Toronto Metropolitan University

Department of Electrical, Computer, and Biomedical Engineering

ELE404 - Electronic Circuits I

Introductory Lab

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Introduction

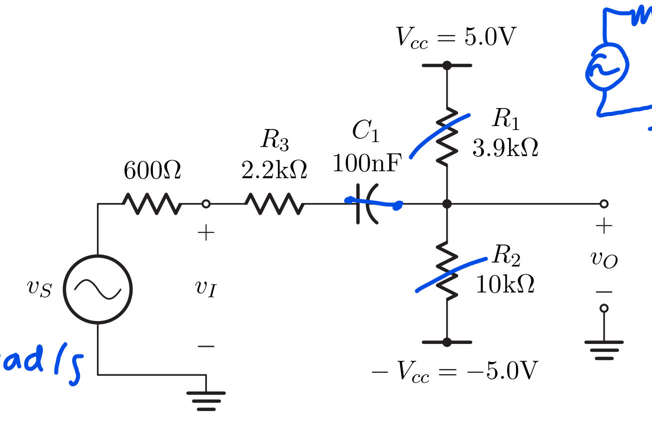
The main objective of this lab is to help you acquaint yourself with the labs in ELE404, in terms of their structure, nature of preparation required, and equipment. The lab will refresh you on one of the most effective circuit analysis techniques, namely, the *superposition* technique, albeit from a standpoint that you have probably not seen before. Furthermore, this lab will also set the stage for teaching the concept of capacitive coupling of AC signals with DC circuits.

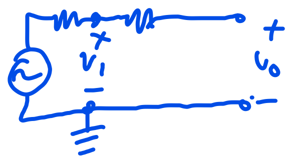
It is highly recommended that you **carefully study the Appendix** of this manual **for a quick overview on the equipment** you will be using regularly in this series of labs.

Pre-lab Assignment

P1. Consider the circuit of Figure 1. Assume that the capacitor is short for AC signals and open for DC signals. Also, assume that voltage v_S in Figure 1 is a 20-kHz sinusoid with a peak-to-peak swing of $4V$ (or, equivalently, with an rms value of $1.41V$). Thus, let $v_S(t) = 2\sin\omega t$ where $\omega = 2\pi \times 20,000\ rad/s$. Then, use the "superposition" principle to determine expressions for voltages v_I and v_O (i.e., the time functions $v_I(t)$ and $v_O(t)$). Use Matlab or Excel to plot your expressions for $v_I(t)$ and $v_O(t)$, for two cycles (periods). Also, complete Table 1 based on your calculations. Show all work.

Hint: *Superposition can be exercised in various ways. For example, one way would be to consider the response of a circuit as the sum of the response due to the AC sources (while the DC sources are "off") and the response due to DC sources (while the AC sources are "off"). Remember that, regardless of AC or DC, an "off" voltage source means a short link, whereas an "off" current source means an open circuit.*





$V_o = V_s$ ·

2 sinωt

ω = 2π·20000rad/s

Figure 1: A circuit involving both AC and DC voltages.

Reminder

The "DC" value (aka the "average" or "mean") of a periodic waveform, $v(t)$, is defined by the following integral:

$$V_{\mathrm{dc}} = \frac{1}{T}\int_{\tau=0}^{T} v(\tau)d\tau$$

where T is the period of the waveform. **All meters in their <u>DC measurement mode</u> display the DC or average value of the measured signal.** The "rms" value of $v(t)$ is defined by the following integral:

$$V_{\mathrm{rms}} = \sqrt{\frac{1}{T}\int_{\tau=0}^{T} v^2(\tau)d\tau}$$

Modern meters in their <u>AC measurement mode</u> display the rms value of the measured signal, as defined by the integral above. A famous special case, which is often generalized, is that of a sinsuoidal waveform: $V_{\mathrm{rms}} = V_m/\sqrt{2}$, where V_m is the peak value of the sinusoid. A number of modern multimeters are also capable of displaying a combined **<u>AC+DC measurement mode</u>**. In this mode, a meter can calculate the rms value of a waveform that contains both an AC and DC component. Thus, the meter displays:

