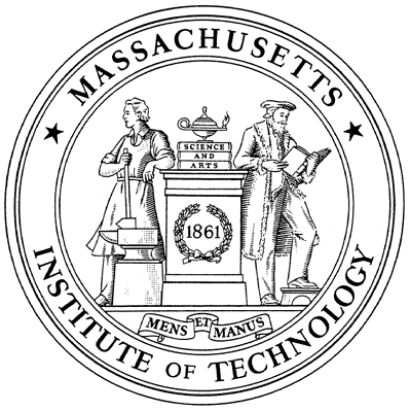


Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
Cambridge, MA 02139

16.03/16.04 Unified Engineering III, IV
Spring 2004

Systems Problem 11

Name: _____

Due Date: 4/29/04

	Time Spent (min)
SP11	

Announcements:

Unified Engineering
Systems Problem 11

21st April 2004

Objectives

After completing this lab, you will

1. Gain an appreciation for the amplitude modulation process, which we will study later in the term.
2. Be able to assemble small circuits out of standard components.
3. Have some experience using an oscilloscope.

Due Date

All students will complete the lab by Wednesday, April 28. Each student will complete the lab exercise individually or in a group of two. If you work in a group of two, each student should do half the assembly. Whether you work alone or in a group, each student should report individually on testing the circuit. You will assemble and test the circuit in a two-hour block of time. Our best estimate is that some students will complete the assembly in as little as an hour; some may take up to three hours. In no event should you take more than three hours. If, after three hours, your circuit is not complete, you may cease work on assembling the circuit, and proceed to take data, using one of the circuits we have already assembled.

You should turn in the data plots you take when testing the circuit, as well as your circuit. Please out your initials on the circuit board with a Sharpie, and staple the circuit (in a baggie) to your lab before handing in. If you work in a team of two, staple the two labs together, along with the circuit. Make sure that you put your name on each page that you turn in. Please turn in only the cover page, and the observed waveforms. You will be graded on how well you have assembled the circuit, and on your observations of the circuit in operation.

Components

Each kit contains the following components:

- 1 Datak 12-617B protoboard
- 1 LMC555 CMOS timer
- 1 8-pin IC socket 8
- 11 resistors: 470 Ω (1); 3.3 kΩ (1); 1 kΩ(3); 4.7 kΩ (4); and 10 kΩ (2)
- 4 capacitors: 100 pF (2); 0.1 μF (1); and 1 μF (1)
- 1 9V battery connector
- 2 PN2222A NPN transistors
- 1 1N914BCT diode
- 1 3-pin pin strip connector
- 1 2-pin pin strip connector

The components are shown in Figure 1.

The resistors are color-coded. To learn about resistor color coding, see, for example, http://www.elexp.com/t_resist.htm. The color codes for the resistors in the kit are given in the table below:

Resistor Value	Color Code
470 Ω	yellow-violet-brown
4.7 kΩ	yellow-violet-red
3.3 kΩ	orange-orange-red
1 kΩ	brown-black-red
10 kΩ	brown-black-orange

The capacitor markings are typically a three-digit number. For example, the 100 pF capacitor is marked "101," meaning **10** $\times 10^1$ pF. The 1 μF capacitor is marked "105," and the 0.1 μF capacitor is marked "104."

In addition to the above discrete components, you will need solder and some wire, which will be available in the lab. In the lab, you will check out tools (a soldering iron, wire cutters, and needle nose pliers).

