Handout #29
E84: Fall '07
12/5/07

E84: Lab 2

Getting credit for the lab: As in the first lab, I will be talking with groups and basically I just want to see each partner understanding what is going on. I should, at any point, be able to ask either member of the group a question about what is going on and they should understand – for the most part – what is happening. Common sense really – I want everyone to be actively engaged in the lab. Prelab can be done outside of lab (if you get the lab before then) and, it can be done as a team of two – however, as I said, I really want everyone to understand all of the calculations being made.

Objectives

- To gain further familiarity with building circuits and wiring them from schematics.
- To gain familiarity with the function generator and the oscilloscope.
- To build more circuits seen in class and verify their behavior.
- To design filters, build them and analyze them.
- To build circuits using diodes.

Prelab Reading

When you arrive in the lab, you will be given a brief tutorial on how to use the function generator and the oscilloscope. After this introduction, you will be given time to build the circuits assigned in the lab and "play" with the new equipment to get a good feel for how things work and what buttons do what. The equipment is rugged, so you should feel comfortable to turn knobs and "see what happens."

Function Generator: Like the power supply was able to provide an adjustable constant DC voltage, the function generator can provide AC voltage. The shape, frequency, amplitude and DC offset can all be adjusted.

Oscilloscope: Again, like the multimeter measured DC voltages and currents, the oscilloscope measures and displays voltages that are changing with time. Using the triggering level, the oscilloscope continually redraws the current voltage for a defined period of time. The oscilloscope has many dials and buttons that you should be familiar with. Rather than describe them all here, we'll go over the oscilloscope in detail (if you haven't already) during lab.

Low-pass filter: There are a few different ways to build a low pass filter. One method uses a simple RC circuit. When the frequency of the input is high, the impedance of the capacitor is quite low and very little voltage is dropped across the capacitor. So, most of the voltage is dropped across the resistor. When the frequency is low, the impedance of the capacitor is high and most of the voltage is dropped across it. So, if the voltage across the capacitor is the output voltage, then this is a low-pass filter. The inverse of the RC time constant determines the what is meant by “high” and “low.”

Another low-pass filter involves using a resistor and a capacitor in parallel as the negative feedback of an op-amp circuit as shown below in Figure 1. The logic behind this circuit is the same as the general RC circuit. A relatively low input frequency will cause the R_1C parallel combination to be approximately equal to R_1. A relatively high input frequency will cause the R_1C parallel combination to be much smaller.

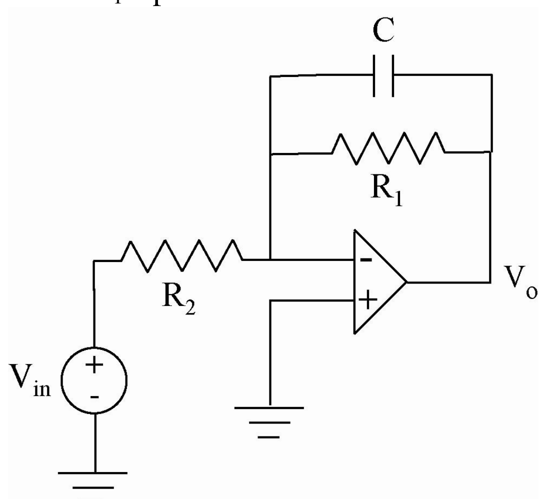


Figure 1: Low-pass filter using an op-amp.

RLC Circuit: We’ve dealt with a lot of RLC circuits in class. In this lab, we’ll build a very simple bandpass filter. By adjusting the values of R, L and C we can tune the design to change the properties of the filter, such as the resonant frequency, the bandwidth and the quality factor. For an RLC series circuit, the resonant frequency is $\frac{1}{\sqrt{LC}}$ and the bandwidth is *R/L*.

Wein-Bridge Oscillator: The circuit shown below in Figure 2 is called a Wein-Bridge oscillator and can be used to **generate** sinusoidal waves at frequencies below 1MHz. This circuit is easy to tune and easy to design. There are two feedback paths. The negative feedback loop controls the gain. The positive feedback loop controls the oscillations. Note that the feedback ratio $\frac{V_2}{V_o} = \frac{Z_p}{(Z_p + Z_s)}$, where Z_s is the series combination of R_1 and C_1, and Z_p is the parallel combination of R_2 and C_2.