$$V_{\mathrm{RMS}} = \sqrt{V_{\mathrm{dc}}^2 + V_{\mathrm{rms}}^2}$$

where

- V_{dc} is the DC (average) component of $v(t)$, which the meter displays in the **DC measurement mode**
- V_{rms} is the rms of the AC component of $v(t)$, which the meter displays in the **AC measurement mode**
- V_{RMS} is the rms of $v(t)$ as a whole, which the meter displays in the **AC+DC measurement mode**

In the discussion above, we used $v(t)$ to symbolize a voltage, however, the discussion applies to any signal, irrespective of its physical nature, voltage, current, etc.

Table 1: Voltage data corresponding to Figure 1.

v_S(peak-to-peak) (V)	v_I (rms) (V)	v_I (DC) (V)	v_O (rms) (V)	v_O (DC) (V)	v_O (RMS) (V)
4	0.303	0	1.886	2.194	2.893

$\sqrt{2.194^2 + 1.886^2} =$

Experiment and Results

E1. Begin by constructing the circuit of **Figure 2**, which consists of two independent sub-circuits, i.e., sub-circuit (a) and sub-circuit(b). Your signal generator (aka the "function generator") has a built-in (or Thevenin equivalent) resistance of 50Ω, while we need a source resistance of $R_s = 600\Omega$, as **Figure 2** illustrates. Therefore, to achieve a source resistance of $R_s = 600\Omega$, place a 560-Ω resistor in series with the output signal of the generator *(yes, it is a bit larger than 600, but that's okay)*. Finally, consider the original signal generator and the additional 560-Ω resistor as the signal

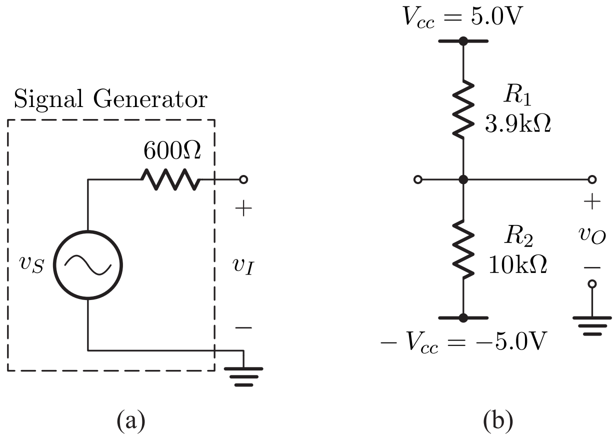


Figure 2: Circuit for Step **E1**.

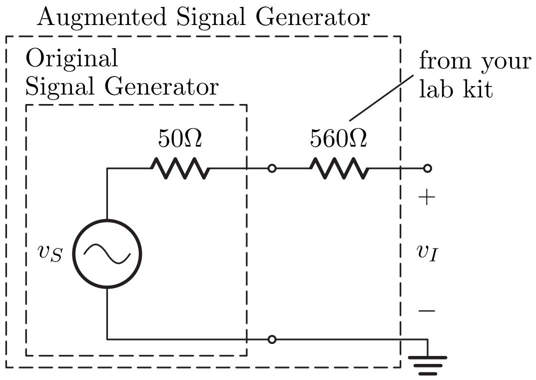


Figure 3: Implementation of the "augmented" signal generator.

generator that is needed for the circuit of **Figure 2**. **Figure 3** illustrates this concept.

