Name/NetID:

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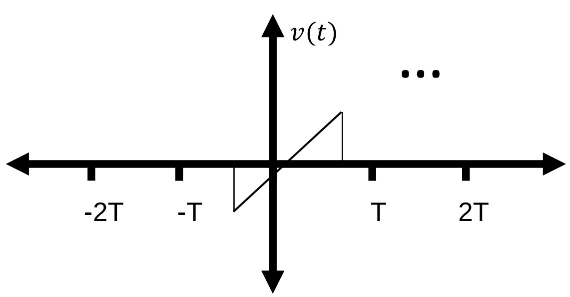
Pre-lab 5: Time-Varying Circuit Tools

Periodic Signals: Amplitude, Period, and Offset

There are several quantities that are used to describe the characteristics of periodic waveforms. You will experiment with only three: amplitude, period (the inverse of frequency), and DC offset.

The periodic attribute of periodic waveforms implies that the waveform (either voltage or current) can be described by a shorter function defined on a finite-time interval but repeated at regular intervals of time. Consider a certain "sawtooth" waveform $p(t)$ shown in Figure 1. This waveform is periodic because the function $v(t) = t$ over the time interval $-\frac{T}{2} < t < \frac{T}{2}$ (shown in Figure 2) can be repeated over and over again to produce a periodic signal $p(t)$. Note that $v(t)$ is assumed to be equal to 0 for t outside of the range $\left[-\frac{T}{2}, \frac{T}{2}\right)$. During the time interval $\frac{T}{2} < t < \frac{3T}{2}$, $p(t)$ can be represented by $v_2(t) = v(t-T) = t - T$ on the interval $\frac{T}{2} < t < \frac{3T}{2}$. When $v(t)$ is repeated over an infinite number of intervals the resulting waveform is periodic. The parameter that describes *the smallest length of time that is repeated* (the length of $v(t)$ in this case) is called the **period**. *The inverse of the period* is called the **frequency** of repetition.



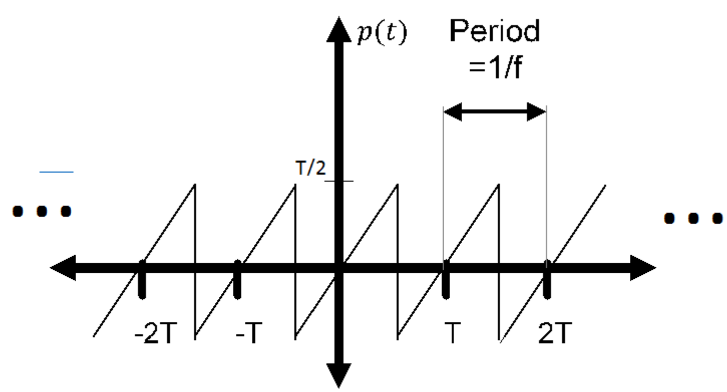


Figure 1: The function $v(t) = t, -\frac{T}{2} < t < \frac{T}{2}$ defines one period of $p(t)$, a periodic sawtooth waveform generated by repeating $v(t)$ at delayed intervals of T forever.

Notes:

The DC-**offset** (for a function generator) is *the amount by which the* ***signal average is shifted away from ground*** *(the 0-Volt reference)*. For example, $p(t)$ above has a DC offset of 0 volts. An offset of +T/2 volts would shift the signal $p(t)$ entirely above the axis (see Figure 3).

Another attribute of periodic waveforms is the amplitude. The **peak-to-peak amplitude** is *the height from its lowest to its highest value*. (NOTE: For sinusoids, often the amplitude is specified as half of the peak-to-peak value…that is, the 0-to-peak value.) For example, the signal described above $v(t) = t, -\frac{T}{2} < t < \frac{T}{2}$ represents the functional form of the sawtooth waveform, but other sawtooths can be formed when multiplied by a constant. For example, multiplying the offset signal $p(t) + \frac{T}{2}$ by a factor of 2 and adding an appropriate offset allows us to obtain another periodic signal $y(t)$ with the same basic form only taller (see Figure 3).