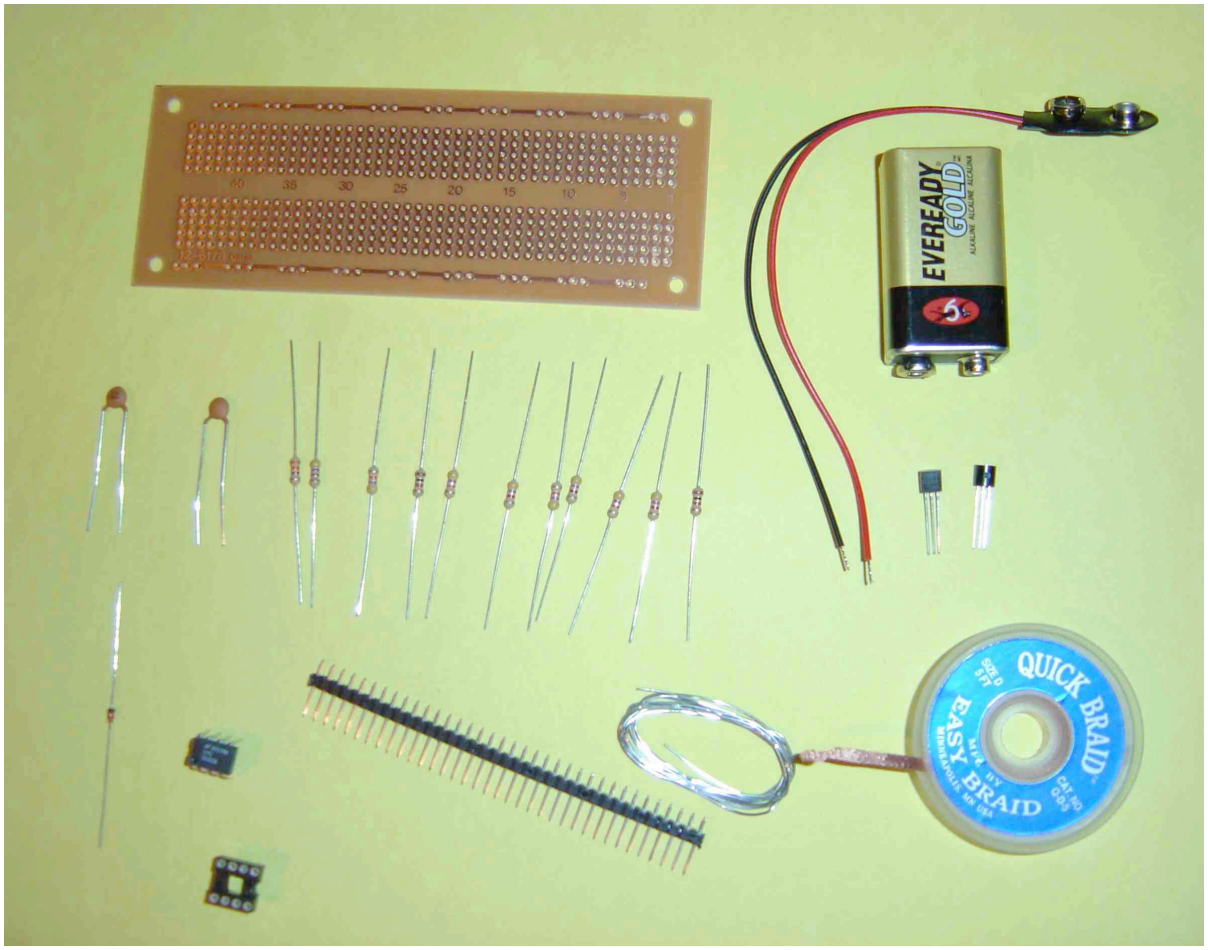


Figure 1: Circuit Components

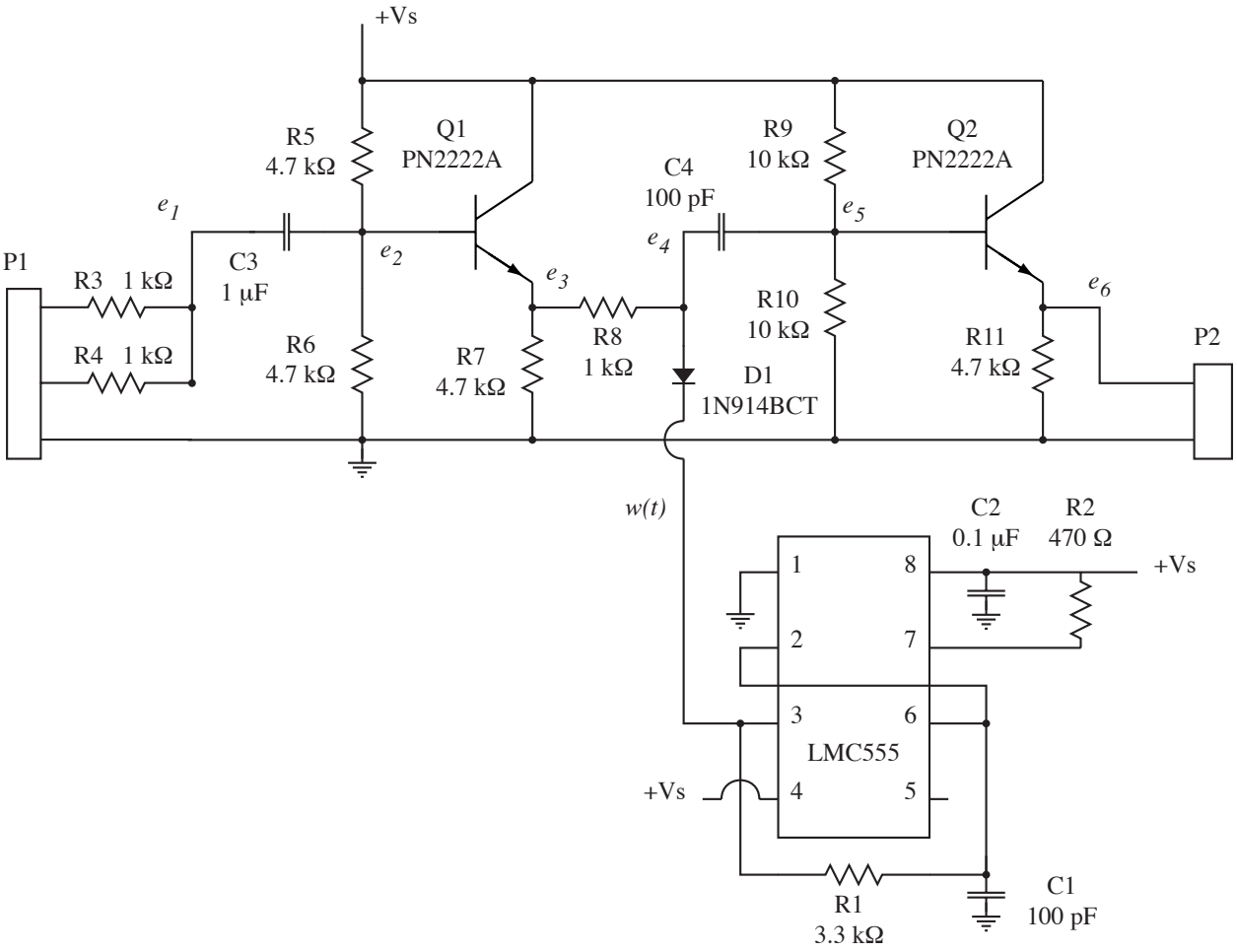


Figure 2: Amplitude Modulation Circuit

Theory of Operation

The circuit diagram is shown in Figure 2. The circuit has two main parts: the oscillator (in the lower right of the circuit diagram), and the modulation and signal conditioning (in the upper part of the circuit diagram). The oscillator is based on the LMC555 timing chip. (See `http://www.national.com/ds/LM/LMC555.pdf` for a description.) The circuit configuration used here is a standard circuit used to produce a square-wave oscillator. The frequency of oscillation is proportional to 1/(R1 C1). We have selected R1 and C1 to produce a frequency of oscillation of about 1 MHz. The output signal, $w(t)$, at pin 3 is then a 1 MHz square wave, which switches between roughly 0 V and 9 V.

The audio input is connected through the pin strip connector P1. Resistors R3 and R4 act to average the left and right audio channels, so that the average audio signal e_1 can be sent as a monaural signal. (AM radio is not designed to transmit stereo.) Resistors R5 and R6 and capacitor C3 act as a high-pass filter on the audio input. The corner frequency of the high-pass is such that essentially all audio frequencies are passed through. More

importantly, R5, R6, and C3 provide a voltage offset to the audio signal. R5 and R6 act approximately as a voltage divided leg, so that the d.c. voltage at the node is approximately 4.5 volts. The capacitor C3 has infinite impedance at d.c. frequencies, so that the circuit to the left does not affect the voltage divider. There is, however, some current out of e_1 through the transistor, so the voltage divider is not perfect. In any event, the signal e_2 is approximately the audio signal e_1, plus a d.c. offset of about 4.5 volts.