Set the augmented signal generator to produce a 20-kHz symmetrical sinusoidal voltage with a magnitude of $4V$ peak-to-peak as the Thevenin equivalent voltage v_S. You may notice that you cannot measure v_S directly so you must achieve the aforementioned goal by monitoring/measuring the terminal voltage, which is v_I in this case. Therefore, use your oscilloscope to monitor v_I and adjust your signal generator to produce a 20-kHz symmetrical sinusoidal voltage with a magnitude of $4V$ peak-to-peak (see **Tips** below if necessary). Note, since nothing other than the oscilloscope probe is connected to the output of the signal generator at this stage of the setup, you are effectively measuring v_S.

Next, using the multimeter, measure the following quantities and complete Table 2. Note, although your meters may not be able to measure AC+DC directly, you can calculate the RMS of the signal using the equation for V_{RMS} provided in the pre-lab.

- The rms value of the AC component of v_I (set the multimeter to AC voltage mode)
- The DC value of v_I (set the multimeter to the DC voltage mode)
- The rms value of the AC component of v_O (multimeter in the AC voltage mode)
- The DC value of v_O (multimeter in the DC voltage mode)

Tips

- The voltages must be measured with respect to the (common) ground. This is the COM terminal on your multimeter.
- Connect **Channel 1** of the oscilloscope to v_I and also use it as the trigger source for the oscilloscope. Set **Channel 1** to the **DC-coupled mode**, adjust the voltage sensitivity, and time-base as necessary ($1V$/div and $10\mu s$/div should be okay).
- Ensure that the multimeter is in the correct mode for each measurement.

Table 2: Experimental voltage measurements corresponding to Figure 2.

v_S(peak-to-peak) (V)	v_I (rms) (V)	v_I (DC) (V)	v_O (rms) (V)	v_O (DC) (V)	v_O (RMS) (V)
4	1.13 V	1 mV	1.09 mV	2.19 V	2.45 mV

E2. Modify the circuit to create the circuit in **Figure 4**. Make sure that you disconnect the DC power supply from the circuit, and connect the uncommon terminals of R_1 and R_2 (which were connected to the power supply lines V_{cc} and $-V_{cc}$) to the ground by two short wires. Also, before inserting R_3 into the circuit, make sure that the amplitude($4V$) and frequency($20kHz$) of v_I have not changed. Once R_3 has been inserted, the amplitude is expected to change.

Using the oscilloscope, save the two captured waveforms of v_I and v_O for approximately two cycles. Note, you can do this by either using the USB utility and Save/Recall button on your oscilloscope, or can take a clear picture with a cellphone. Finally, use the multimeter to measure and record the quantities listed in Table 3.

Tip

- Connect **Channel 1** of the oscilloscope to v_I and **Channel 2** to v_O, and use **Channel 1** as the **trigger source** for the oscilloscope. Set both channels to the **DC-coupled mode**, with voltage sensitivities of $1V$/div for both channels, and set the oscilloscope time-base to $10\mu s$/div.

E3. Change the circuit of **Figure 4** to that of **Figure 5** and repeat **E2**. That is, reconnect the power supply lines to the circuit, remove R_3, and add C_1. Once again, ensure that v_I has the same peak-to-peak swing and frequency as **E1** (i.e., $4V$ and $20kHz$). Capture the waveforms of v_I and v_O

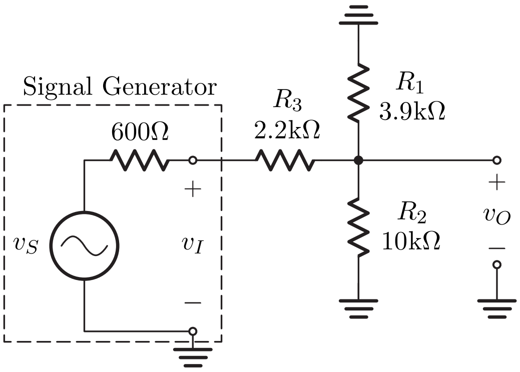


Figure 4: Circuit for Step **E2**.

