电子科技大学格拉斯哥学院

Glasgow College, UESTC

Communication Circuits Design – 2018-19, semester II

Lab 3 - Week 9

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Phase-shift oscillators

The objective of this lab is to become familiar with oscillators and Barkhausen criteria for oscillation with reference to a simple design using operational amplifiers and RC feedback networks.

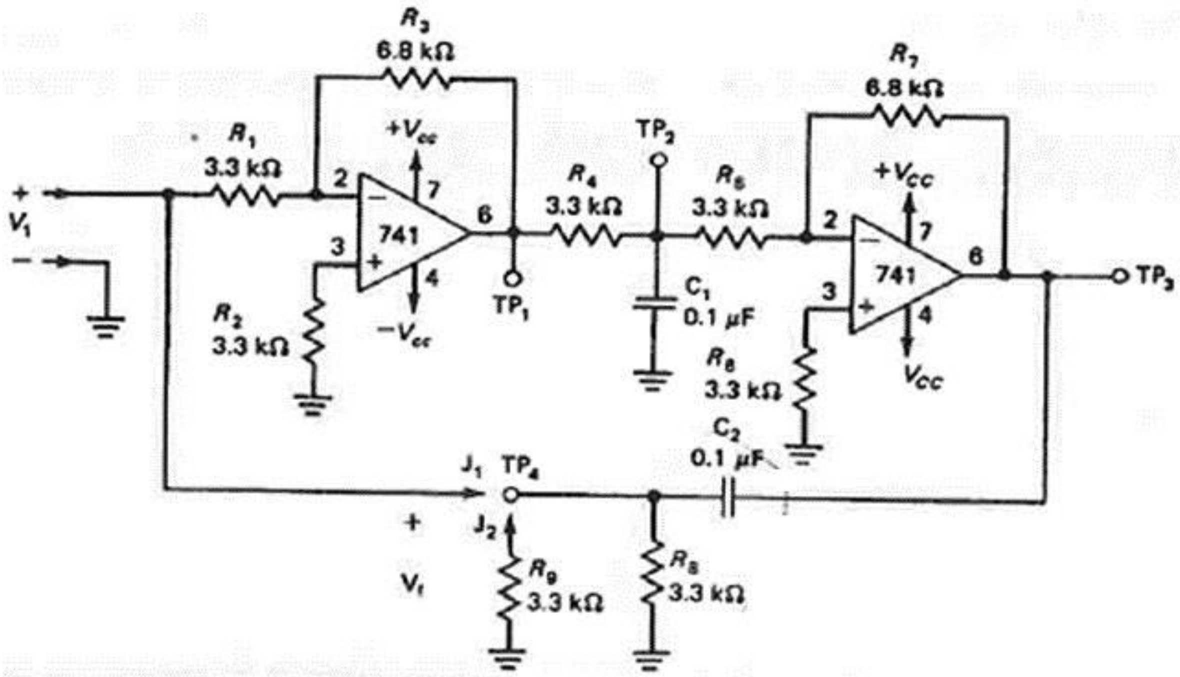
Theory recap.

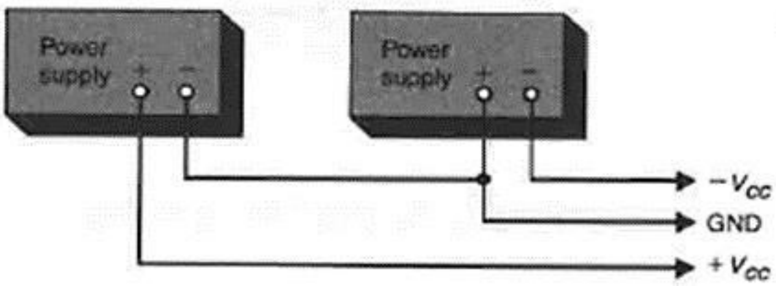
The necessary theory was explained in the second week of the course, where we saw that

- An oscillator is typically modelled by an amplifier section of gain Av and a feedback section of gain β (or a cascade of these sections) forming a loop
- The total gain of the loop has to be such that $|A_v\beta|\geq 1$
- The total phase shift of the loop has to be an integer multiple of 360 degreesThe oscillator can be studied in open-loop to characterise its overall gain and phase shift, as long as the input/output impedances of the amplifier and feedback network are taken into account correctly.

Practical procedure.

