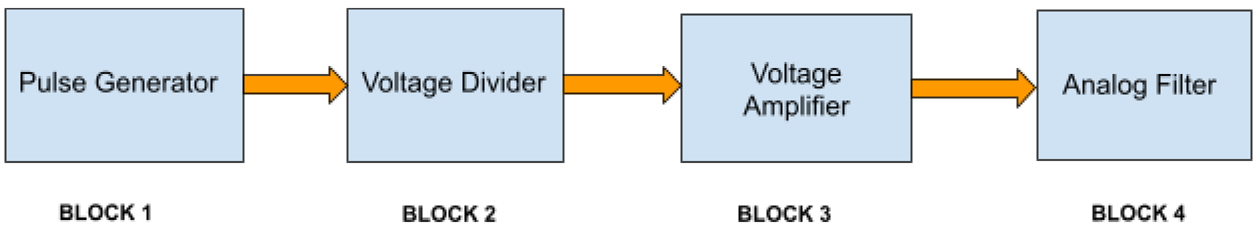
Electronics Laboratory

Objectives:

- Attaining a high level of familiarity and comfort using TEKTRONIX oscilloscopes
- Understanding basic electrical concepts through application
- Reducing circuit diagrams to functional circuits using a breadboard
- Use of two types of devices: Operational Amplifier and 555 Timer
- Developing a circuit that is the integration of multiple components represented in the following block diagram:



Note: The Appendix Section of this Instruction Manual contains basic information regarding use of the oscilloscopes in the lab. There are 3 different models of the TEKTRONIX scopes but they all have essentially the same features for data capture.

Procedure:

Each component depicted in the Block Diagram will be constructed and tested separately or in combinations with other Blocks and the final unit constructed from the integration of all the units. Two types of Analog Filters will be designed, built and tested.

Equipment:

- Breadboard
- Lead wires, jumper wires, 555 timer, Operational Amplifier, resistors and capacitors
- DC power supplies: 9V rechargeable batteries
- TEKTRONIX Oscilloscope
- USB Storage Drive

Note: Details of the use of the breadboard are found in the Appendix under the section BREADBOARD USE which is an excerpt from the Analog Computer Lab

SECTION 1: BLOCK 1 - PULSE GENERATOR

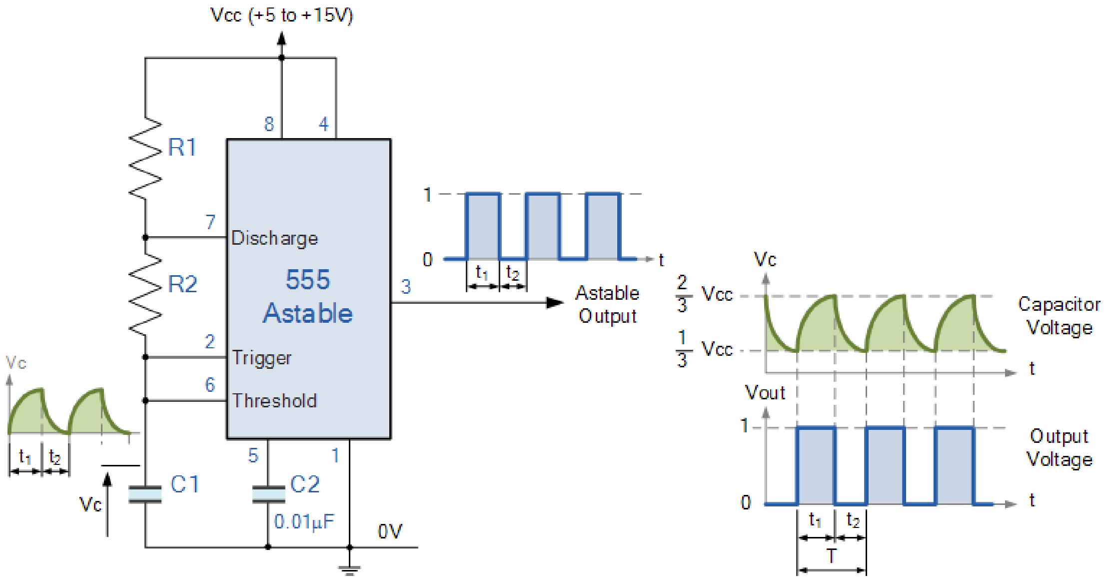


Figure 1: Basic Circuit for using the 555 to generate continuous pulses. V_{cc} is the label for the supply voltage. Actual pin configuration of the 555 timer is found in the Appendix (Figure A6)

Oscillator ON (t_1) and OFF (t_2) times are dictated by the application of R_1, R_2 and C_1 in the following manner:

$t_1 = 0.693 \cdot (R_1 + R_2) \cdot C_1$ and $t_2 = 0.693 \cdot R_2 \cdot C_1$

Additional information regarding the charging and discharging of this capacitor is shown in the figure. Choose a capacitance of 10µF for C_1 and start with $R_1 \sim 1k\Omega$ and $R_2 \sim 2k\Omega$. Measure the values of the capacitor (C_1) and resistors with a Digital Multimeter (DMM). Compute the values of t_1 and t_2 and compare these with measurements on the oscilloscope. For one combination of R_1, R_2 and C_1, obtain a screenshot of both the output voltage and the voltage across C_1. Compare with similar signals shown on the right hand side of figure 1. We will take two screenshots using two different modes of data capture. Send the signal from pin 3 to CH1 and that from pin 6 to CH2. Use the TRIGGER MENU options to trigger off CH1. Adjust the trigger threshold voltage to get a steady signal of both traces in NORMAL mode. Obtain screenshots using two modes from the ACQUIRE MENU: a) SAMPLE and b) AVERAGE (use 32 samples to average). Present both screenshots in your report. Keeping the **same** values of C_1 and C_2 , **vary** the values of R_1 and R_2 ,and check the timing on the oscilloscope (pick two values for each resistor so you can generate 4 combinations). Compare theory and the experimental values of t_1 and t_2. Use screenshots to support your comparison if necessary.
Take a digital image of the circuit you built and include it in your report. You will be graded on neatness.

SECTION 2: BLOCK 2 - VOLTAGE DIVIDER

We will use a voltage divider to reduce the input voltage into the OP-AMP (Operational Amplifier) in Block 3:(Operational Amplifier). Figure 2 shows four different styles of a schematic for voltage dividers that you will find in various documentation.

