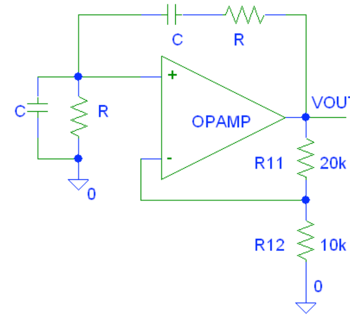
ECE 100 **Lab 5** **Design of an Oscillator** **Fall 2011**

We have given a good deal of thought to preventing circuits from oscillating, but, of course, there are times when you want the circuit to oscillate. Such a circuit is the "Wien-Bridge Oscillator". It has been a popular oscillator in the audio frequency range and is of historical interest because it was the first product developed and sold by the Hewlett-Packard company.

The basic oscillator is sketched to the right. It is based on an amplifier with a voltage gain K = 3, here shown implemented as a follower with gain. The feedback is through the RC network shown where the two R's and the two C's are the same.



1. System Level Design:

Show that the feedback factor $B(s) = sRC/(1 + 3sRC + (sRC)^2)$. The loop gain will be $T(s) = -K\,B(s)$ because the feedback is to the positive input terminal. For this circuit the Nyquist plot is quite useful. You can do it with Matlab as follows:

```
>> s=tf('s');
>> tau = 1e-4;
>> t = -3*s*tau/(1+3*s*tau+(s*tau)^2);
>> nyquist(t)
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You will see a beautiful circular trace that goes right through the –1 point twice, meaning there are two poles on the ω axis. If K > 3 the poles are in the RHP and if K < 3 they are in the LHP. The resonant frequency is $\omega_0 = 1/RC$. To make a real oscillator we need K a bit greater than 3 so the oscillator will start up, but when it reaches the desired amplitude we need to decrease K until it is exactly equal to 3.

2. Circuit Level Simulation:

(a) The effective gain of the amplifier can be reduced by a nonlinearity. For example we can let the amplifier clip at the power-supply voltages. This will limit the amplitude to about ±13v. Try this using an LF411 opamp. Change the 20K resistor to a 15K and 6K in series. This will give you k=3.1. Choose R=10K and C=16nf. This will give you a resonant frequency of 1 Khz.

You will need to run the transient simulation for long enough that the oscillation builds up and saturates at the final amplitude. However if Pspice analyzes the transient in the normal way, by finding the bias point first, the oscillation will never start because no noise spike will occur. To get the oscillation started you will need to skip the initial bias point calculation (in the transient setup menu), and give the amplifier input voltage a non-zero initial condition (say a few mv). You can specify the initial condition (voltage) on the capacitor connected from the input to ground.

Run the transient response for about 100 ms. You should see the oscillation start from nothing and grow to full amplitude in 40 ms or so. Sometimes Pspice will not sample the waveform as finely as you would like. You can see a "step ceiling" in the transient setup menu to prevent this. A ceiling of 10us works well in this case. Make a copy of this for your report. Expand a few cycles of the full amplitude to show the wave shape. You will see that it looks a bit flat on top. Clipping the wave in this way does prevent the oscillation from growing but gives a distorted waveshape.

(b) The performance of oscillators is traditionally judged by the waveshape in the frequency domain. That is we do a Fourier transform and compare the power in the fundamental frequency with the power in the harmonics. This can be done in Pspice using the FFT control. First set the no-print delay in the transient setup menu so the output is constant amplitude (about 30ms). Try this and set the y axis of the FFT to log scale. Measure the amplitude of the 1 Khz spike and also the amplitude of the 3 Khz spike. The ratio of those (in dB) is an important measure of performance.

(c) Allowing the amplifier to saturate at the power supply voltage has a couple of disadvantages. It means that the amplitude depends on the power supply level, and it also means that the amplitude is quite large. We would often prefer a smaller amplitude output to avoid slew rate limiting at high frequencies. We can obtain a smaller amplitude by clipping the voltage across the 6K resistor with back to back diodes. Use the 1N4148 diode. Put one in parallel with the resistor in one polarity and the other also in parallel but with the other polarity. This will prevent the voltage across the resistor from exceeding about 0.7v and thus limit the signal amplitude. What amplitude do you get with this modification? Expand a couple of cycles. Can you see any sign of clipping? Re-measure the power ratio of the 1Khz and 3Khz harmonics (in dB). How much has it changed?

In fact the original HP oscillator used a softer nonlinearity and obtained significantly lower distortion. They used a lamp filament which increases resistance as it is heated. Diodes have a much harder limiting characteristic.

3. Measurement:

Build your oscillator and give it a test. It will start by itself because the circuit noise will be sufficient. Take a screen shot of the waveshape.

What happens if you put the two back to back diodes across the 15K resistor instead of the 6K resistor?

Try increasing the frequency by a factor of 10. Take another screen shot. Can you get it to go still another factor of 10? Note that you should not reduce the resistor R below 1K because it will draw too much current from the opamp. However you can change the capacitance C to compensate. What is the highest frequency? What seems to limit the maximum frequency?

What about lower frequencies? Can you get it down to 1 Hz? What seems to limit the lowest frequency?

Don’t forget to photograph your circuit, and include it with your report.