YOUR NAME:	YOUR SID:
YOUR PARTNER'S NAME:	YOUR PARTNER'S SID:

Pre-Lab Score: ___/50
In-Lab Score: ___/50
Total: ____/100

RC Oscillators

LAB 5: RC Oscillators

ELECTRICAL ENGINEERING 40

INTRODUCTION TO MICROELECTRONIC CIRCUITS

University Of California, Berkeley

Department of Electrical Engineering and Computer Sciences

Professor Michel Maharbiz, Vincent Lee

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Lab Objectives

In this lab we will learn to analyze and build RC oscillators by starting with the oscillator that you soldered in Lab 1. We will then design and build an oscillator that we will use as one of our modules for the final project. This oscillator will act as a signal generator for you to use as a test signal for your EEG.

Background

Many circuit applications that require precision timing or PWM control need an input waveform that oscillates between two voltages. To accomplish this we exploit the properties of capacitors to create these oscillating circuits. Often times we will have to settle for triangle or square wave form since sinusoidal waveforms are notoriously difficult to produce from simple RC oscillators.

These waveforms are used in mechanical applications such as motors that require pulse width modulation (PWM) control or timing circuits for synchronous digital applications. One of the advantages of PWM is that it draws less power than a DC input.

However, in our application, we will simply exploit the fact that it can function as a signal generator.

Pre-Lab Component

In the first solder lab, you should have been able to get your two LEDs to blink depending on how you configured the potentiometer. You may have noticed that one of the LEDs changed luminosity more gradually than the other. This is because one of the LEDs took a square wave signal while the other LED took a triangle wave input.

But how exactly does this work? Good question…

The circuit that we built in the first lab was a relaxation oscillator in conjunction with a triangle wave generator. The circuit is shown below:

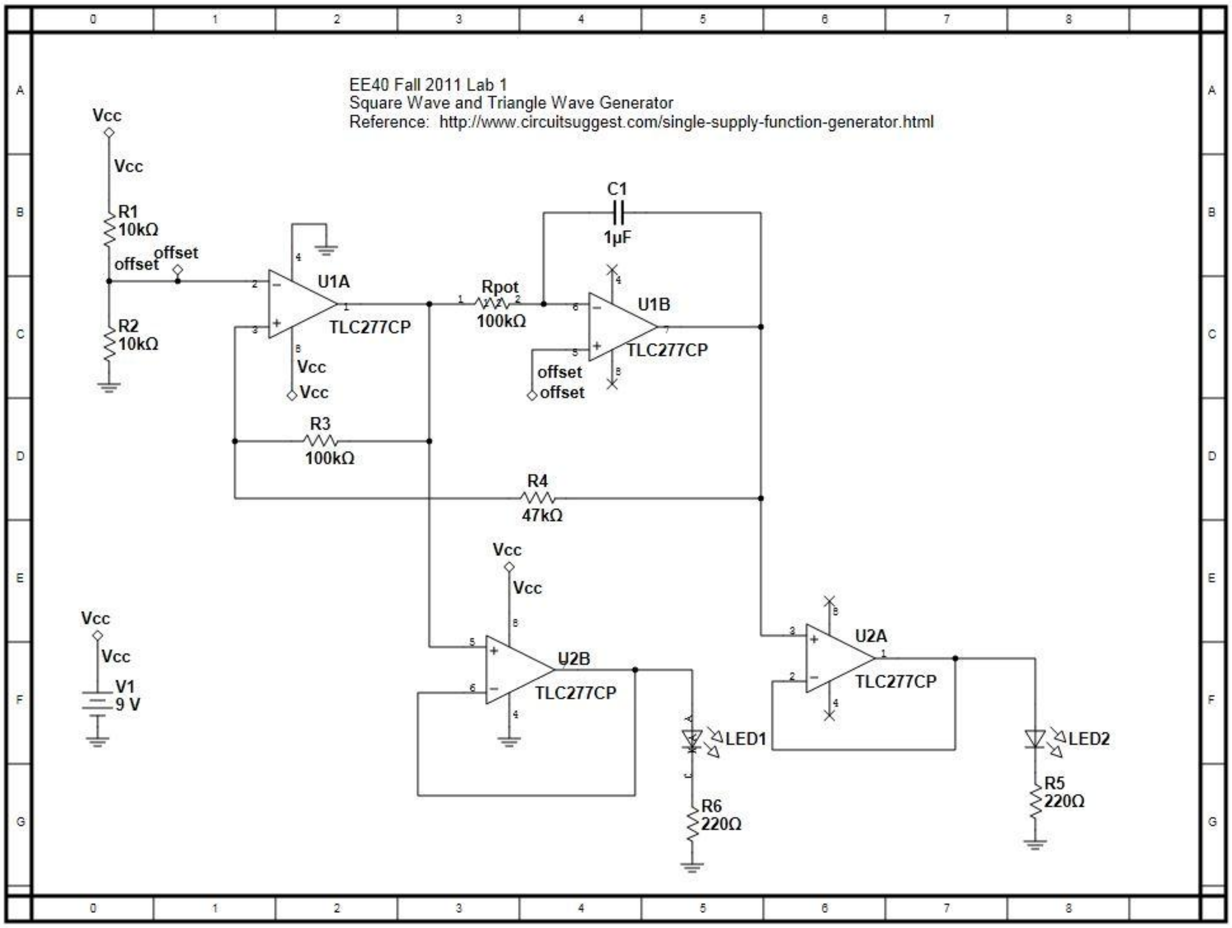

Fig 1. Square wave and triangle wave generator

Note that we will not be building this circuit in this lab, but a simpler version. Analyzing this circuit as a whole is mildly annoying so we'll start by taking a look at the relaxation oscillator which produces a square wave.

The Relaxation Oscillator

Reproduced below is a schematic of the relaxation oscillator. We'll use this as a square wave generator. Notice that it is configured in a positive feedback configuration.

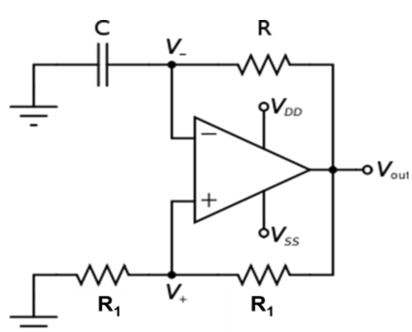

Fig 2. Relaxation Oscillator[i]

Now to actually figure out how it works... Initially the relaxation oscillator will start off with zero output but due to the positive feedback, will saturate randomly (due to noise) to one of the rails since it is in a positive feedback configuration. Once the operational amplifier saturates to one of the rails, the capacitor that is connected to the non-inverting terminal will begin to charge or discharge through the feedback loop depending on the state.

Remember, negligible current flows into the operational amplifier input terminals. Also the supplies to the operational amplifier are V_{cc} and $V_{ss} = -V_{cc}$ so the output of the operational amplifier is always either $+V_{cc}$ or $-V_{cc}$ giving us really only two states to analyze. Intuitively, the square wave comes primarily from the abrupt saturation from the positive rail to the negative rail or vice versa. But what about frequency and duty cycle? Good question…

In the space provided below, prove that the frequency of the output signal of the relaxation oscillator is given by:

$$f = \frac{1}{2\ln(3)\,RC}$$

You may find the following equation helpful: $V(t) = V_f + \left(V_i - V_f\right)e^{-t/RC}$, where $V_f = V(t = \infty)$ and $V_i = V(t = 0)$. Show all relevant mathematical derivations and work. Also, simulate the circuit in Multisim and attach it to this lab report. The simulation is worth **10 points.**

Score:__/15

More workspace…

The Triangle Wave Generator

In Fig 1., the square wave output of the relaxation oscillator is also fed into the triangle wave generator. The triangle wave generator is actually just a simple integrator shown below.

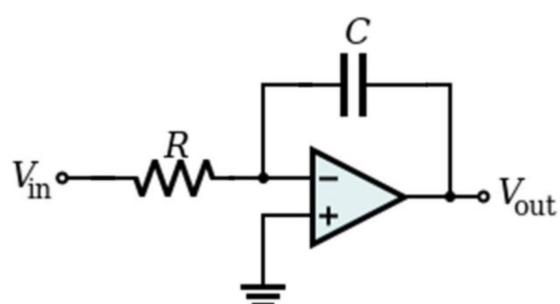

Fig 3. Inverting Integrator[ii]

In the space provided below, prove that the output of the above circuit actually integrates and inverts the input signal by showing the output signal is given by the following. Assume all initial conditions are zero

$$V_{out} = -\int_0^t \frac{V_{in}}{RC}\,dt$$

Then prove how this generates a triangle wave from the square waveform. What conditions for the square input waveform must be satisfied for this to actually produce a triangle wave? If V_{in} is a 10-Hz square wave with 5-V amplitude, how would you pick the value of R and C to generate a triangle waveform with 4-V amplitude? Simulate the circuit in Multisim and attach it to this lab report. The simulation is worth **10 points.**

Score: __/15

Lab Section

So why exactly do we care about an RC oscillator that produces a square and triangle wave?