For sine wave oscillators to maintain oscillations, they must meet what is called the *Barkhausen criteria:*

1) The overall gain of the oscillator must be unity or greater.
2) The overall phase shift from input to output and back to input must be 0. To satisfy the 2nd requirement, V_2 must be in phase with V_0. This implies that the imaginary part of $\frac{Z_p}{(Z_p + Z_s)}$ is 0. The math follows that the oscillation

frequency $\omega_o = \dfrac{1}{\sqrt{R_1C_1R_2C_2}}$. For practical reasons, R_1 usually equals R_2 and C_1 usually equals C_2. So, if $R=R_1=R_2$ and $C=C_1=C_2$, then $f_o = \dfrac{1}{2\pi RC}$.

The 2nd criterion pertains to the gain. For a non-inverting amplifier, recall that $\dfrac{V_2}{V_0} = 1 + \dfrac{R_f}{R_g}$. So, it can also be shown that to satisfy the *Barkhausen criteria*, $\dfrac{V_o}{V_2} = \dfrac{1}{3}$, so, $R_f=2R_g$. Finally, it should be noted that because op-amps have a built-in delay, these oscillators are limited to a frequency range of 1MHz or less.

So, where does the power come from? Well, remember, op-amps require positive and negative power supplies.

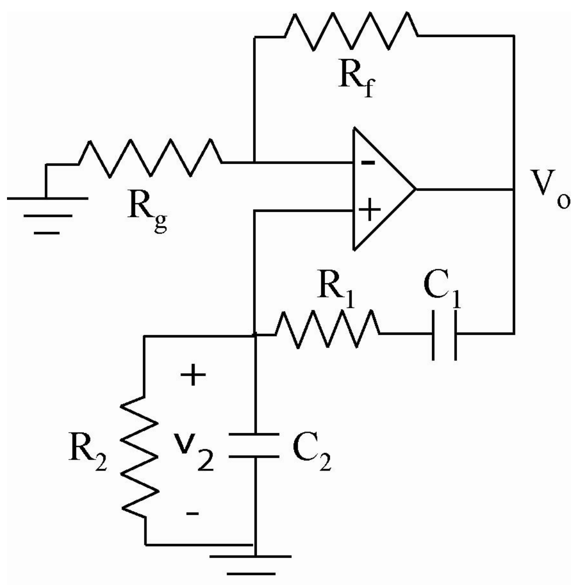


Figure 2: Wein-bridge Oscillator

Prelab Questions

1) Derive the expression for the gain and phase of voltage across the capacitor for an RC series circuit. Assume a sinusoidal input with frequency f. Using resistors 10Ω to 3.6MΩ and capacitors from 0.001μF to 1μF. Design a low-pass filter with a corner frequency of 800Hz. We limit our capacitors to non-electrolytic capacitors because we need the capacitance to be the same in both directions.
2) Now do the same thing for an RC op-amp circuit.
3) Design an RLC bandpass filter. We have access to a 0.5 H inductor, our smallest resistor is 10Ω and we have the same range of capacitors listed above. Our design should have a resonant frequency and bandwidth such that we can see both the peak and both cutoff frequencies. Meaning, 1/2BW<resonant frequency.

4) Using the equations above, design a Wein-Bridge oscillator that can oscillate at 1kHz. Remember the limitations on our parts. Try to use resistors in the 100Ω to 200Ω range.
5) Refamiliarize yourself with the full-wave rectifier from HW9, Problem 6.44 – as shown below. You will be building this circuit in the lab.

7. (10 points) FoEE 6.44

6.44 The ideal-diode circuit shown in Fig. P6.44 is known as a **full-wave** (or **bridge**) **rectifier circuit.** Determine which diodes are ON and which are OFF when (a) $v_S > 0$ V, and (b) $v_S < 0$ V. Sketch the output voltage v_o for the case that the input voltage is $v_S = A \sin \omega t$ V.

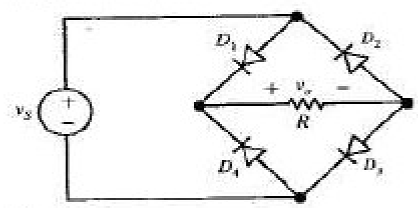


Fig. P6.44

Figure 3: Full wave (bridge) rectifier circuit

6) Write out a truth-table for the circuit shown in Figure 4. In this truth table, A and B should take on the values 0V or 5V, so your truth table should have 4 possible combinations. What gate is this?