The transistor Q1 and the resistor R7 are an "emitter follower" amplifier. The emitter is the leg of the transistor connected to R7 at node e_3. In this configuration, with the transistor *collector* connected to $+V_S = 9$ volts, and the transistor *base* connected to the node e_2 with voltage greater than 0 volts and less than 9 volts, the transistors acts as a sort of valve, which allows just enough current to flow from the collector to the emitter to ensure that the emitter and base voltages are the same. (In fact, the emitter voltage will be about 0.6 volts less than the base voltage.) Very little current flows through the base of the transistor. Hence, the emitter follower acts as a buffer, preventing the circuit to the right of Q1 from having much influence on the circuit to the left of Q1.

The resistor R8 and the diode D1 act as a *chopper*. When $w(t)$ is high (close to 9 volts), the voltage $e_3(t)$ will be lower, and the diode will be *reversed biased*, so that almost no current will flow through it. As a result, the voltage $e_4(t)$ will be the same as $e_3(t)$. When $w(t)$ is low (close to 0 volts), the voltage $e_3(t)$ will be higher, and the diode will be *forward biased.* In this state, the diode allows as much current to flow as is necessary to make the voltage across the diode close to zero. (In fact, the voltage drop across the diode will be very close to 0.6 volts.) As a result, the signal $e_4(t)$ can be expressed approximately as

$$e_4(t) = e_3(t)\bar{w}(t)$$

where $\bar{w}(t)$ is a 50% duty cycle square wave, which is 0 for half of each cycle, and 1 for half of each cycle. The nominal frequency of the square wave is 1 MHz.

The capacitor C4 and the resistors R9 and R10 act as a high-pass filter, much like C3, R5, and R6. In this case, the capacitor value is much lower, so that the corner frequency is well above audio frequencies. This has the effect of removing the low-frequency (audio) frequencies from e_4, which will not be transmitted, but passing the modulated audio frequencies near 1 Mhz on to the output stage. In addition, the resistors R9 and R10 add an offset to the signal of about 4.5 volts, so that the resulting signal e_5 is in the right voltage range, between 0 and 9 volts. Finally, transistor Q2 and resistor R11 are another emitter follower amplifier, which buffers the output. The output can be measure through connector P2. With a slight change to the circuit, this output stage could be used to drive an antenna, so that the AM signal is transmitted over a short range. Note: Transmitting an AM signal requires an FCC license. Please do not do this!

Assembling the Circuit

The assembled circuit is shown in Figure 3. The circuit is assembled by inserting components into the protoboard from the front side, and then soldering the component to the protoboard on the reverse side. The components must be inserted so that all the component terminals that meet at a node are soldered to the same piece of copper, called a

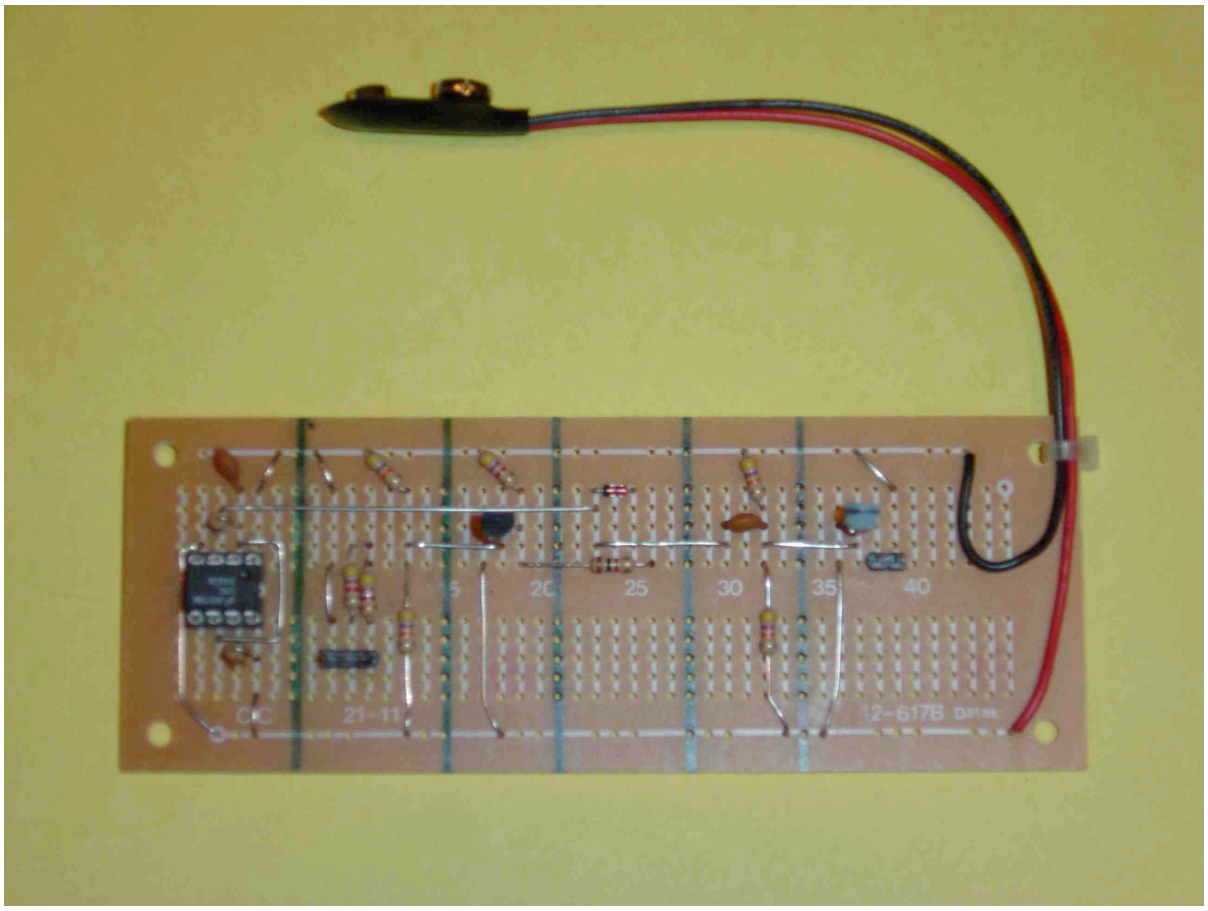
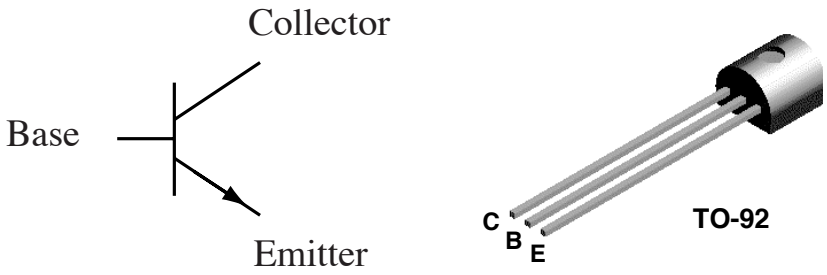


Figure 3: Assembled Amplitude Modulation Circuit.

land. I would suggest using the figure to place the components exactly as I have in the prototype. On the prototype in the figure, the LMC555 and associated components are on the far left, and the rest of the circuit is to the right, generally in the same order as in the circuit diagram.