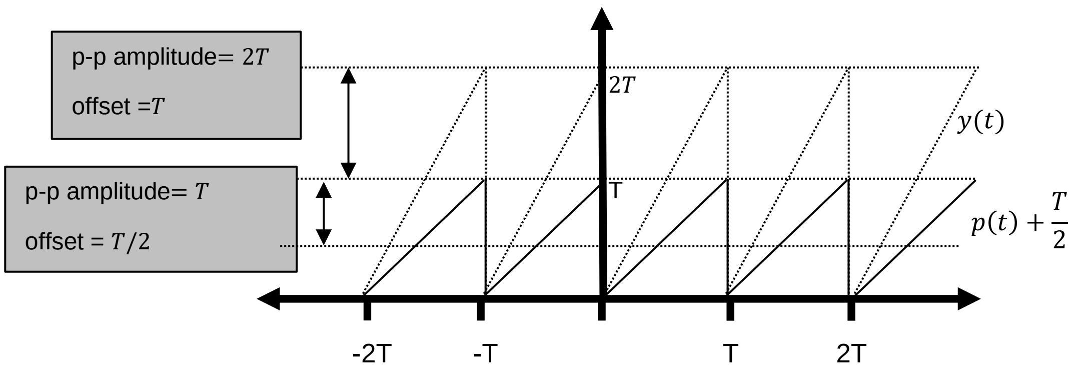
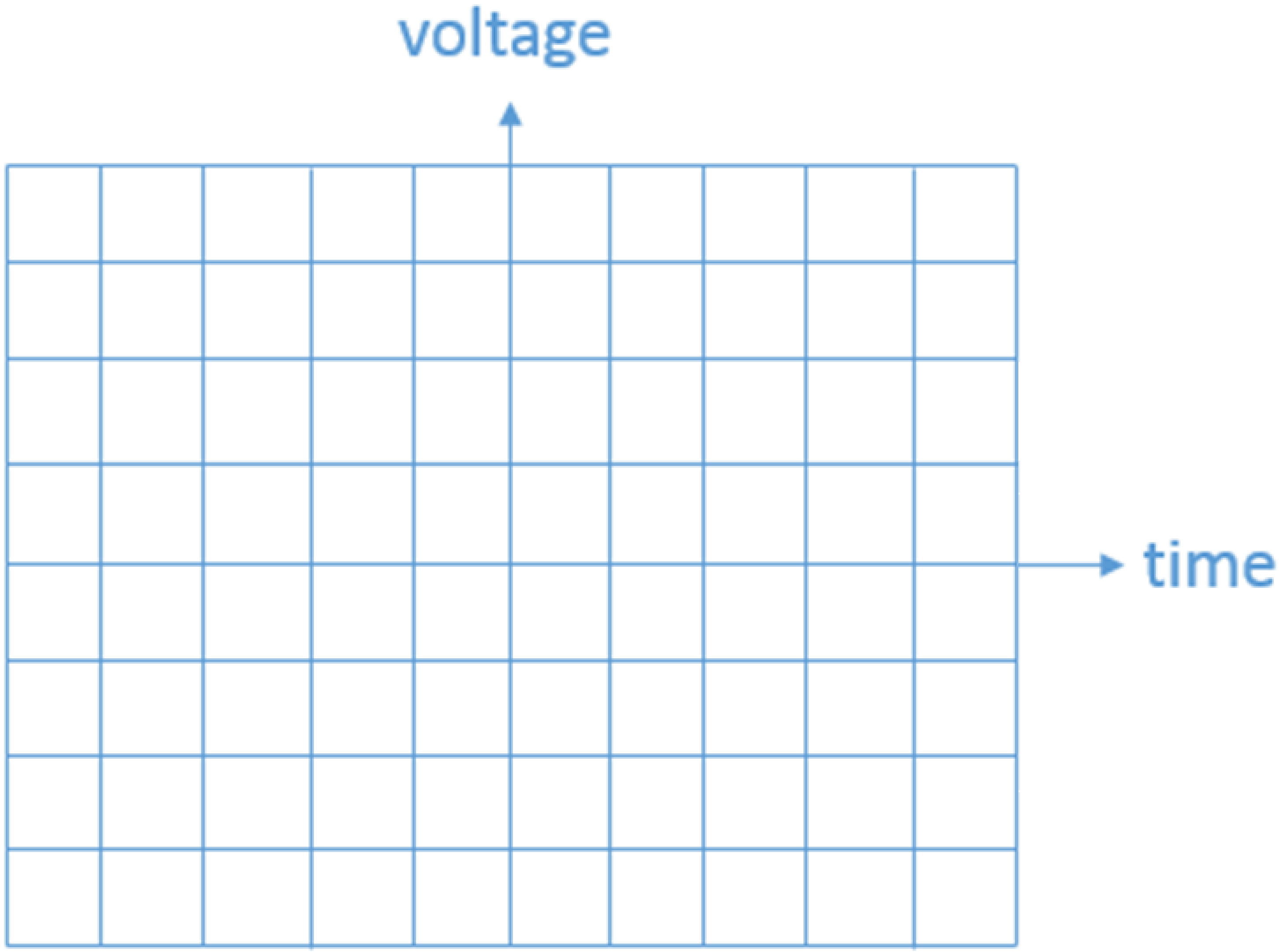