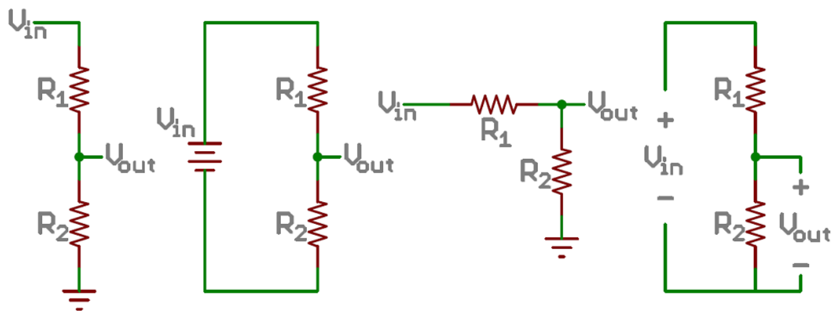


Figure 2: A voltage divider network represented in different configurations but having the same functionality. It is also called an attenuator. V_{in} and V_{out} are the input and output voltages respectively.

From your previous experience in circuits (re: Physics 2) - work out the ratio of V_{out}/V_{in} in terms of R_1 and R_2. Include this in your report.

Choose a pair of values of R_1 and R_2 to generate an attenuation of 10 (i.e. a ~ 10x reduction in voltage), wire them up on a breadboard and verify that the ratio (or attenuation) is correct using a DC source (constructed using a **single** 9V battery connected to the **positive terminal** of the connector shown in Figures A7-A9) and a DMM. If the measured ratio is incorrect, can you account for the inaccuracy?

Having picked the pair of resistors and verified the attenuation, connect the output of the circuit you just built (Figure 1) to the input of the voltage divider (generally labeled as V_{in}) and measure V_{out} using the oscilloscope. Verify that the signal you measure is consistent with the attenuator you just built. Display both signals (V_{in} and V_{out}) on the oscilloscope and do a screen capture which will be included in your report.

SECTION 3:

BLOCK 3: VOLTAGE AMPLIFICATION USING AN OPERATIONAL AMPLIFIER; Integration of BLOCK 1, BLOCK 2 and BLOCK 3

Excerpt from "Handbook of Operational Amplifier Applications by Burr-Brown" (1963):

*"**Originally, the term, "Operational Amplifier," was used in the computing field to describe amplifiers that performed various mathematical operations**. It was found that the application of negative feedback around a high gain DC amplifier would produce a circuit with a precise gain characteristic that depended only on the feedback used. By the proper selection of feedback components, operational amplifier circuits could be used to add, subtract, average, integrate, and differentiate………*

***….What the operational amplifier can do is limited only by the imagination and ingenuity of the user**."*

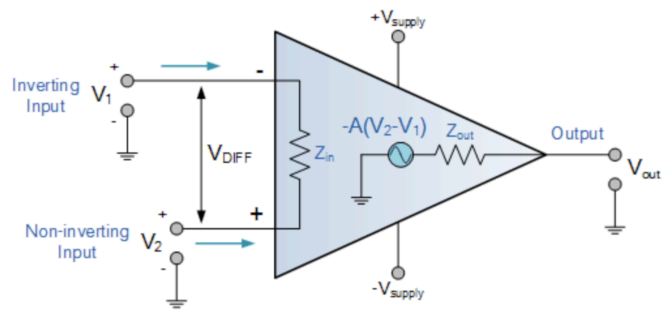


Figure 3: Model of an ideal op-amp (in open-loop configuration).

Figure 3 is the symbolic representation of an op-amp in open loop configuration. An ideal op-amp has Z_{in} approaching infinity, Z_{out} approaching zero and the gain, A approaching infinity. V_{diffi} is the voltage difference between the input terminals and V_{out} is the output voltage applying the gain, A to V_{diff}. The supply voltages (positive and negative) for the device are labeled as $+V_{supply}$ (positive potential) and $-V_{supply}$ (negative supply). For operating the device, these supply voltages are equal in magnitude i.e. $+V_{supply}$ = $-V_{supply}$ and range anywhere between 5 to 15 volts (DC).

Figure 4 is typically used in circuit diagrams, oftentimes without the supply voltages included. It is assumed in those cases that the user knows that the supply voltages are implicit in the description of the device. Note that the negative and positive polarities assigned to V_1 and V_2 respectively are the inverting (V_1) and non-inverting (V_2) inputs.

Figure 5 shows details of a popular Op-Amp, the µ741, with all the necessary connections for operating the device. Note the designation of inverting and non-inverting inputs. **Note that any time you use an Op-Amp, you must look up the pin designation, as it varies from device to device.**

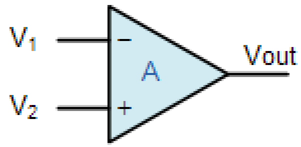


Figure 4: Typical Symbol of an Op-Amp

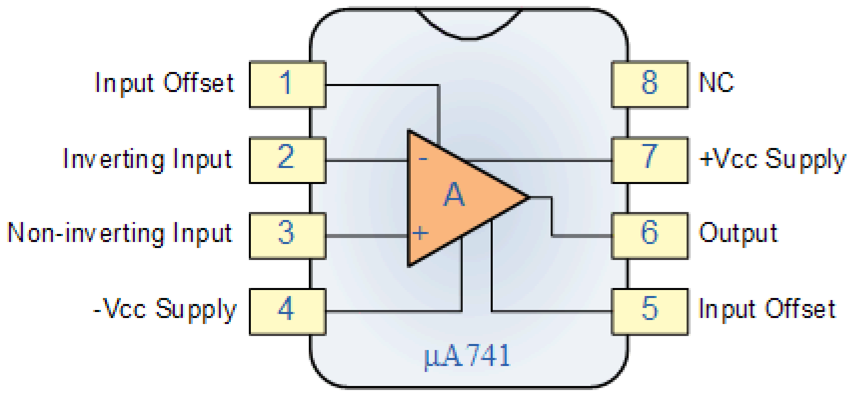


Figure 5: Details of the connecting pins for the Op-Amp µA 741. Pin designation always needs to be checked for any Op-Amp as they might differ between manufacturers.

