Chapter 6

Oscillator Circuits

6.1 Objective

Choose an oscillator circuit, analyze its behaviour (including performing a simulation), build the circuit and determine whether its performance fits what you expect.

6.2 Background

It can be shown that the voltage gain of a feedback amplifier is given by

$$A' = \frac{A}{1 - \beta A} \tag{6.1}$$

where A is the open loop gain of the amplifier. If a circuit is designed using positive feedback, so that

$$A\beta = 1 \tag{6.2}$$

the closed loop gain would be infinite. This condition gives rise to self-sustaining oscillations. Equation 6.2 is called the **Barkhausen criterion**, and is met when the overall phase shift of the feedback is 360°.

6.2.1 Transistor Oscillators

Phase Shift Oscillator

Figure 6.1 shows the circuit for a phase shift oscillator, in which the feedback circuit employs three cascaded RC sections to shift the phase by 180°. An

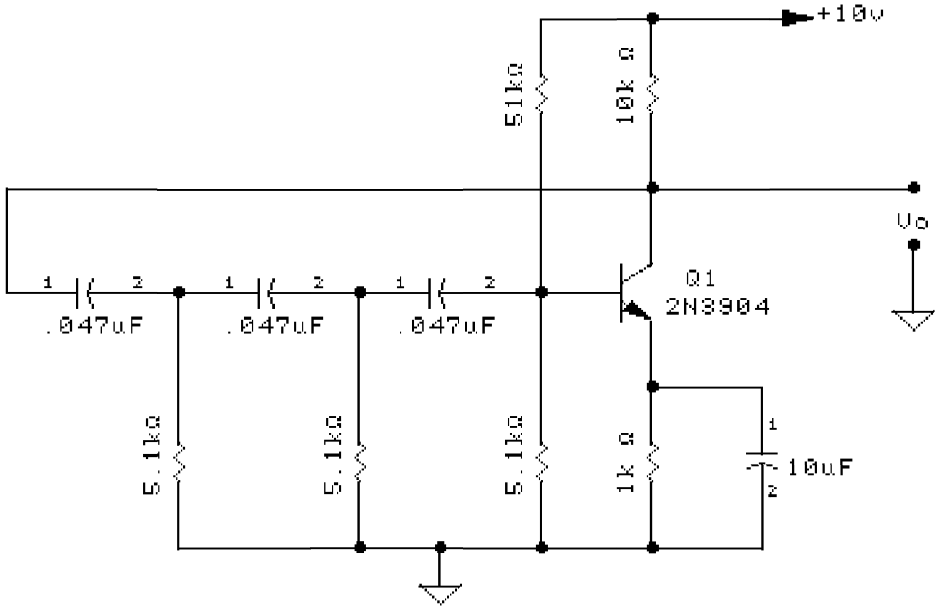

Figure 6.1: Phase Shift Oscillator

additional shift of 180° is obtained by taking the feedback from the collector of the transistor. Ignoring loading effects, β can be calculated over the feedback network, and is given by:

$$\beta = \frac{V_i}{V_o} = \frac{1}{1 - 5/(\omega RC)^2 + j(1/(\omega RC)^3 - 6/\omega RC)} \tag{6.3}$$