Soldering the components in place requires a little practice. A good resource on soldering is at `http://shop.eecs.ku.edu/solder.html`. The general procedure is to bend the leads of the component so the component fits into the desired holes. The circuit board is then turned over and the leads soldered. To prevent the component from falling out when the board is turned over, you can bend the leads outward a little, or use a small piece of tape. It's important to use enough solder to cover the area of copper land around the lead, but not more than that. It's also important that you don't get a *cold* solder joint. A cold joint occurs when the leads is moved before the solder cools. A cold solder joint is fairly obvious — the joint is a dull, gray color, rather than having a shiny surface. After the leads are soldered, the lead is clipped with wire cutters close to the colder joint.

There are a couple of things that can go wrong that you should watch out for. First, excessive heat can ruin a component, especially for the semiconductor devices (transis-



(a) Transistor symbol (b) Transistor package

Figure 4: PN2222A Transistor.

tors, diode, and integrated circuit). To prevent damage to the integrated circuit, an IC socket is soldered to the board, and the IC is inserted into the socket later. To prevent damage to the transistors and diodes, do not apply heat for longer than necessary, and let the component cool after soldering each lead before moving on to the next lead. Don't insert the transistor very far into the protoboard — use almost the complete length of the leads to prevent the heat from reaching the sensitive part of the transistor.

Second, some of the components are sensitive to static electricity, especially the integrated circuit (LMC555). Don't handle this component except when necessary, and then make sure that you have discharged any static on your body by grounding your hand against the table before touching the component.

Third, some of the components (transistors, diodes, and integrated circuit) have leads that are not interchangeable. The black stripe on the diode points in the same direction as the diode symbol. Figure 4 shows how the leads come out of the package for the transistor used in this lab. The datasheet for the transistor is at `http://www.fairchildsemi.com/ds/PN/PN2222A.pdf`.

Finally, if you make a mistake soldering (e.g., putting a component in the wrong place, or using to much solder), you can remove the solder using the solder wick, which is a braided copper tape. By applying the wick to the solder joint and heating, the solder will be wicked away by the braided copper. Note that it often takes a little while to get the wick hot enough to melt the solder, so be patient.

Testing the Circuit

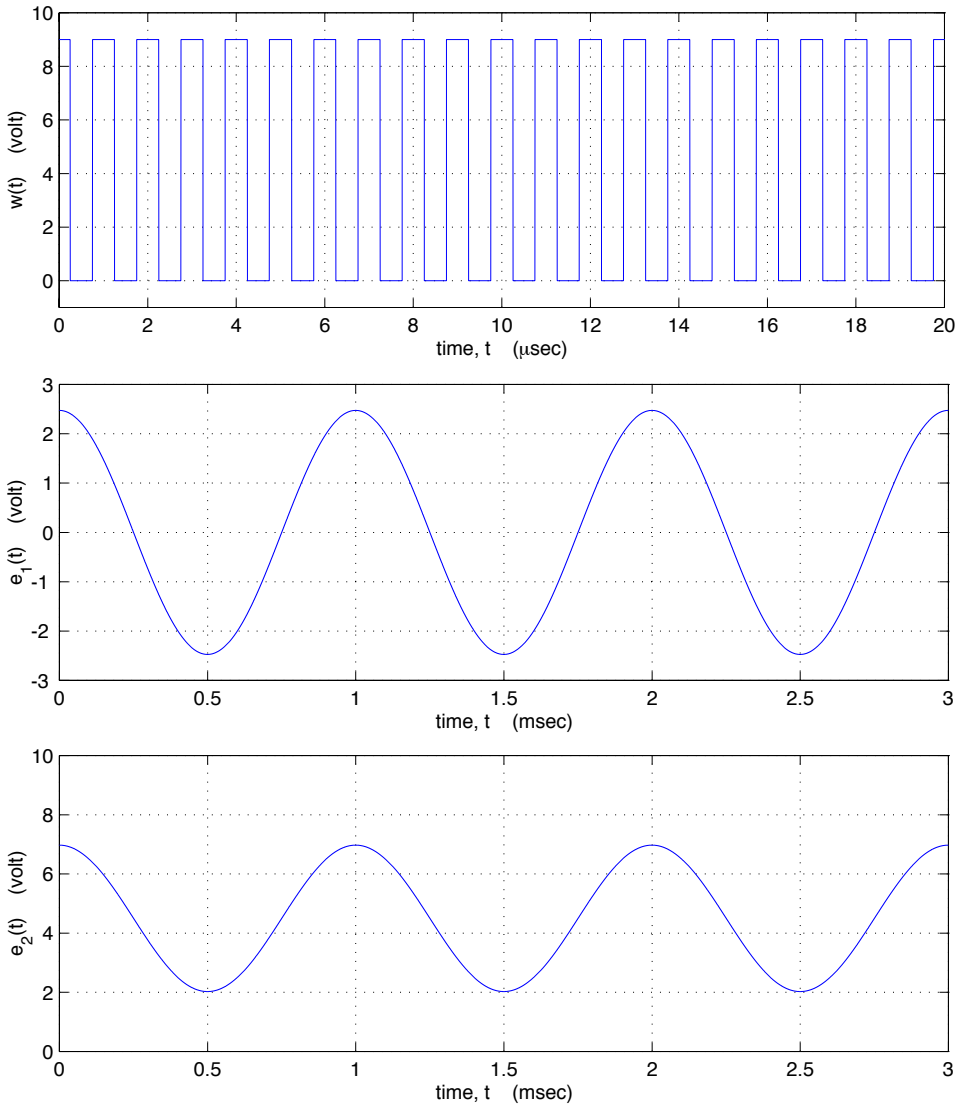
After you have completed the circuit, you will test it to see how it performs. Ideally, your circuit will work as desired. If it does not, the lab instructors may be able to help you debug the circuit and get it working. If not, don't worry — you can use one already built to perform this part of the lab.

