10^{-4} \pm 7.93) * 10^{-6} \frac{V}{deg}$ represents the number of volts produced by a one degree control knob increment.

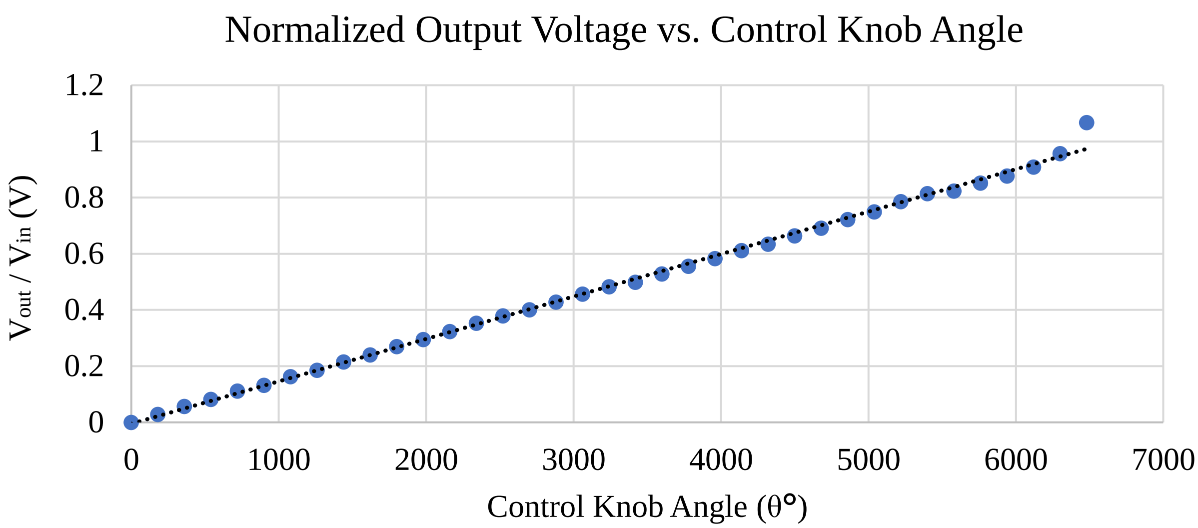

Figure 2: A second linear regression superimposed on a plot of normalized output voltage (V_{out} / V_{in}) vs. control knob angle (θ) on a linear taper potentiometer. The constant V_{in} is $5.00V$. The regression line has a coefficient of determination $R^2 = 0.996$. The y-intercept and slope for equation (8) are $b = (-0.00569 \pm 0.00605)V$ and $m = (1.51 * 10^{-4} \pm 1.58) * 10^{-6} \frac{V}{deg}$, respectively. The regression formula in full is therefore $V_{out}/V_{in} = (1.51 * 10^{-4} \pm 1.58) * 10^{-6}\theta \frac{V}{deg} + (-0.00569 \pm 0.00605)V$.

From Fig. 2, it is once again evident that potential difference is directly proportional to the control knob angle. Interestingly, the residual with the largest absolute value on the normalized output voltage regression is $r_{max} = 0.0929V$, while the residual with the lowest absolute value is $r_{min} = 3.68 * 10^{-4}\ V$. It is possible to evaluate percent deviation with the formula:

$$\%\ deviation = [(residual * 100)/V_{in}] \tag{11}$$

This yields a deviation of $\pm 1.85\%$ for r_{max} and $\pm 0.00736\%$ for r_{min}. The manufacturer of the potentiometer claims that the device has a maximum tolerable independent linearity of $\pm 0.25\%$; the maximum deviation observed in this experiment was much higher than that. However, the value of r_{max} is an outlier. The second-largest residual is 0.0148V, which produces a deviation of $\pm 0.296\%$. Still, this value is inconsistent with the manufacturer's claim. It is likely that the true maximum tolerable independent linearity of the potentiometer used in this experiment is greater than $\pm 0.25\%$.