1. Build the circuit shown in the figure below. Connect the two channels of the power supply as indicated in the bottom figure to generate +Vcc and –Vcc. Connect the signal generator to be V1. Set the power supply to produce ±12V DC feed for the operational amplifiers.





2. Connect resistor R9 to the output of the phase shift network (C2 and R8) by connecting the wire J2 to the test point TP4. This sets up the oscillator in an open-loop mode, where R9 simulates the load resistance that the first amplifier would place on the feedback network if the amplifier would run in closed-loop.

3. Using a voltmeter perform a DC voltage check at the points TP1 and TP3 to verify that the output voltage levels are at 0V. If there is ±12V, then most likely there is a problem with the amplifier chip, and you may want to replace it (check with a GTA first).

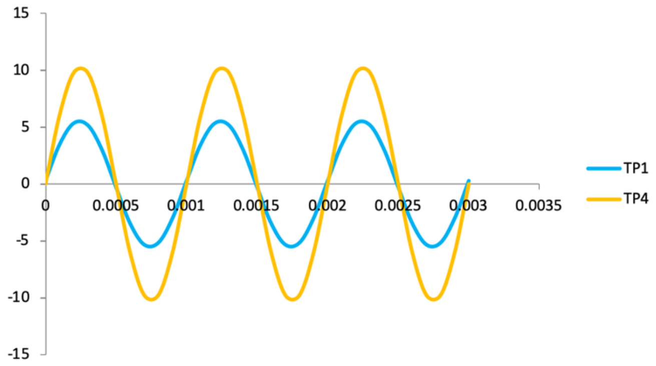
4. Turn on the function generator to produce a 100 mV peak-to-peak sine wave with frequency equal to 1 kHz.
   Measure V1 (input of the open loop) and Vf (output of the open loop) at approximately 10 equally spaced frequency points from 500 Hz to 2 kHz. Also determine the phase difference Φ between the two signals V1 and Vf at each of these frequencies (this will be positive if the output Vf leads the input V1, and negative if the output Vf lags the input V1.
   Use the table below to record the results (ignore the gain column for now); for voltages just refer to the peak to peak value.

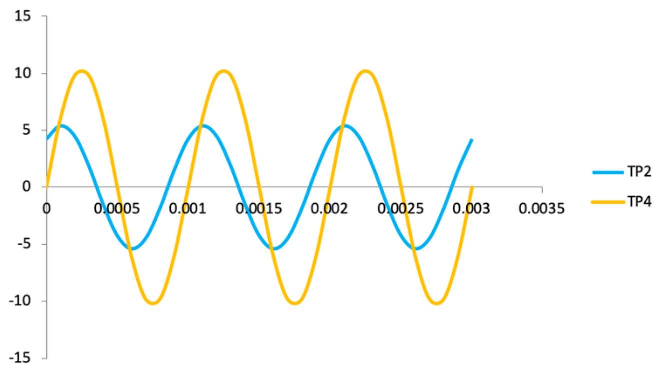
Frequency [Hz]	V1 [V]	Vf [V]	Φ [deg]	Leading or lagging?	Gain
500	101	89	-20.00	lagging	0.88
650	102	95	-11.76	lagging	0.93
800	102	98	-5.88	lagging	0.96
950	102	101	-1.76	lagging	0.99
1100	101	112	1.76	leading	1.11
1250	100	109	7.06	leading	1.09
1400	101	107	8.24	leading	1.06
1550	101	104	12.35	leading	1.03
1700	102	101	14.71	leading	0.99
1850	102	98	17.65	leading	0.96
2000	102	90	20.00	leading	0.88

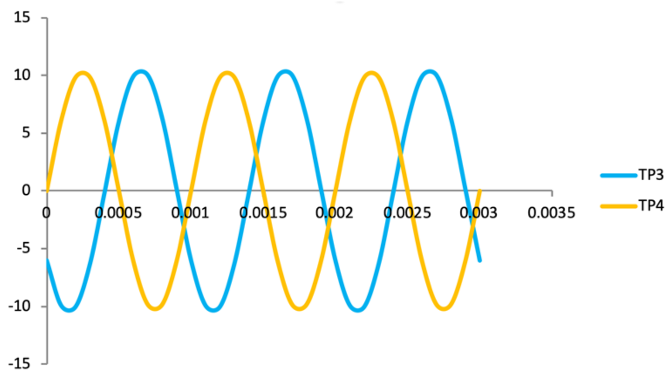
5. Now the oscillator will be tested for proper closed-loop operation. Disconnect the simulated load resistor R9 from TP4 and close the loop by connecting J1 wire to TP4. At this stage you no longer need the signal generator as the whole idea of the closed-loop oscillator is that the internal noise of the system is enough to kick-start the oscillatory behaviour, maintained through the amplification & feedback loop.
   Measure the frequency of the oscillation by connecting the oscilloscope to the output test point TP3 (and then use the built-in functionality to measure frequency).

