EXPERIMENT #6
VOLTAGE CONTROLLED OSCILLATOR

INTRODUCTION:

In many applications, it is necessary to produce an output frequency that is dependent upon an input voltage. An FM transmitter does exactly this -- it converts intelligence amplitude into output *frequency*. A VCO is one circuit that can be used for this job; in essence, it is a voltage-to-frequency converter.

CIRCUIT ANALYSIS:

This oscillator uses a special IC chip, the LM565, that is designed to function as a phase locked loop (PLL). The chip contains a VCO (which we will utilize in this experiment) and a phase detector. A combination of an input control voltage on pin 7 and the RC time constant formed by the components on pins 8 and 9 set the VCO output frequency.

The VCO within the LM565 is not designed like a conventional oscillator. It is really a *current controlled* oscillator. Remember that as the charging current in a capacitor is increased, the rate of capacitor charging (as evidenced in its voltage rise) also increases. The same is true for capacitor discharging as well. The LM565 simply translates the *control voltage* on pin 7 into a charging and discharging current for the *timing capacitor*, C1. So what is the function of the resistors on pin 8?

The resistors on pin 8 also help set the charge and discharge current for the timing capacitor C1. In other words, the output frequency of the LM565 VCO depends on three factors:

1) The control voltage on pin 7;

2) The total resistance on pin 8 (R3 and R4);

3) The capacitance on pin 9 (C1).

When a capacitor is charged by a constant current, its voltage rises linearly (straight-line). Thus, one of the output waveforms of the LM565 is a triangle wave. The other output is a square wave -- the result of the triangle wave going through a Schmitt trigger.

Two different LM565 VCO circuits will be examined in this experiment, and they are shown in Figures 1 and 2. In Figure 1, the *control voltage* of the VCO is held constant by resistors R1 and R2, and the RC time-constant is varied by R3. (Note that the total resistance *Rt* in Figure 1 is the series combination of R3 and R4).

In Figure 2, the timing resistance *Rt* is equal to R2, and is constant. A potentiometer has been substituted in R1's place, allowing the control voltage to be varied over a range of approximately 7.5 V to 15 V. Note that the control voltage should be adjusted to be in the range 11.25 V to 15 V in part two of this experiment.
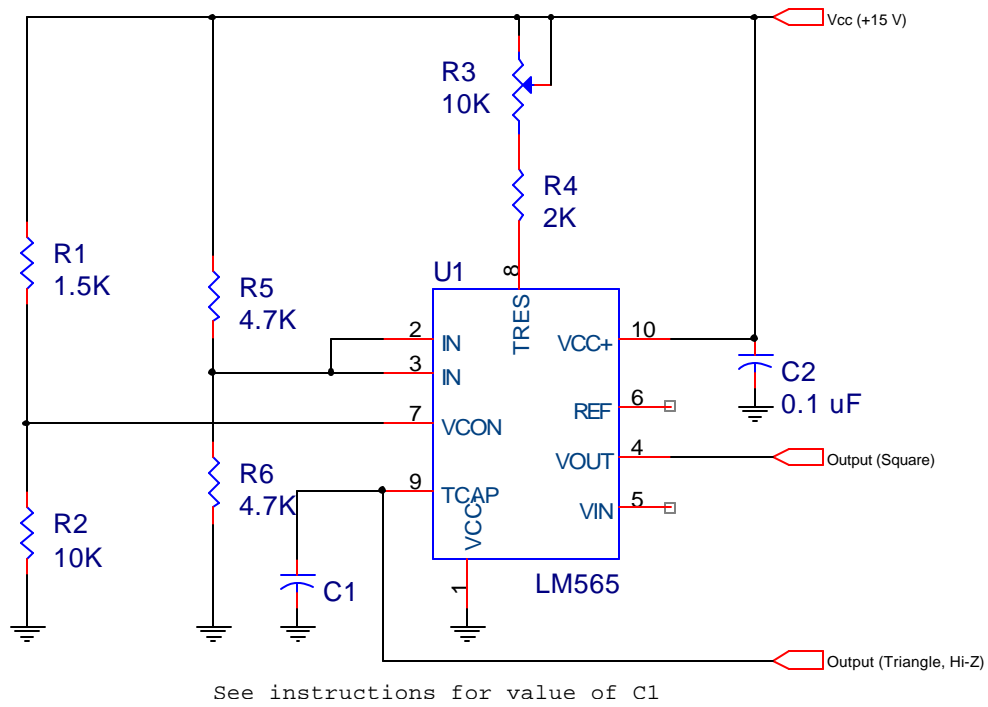
See instructions for value of C1