The Golden Rules for understanding OP-AMP with external feedback:

Here are some simple rules for working out op-amp behavior with external feedback:

First, the gain of the op-amp (open loop i.e. without feedback - ref. Figure 4) is so high that a fraction of a millivolt between its input terminals will swing the output over its full range.

GOLDEN RULE 1: The output attempts to do whatever is necessary to make the voltage difference between the inputs zero

Second, op-amps draw very little input current.

GOLDEN RULE 2: The inputs (both the inverting and non-inverting) draw no current

Analysis of Inverting Amplifier (*we will build this for Block 3*)

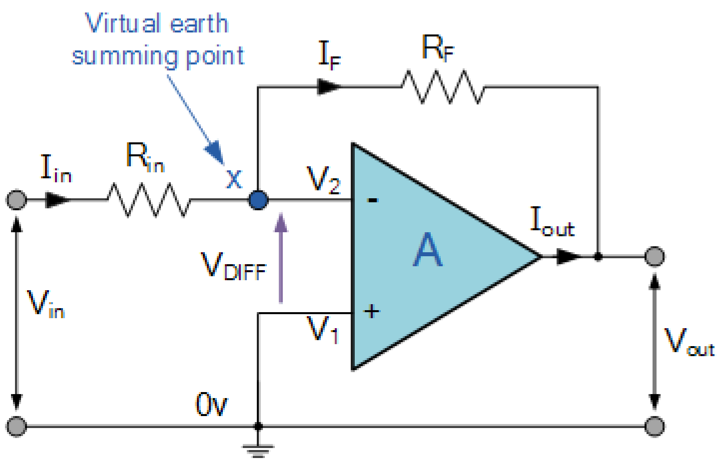


Figure 6: Schematic of an Inverting Amplifier using Negative Feedback. Pls note that the designations of V_1 and V_2 are different from Figure 3.

We can analyze the circuit by applying the Golden Rules:

1. V_1 (voltage at non-inverting input) is at ground so V_2 (voltage at inverting input) is also at ground when we apply Golden Rule 1.
2. This means that the voltage across R_F is V_{out} and voltage across R_{in} is V_{in}.
3. Using Golden Rule 2, implies that $V_{out} / R_F = - V_{in} / R_{in}$
4. The voltage gain (also known as the closed loop gain) of this inverter is: $V_{out}/V_{in} = - R_F/R_{in}$ - the negative sign indicates that the signals are out of phase with each other by 180^0 because of the negative feedback.

Use the connector and the 9V batteries shown in Figures A7-A9 to construct the +/-9V power supply needed to power the operational amplifier. If you have an amplifier that has the pin arrangements depicted in Figure 5, the +9V would be applied to pin 7 and the -9V to pin 4. Check the pin arrangements for the amplifier you are using by finding the appropriate datasheet on the internet.
Choose values of R_{in} and R_F (choose values in the 10s and/or 100s of kΩ range) to give a close loop gain between 10 and 20 for the inverting amplifier and combine this with BLOCK 1 and BLOCK 2. **Choice of the close loop gain depends on the input voltage. Do not choose a gain such that the output voltage is equal to or larger than the supply voltage from the batteries.** Make estimates of your output signal using measured values of your input signal, which is the attenuated voltage coming out of the voltage divider. Make sure this estimated value of the output signal does not exceed the supply voltage. Note that for BLOCK 2, the output of the voltage divider will become the input of the inverting amplifier. Measure the appropriate signals on the oscilloscope and verify that the computed closed loop gain is correct. If it is not, can you explain the reason for the difference.
Take a digital image of the circuit you built (BLOCK 1 + BLOCK 2 + BLOCK 3) and include it in your report. You will be graded on neatness.

Non-inverting Amplifier problem: (5 pts)

DO NOT BUILD THIS CIRCUIT! This is a purely analytical design problem.

Apply the Golden Rules to Figure 7a & 7b, a non-Inverting Amplifier and prove the gain = 1 + R_f/R_2. Show your work. Include this in your Jupyter Notebook.

Using Figure 7b as a representation of the non-inverting amplifier, derive the closed-loop gain of the amplifier in Figure 7a by applying the Golden Rules to the Potential Divider Network shown in Figure 7b.

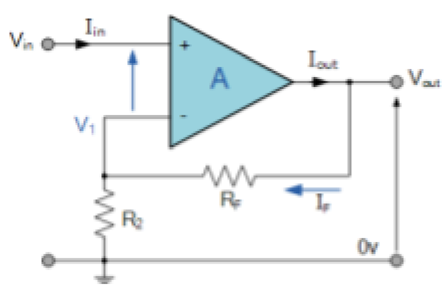


Figure 7a: Non- inverting Amplifier

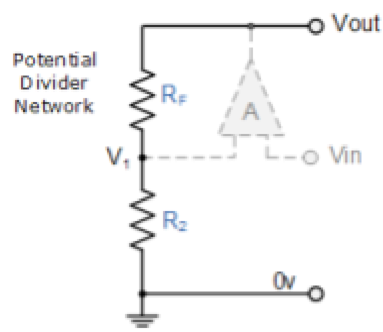


Figure 7b: Equivalent Potential Divider Network of Figure 7a for Analysis

SECTION 4:

BLOCK 4: Passive Analog Filters: Low Pass/High Pass/ Band Pass Filters;
Integration with BLOCK 1 + BLOCK 2 + BLOCK 3

Note: In this section you will only need to build <u>EITHER a Low Pass OR a High Pass Filter</u> to represent BLOCK 4. Do only the calculation relevant to your choice of filter

Depending on the need, combinations of passive elements like resistors, capacitors and inductors can be used to construct various types of analog filters. In the interest of time, we will only explore one of these in this final section.

Function of analog filters - they "filter-out" unwanted signals and an ideal filter will separate and pass sinusoidal input signals based upon their frequency. In low frequency applications (up to 100kHz), passive filters are generally constructed using simple RC (Resistor-Capacitor) networks, while higher frequency filters (above 100kHz) are usually made from RLC (Resistor-Inductor-Capacitor) components.

Passive filters are made up of passive components such as resistors, capacitors and inductors and have no amplifying elements (transistors, op-amps, etc) and have no signal gain, **therefore their output level is always less than the input**.

Filters are so named according to the frequency range of signals that they allow to pass through them, while blocking or "attenuating" the rest. The most commonly used filter designs are the:

The Low Pass Filter (LPF)– the low pass filter only allows low frequency signals from 0Hz to its cut-off frequency, f_c ,point to pass while blocking those any higher.