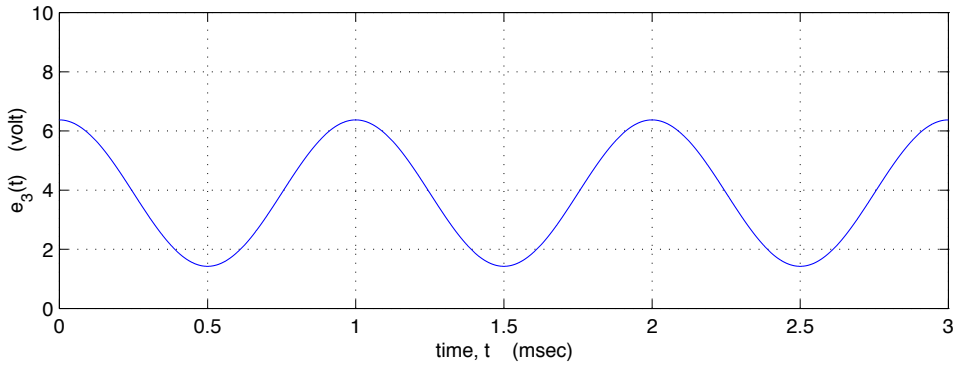
To test the circuit, the signal generator should be set up to produce a 1000 Hz sine wave, with an amplitude of 3 V. Then ideally, the signals would appear as shown in the

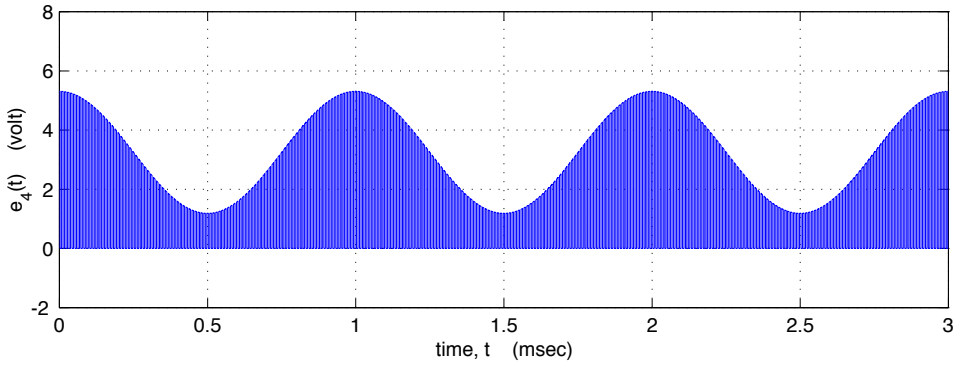
figures below. e_1 is the same as the audio input, but slightly smaller in amplitude, since $R3||R4$ and $R5||R6$ act as a voltage divider. e_2 is the same as e_1, but it's average value is increased by 4.5 V, since here $R5$ and $R6$ act as to divide the voltage $V_S = 9$ V by 2. e_3 should be about 0.6 V less than e_2, since the drop across the base-emitter leg of a transistor is always about 0.6 V. e_4 is a modulated version of e_3 — $e_4 = e_3$ when $w(t)$ is in its high state (9 V), and $e_4 = 0$ when $w(t)$ is in its low state (0 V). (Actually, e_4 is a little less than e_4 when $w(t)$ is high, since $R9||R10$ and $R8$ act as a voltage divider.) e_5 is the same as e_4, with the low frequency components filtered out, and shifted up by 4.5 V. Finally, e_6 is the same as e_5, reduced by the 0.6 V drop across the transistor.

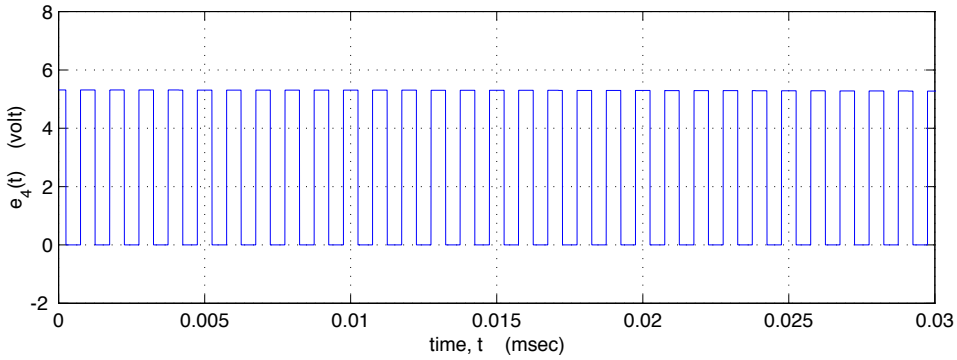
For each of the figures below, look at the corresponding signal on the oscilloscope, and sketch the signal on the graph paper provided. Be sure to label the axes of each graph appropriately with units.

