

## NOISE AND SIGNALS AROUND US: A Search, Using An Oscilloscope

### Preparatory Questions.

Go to the Web page [http://www.tek.com/Measurement/App\\_Notes/XYZs/](http://www.tek.com/Measurement/App_Notes/XYZs/) , read at least the first four subsections of the section on "Trigger Controls" and answer the following questions.

1. What is the difference between 'Auto' and 'Normal' trigger modes?
2. What does the Trigger Slope Control do?



### Objectives:

- to recognize *noise* signals around us, where they come from and how they affect observation
- to develop facility in using a digital oscilloscope
- to develop facility in devising ways of looking for signals

### Introduction:

We live in an environment of many electrical signals of various frequencies. The electric power that runs through the wires around us is at a frequency of 60 Hz. The radio broadcasts that we pick up are about 1 MHz (AM) and 100 MHz (FM). Computer monitors show signals in the tens of kHz.

In the lab, much instrumentation is electronic, and the presence of these signals becomes "noise" in the process of experimentation. (Noise is any observed effect which is not the effect we are trying to observe. Signal is the effect we are trying to observe.) In order to make reliable measurements, we want to maximize the signal-to-noise ratio.

In this experiment you will be using an oscilloscope which is a sensitive voltmeter that graphs the voltage on its input as a function of time. The oscilloscope you use will let you look at voltages as low as 1 mV ( $10^{-3}$  Volts) and currents as low as 1 nA ( $10^{-9}$  Amperes) and look at waveforms at frequencies up to 100 MHz.

For the early stages of the experiment, we suggest settings for the oscilloscope controls. Once you get the hang of them, you will find that it is often quicker to play around with the settings till you arrive at the display that you want. Also note that many of the measurements you make will be approximate, so use your judgement on whether error estimates are appropriate or not.

## The Oscilloscope:

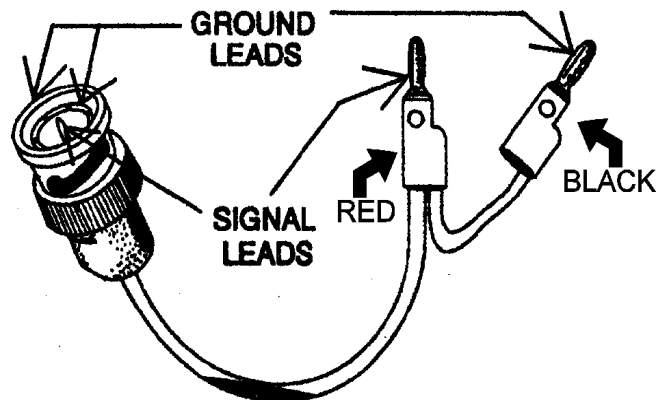
On all oscilloscopes, the controls can be grouped according to three basic functions:

- Controls governing **vertical** (y) motion of the trace on the screen; (vertical position, vertical sensitivity [volts/div], CH1 → CH2 beam selection, DC-AC-Ground input coupling).
- Controls governing **horizontal** (x) motion of the trace; (horizontal sweep speed [sec/div], horizontal position).
- Controls governing the **time** base circuits which internally feed the x deflection of the trace; (trigger level, trigger slope, trigger source, trigger mode). The time base is the circuitry that makes the x deflection into an actual time axis on the screen and synchronizes that time scale so that the trace's position matches the time of arrival of the signals being measured.

The Tektronix TDS210 has 7 turnable knobs and a number of buttons, all grouped according to the above systematics. With the knobs you dial-up vertical sensitivities, sweep speeds, vertical and horizontal positions, and trigger levels. You can set the parameters of each of CH1, CH2, **Horizontal** and **Trigger** by pressing the appropriate "Menu" button, and using the unlabelled buttons next to the different settings that appear on the right hand side of the screen.

The input to the oscilloscope is via a coaxial cable, consisting of two wires, one being the centre wire and the other being the surrounding shielding wire braid; the braid is covered with the black outer coating of the cable. (Look at the sample of coaxial cable available.)

The outer braid is connected to the frame of the oscilloscope and from there to the round pin of the power plug which connects to a water pipe in the basement of the building. It is called the ground wire. The centre wire is connected to the electronics inside the oscilloscope. The oscilloscope measures the voltage between the centre wire and the outer braid. For convenience, you are provided with leads that have a "BNC" connector on the end that goes to the oscilloscope, and, at the other end, two plugs which are the connections *you* use, the red one connected to the centre wire and the black one connected to the grounded outer braid.