The High Pass Filter (HPF) – the high pass filter only allows high frequency signals from its cut-off frequency, f_c , point and higher to infinity to pass through while blocking those any lower.

The Band Pass Filter (BPF) – the band pass filter allows signals falling within a certain frequency band setup between two points to pass through while blocking both the lower and higher frequencies either side of this frequency band.

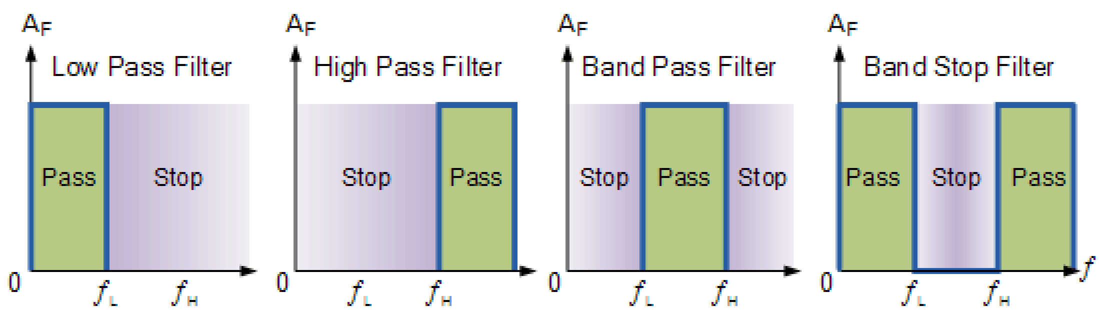


Figure 8: Ideal Filter Curves showing the differences between various types of analog filters. Amplitude (A_F) is on the y-axis and frequency is on the x-axis. f_L and f_H are the upper and lower cut-off frequencies.

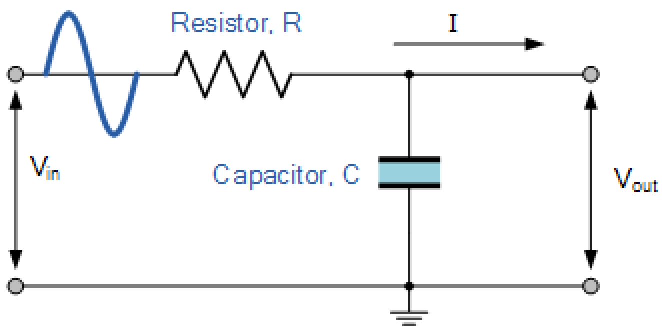


Figure 9: Circuit for implementing a low pass filter

Figure 9 shows how to implement the passive low pass filter. There is a similarity with the voltage divider we just built but with a frequency dependent component, the capacitor. One can show that the voltage division for this configuration is:

$V_{out} = V_{in} \cdot \frac{X_c}{\sqrt{R^2+X_c^2}}$ where R is the resistor value and X_c is the capacitive reactance ($= 1/2\pi f C$, where f is frequency and C is the capacitance).

Problem to work out:

Calculate V_{out} when V_{in}=10Vpp when R=4.7kOhms, C=47nF at two different frequencies: 100Hz and 10kHz.

When we build a low pass filter (BLOCK 4) and connect it to the output of BLOCK 3 (which is a square pulse), we will expect to see signals that look like those in Figure 10 at low, intermediate and high frequencies. We will focus on the low frequencies by choosing the filter components to be the same ones in the problem i.e. R=4.7kOhms, C=47nF (you will need to combine two capacitors which each have a capacitance of ~ 95nF to get this value. How would you do that?). Check that the settings of each channel of the scope, using the CH1 MENU or CH2 MENU, are set to: COUPLING: DC; BW LIMIT: OFF and PROBE: 1X. Send the input signal from the BLOCK 3 into CH1 and the output of the LPF into CH2. Adjust the time scale of the scope and obtain one cycle using CH1 as the reference signal.

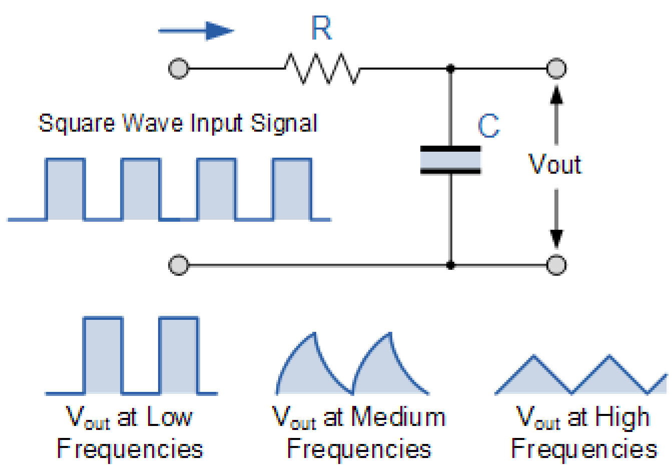


Figure 10: An "RC Integrator Circuit" that changes the shape of the input signal at the output due to the fast changing signal

Use the rising edge of the signal in CH1 to trigger the scope. Obtain a screenshot of both signals. Zoom in on the rising edge and then on the falling edge of CH1 and grab screenshots of both instances. Use the screenshots to explain what you observe on the scope traces using your understanding of how the LPF works. If necessary, use the vertical cursors to get temporal data to support your explanation.

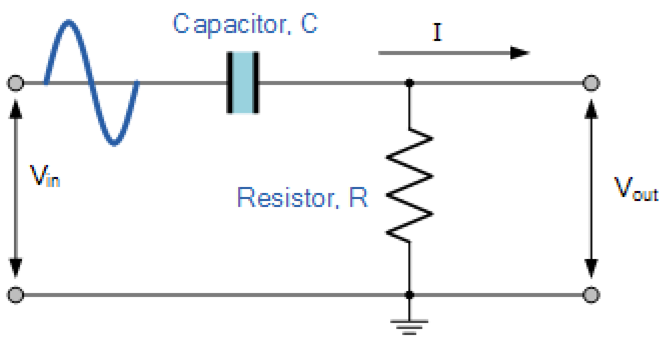


Figure 11: Circuit for implementing a high pass filter

Figure 11 shows how to implement the passive high pass filter. There is a similarity with the voltage divider we just built but with a frequency dependent component, the capacitor. One can show that the voltage division for this configuration is:

$V_{out} = V_{in} \cdot \frac{R}{\sqrt{R^2+X_c^2}}$ where R is the resistor value and X_c is the capacitive reactance ($= 1/2\pi f C$, where f is frequency and C is the capacitance).