Table 3: Experimental voltage measurements corresponding to Figure 4.

v_S(peak-to-peak) (V)	v_I (rms) (V)	v_I (DC) (V)	v_O (rms) (V)	v_O (DC) (V)	v_O (RMS) (V)
4	1.15	0.4	0.85	0.88	1.22

Table 4: Experimental voltage measurements corresponding to Figure 5.

v_S(peak-to-peak) (V)	v_I (rms) (V)	v_I (DC) (V)	v_O (rms) (V)	v_O (DC) (V)	v_O (RMS) (V)
4	1.15	39 mV	0.85	2.19	2.35

for two cycles and save them as Graph E3. Using the multimeter, measure and record the quantities listed in Table 4.

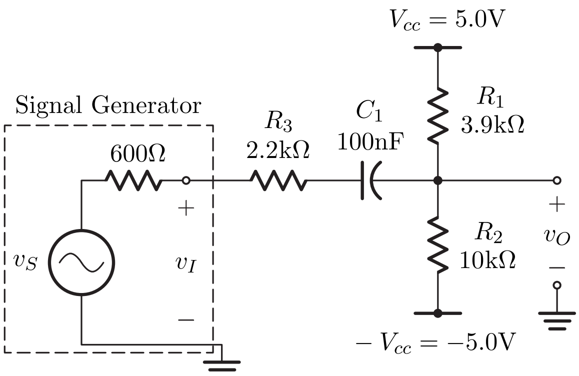


Figure 5: Circuit for Step **E3**.

Conclusion

C1. Compare the results of Table 1 and Table 4 and comment on any noticeable discrepancies. Do the results agree with the equation presented in Part **P1** for the rms value of a composite signal?

C2. Justify the waveform of v_O in **E3**, based on the principle of superposition and what you observed in **E1** and **E2**.

C3. Using Multisim (or any other suitable circuit simulation software) simulate the circuit shown in Figure 1 (which is the same circuit shown in Figure 5), based on the assumption that the voltage v_S is a 20-kHz sinusoidal signal with a peak-to-peak swing of $4V$. Include the simulation waveforms for v_S, v_I, and v_O, all plotted and clearly labelled in one single frame. Additionally, include a screenshot of the circuit schematic that you simulated. Comment on the waveforms obtained from the simulation with those of Graph E3. Are they the same? Are they different? How so?

TA Copy of Results

Table 5: Experimental voltage measurements corresponding to Figure 2.

v_S(peak-to-peak) (V)	v_I (rms) (V)	v_I (DC) (V)	v_O (rms) (V)	v_O (DC) (V)	v_O (RMS) (V)
4	1.127	0.01mV	1.09 mV	2.196	2.45 mV

Table 6: Experimental voltage measurements corresponding to Figure 4.

v_S(peak-to-peak) (V)	v_I (rms) (V)	v_I (DC) (V)	v_O (rms) (V)	v_O (DC) (V)	v_O (RMS) (V)
4	0.41	1.45	0.85	0.88	1.22

Table 7: Experimental voltage measurements corresponding to Figure 5.

v_S(peak-to-peak) (V)	v_I (rms) (V)	v_I (DC) (V)	v_O (rms) (V)	v_O (DC) (V)	v_O (RMS) (V)
4	1.15	39mV	0.85	2.19	2.35

Student Name	Pre-lab (/20)	Set-up (/10)	Data Collection (/10)	Participation (/5)
Nini		✓	✓	✓
Usba		✓	✓	✓

Hamid

Appendix - Introduction to Equipment

Digital Multimeter

The digital multimeter (or simply, the multimeter) is a multi-purpose instrument whose main function is to measure AC and DC voltages, AC and DC currents, and resistance. Most modern multimeters, however, can also measure capacitance, signal magnitudes in dB, frequency, connectivity, and much more. You have two Fluke 45 digital multimeters at your workstation. Examine your multimeter and familiarize yourself with the following:

- Different major functions that the multimeter can perform,
- The way that the multimeter must be set up for measuring voltages, small currents (in the range of mA), and resistances, and
- The way the multimeter must be set up for DC and AC measurements

Breadboard

The breadboard, also called the prototyping board, offers a convenient way for rapid prototyping of simple electronic circuits. Figure 6 shows the top view of a typical breadboard. As the figure shows, the breadboard has many tapered holes (receptacles) that are connected inn groups to corresponding metallic strips which are enclosed and insulated from each other by the plastic enclosure. Thus, thin wires and pins of small electronic components can be inserted into the holes to make electrical connections with other components.