In this experiment, you will mostly be using only one input of the oscilloscope, and will have only one trace on the screen. To do this, channel 2 should be turned off and the input lead should be connected to channel 1. Push the "CH1 MENU" and "CH2 MENU" to turn on and off a channel. The small arrow on the left side of the screen shows the channel number and the position of zero volts.

## What to do:

*As a general guide, we expect that most students will be able to complete parts 1 through 6 during the first session devoted to this experiment, and the remaining sections during the second session.*

**PLEASE NOTE:** *The "HARDCOPY" gives a printout of what's on the screen, and it is very tempting - Please resist temptation, save our forests and your demo's time - choose carefully!*

When the oscilloscope is turned on, it starts off configured just as it was before it had been turned off. Push "AUTOSET" to give the default settings, often a good place to start.

The "RUN/STOP" is a very convenient button that allows you to freeze the display at any time.

1. Look at low frequency electrostatic fields. To start, use the following oscilloscope settings:

*CH1 menu and knobs:* Coupling=DC, BW Limit=ON(20MHz), VOLTS/DIV=(change as required)  
*TRIGGER menu:* Source=AC Line, Mode=Auto, Coupling=DC  
*HORIZONTAL:* SEC/DIV=between 1ms and 25ms - change to get the pattern you want

Hold the red lead in one hand and report what you observe. Now bring it close to a power wire plugged into the electric source, and again report what you observe. To measure the frequency and voltage of the signals you observe, press "Cursor" with "Source=CH1" and rotate the two "Vertical Position" knobs to move the cursors. The Voltage can be read off when the setting is "Type=Voltage" and the frequency can be read off with the "Type=Time" setting.

2. Look at higher frequency (above 60 Hz but below 20MHz) electrostatic fields. To start, use the following oscilloscope settings:

*CH1 menu and knobs:* Coupling=DC, BW Limit=ON(20MHz), VOLTS/DIV=2.00mV  
*TRIGGER menu and knob:* Source=CH1, Mode=Auto, Coupling=DC, TRIGGER LEVEL=0.00V  
*HORIZONTAL:* SEC/DIV=between 5ns and 1ms, Position=0.000s

Here you have changed the trigger source and level and have changed the sweep speed. Bring the red lead near the oscilloscope screen. Sketch the wave shape produced by the refresh circuitry, and measure its frequency. Repeat near a computer screen to view the scan of the electron beam and also the much slower refresh rate. Then look at the patterns from a digital multimeter and a hand calculator. Does the relative magnitude of these frequencies make sense, given the function of the different electronic instruments you are observing? Note that changing the "trigger level" can sometimes make a stationary pattern more visible.

**3.** Look at high frequency magnetic fields from the local radio stations. Make a small loop of wire by connecting the black input wire to the red input wire. Time-varying magnetic fields through the loop produce a voltage detectable by the oscilloscope. Observe signals as you did in the last section (2). To look at frequencies above 20 MHz, turn the "BW Limit" to "OFF (60MHz)" in the "CH1" menu and **keep the "volts/div" to 10.0mV or higher** (the 'scope loses sensitivity at the lowest settings, so you may miss the signal you are looking for). Note that the bandwidth limit switch ("BW") enables you to limit the maximum frequency the oscilloscope is capable of detecting. Do your observations indicate why we advise that the "BW Limit" switch always be kept "ON (20MHz)" except when fast high frequency signals are being observed? Measure the voltage and frequency of these signals.

**4.** Look at electrostatic charge pickup from a styrofoam cup or a plastic supermarket bag. Choose initial settings of:

*CH1 menu and knobs:* Coupling=DC, BW Limit=ON(20MHz), VOLTS/DIV=20.0mV  
*TRIGGER menu and knob:* Source=CH1, Mode=Normal, Coupling=DC, TRIGGER LEVEL=0.00V  
*HORIZONTAL:* SEC/DIV=50mS

The coaxial cable acts as a cylindrical capacitor with the red lead at the centre. Pass the cup (or the crumpled plastic bag) by the end of the red lead. Explain the shape of the pulse and deduce the sign of the charge on the cup (or plastic bag). If the pulse from the bag is complicated in shape, shake it in the air, ground yourself, and try again. Adjust the "Trigger Level" to obtain a stationary picture of the pulse.

