EE431 Lab 5
Oscillator Circuits

Dec. 27, 2014

The purpose of this lab is to gain experience with sine and rectangular wave oscillators.

The sine wave oscillator you will build has historical significance. It is a modern version of the famous oscillator that Bill Hewlett first built in 1938 as part of a master's thesis project at Stanford University in Palo Alto, California under electrical engineering professor Dr. Frederick Terman who is regarded as the father of Silicon Valley. That oscillator became the model 200A and was the first product of the Hewlett-Packard Company (frequently referred to as HP) which was founded in 1939 and was among the first technology companies in what would later become known as Silicon Valley. HP was an electronic instrument company prior to becoming a dominant computer company. The instrument portion of the business was spun off as Agilent Technologies in 1999 and became Keysight Technologies in 2014.

A classic sine wave oscillator is a feedback circuit that requires that the system poles be exactly on the jw axis – an impossible feat with linear components. Bill's circuit was based on a two-stage, high-gain vacuum tube amplifier that included both positive and negative feedback. The mathematics of the circuit indicates that the system poles are exactly on the jw axis when the positive and negative feedback factors are exactly the same. The poles are in the left-half s-plane if the negative feedback exceeds that of the positive and in the right-half s-plane if the positive feedback exceeds the negative. Bill cleverly made use of the fact that the resistance of a light bulb's filament (tungsten) increases with temperature and thus the voltage across the bulb. By placing the light bulb in the negative feedback path the degree of negative feedback would be a function of the signal output voltage. At power on or low output levels the resistance of the lamp is low and the negative feedback is low thus causing the system poles to be in the right-half s-plane leading to an exponential rise in the output signal. However, as the signal increases the voltage across the lamp increases thus increasing its temperature thus increasing its resistance thus increasing the negative feedback until the stable operating point is attained with the system poles precisely on the jw axis. Oscillators using this remarkably simple concept were sold by HP from 1939 to 1985. In the 1950s the dynamic resistance of a forward biased diode would be used to accomplish the same thing and in the 1960s the variable resistance feature of low-biased field-effect transistors would be used as well.

The circuit you will build for lab is identical to Bill's circuit except that instead of a high-gain vacuum tube amplifier, you will use a high-gain operational amplifier. You should not see any light from the light bulb as it is operated at a low temperature well below the onset of visible radiation. The cold resistance of the type #2185 light bulb (28 V, 40 mA) in your circuit is close to 124 ohms. At the stable operating point of your oscillator circuit the resistance of the light bulb increases to half of the feedback resistance (R3) thus making a nominal non-inverting gain of 3 as required for the Wien Bridge oscillator. The Wien Bridge was a frequency selective network useful for measuring frequency and was owned by the Western Electric Company. Bill used that concept for tuning the oscillator to a desired frequency and added feedback and the lamp to make stable sine waves. The thermal time constant of the filament is significantly longer than a cycle of the frequency your circuit will oscillate at. Thus the lamp resistance is constant even though the signal level is significantly changing over the cyclic period. That is required for the sine wave to not be distorted. By building and exploring this circuit you are reliving a famous period of time in the history of electronic technology that led to a multibillion dollar company.

1.0 Measure lamp resistance versus voltage characteristic. Your lamp is a type 2185 which is specified for 28 volt operation with a current of 40 milliamperes. The operating point for your oscillator will be significantly below that – approximately 7 Vrms. This lamp was chosen because it has higher resistance and is (barely) within the drive capabilities of a typical operational amplifier.

1.1 Build the circuit in Figure 1. Be careful installing the leads of the lamp as they are small and fragile.

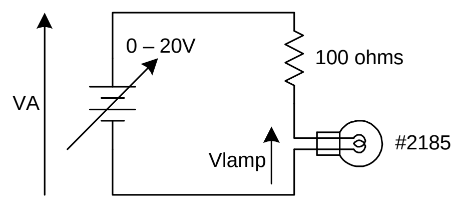

Figure 1: Lamp Test Circuit

1.2 Apply the following nominal values of voltage, VA, and record the actual value of VA and the corresponding value of VL with a resolution of 1 mV. There is no need to fine tweak the power supply to achieve the exact nominal values. The word, nominal, is used to indicate a target value for which precision is not required. Accurate measurement of the actual values is the important thing. Use a nominal VA of 0.2, 0.5, 1.0, 1.2, 1.5, 2, 3, 4, 5, 7, 10, 12, 15, and 20 volts. Note the lowest voltage that results in barely visible light from the lamp.