Figure 1: LM565 VCO with Constant Control Voltage

VCO Control Voltage (Measurement Point)
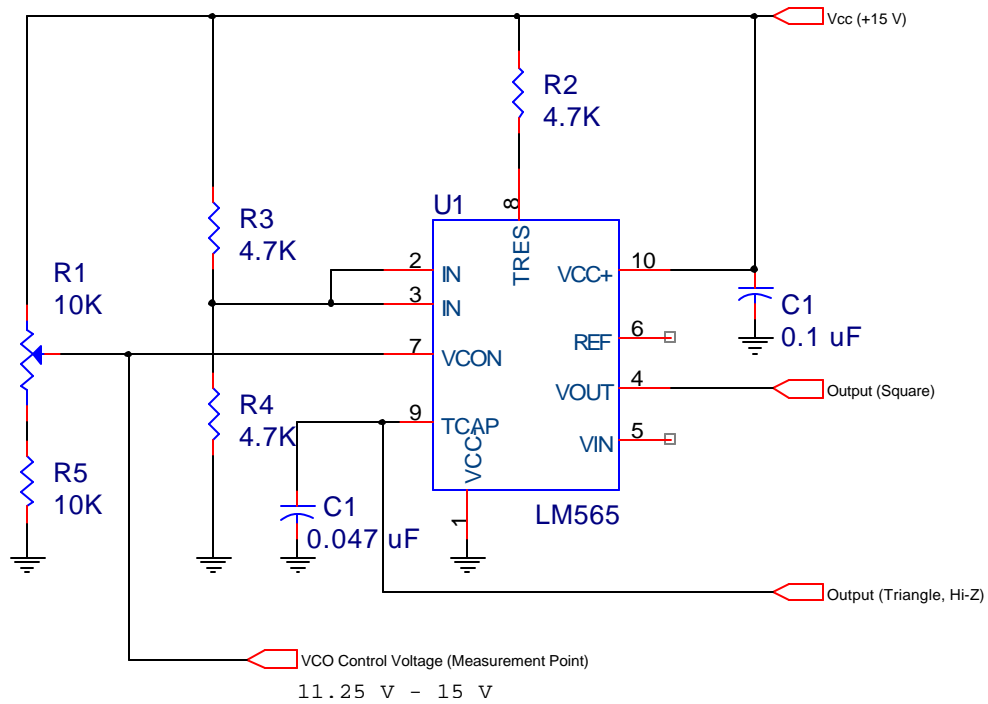
11.25 V - 15 V

Figure 2: LM565 VCO with Variable Control Voltage

LABORATORY PROCEDURE:

Name _____ Sign-off _____

In this experiment, you will verify the three methods of controlling the frequency of the 565 VCO. The frequency can be changed by varying the timing resistor, the timing capacitor, or the input control voltage. You will graph the output frequency -vs- control voltage to see if the VCO output frequency is linearly related to the input frequency.

PART I: EFFECT OF CHANGING R_t and C_t

1. Build VCO circuit #1 of Figure 1. Please take care to adjust the *Vcc* supply accurately (use a DVM to verify its value), or your calculations may not match your measurements.
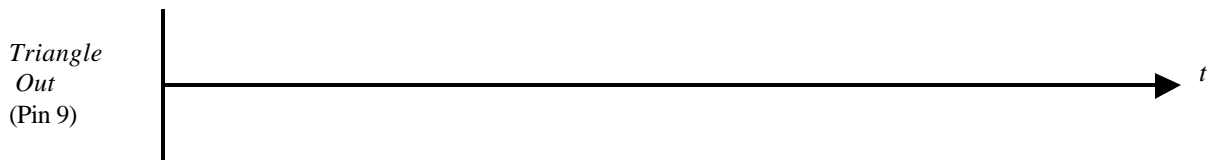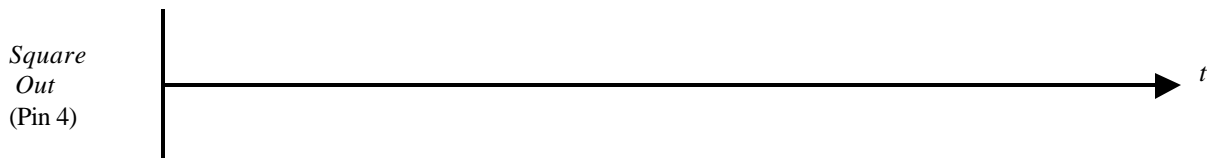
   For the LM565 VCO chip, the output frequency can be CALCULATED as:

$$f_{out} = \frac{2(Vcc - Vc)}{VccRtCt}$$

   Where: Vcc = the supply voltage on pin 10 of the chip;
   Vc = the control voltage on pin 7 of the chip;
   Rt = the value of the timing resistance on pin 8;
   Ct = the value of the timing capacitor on pin 9.