Figure 3: Other waveforms with the same functional shape can be generated by changing the amplitude.

Notes:

Question 1: Sketch a sawtooth waveform with a period of T, a peak-to-peak amplitude of $2T$, and an offset of $-T$ (negative T).



Oscilloscope

The oscilloscope (often called an "o-scope" or "scope" for short) is a measurement device that can capture a time history of a signal. At first glance, it appears to be a very complex piece of hardware. As you learn to use it, however, you will learn that most common adjustments use only a few of the controls present on the front panel of the device. **Horizontal controls** *change the scale of the time axis* allowing you to see more or less time range of the waveform. **Vertical controls** *change the scale of the voltage axis* allowing you to shrink the waveform so that it fits within the screen or expand it to better fill the screen and make a more-accurate measurement. The third key menu consists of the **triggering controls**. The description of the trigger is less intuitive than scale so we will spend much more time investigating its key role: displaying voltage waveforms in a human-readable format.

Suppose we are to measure the periodic voltage signal $V_1(t) = 4\cos(2\pi 200t)$ volts.

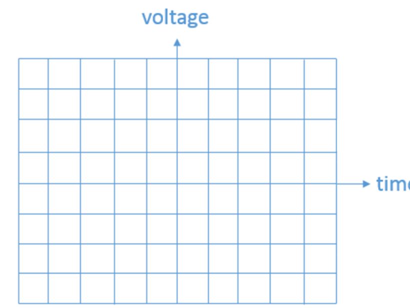
Question 2: If the oscilloscope has a total of 8 vertical sections, what vertical scale would cause the display to just contain the highest and lowest voltage levels of $V_1(t)$?

a. 500 mV/div
b. 1 V/div
c. 2 V/div
d. 4 V/div
e. 8 V/div

Question 3: If the oscilloscope has a total of ten horizontal sections, what horizontal scale would cause the display to just contain ten periods of the periodic signal $V_1(t)$?

a. 1 ms/div
b. 5 ms/div
c. 20 ms/div
d. 100 ms/div
e. 200 ms/div

Notes:



The oscilloscope screen is divided into eight vertical sections and ten horizontal sections.

Notes:

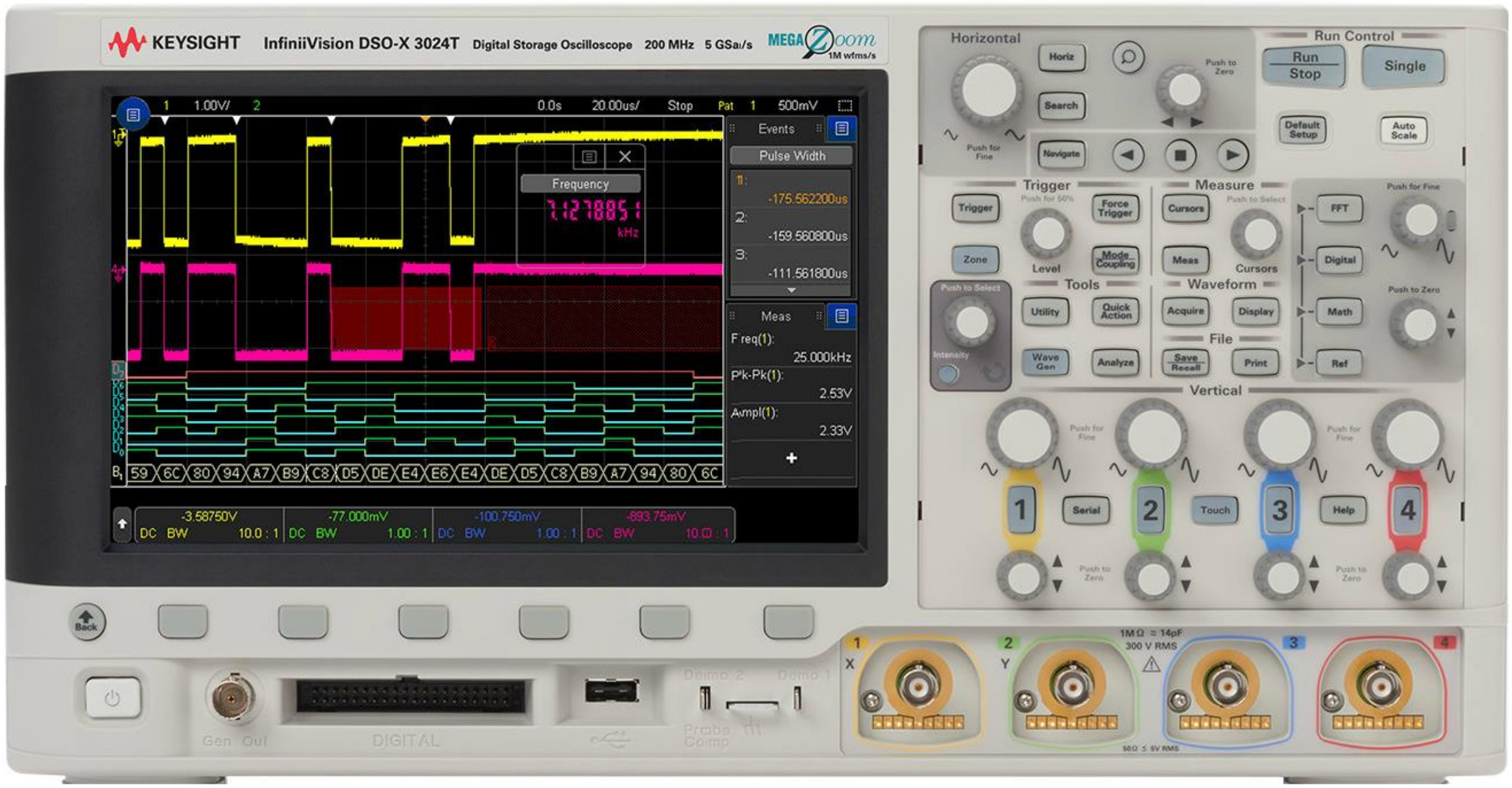


Figure 4: *A KEYSIGHT Technologies oscilloscope similar to that used in the lab. Image Source: KEYSIGHT*