Glad you asked. Square waves and triangles waves make excellent test signals especially for sensors like the EEG that we are going to build for our final project. This is because they are periodic and predictable unlike real world analog signals that you may be measuring.

In this lab component, you will be building the appropriate oscillator for your final EEG project to act as you test signal source. A list of specifications as to what exactly your generator will need to satisfy is explained in detail in the next section.

Your Oscillator

Obviously we can't just use any arbitrary oscillator with arbitrary specifications for our EEG and some test signals are better than others. Let's start by taking a look at the application. The EEG that we will be building is supposed to pick up signal on a microvolt level through a pair of electrodes. In addition, the brain wave frequency that we are primarily interested in, lies around $10Hz$ so we want to at least be able to produce that frequency.

However we will be using the oscillator as a test source so we might as well be able to sweep multiple frequencies. This will enable us to both simulate the brain wave frequency we are looking for with the EEG and to test if our circuit appropriately rejects undesired frequencies.

The circuit that you built on the solder board, had a minimum frequency of about $5Hz$ so you will have to modify that circuit.

Thankfully, you've done all of the derivations already for both of the oscillators so adjusting the design to fit the following parameters should be fairly simple.

In the space provided below, pick appropriate component values for the relaxation oscillator so that it's minimum frequency is $10Hz$. You may use one potentiometer in your design.

Score:__/10

More workspace…

Now that you have calculated the component values, it's time to build this on your breadboard. Before we implement that microvolt level signal generation, you will first want to test to see if your oscillator is working properly so let's build the oscillator.

As always, some useful tips before you start breadboarding it up:

- Set current limits. Anything greater than a reasonable amount of current will destroy your circuit, and you and your chips will be very sad.
- If components are getting hot, make sure your wires are not shorting and things are connected correctly. Check supplies to make sure the high and low supplies are not swapped.
- The multimeter and oscilloscope are your friends. Use your simulations to help you figure out what signals and voltages you should expect where on your circuit.

i) Build the relaxation oscillator (Fig 2). Pick R, C based on your previous calculation. You can use a 100-kΩ potentiometer for R. Use a 20-kΩ resistor for R1. What is the oscillation frequency? Tune the potentiometer until the frequency of the square wave is 10 Hz and show it to your GSI.

Your GSI Signs Here **(15 Points)**

ii) Build the triangle wave generator (Fig 3). The input comes from the square wave generated by the relaxation oscillator. Pick R, C based on your previous calculation. You can use a 100-kΩ potentiometer for R. What is the amplitude of the triangle waveform? Tune the potentiometer until the amplitude is 4 V and show it to your GSI.

Note: You may want to put a 100-kΩ resistor across C to discharge excess charge.

Your GSI Signs Here **(15 Points)**

iii) Once you have finished building the oscillator, it would be nice to see some indication that it works. To accomplish this, we can attach an LED to the outputs.

Add an LED to the output of your relaxation oscillator in series with an appropriate resistor. Usually a resistor between 200Ω and $1k\Omega$ should do the trick. You should now have a blinking LED at 10 Hz. Turn the potentiometer and show the LED blink at different frequencies. Now connect a second LED and resistor to the output of your triangle wave generator. Does the intensity of the LED change with time? Show your set up to your GSI for check off

Your GSI Signs Here **(10 Points)**

Lab Report Submissions

This lab is **due at the beginning** of the lab section. Make sure you have **completed all questions** and **drawn all the diagrams** for this lab. In addition, attach any loose papers specified by the lab and submit them with this document.

These labs are designed to be completed in **groups of two**. Only one person in your team is required to submit the lab report. Make sure the names and student IDs of **BOTH** team members are on this document (preferably on the front).

Image Citations

[i] http://en.wikipedia.org/wiki/File:OpAmpHystereticOscillator.svg
[ii] http://en.wikipedia.org/wiki/File:Op-Amp_Differentiating_Amplifier.svg