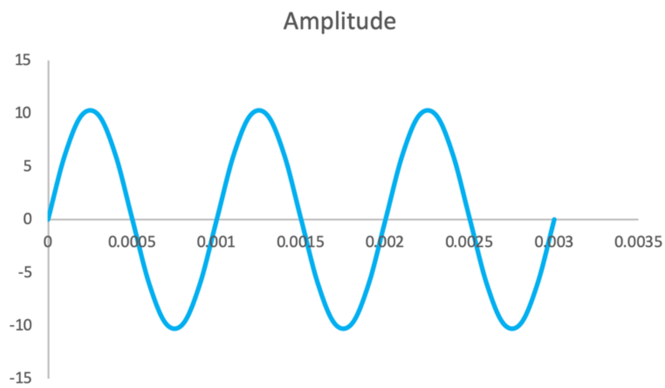
   Oscillation frequency = 987.23 Hz

6. Sketch the resulting waveforms of the voltages at the four test points TP1, TP2, TP3, and TP4. Also note in the sketches the voltage amplitude and the phase, assuming that the voltage TP4 is the phase reference (i.e. it is the zero for any relative phase difference measurements).









TP	Amplitude [V]	Phase[rad]
TP1	5.7	0.0502
TP2	5.6	0.9052
TP3	10.5	-2.5387
TP4	10.3	0

7. Using the data gathered at step 4, calculate the total oscillator loop gain ($|A_v\beta|$) by dividing the open-loop output voltage Vf by the applied input V1. Fill in the gain column of the table at step 4 accordingly.

Frequency [Hz]	V1 [V]	Vf [V]	Φ [deg]	Leading or lagging?	Gain
500	101	89	-20.00	lagging	0.88
650	102	95	-11.76	lagging	0.93
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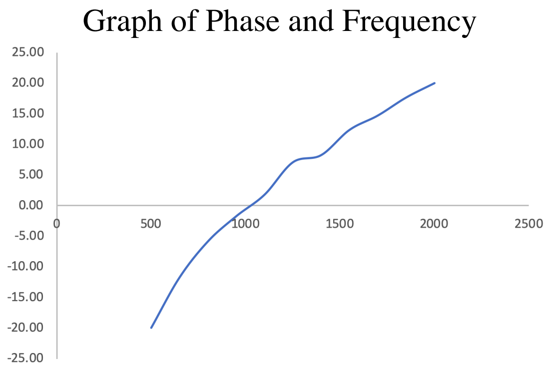
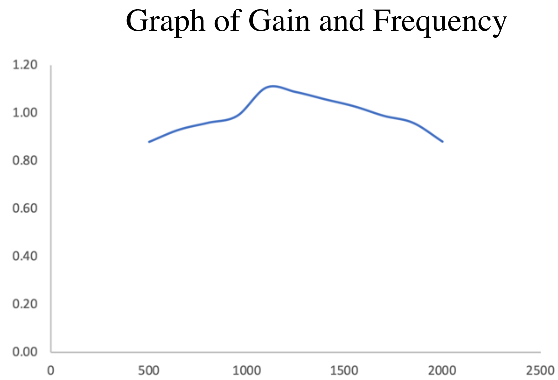
8. Look at the data you gathered in the table. At what frequency does the oscillator loop gain exceed unity? At what frequency does the oscillator loop phase difference between Vf and V1 equal zero degrees? How do these frequencies compare to the frequency of oscillation measured in step 5?