1.3 Create a table in Excel with the following columns and tabulate your measurements from 1.2 (VA_actual, VLamp, ILamp, RLamp). You will compute ILamp from (VA_actual – VLamp) / R. You will compute RLamp from VLamp / ILamp. For reference, ILamp should be a few milliamperes at low voltages and increase to around 25 milliamperes, give or take, at the highest voltage. RLamp should be around 120 ohms at low voltages and increase to several hundred ohms at the highest voltage.

1.4 Using Excel, create a plot of ILamp versus VLamp (primary Y axis) and RLamp versus VLamp (secondary Y axis) with VLamp on the X axis.

2.0 Oscillator circuit

2.1 Build the circuit in Figure 2. Use R1 = R2 = 4.7K, C1 = C3 = 0.1 uF, and R3 = 390 ohms – this value might have to be adjusted in step 2.2.

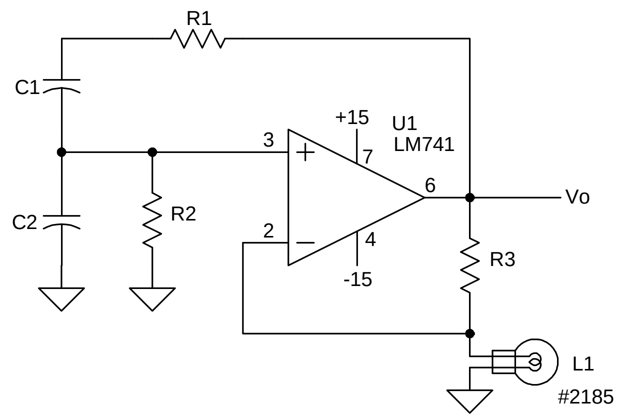

Figure 2: Wien Bridge Oscillator

2.2 Apply power to the circuit and note if the output is a pure sine wave of about 20 volts peak-peak at approximately 340 Hz. Adjust the value of Rf over the range of about 300 to 600 ohms to set the output as close to 20 volts peak-peak as practical. The most common reason if this does not work right is that either C1 or C2 is not the correct value. The output level is proportional in a non-linear way to Rf. Correct any wiring errors if the waveform is distorted or non-existent. As a last resort, try other op-amps as some LM741 amplifiers might not be able to source the peak current required by the lamp. Do not proceed until this step works.

2.3 Measure the frequency of oscillation and compare with the calculated value.

2.4 Measure the output peak-peak amplitude and convert to rms.

2.5 Using your chart from 1.4, what voltage across the lamp would result in a lamp resistance of half the value you used for Rf, i.e. for a non-inverting gain of three? Multiply that voltage by three and compare with your measured rms output voltage in step 2.4. Explain why there should be agreement.

EE431 Lab 5
Oscillator Circuits

3.0 Comparator oscillator (LM555)

3.1 Develop the design equations to determine the two resistor values that will produce a rectangular waveform at a given frequency and with a given percentage of the cycle time the output waveform is a logic ‘1’ using a chosen capacitor. This results in a unique resistor set.

3.2 Use the method of 3.1 to design an oscillator with a frequency of 5 kHz and that the output waveform is a logic ‘1’ 75 percent of the time (a duty cycle of 75%). Choose the capacitor to be 10 nF. Round resistor values to nearest standard.

3.3 Build the circuit of Figure 3 using the results of step 3.2.

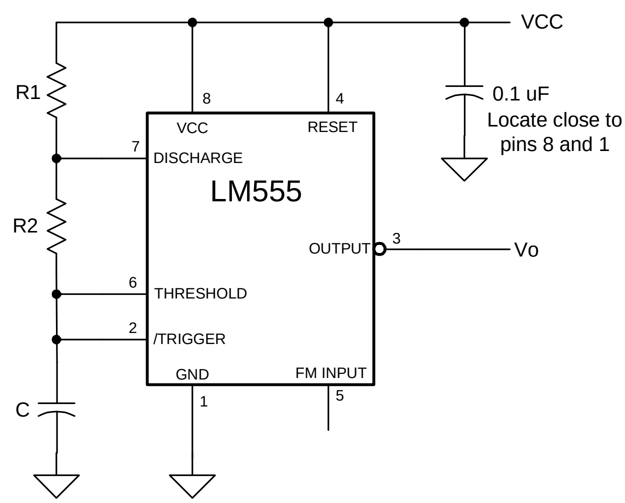

Figure 3: LM555 Oscillator

3.4 Measure the actual output frequency and duty cycle. Compare the results with the design. Small differences are the results of component tolerance. Significant differences are the result of some error. Fix any error before proceeding.

3.5 Revise the design so that the output frequency remains at 5 kHz but the output waveform is a logic ‘1’ 90 percent of the time. Round resistor values to nearest standard.

3.6 Revise the circuit and measure the output frequency and duty cycle. Compare the results with the design. If the comparison is poor then determine and fix whatever is wrong.