For a phase shift of 180°, the imaginary part is zero, which leads to

$$\omega_0 = \frac{1}{\sqrt{6}RC} \tag{6.4}$$

Then

$$\beta = -\frac{1}{29}$$

and the gain required by the Barkhausen criterion is

$$A = \frac{1}{\beta} = -29$$

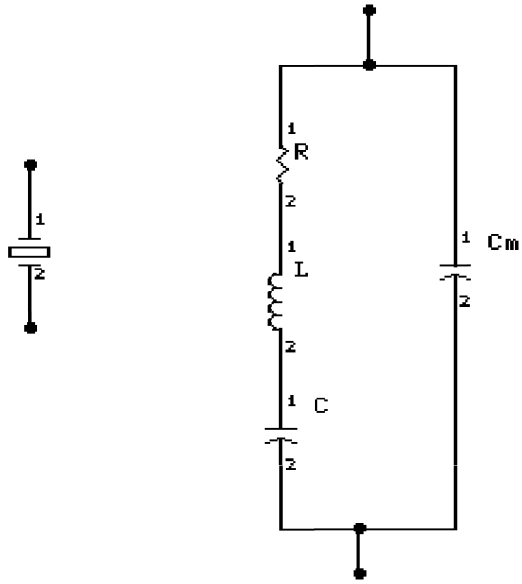

Figure 6.2: Crystal Equivalent Circuit

Crystal Oscillator

You can see that the previous circuit lacks precision. Another way to design an oscillator is to set up a resonant circuit in the feedback network. In order to increase the precision, the **quality factor**, Q, of the resonant circuit must be large.

High Q factors can be achieved by using a piezo-electric crystal, usually made of quartz. Piezo-electric means that when the crystal is put under mechanical stress across its faces, a potential difference will be developed between the opposite faces. Conversely, if a potential difference is applied between the faces, the crystal will distort. Most crystalline materials will vibrate at a natural resonant frequency. If we apply an AC voltage to the quartz crystal, it will resonate and produce an electrical resonance that can be amplified. Figure 6.2 shows the symbol and the electrical equivalent of a crystal. Crystal losses, represented by R, are small and therefore Q is large — on the order of 20,000 and higher. Note that the circuit equivalent shows that the crystal has series and parallel resonance.

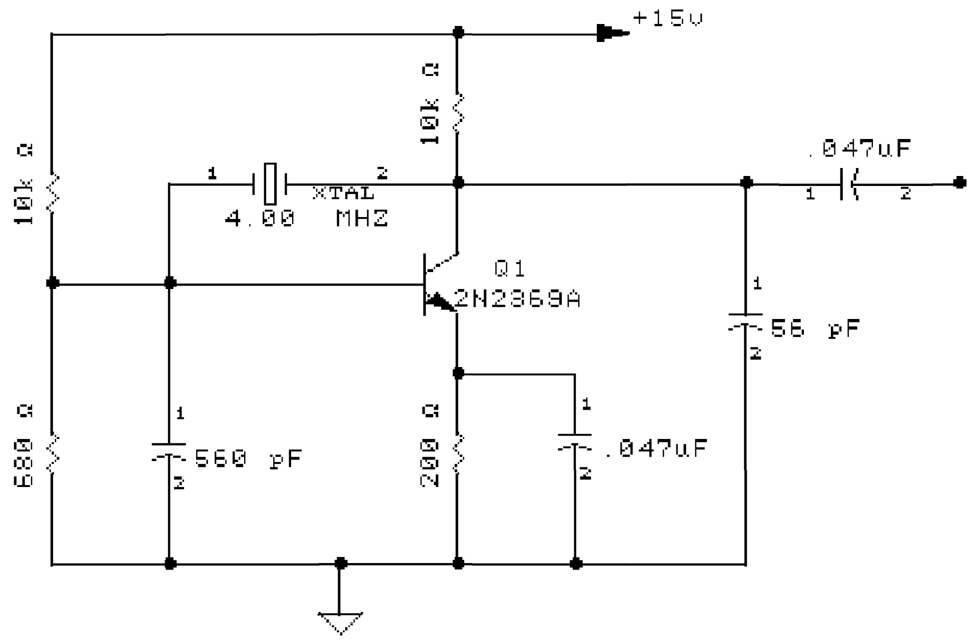

Figure 6.3: Crystal Oscillator Circuit

6.2.2 Operational Amplifier Oscillators

Since operational amplifiers have almost infinite gain and infinite input impedance, they are ideal for use in oscillator circuits. Since the open loop gain A is almost infinite, Equation 6.1 reduces to

$$A' = -\frac{1}{\beta} \tag{6.5}$$

Therefore, if we use two feedback networks, where A' sets the gain to $-1/\beta$, the condition for oscillation is met.