1. At around 990Hz, the oscillator loop gain exceed unity, shown in above graph.
2. At around 960Hz, the oscillator loop phase difference between Vf and V1 equal zero degrees
3. The above frequencies is approximately the same as that of oscillation measured in step .5

9. Final comment. If you look back at the circuit you built, you can see that there are four main blocks between the input V1 and the output Vf as shown below. There are two amplifiers and there are two phase shift networks, one between the first and second amplifier (R4 C1 and R5), and one as feedback loop (C2 R8 and R9). The first network behaves more or less as a RC (low-pass) filter, the second one behaves more or less as a CR (high-pass) filter
   A. If you look at the two amplifiers, what would be their (theoretical) phase shift at the output with respect to the input? Tip: what configuration is each single amplifier?
   B. What would be the phase shift of the two RC/CR networks? You should know this from Circuits Analysis & Design…Tip: within the pass-band of the high/low pass filter, the phase difference is close to zero, but in the stop-band…

So, what can you conclude about the Barkhausen criterion for the phase of the overall loop of this oscillator? Explain in a few words below.

Question A: Under the Barkhausen criteria, the overall loop with 2 amplifier have the phase shift 2π. So Theoretical phase for this loop with only one amplifier is: π

Question B:

The phase shift for the RC network is:

$$H(jw) = \frac{1}{jwRC + 1}$$

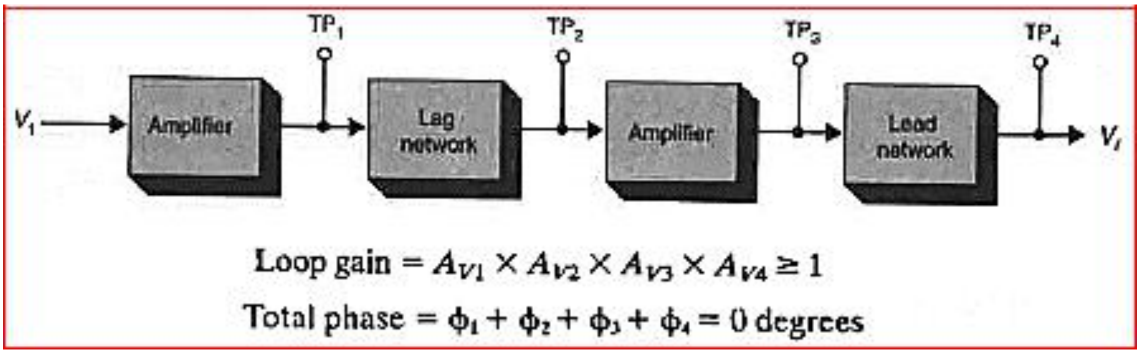
$$\emptyset(H(jw)) = -\arctan(wRC) = -\arctan\left(\frac{R_4 R_5 W C_1}{R_4 + R_5}\right) = -1.10\,rad = -0.35\pi\text{ rad} = -63.03^{\circ}$$

The phase shift for the CR network is:

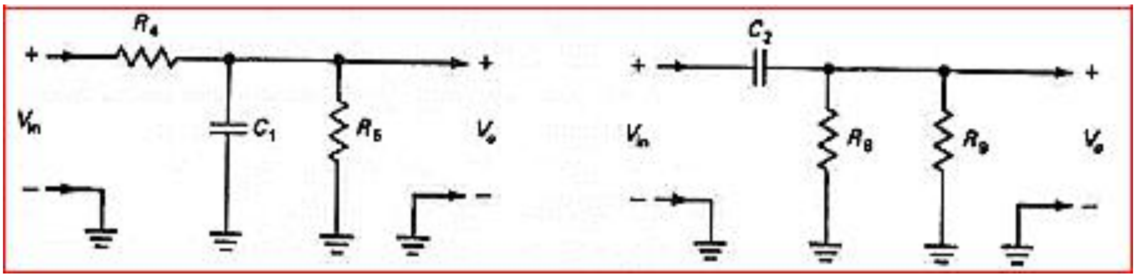
$$H(jw) = \frac{jwRC}{jwRC+1}$$

$$\emptyset(H(jw)) = -\arctan\left(\frac{1}{wRC}\right) = \frac{\pi}{2} - \arctan\left(\frac{R_8 R_9 W C_2}{R_8 + R_9}\right) = 0.47\, rad = 0.15\pi \text{ rad} = 26.93^{o}$$

So we can find the overall phase for this loop is: $2\pi n$ which means the total phase shift around the loop is 0 or integral multiples of 2π



View of the oscillator as a sequence of blocks (amplifier and phase shift blocks)



RC (phase lagging) network on the left-hand side, and CR (phase leading) network on the right-hand side.