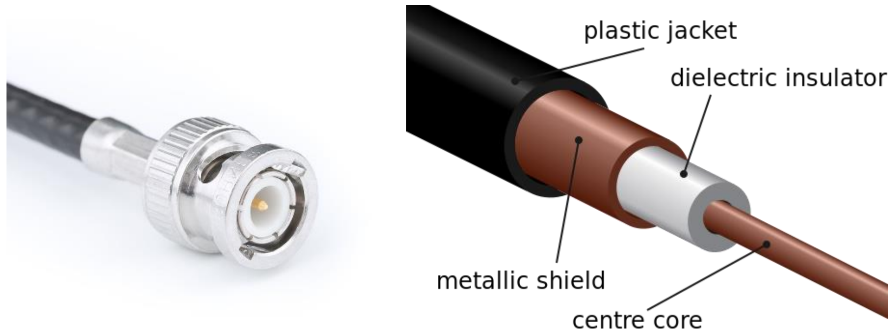


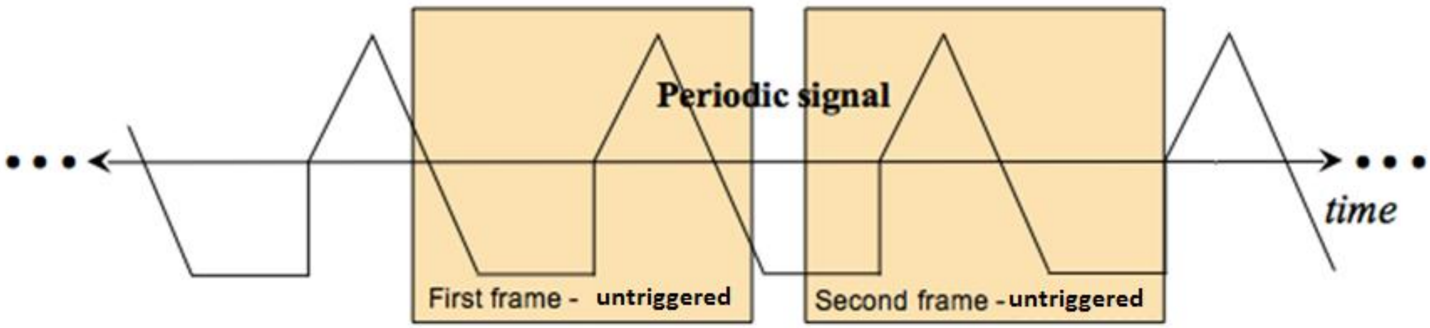
Figure 5: *A coaxial cable with a BNC connector appropriate for use with the KEYSIGHT oscilloscope. Note that although the cable on the left would seem to be a single wire, the actual construction has two conductors, a core and a shield. Image Source: Wikipedia*

Oscilloscope Triggering

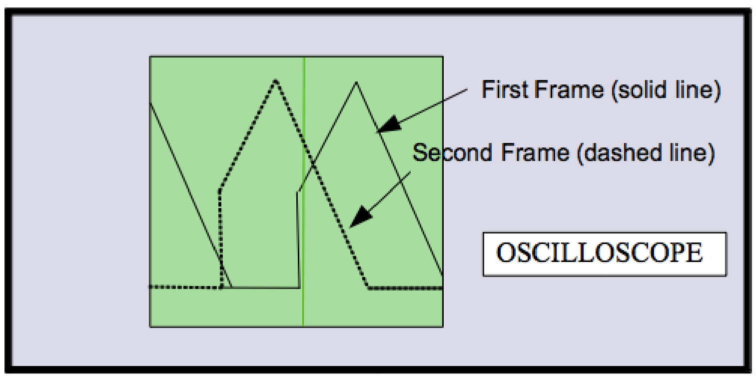
Triggering allows the user to specify how the oscilloscope draws and redraws a signal on the screen. Our oscilloscopes are digital scopes. A digital scope reads the analog signal (**analog**: *continuous in time and continuous in amplitude*) applied to each channel and converts it into a series of binary numbers sampled in time that represents the original signal. These numbers are stored in memory continuously with new numbers always replacing the old. Triggering is used to tell the oscilloscope how to display the signals in a manner that underscores the periodic nature of the waveform.

Suppose we input a periodic signal into channel 1 of the oscilloscope. Without triggering, each plotted **frame** (*a short time-sweep of the voltage*) will begin at arbitrary point in the waveform and, with each sweep, the signal will jump around on the time axis so fast that the plot will just look like garbage. The explanation is simple. Refer to **Figure 6** below. For the first frame, the computer inside the oscilloscope will collect a waveform (frame) starting at an arbitrary point in time. A second frame is also collected starting at a later, but at a point in time unrelated to the period of the periodic signal. The second frame will be an arbitrarily-time-shifted version of the first. It is this arbitrary time shift between consecutive frames that causes the waveform to appear on the oscilloscope placed at random time intervals. If only the oscilloscope had some way of estimating the period of the waveform, it might be able to produce a stable display of one or more periods. So we note that many “basic” period waveforms (like sinusoids, square waves, and triangular waveforms) do something specific only once or twice each cycle…like transitioning across a certain voltage value.