**5.** The material of the cable also builds up electric charge when it is distorted (piezoelectric effect). To see noise from motion of the cable inner insulation, use the initial settings of section (4) and tap the cable with your finger or a pen. Increase the oscilloscope sweep speed control in order to see the shape of the noise. The frequency of oscillation depends on the mechanical properties of the cable. If the noise is a result of the piezoelectric effect, you should be able to see noise from just flexing the cable. Change the trigger mode to "Auto" and increase the "Volts/Div" sensitivity. Flex the cable and decrease the horizontal scan rate until you can demonstrate that the signals observed are a result of the flexing of the cable.

**6.** We have provided a microphone so that you can explore sound signals (or noise). Starting with settings of:

*CH1 menu and knobs:* Coupling=DC, BW Limit=ON(20MHz), VOLTS/DIV=2.00mV  
*TRIGGER menu:* Source=CH1, Mode=Normal, Coupling=DC  
*HORIZONTAL:* SEC/DIV=10mS to 100 $\mu$ S

investigate the effect of various settings of "TRIGGER LEVEL" on your ability to see the traces. Investigate the range of frequencies you can cover with a (quiet!!) whistle. There is high frequency and low frequency "noise"? Which noise is from sound pickup and which is from electrical pickup? Note that pressing "Force Trigger" always makes a trace appear.

Sing a "single" note and measure its frequency. Sing a note an octave higher (DO, RE, ME, FA, SO, LA, TI, DO) and measure its frequency. What change in frequency is an octave?

## 7. Charge and Discharge of a Capacitor.

A capacitor is a device for storing charge; in its simplest form it consists of two parallel conducting plates separated by a thin layer of insulator. The greater the charge stored,  $Q$ , the greater is the voltage,  $V$ , across the capacitor plates. The relationship between the two is  $Q=CV$ , where  $C$ , a constant that depends on the area and separation of the capacitor plates, is called the *capacitance* of the capacitor.

If a charged capacitor is connected to a resistor,  $R$  (measured in ohms), the charge will leak away at a rate determined by what is called the *time constant*,  $\tau$ . The expression for the rate of decay of the voltage across the capacitor from its initial value  $V_0$  is given by

$$V(t) = V_0 e^{-\frac{t}{\tau}} = V_0 e^{-\frac{t}{RC}}$$

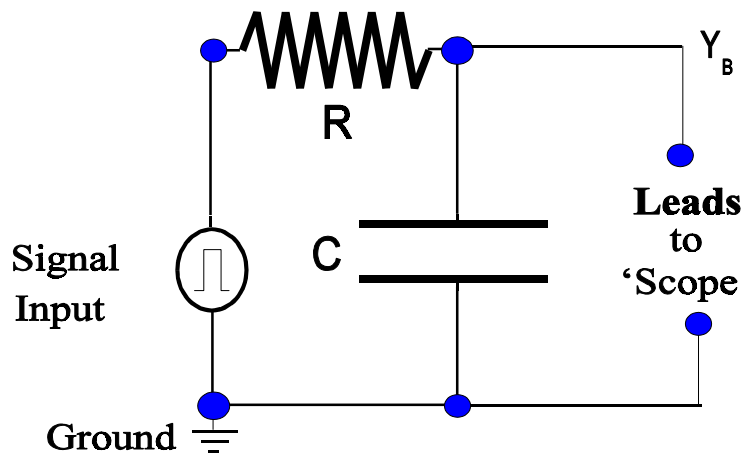
Similarly, when a capacitor is charged up through a resistance the voltage builds up to its maximum voltage  $V_0$  according to the equation

$$V(t) = V_0 (1 - e^{-\frac{t}{\tau}}) = V_0 (1 - e^{-\frac{t}{RC}})$$

It is convenient to charge and discharge the capacitor using a voltage that turns on and off in a periodic way. Such a voltage is produced by a signal generator producing a square wave. The capacitor will then charge up and discharge every period, and its voltage can be displayed on the oscilloscope.

The DataStudio 750 interface produces the required signal. Open DataStudio, and drag the Signal Output icon on to the outputs on the picture of the 750 interface. Push the Auto button, on the Signal Generator window and the On - Off switches will become active. Choose the Square Wave Function; the frequency and amplitude of the signals can then be chosen as required. For this experiment a frequency of around 100 Hz is reasonable place to start.

Use the circuit shown; first connect the largest capacitor and the largest resistor on the "breadboard" in series to the output signal generator of the 750. Then connect the CH1 oscilloscope leads across each side of the capacitor; make sure that the ground (black) lead is on the same side of the circuit as the ground output from the signal generator. Now use your expertise with the oscilloscope to obtain a stationary pattern on the 'scope. Then adjust the frequency of the signal till the capacitor is fully charged up by the end of the positive square wave cycle (and also, of course, fully discharged by the end of the negative square wave cycle.)