Problem to work out:

Calculate V_{out} when V_{in}=10Vpp when R=4.7kOhms, C=47nF at two different frequencies: 100Hz and 10kHz. Include this in your report.

When we build a high pass filter (BLOCK 4) and connect it to the output of BLOCK 3 (which is a square pulse), we will expect to see signals that look like those in Figure 12 at low, intermediate and high frequencies. We will focus on the low frequencies by choosing the filter components to be the same ones in the problem i.e. R=4.7kOhms, C=47nF. Check that the settings of each channel of the scope, using the CH1 MENU or CH2 MENU, are set to: COUPLING: DC; BW LIMIT: OFF and PROBE: 1X. Send the input signal from the BLOCK 3 into CH1 and the output of the HPF into CH2. Adjust the time scale of the scope and obtain one cycle using CH1 as the reference signal.

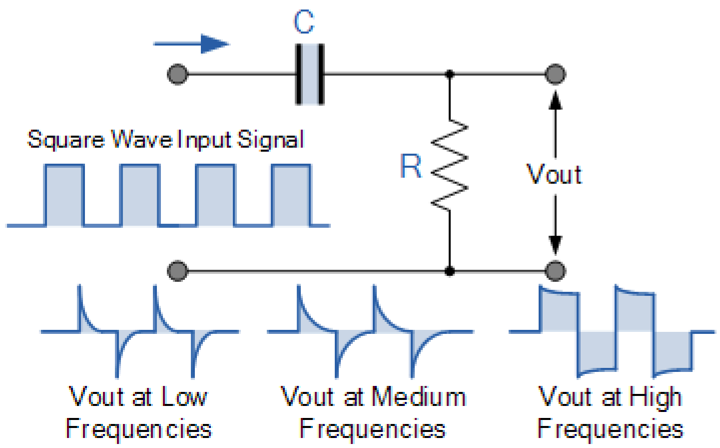


Figure 12: An "RC Differentiator Circuit" that changes the shape of the input signal at the output due to the fast changing signal

Use the rising edge of the signal in CH1 to trigger the scope. Obtain a screenshot of both signals. Zoom in on the rising edge and then on the falling edge of CH1 and grab screenshots of both instances. Use the screenshots to explain what you observe on the scope traces using your understanding of how the HPF works. If necessary, use the vertical cursors to get temporal data to support your explanation.

The lab report should include the following:

- Details of calculations, if any, required in the designs used for developing BLOCK 1, 2, 3 and 4.
- Derivation of the gain of a non-inverting amplifier (Section 3)
- Screen captures or plots from raw data files exported from the oscilloscope to verify the designs. Note that you can use your smartphone to capture the signal traces on the oscilloscope instead of downloading the data through the USB port. Make sure that the captured images clearly show details of the screen to support your work.
- Digital images of BLOCK 1 and the circuit comprising integration of BLOCK 1, BLOCK 2 and BLOCK 3
- Digital image of the final integrated circuit of BLOCK 1, BLOCK 2, BLOCK 3 and BLOCK 4
- Explanations, where appropriate, of differences in the output signals when compared to theory.

APPENDIX

BREADBOARD USE (taken from ANALOG COMPUTER LAB INSTRUCTIONS, modified for this lab)

The breadboard has conducting strips that allow for a consistent voltage to run vertically along neighboring holes. The columns are not attached across the white strip in the middle. The top two and bottom two rows are attached horizontally, but not vertically. This lab is meant to grow your skills in assembling circuits. Circuits can be tricky to debug. In order to help the TAs help you, keep your circuits as organized as possible.

Power the breadboard in a clear, understandable way, using the DC power source which are the 9V batteries wire back-to-back to generate +9V and -9V. It is highly suggested to use red leads for positive DC Voltage, black for negative DC voltage, and green for ground, as well as using the same color jumper wires to power the op-amps as in the example below (Figure A0). Use consistent color coding: in our example, blue is used to power op-amps, purple for grounding components (green would also be a good choice), white or yellow will be used for the actual signal that is being observed. Avoid adding "risky components" such as exposed wires that could touch each other to your circuit. These are sources of error that will significantly increase the time it takes you to narrow down why the circuit isn't working. If your signal is unsteady, the first places to check are your ground leads. Make sure the connections are tight, and that all grounded components go to the common ground. You will be held accountable for putting away all circuit components once you have completed the lab. Points will be taken off if this step is skipped. Account for the time this will take at the end.

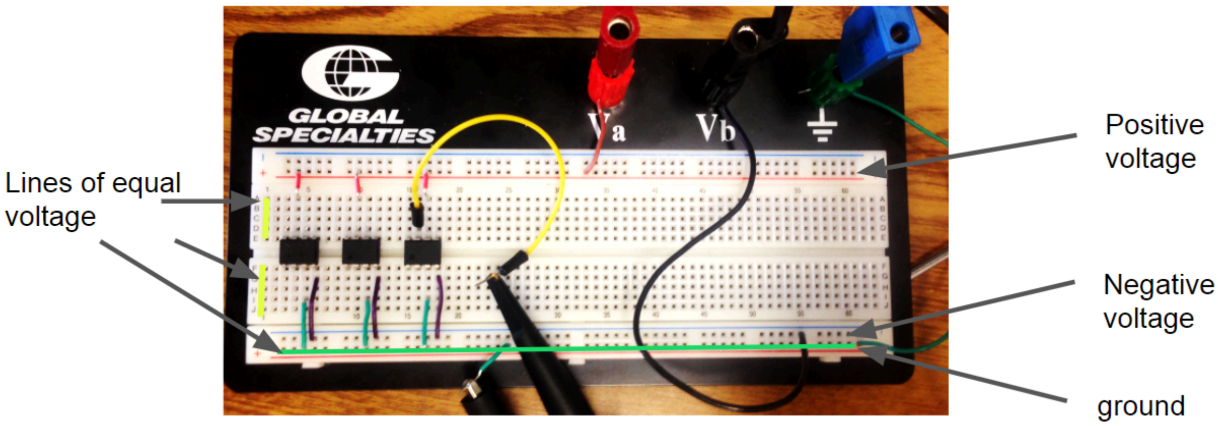


Figure A0: Circuit Guidelines with op-amps

TEKTRONIX OSCILLOSCOPE USE:

We have three different models of oscilloscopes manufactured by TEKTRONIX. The control buttons and screen menu options are essentially the same. It is important you recognize and be comfortable using the various features of the instrument for efficient data capture. All the scopes have two input channels and a separate input for an external trigger. For triggering purposes, you can also use the signals at CH1 or CH2 if you don't have a separate signal for the external trigger. It setting up the instrument for data capture, you will need to find the configuration which will give you a stable, static display. The USB drive can be used for storing data as ASCII files for further analysis or Screen Capture Images using a USB Storage Device.