Phase Shift Oscillator

Figure 6.4 shows the circuit for a phase shift oscillator, using an op amp instead of a transistor. Note the similarity to the corresponding transistor oscillator.

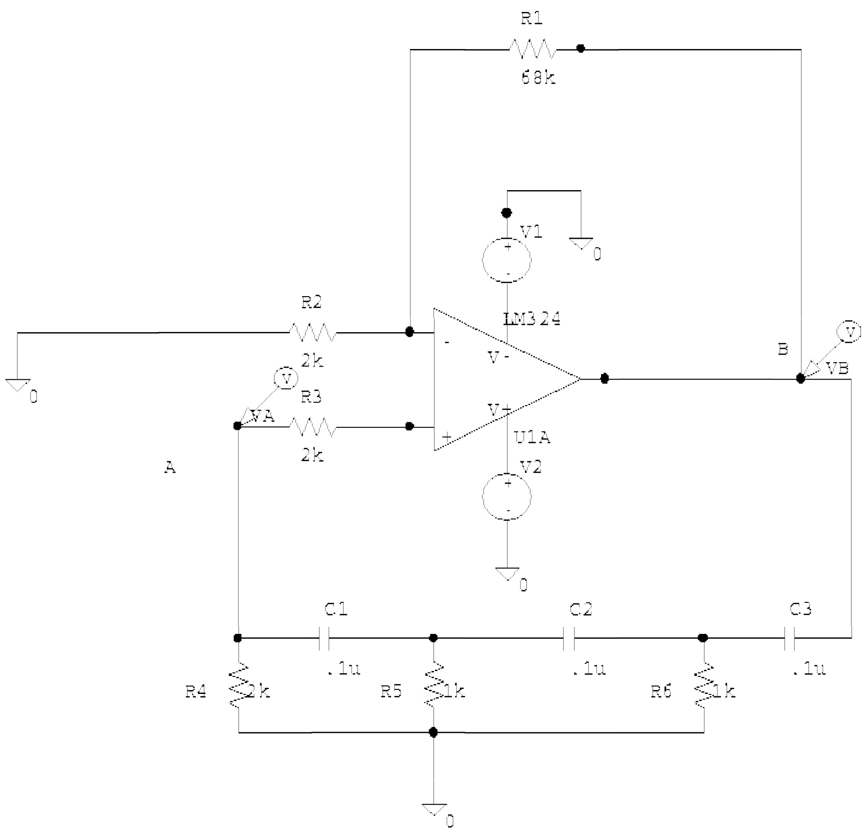

Figure 6.4: Operational Amplifier Phase Shift Oscillator

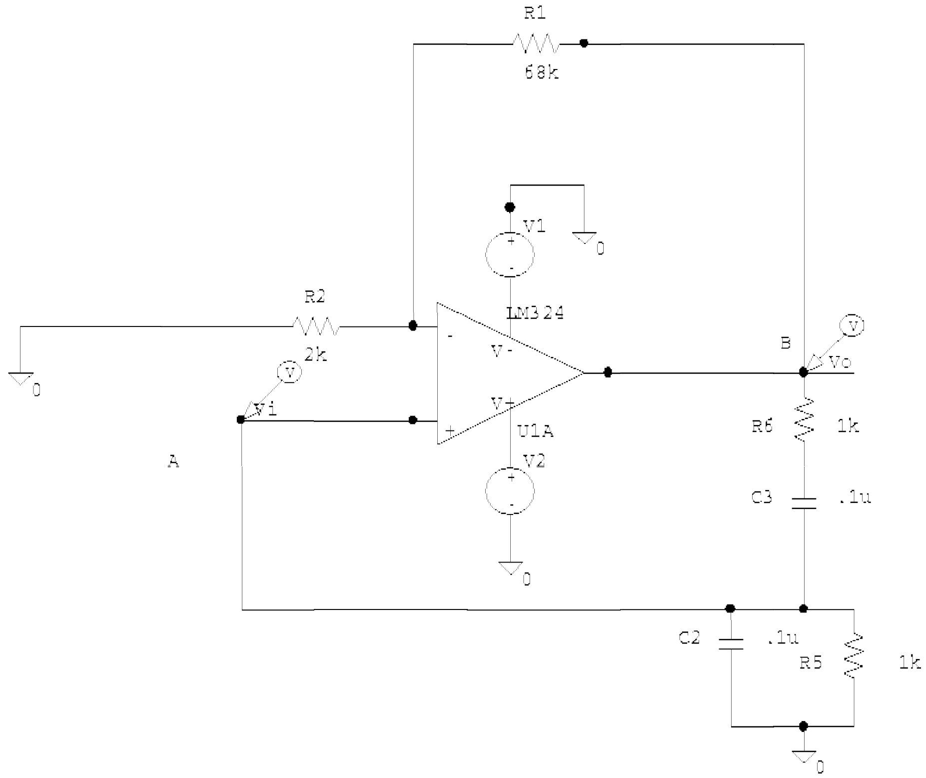

Figure 6.5: Operational Amplifier Wein Bridge Oscillator

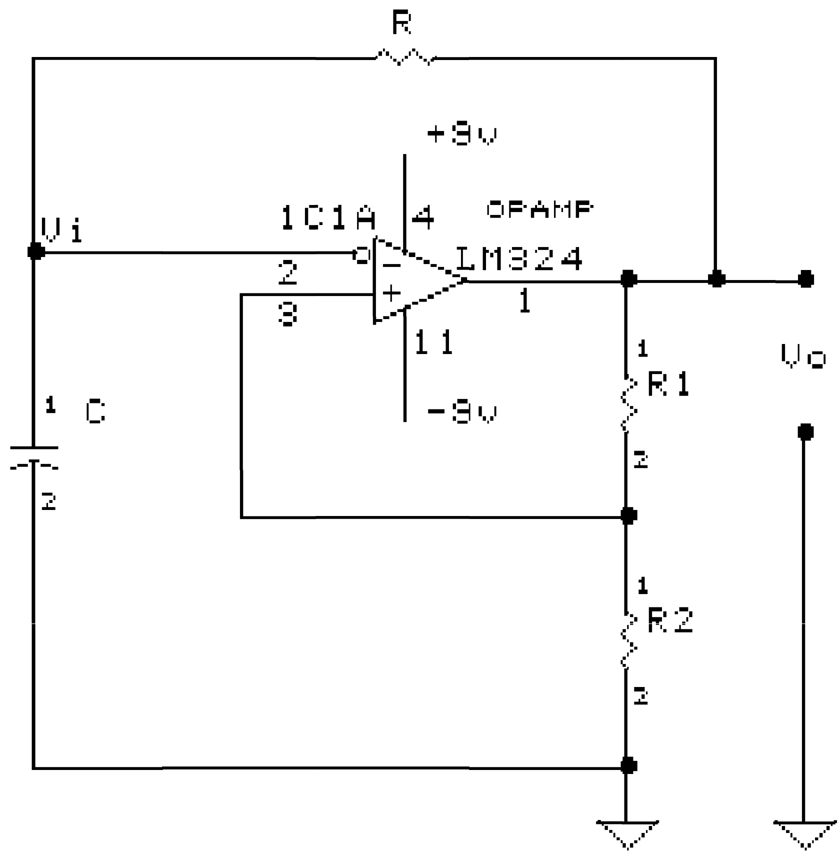

Figure 6.6: Square Wave Oscillator

The Wein Bridge Oscillator

With reference to Figure 6.5, at a frequency of

$$f_0 = \frac{1}{2\pi RC} \tag{6.6}$$

the feedback ratio is

$$\beta = \frac{V_i}{V_o} = \frac{1}{3} \tag{6.7}$$

where V_i and V_o are the voltages at the input and output of the feedback network, respectively. In order to obtain a loop gain greater than unity, the magnitude of the gain A' must be greater than 3.