Notes:



(a)



(b)

***Figure 6**: Two frames of an un-triggered periodic signal shown in time (a) and plotted simultaneously (b).*

Notes:

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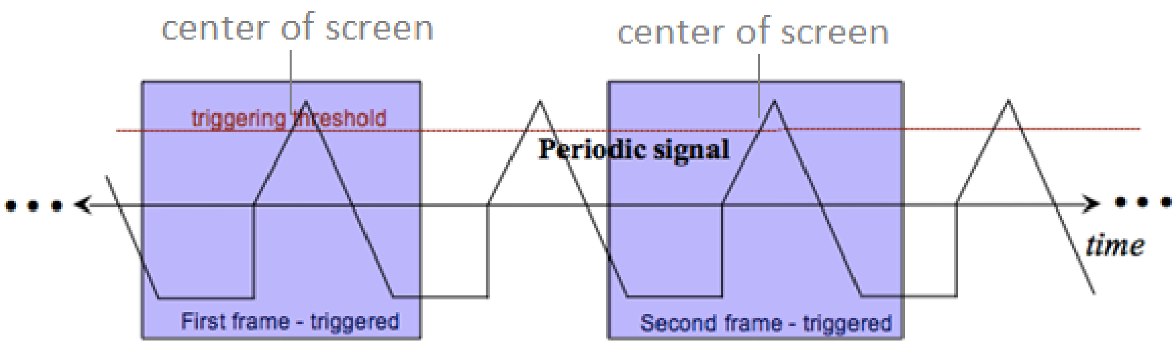
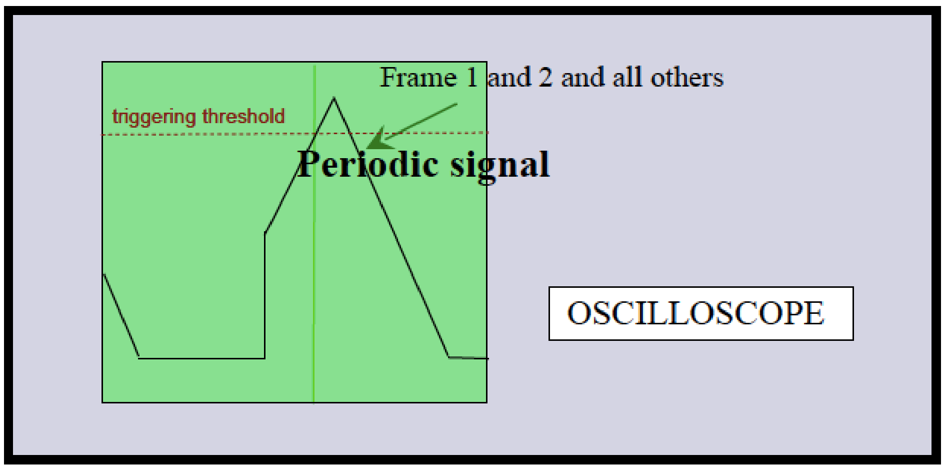
The oscilloscope does not actually estimate the waveform's period. It does something clever with a "trigger". The **trigger** is *a voltage threshold that we choose*. We specify a particular voltage level and the oscilloscope starts to sketch a new frame when the voltage waveform crosses that threshold.



(a)



(b)

***Figure 7**: Two frames of a triggered periodic signal shown in time (a) and plotted simultaneously (b).*

Since the signal is periodic, each frame will typically be identical (even if several periods are missed between frames!). Therefore, the oscilloscope display overlays identical frames and the image it shows will be steady. With a steady display, the parameters of the waveform will be easy to measure. Note that we assumed the trigger occurs when the signal rises across the trigger set point and not when it falls across the set point; actually, we will find that the oscilloscope can be told to do either!

Question 4: The signal $V_2(t) = 2\cos(2\pi 200t)$ volts is measured using an oscilloscope. In the trace shown below, what is the vertical scale per division, the horizontal scale per division and the triggering threshold in volts?