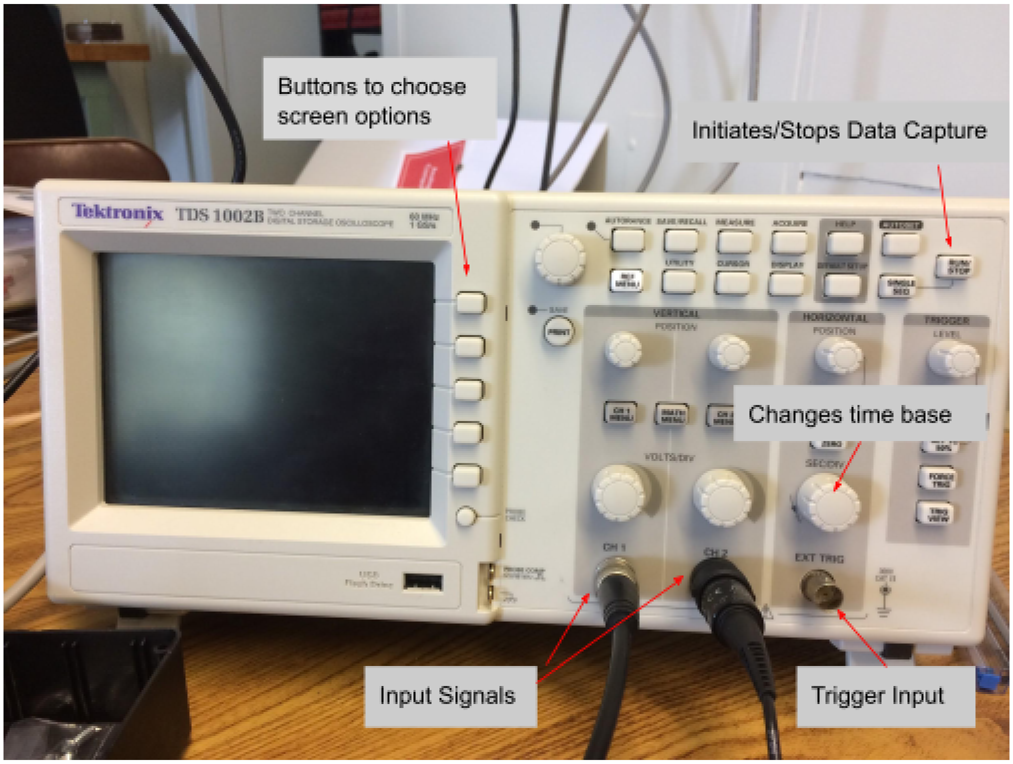


Figure A1: Key inputs and controls for the oscilloscope

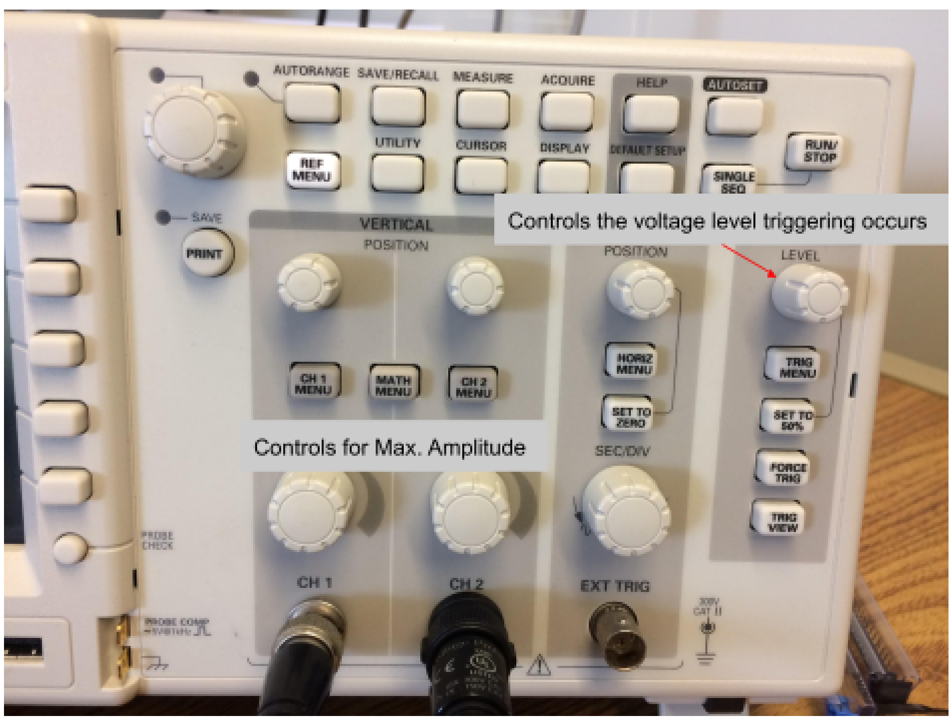


Figure A2: Close up View of Control Panel. Buttons with “MENU” when pushed will bring up options on the screen