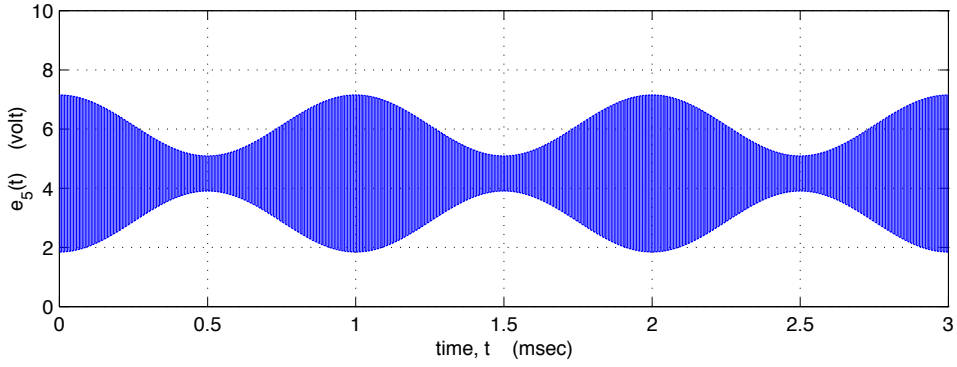
Ideal Waveforms

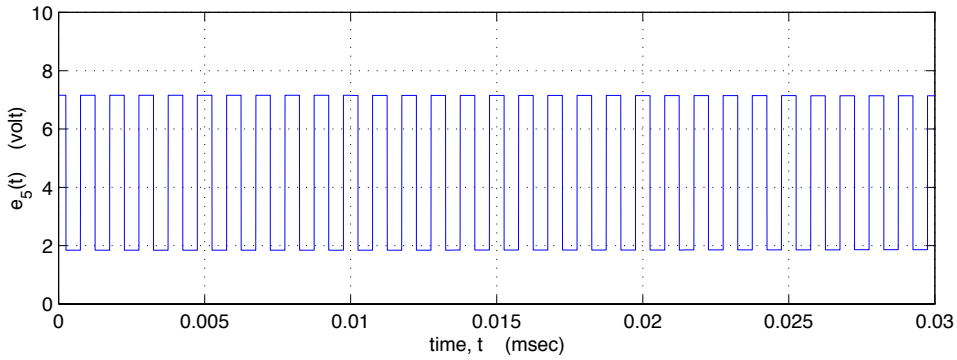


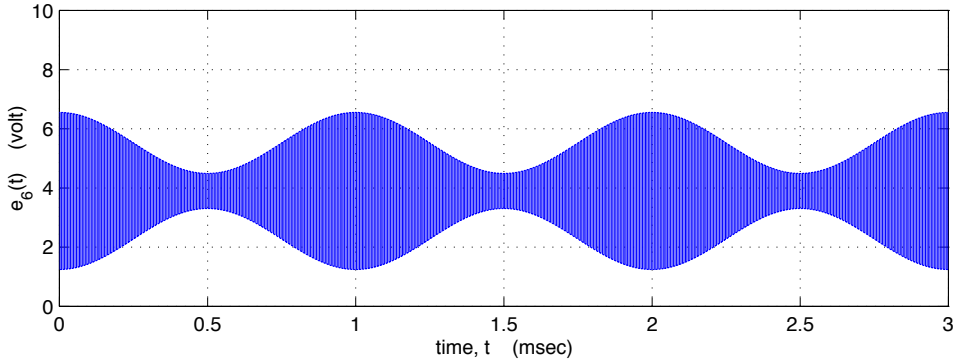

10
8
6
4
2
0
e3(t) (volt)
0
0.5
1
1.5
2
2.5
3
time, t (msec)

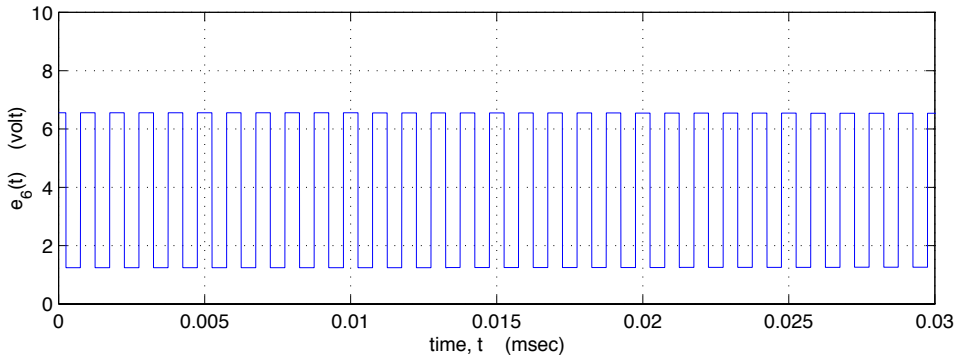

8
6
4
2
0
-2
e4(t) (volt)
0
0.5
1
1.5
2
2.5
3
time, t (msec)


8
6
4
2
0
-2
e4(t) (volt)
0
0.005
0.01
0.015
0.02
0.025
0.03
time, t (msec)


10
8
6
4
2
0
e5(t) (volt)
0
0.5
1
1.5
2
2.5
3
time, t (msec)


10
8
6
4
2
0
$e_5(t)$ (volt)
0
0.005
0.01
0.015
0.02
0.025
0.03
time, t (msec)


10
8
6
4
2
0
$e_6(t)$ (volt)
0
0.5
1
1.5
2
2.5
3
time, t (msec)


10
8
6
4
2
0
$e_6(t)$ (volt)
0
0.005
0.01
0.015
0.02
0.025
0.03
time, t (msec)