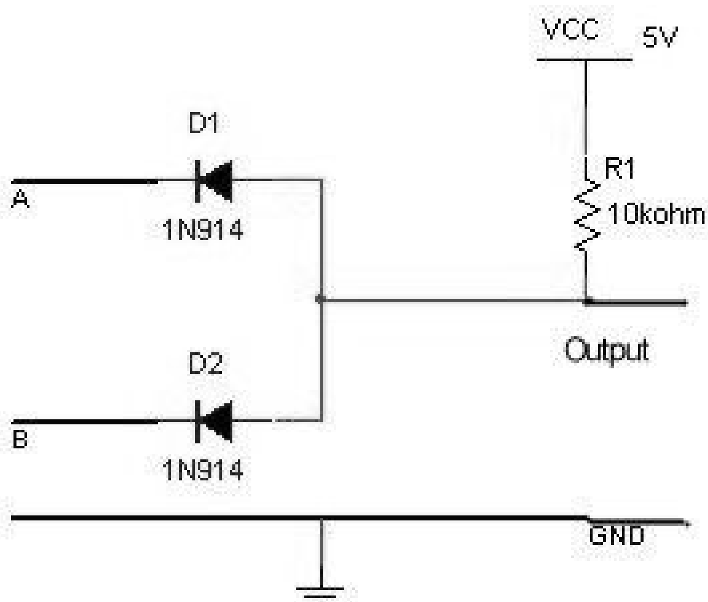


Figure 4: Mystery Gate

Lab Assignment

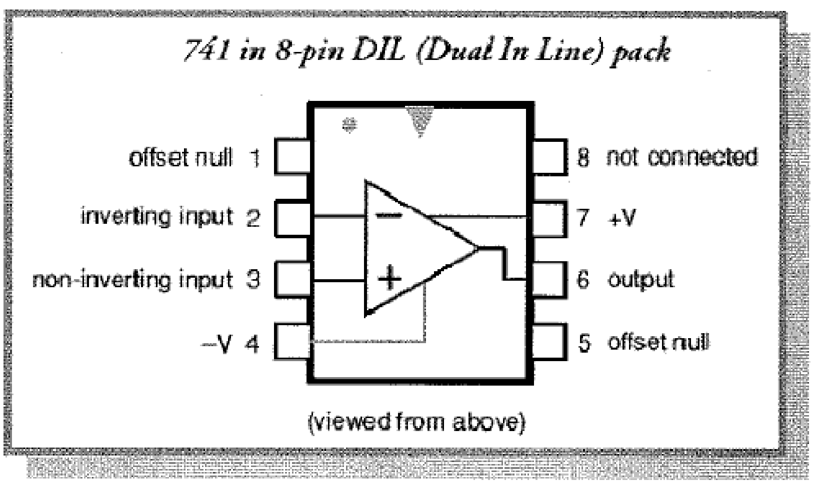
Part 1:

1) Using the function generator, produce a 1kHz sine wave that oscillates from 0V to 5V. So, this would be 2.5+2.5sin(2*pi*1000*t). Connect the input to the oscilloscope and show at least three periods on its display.

2) Build the RC series circuit that you designed in the prelab. Using the voltage across the capacitor as the output, use the two channels on your oscilloscope to view the input and output simultaneously. What is the gain at 10Hz, 1kHz and 100kHz. Experimentally, find the half-power frequency. What is it? What happens to the phase as you adjust the frequency.

3) Repeat the above for the RC op-amp low-pass filter. Are there any noticeable differences? Any reason why you'd want to use this circuit over the other circuit.

4) Now, build the RLC circuit that you designed in the prelab. Experimentally find the resonant frequency. What is the gain and phase at that frequency? Experimentally find the two half-power frequencies. If you have problems, try using L=500mH, R=300Ω and C=0.1μF. And, when you build it, don't actually include a resistor. The inductor we are using has an internal resistance of 300 Ω.



Part 2:

1) Build the Wein-Bridge oscillator that you designed in the prelab. Does it produce the signal that you expected to see? You should see a sinusoidal signal of around 6V peak to peak. Tweak things until it works. One very common problem is the gain isn't quite enough – so using a slightly different pair of resistors can make a difference.

Part 3:

1) Using LEDs and the voltage source from part 1 scaled down to a frequency of 1Hz build the full-wave rectifier. You should use a 200Ohm resistor for the R value.

2) Build the "gate" from Figure 4. Use 47Ohms instead of 10KOhms. Also, use LEDs instead of the diodes listed. Go through the different combinations of A and B and draw the truth table. Remember, you're trying to measure the voltage at the output for the four different combinations of A and B set to 0V and 5V.