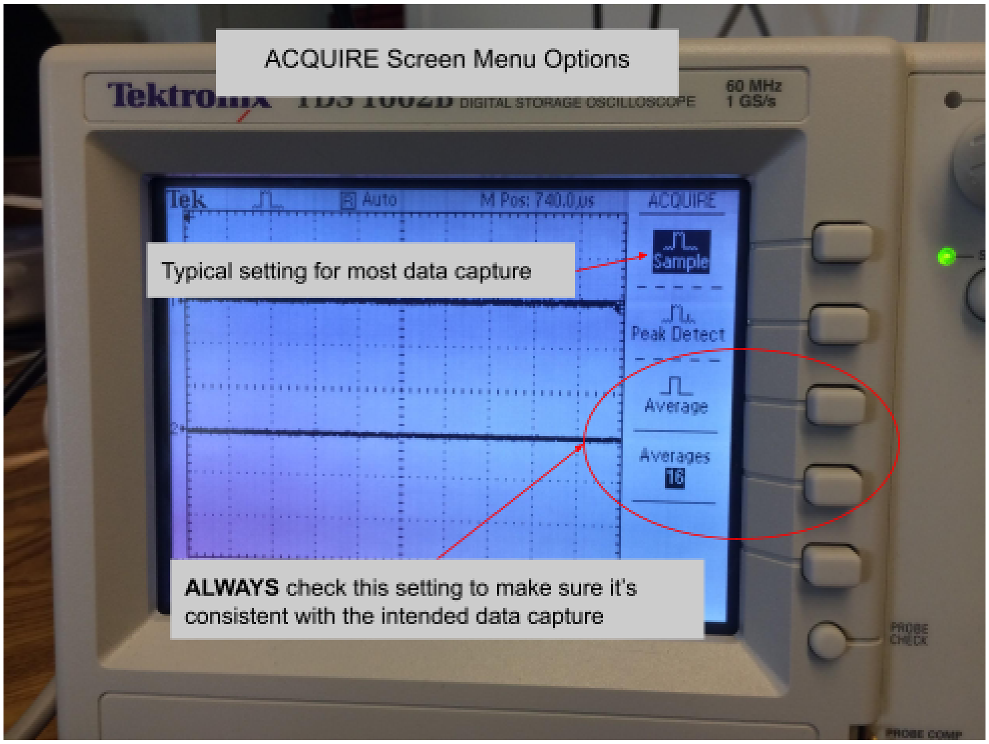


Figure A3: Screen Options for ACQUIRE MENU

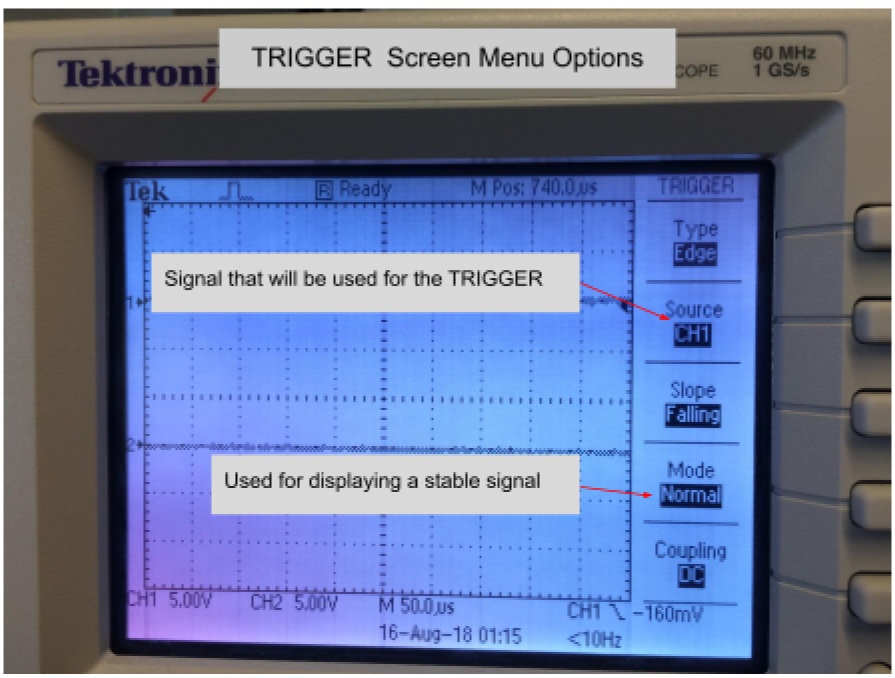


Figure A4: Screen Options for TRIGGER MENU. The options for “Slope” are either “Falling” or “Rising” - make the appropriate choice depending on the signals you are capturing.

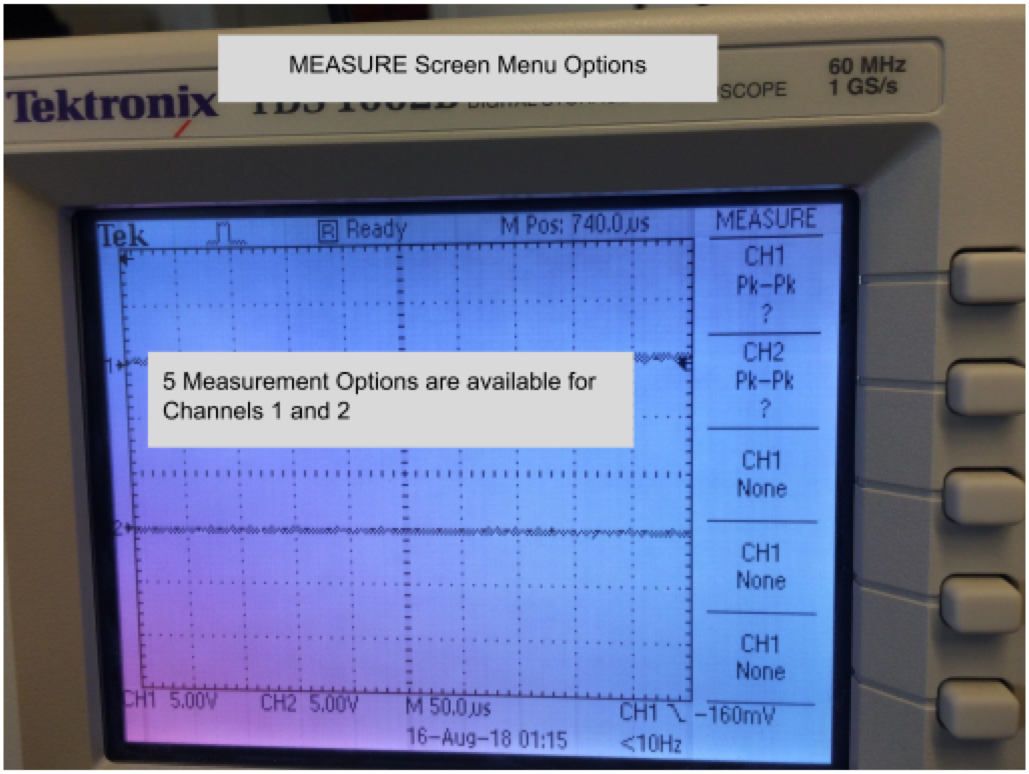


Figure A5: Screen Options for MEASURE MENU. Choices are seen by pushing each button on the far right of this figure. Make sure you understand what the measurement means before choosing it.