Observed Waveforms

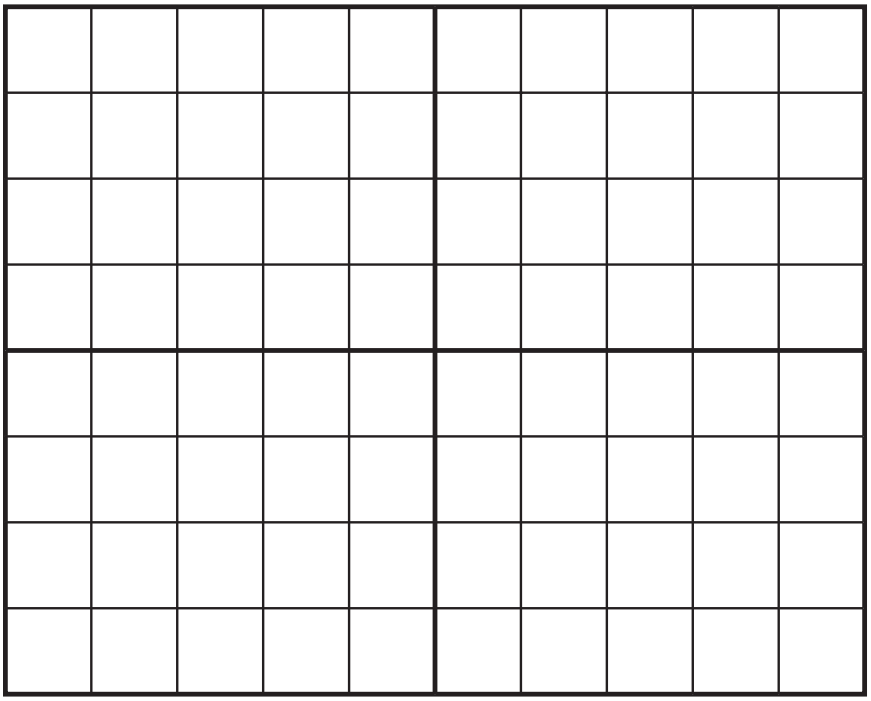


Figure 5: Observed waveform $w(t)$

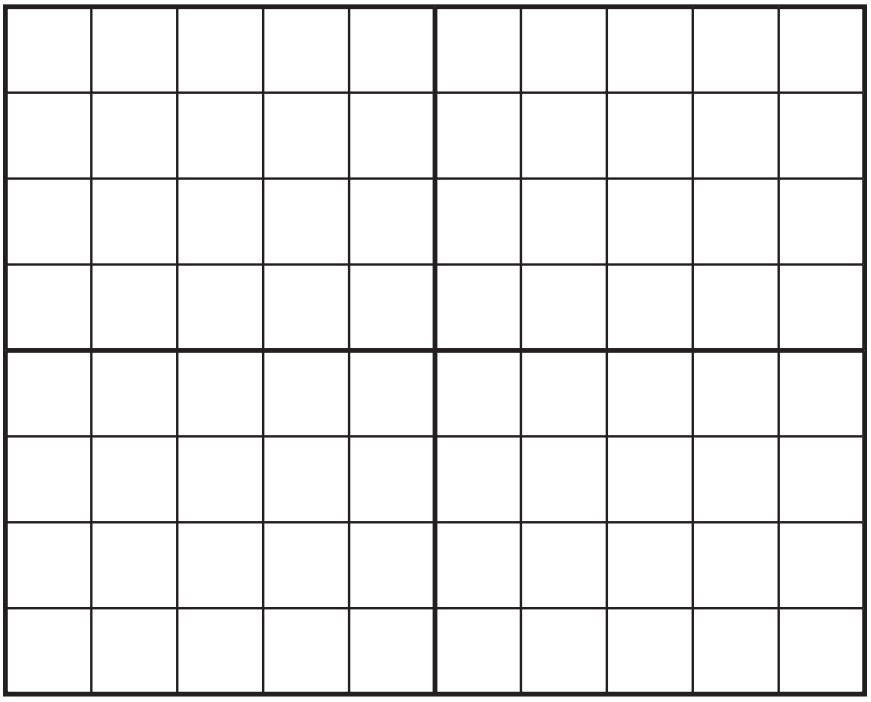


Figure 6: Observed waveform $e_1(t)$

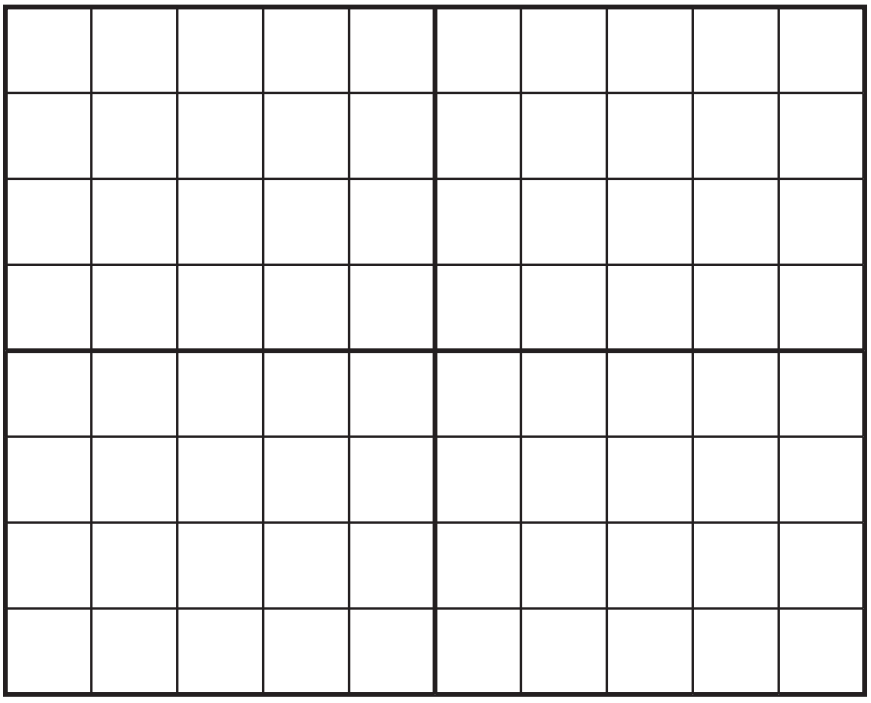


Figure 7: Observed waveform $e_2(t)$

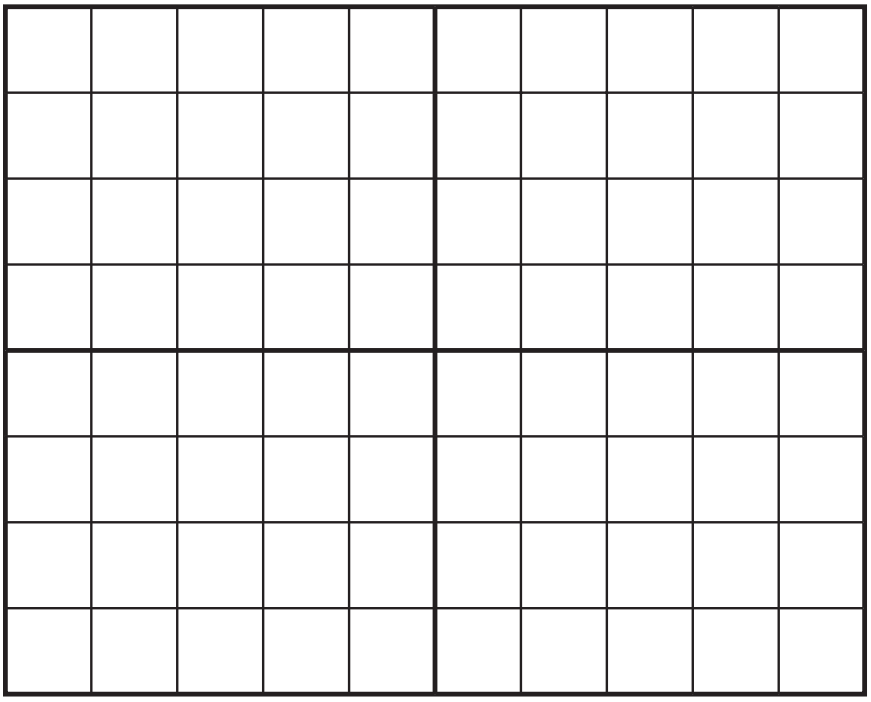