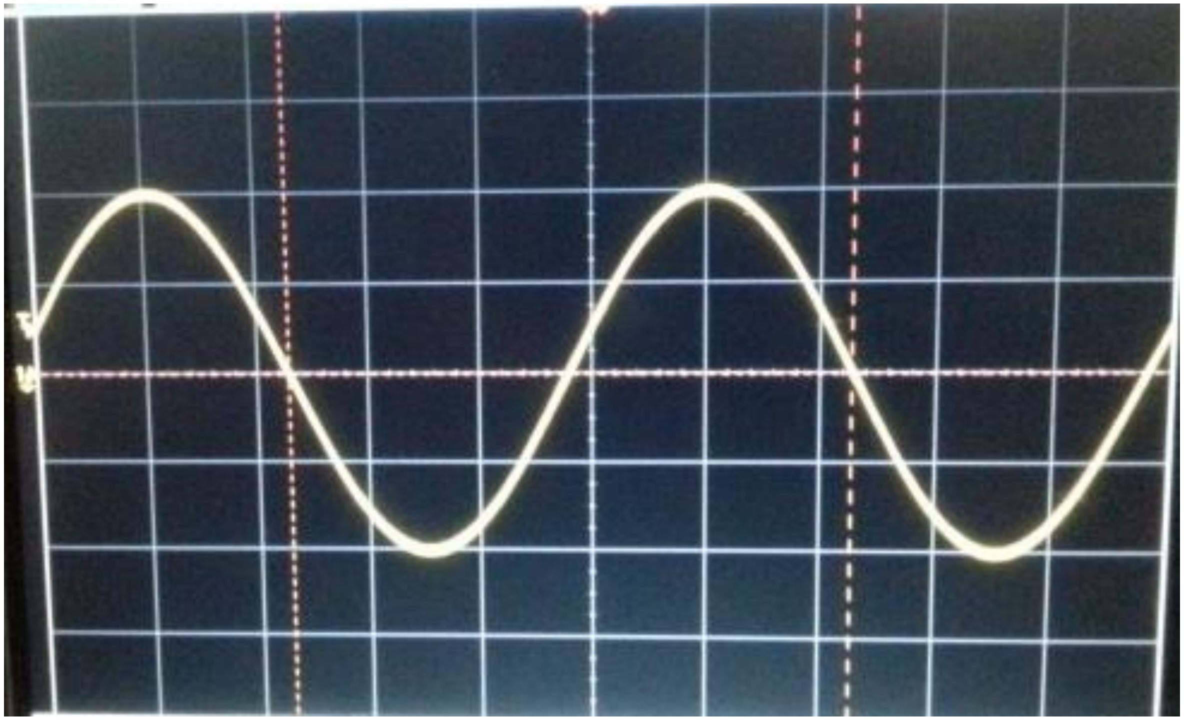


Figure 8*: An actual oscilloscope plot to be used in answering the previous question. Note that there is a small symbol indicating the ground reference and another small "T" indicating the trigger level on the left-hand side.*

Notes:

Question 5: Build the circuit shown below in **Figure 9** (minus the 3.3-V source). This basic microphone circuit will produce a signal that you can view on the oscilloscope at the end of your lab session! Have your TA view your circuit and sign below.

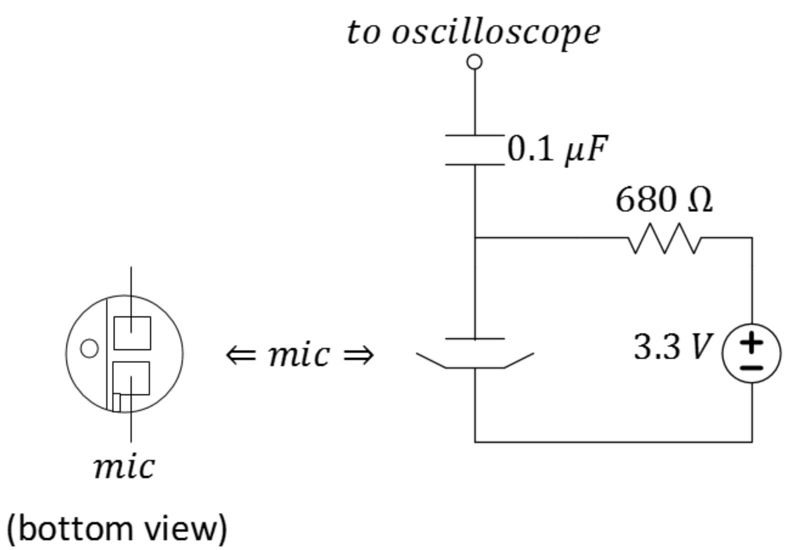


__Figure 9:__ A simple microphone circuit. Build on your breadboard minus the 3.3-V source.

☐ TA signature:

Notes:

Comment:

A 3.3-V source is available from your RedBoard.