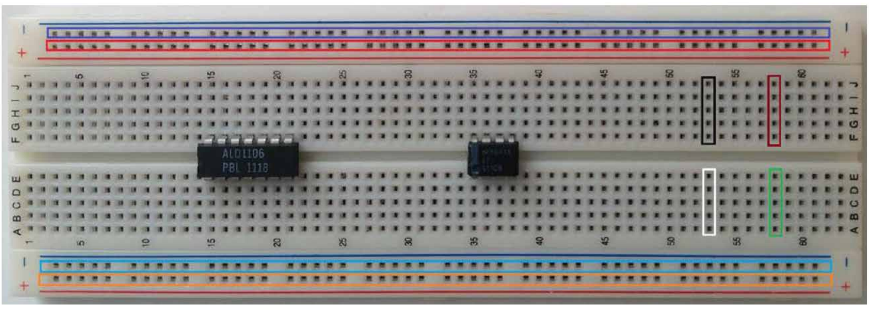


Figure 6: Top view of a typical breadboard with its connections highlighted.

The breadboard shown in the figure has four horizontal rows of holes; two at the top and two at the bottom. The rows are paired and marked with a blue line and a minus sign, and with a red line and a plus sign. In each of these rows, the holes are interconnected, but isolated from those of the other rows. These rows are commonly used as power supply and ground bars for the circuit.

Figure 6 also shows that the breadboard has two sets of vertical columns, each with 5 holes, which are separated from each other by a trench. Thus, the holes in each column are interconnected, but isolated from those of the other columns (and rows). The columns, numbered in the breadboard of Figure 6 from 1 to 63, are commonly used to establish connections between circuit components as well as Integrated Circuits (ICs) in a Dual In-Line Package (DIP). For example, the breadboard of Figure 6 hosts a 14-pin chip (ALD1106) and an 8-pin chip (LF411CN). In particular, pin 1 of ALD1106 is connected to holes A-15, B-15, C-15, D-15, and E-15, whereas pin 14 is connected to F-15, G-15, H-15, I-15, and J-15, and so on.
Figure 6 also summarizes the foregoing description by illustrating that the holes within each rectangle are connected, but isolated from other holes. It should be pointed out that more sophisticated packages of breadboards are commercially available. Figure 7 shows an example of a breadboard where two breadboards are installed on a metallic back plate furnished with power supply receptacles.

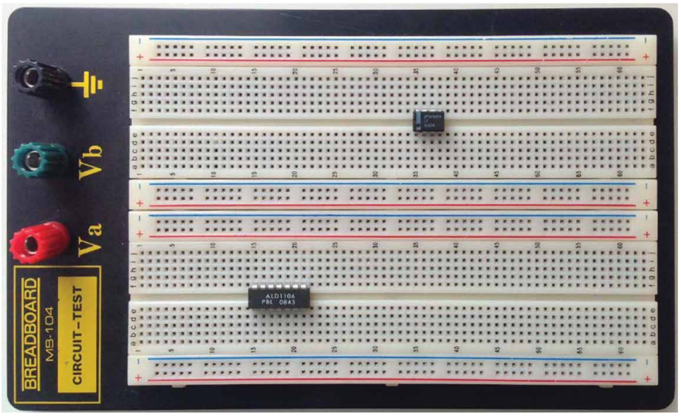


Figure 7: Two breadboards installed on a metallic back plate that also includes power supply receptacles.