Figure 8: Observed waveform $e_3(t)$

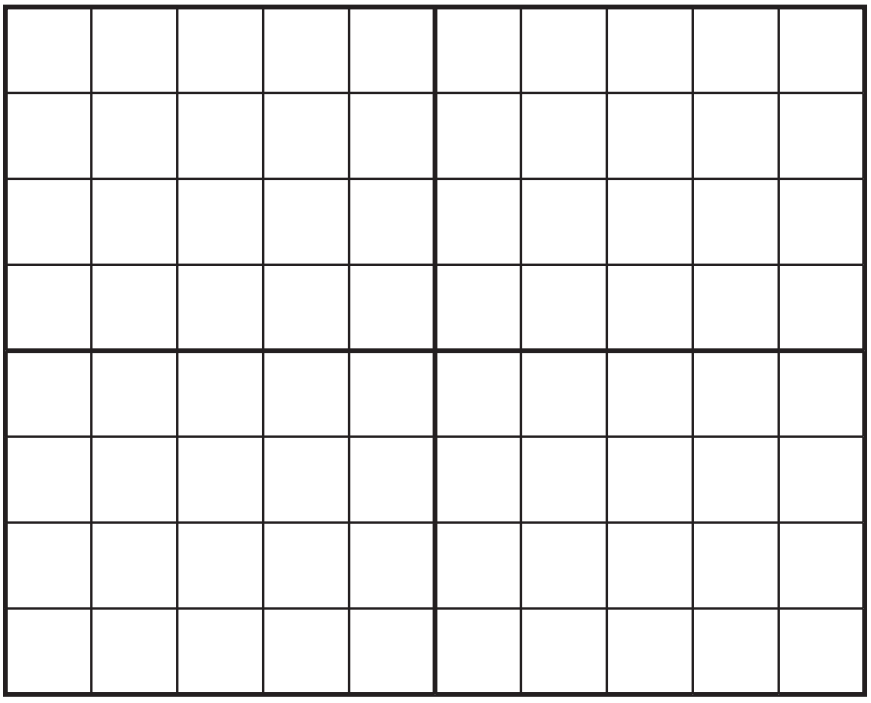


Figure 9: Observed waveform $e_4(t)$

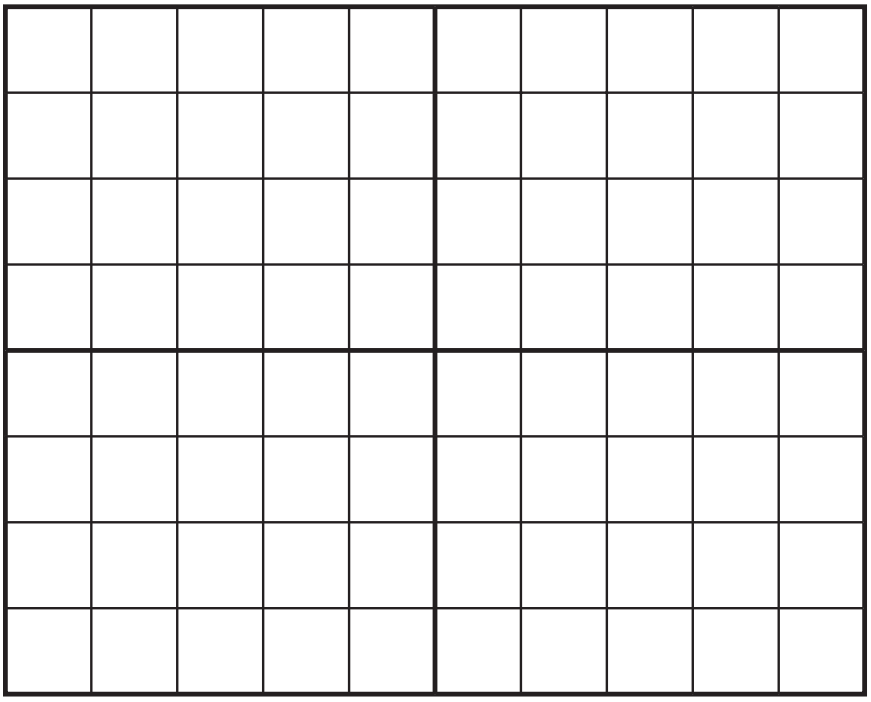


Figure 10: Observed waveform $e_5(t)$

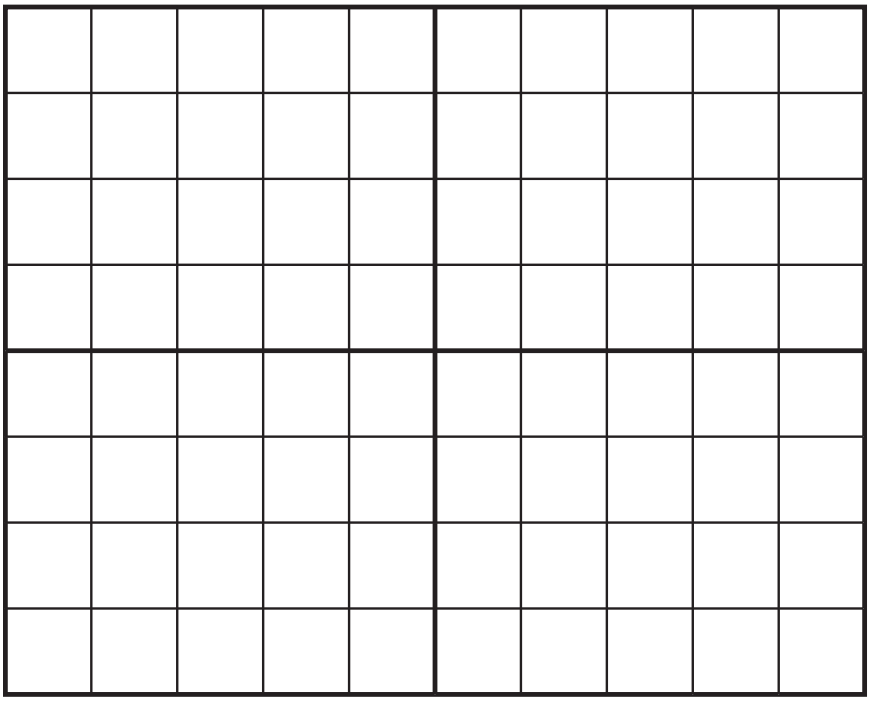


Figure 11: Observed waveform $e_6(t)$