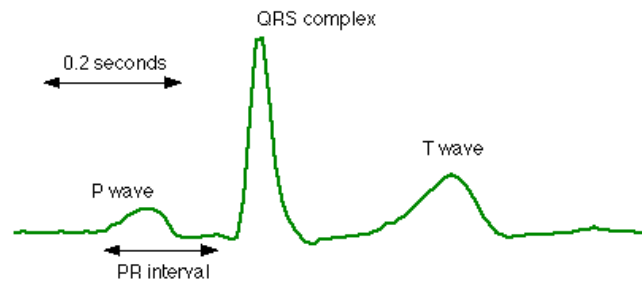


Using the cursor, measure the time constant of your circuit, by finding the point at which the charging capacitor reaches  $(1-e^{-1})$  of its asymptotic value (or, alternatively, the point at which the discharging capacitor falls to  $e^{-1}$  of its initial value). Repeat for the other three R-C combinations available to you on the breadboard, and compare to expectation (Note: the quoted value of the capacitance is good to about 10%; the approximate values of the resistors can be read off using the colour code - see the relevant section in the Laboratory Manual - or, more accurately, measured directly using a multimeter).

**NOTE:** a fuller description of this experiment is contained in the guide sheets for the experiment *Charge and Discharge of a Capacitor*; follow the links on the PHY140Lab or PHY180Lab Web pages.

**8. Heart Monitor.** (Optional; if you have time, this is an interesting exercise. Pick up the amplifier from the Resource Centre).

Muscle action is accompanied by production of electrical potential differences. In particular, the heart, a large muscle, produces a voltage that can be detected between your left and right hand. This voltage is of the order of a few millivolts. (Compare this with the levels of noise you detected in section (1) of this experiment.)



The heart monitor amplifier measures the difference between the voltages from the handles (relative to the ground ankle lead) but filters these signals to eliminate frequencies higher than about 20 Hz in order to filter out the predominant noise frequencies. Connect the ankle connector to the amplifier's "LEG" lead to reduce noise pickup, the handles to the amplifier's "LEFT" and "RIGHT" leads, and the amplifier's output connector to the "CH1" input of the oscilloscope. Convenient oscilloscope settings are:

*CH1 menu and knobs:* Coupling=DC, BW Limit=ON(20MHz), VOLTS/DIV=500mV

*TRIGGER menu:* Source=CH1, Coupling=DC

*HORIZONTAL:* SEC/DIV=250ms (Normal pulse rate is of the order of one to one-and-a-half pulses per second.)

Start with the trigger on "AUTO" in order to have the trace sweeping all the time. This will help you see when the amplifier is working. (The amplifier tends to be temperamental and demands good hand contact with the handles - sometimes even wanting slightly moist hands, and it sometimes takes up to a half-minute to "settle-down" after your hands are squeezed around the handles.) If you wish to freeze the trace on the screen, it's then easiest to switch to "NORMAL" trigger with an appropriate trigger level, and once you have caught a good trace, push "RUN/STOP" to freeze the trace on the screen.

To investigate just how good a job the amplifier is doing in reducing noise, see if you can find your heart beat *without* using the amplifier. Keep the grounding lead connected to your right ankle. Use the oscilloscope settings:

*CH1 menu and knobs:* Coupling=DC, BW Limit=ON(20MHz), VOLTS/DIV=20.0mV

*CH2 menu and knobs:* Coupling=DC, BW Limit=ON(20MHz), VOLTS/DIV=20.0mV

*TRIGGER menu and knob:* Source=CH1, Mode=Auto, Coupling=DC, TRIGGER LEVEL=0.00V

*HORIZONTAL:* SEC/DIV=500ms, Position=0.000s

Connect the two handles to the oscilloscope CH1 and CH2 inputs (red leads) and connect the ankle connector to the oscilloscope ground (EXT TRIG). With channel 1 turned on and channel 2 off, grab the two handles, and notice the trace. Do the same with channel 1 turned off and channel 2 on. Do you see all the noise pickup?

Now try to reduce noise pickup by looking at the difference between the channel 1 signal and the channel 2 signal. To do this, select "MATH MENU" and choose "CH1-CH2". Does your imagination allow you to see any heart signal in all that noise? If so, call over your demonstrator!

We hope that you are now convinced that it sometimes takes an effort to bring a signal out of the noise.