Bench-Top Power Supply
The power supply has three ports. Two of the ports have a common ground and thus provide positive and negative potentials with respect to the ground. The third port, however, is isolated from the other two. All three ports are isolated from the power line earth. You have one E3630A power supply on your desk. Examine the power supply and identify the following:

- The maximum voltage and current available at each port
- The ground terminal of the power supply

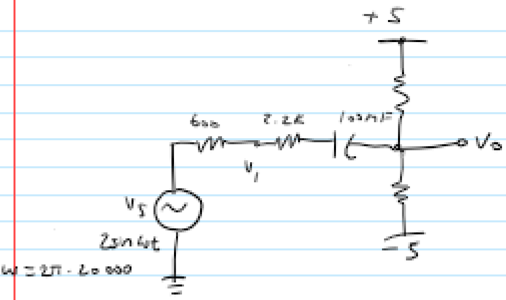
Oscilloscope
The oscilloscope is an instrument for monitoring waveforms and signals. It has more than one channel (up to 4) and can thus be used for simultaneous monitoring of

multiple signals. The oscilloscope can also plot signals against one another (the X-Y mode). Examine the oscilloscope and familiarize yourself with the:

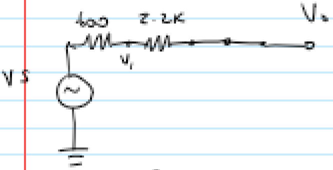
- Probes and their BNC connectors
- Screen and its grid
- Vertical voltage-per-division and time-per-division (time-base) controls
- Vertical and horizontal position controls
- DC and AC coupling modes and their control
- Trigger source and level controls

Signal Generator (Function Generator)
The signal generator is an instrument that can produce time-varying signals of different shape, magnitude, and frequency. Examine the signal generator provided at the workstation and become familiar with the:

- Output connectors and cable
- Waveform selection buttons
- Amplitude and frequency controls
- DC offset control



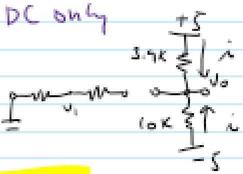
AC only:



$$V_o = V_S \cdot \left(\frac{2.2K}{600+2.2K}\right) \qquad V_1 = V_S \cdot \left(\frac{600}{2.2K+600}\right)$$

$$\boxed{V_o = 3.143\ V} \qquad \boxed{V_1 = 0.857\ V}$$

DC only



$$V_o = +5\left(\frac{10K}{3.9K+10K}\right) + (-5)\left(\frac{3.9K}{3.9K+10K}\right)$$

$$= 3.597 - 1.403$$

$$\boxed{V_o = 2.194}$$

$$\boxed{V_1 = 0\ V}$$

$$V_{oT} = 3.143 + 2.194 = 5.337\ V \qquad V_{1T} = 0.857 + 0 = 0.857\ V$$

$$V_{p\text{-}po} = \frac{V_{oT}}{2} = \frac{5.337}{2} \qquad V_{p\text{-}p1} = \frac{0.857}{2}$$