NOTE: Due to the internal design of the LM-565, the control voltage Vc should be in the range 3/4 Vcc to Vcc. For this circuit, that means that Vc must be in the range of 11.25 V to 15 V.

2. Place a .047 μF capacitor in C1's position. Adjust R3 for *maximum* resistance. Power up the circuit and measure the following waveforms with an oscilloscope:

Square
 Out
(Pin 4)   *t*

Triangle
 Out
(Pin 9)   *t*

3. What is the output frequency? Use a frequency counter to measure.

Output frequency: _____

If you got something close to 460 Hz (+/- 25%), great!

4. Let's calculate the theoretical output frequency of the circuit, to see if it agrees with our measurements. What things do we need to know to calculate the output frequency? ... (Ahem...Look back at the formula in step 1!)

Right! We need to know Vcc (15 Volts -- easy, ha!) We also need R_t and C_t; looks pretty straightforward. (Yes, R_t is the combination of R4 and R3 in series). But we didn't give V_c, now did we? Wait a minute...is that a brainstorm over there in back row? Yes, I do believe we can just go out there and measure *Vc (at pin 7 of the LM565)*, now can't we?

What is the measured Vc in your circuit? _____

Is there any other way we could get Vc? Well, R1 and R2 look like a voltage divider to me. I bet that if we work it out, we will find a voltage calculated for pin 7 very close to that voltage we just measured. But of course, for the sake of calculations, we'll just use the value we measured.

Using the formula from step 1, now calculate the theoretical output frequency of the VCO circuit. Show your work, please!

F_{out} - Theory: _____

What is the percentage of error in the measured output frequency of the circuit? (Remember the formula from lab 1?) Show your work.

Percentage of Error: _____

5. Change R3 to its *minimum* value. What will the value of R_t now be? (Don't forget, R_t is R3 and R4 in series.)

R_t value now: _____

Re-measure the output frequency:

Fout:_____

Now calculate the theoretical output frequency again, for the new value of Rt:

Fout- Theory:_____

How did reducing R3 affect the output frequency?

_____

6. By adjusting R3, what are the *maximum* and *minimum* frequencies that can be obtained from the circuit?

   F_{out} (maximum): _____

   F_{out} (minimum): _____

7. Let's see what happens when C1 is changed. Double the value of C1, by adding another .047 uF capacitor in parallel with it.

   What are the new minimum and maximum output frequencies?

   F_{out} (maximum): _____

   F_{out} (minimum): _____

   How did increasing C1 affect the output frequency?

   _____

PART II: CONTROL VOLTAGE EFFECTS

8. Modify your circuit so that it matches Figure 2.

9. What are the minimum and maximum *legal* values for the control voltage, *Vc*? (Assuming that *Vcc*=15V).
   (Conditions given in step 1.)

   Vc (minimum) = _____

   Vc (maximum) = _____

10. Let's build a table with the circuit input and output values. Later we can use the information in the table to plot a graph of the circuit performance.

Control Voltage, Vc	11.25	11.66	12.08	12.5	12.92	13.3	13.75	14.2	14.58	15.0
F_{out} Measured										
F_{out} Calculated (Theory)										

Note: The calculated frequency at the lowest control voltage should be 2.2 KHz. If you don't get this result, carefully check your work before continuing.

11. OK, I can see you saw this coming! Carefully adjust Vc to each value in the table above. Then measure the actual output frequency at that point; then calculate the theoretical output frequency to see how close it matches. (You may wish to use a programmable calculator or spreadsheet program to calculate each theoretical F_{out}.)

12. You get a coffee (or whatever your favorite drink is) break after this. I promise. Take the data from your table in step 10 and neatly plot it on linear graph paper. (You may a computer graphing tool if you desire). The horizontal axis should be labeled with CONTROL VOLTAGE, and the vertical axis should be labeled with OUTPUT FREQUENCY.

Use two different line styles to show *measured* and *calculated* relationships.

QUESTIONS

1. What three factors affect the output frequency of a VCO?

_____

_____

_____

2. How would increasing the capacitance change the frequency of the VCO?

_____

_____

3. If the resistance Rt increases, what will happen to the output frequency
of the VCO?

_____

_____