PIN CONFIGURATION OF 555 TIMER

Figure 1 is the wiring diagram of the 555 Timer Chip. However, the pins are not shown in the order that they are on the actual chip. Figure A6, taken from the datasheet shows the actual pin configuration.

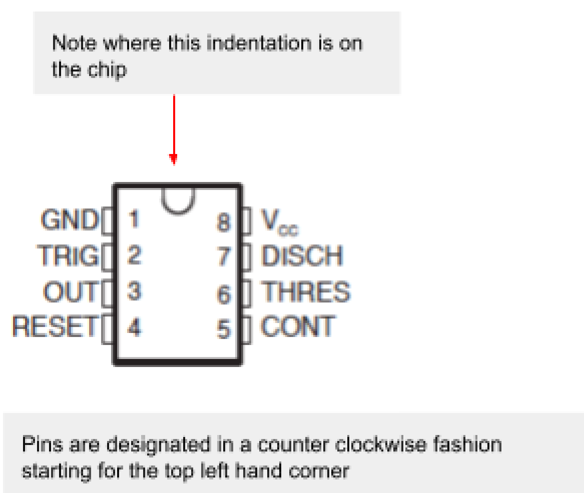


Figure A6: 555 Timer pin configuration

USE OF CONNECTOR FOR +/-9V POWER SUPPLY

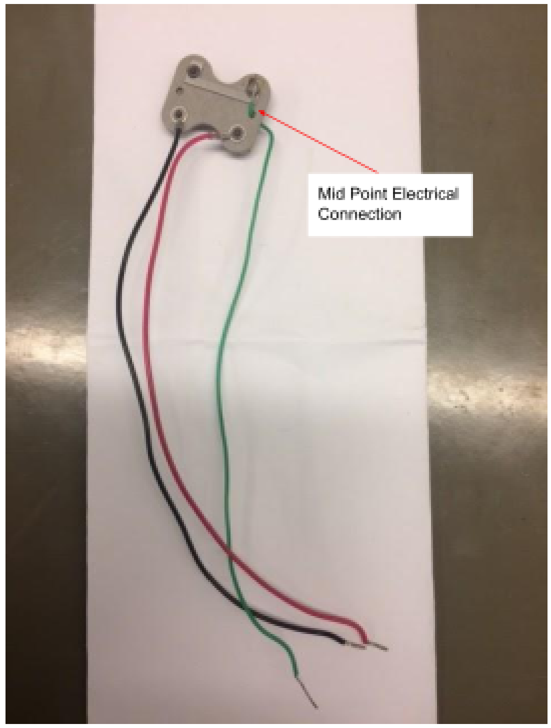


Figure A7: Connector showing position of mid point electrical connection. This is used as the grounding point.

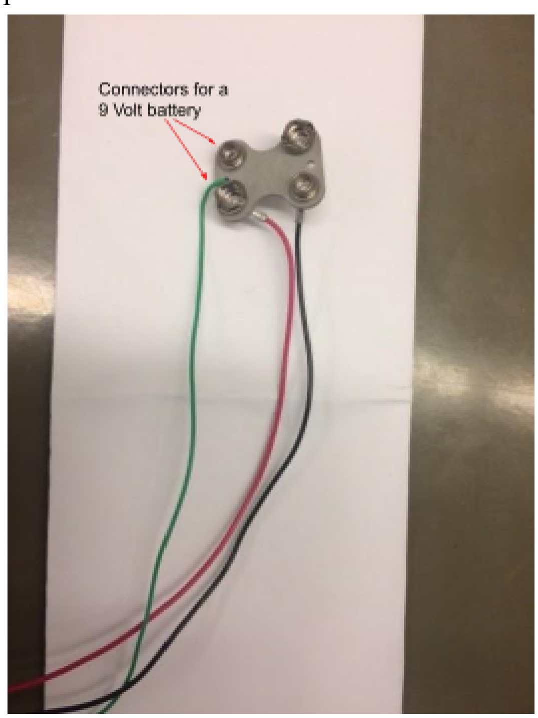


Figure A8: Opposite side of Figure A7 showing a pair of connectors that will be used with one 9V battery

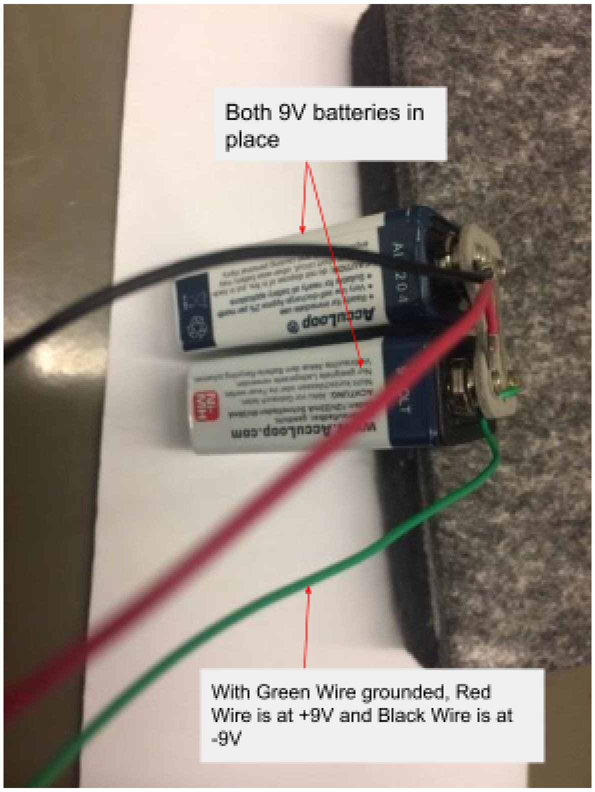


Figure A9: With both 9V batteries in place AND the green wire connected to ground, the red wire is at +9V and the black wire is at -9V