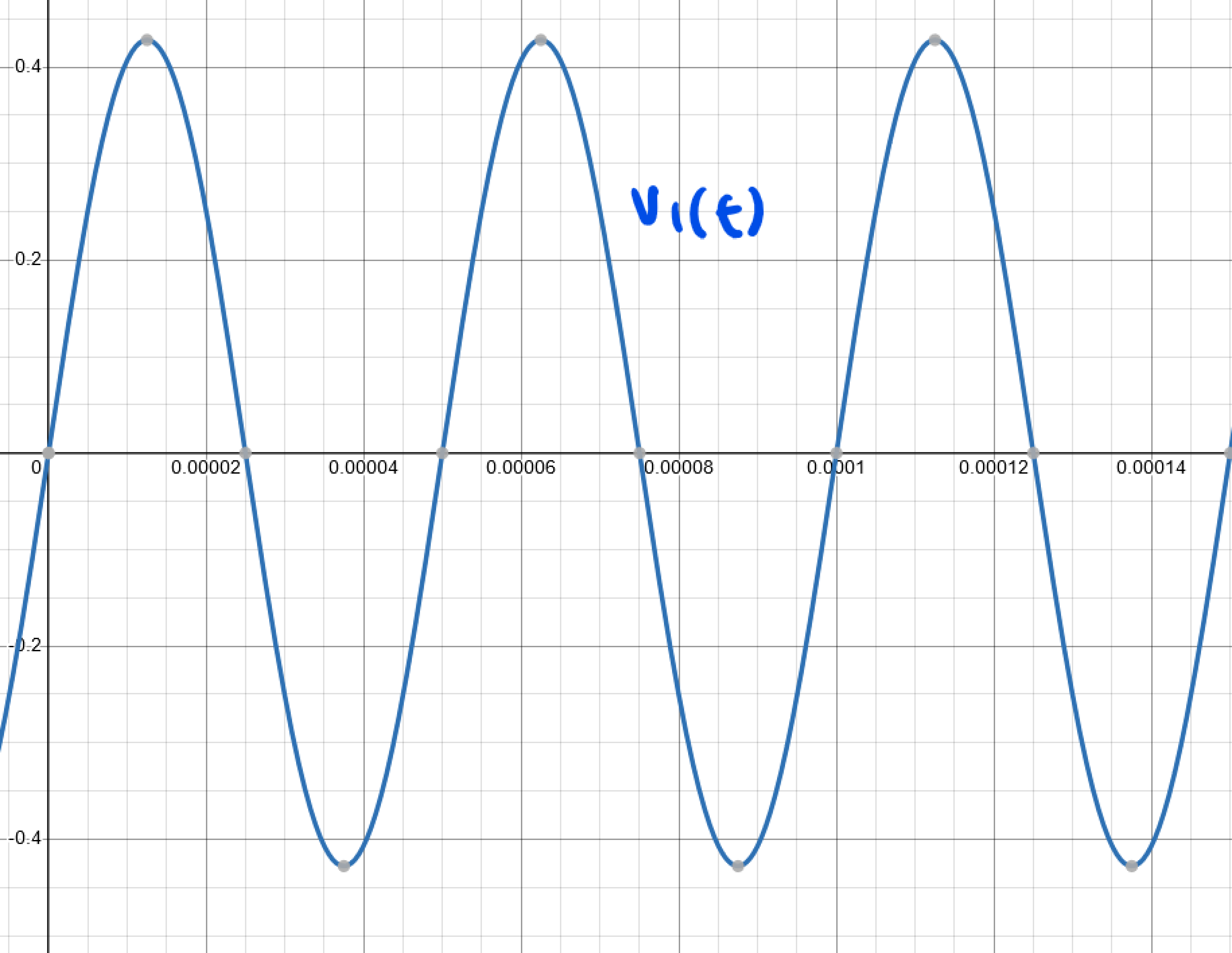
$$V_{p\text{-}po} = 2.668\ V \qquad V_{p\text{-}p1} = 0.428$$

$$V_o(rms) = \frac{V_{p\text{-}po}}{\sqrt{2}} = \frac{2.668}{\sqrt{2}} \qquad V_1(rms) = \frac{V_{p\text{-}p1}}{\sqrt{2}}$$