The Square Wave Generator

A square wave generator is shown in Figure 6.6. The feedback factor associated with the circuit is

$$\beta = \frac{R_2}{R_1 + R_2} \tag{6.8}$$

The output saturation levels of the op-amp, $V_{0_{\mathrm{sat}}}^{+}$ and $V_{0_{\mathrm{sat}}}^{-}$, are given in the op amp manufacturer's data sheet. The duration t_1 for which the output remains at $V_{0_{\mathrm{sat}}}^{+}$ is given by

$$t_1 = RC \ln \left(\frac{V_{0_{\mathrm{sat}}}^{+} - \beta V_{0_{\mathrm{sat}}}^{-}}{V_{0_{\mathrm{sat}}}^{+}(1-\beta)} \right) \tag{6.9}$$

and the duration t_2 for which the output remains at $V_{0_{\mathrm{sat}}}^{-}$ is

$$t_2 = RC \ln \left(\frac{V_{0_{\mathrm{sat}}}^{-} - \beta V_{0_{\mathrm{sat}}}^{+}}{V_{0_{\mathrm{sat}}}^{-}(1-\beta)} \right) \tag{6.10}$$

If $C = 0.1\mu$F and $R = 10$KΩ, calculate t_1, t_2 and the output frequency for $\beta = 0.5$.

6.2.3 Digital Oscillators

Crystal Oscillator

Many computer systems use TTL oscillators to generate required clock pulses. The circuit shown in Figure 6.7 oscillates at a frequency determined by the crystal, which can have a value between 4MHz and 20MHz.

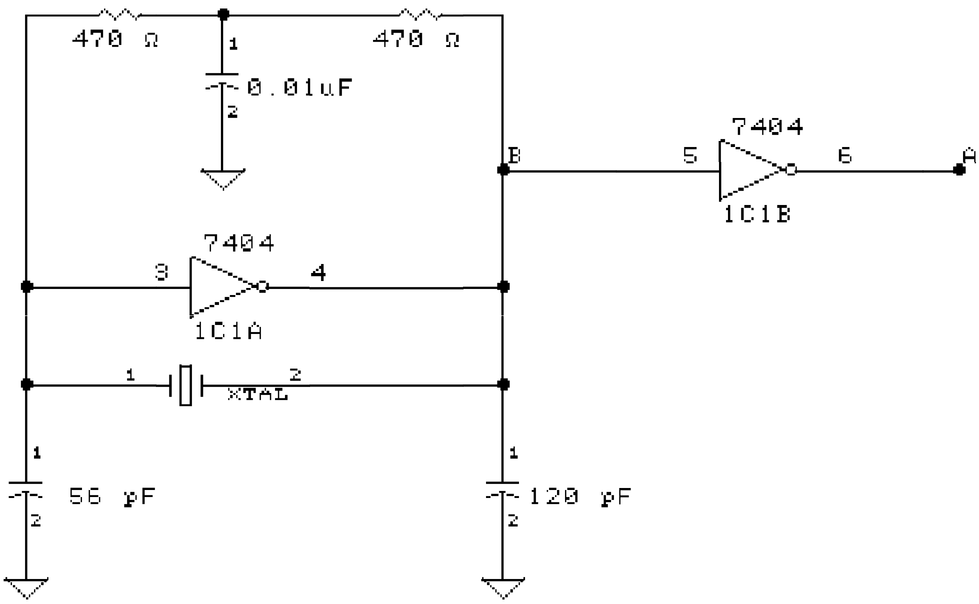

Figure 6.7: TTL Oscillator