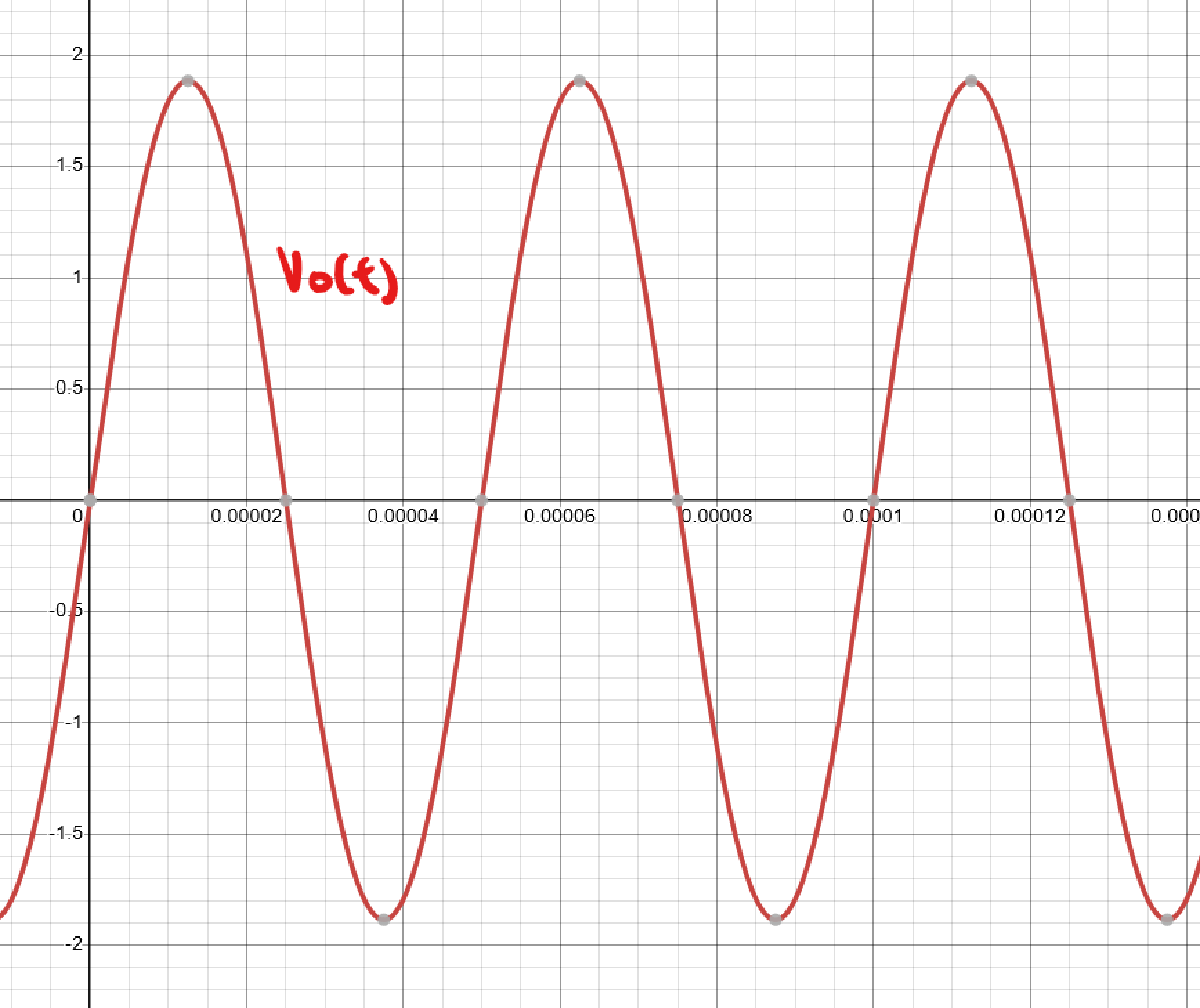
$$\boxed{V_o(rms) = 1.886\ V} \qquad \boxed{V_1(rms) = 0.303\ V}$$

$$V_o(t) = 2.668 \sin(2\pi \cdot 20\,000t) + 2.194$$

$$V_1(t) = 0.428 \sin(2\pi \cdot 20\,000t) + 0$$



0.4
0.2
-0.2
-0.4
0
0.00002
0.00004
0.00006
0.00008
0.0001
0.00012
0.00014
$v_1(t)$



Vo(t)
2
1.5
1
0.5
0
0.00002
0.00004
0.00006
0.00008
0.0001
0.00012
-0.5
-1
-1.5
-2