# Unit 53 Sinusoidal oscillators

- Sinusoidal voltage waveforms are obtained by using an amplifier
  - with positive feedback,
  - with a loop gain of 1 and
  - with a frequency selective feedback network.

Consider the amplifier shown in Figure 53.1. A sinusoidal signal which is applied to the input is phase shifted and attenuated in each of the three $CR$ filters. Assume for simplicity that the three filters are noninteracting; that is, that we can calculate the effect of each filter without having to allow for loading effects of the other filters. Also select the transistor bias so that the input resistance of the transistor amplifier is equal to the value of the resistors used in the $CR$ stages of the filters.

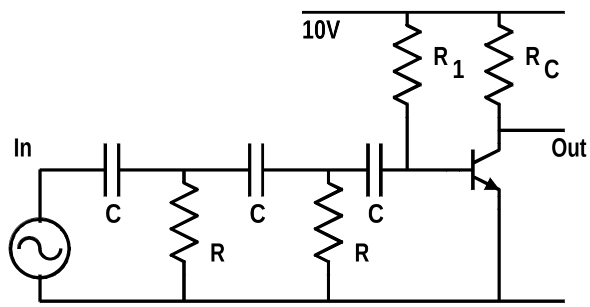


Figure 53.1: Phase shift network and amplifier.

The phase shift in a single $CR$ stage is given by:

$$\phi_1 = \tan^{-1}\left(\frac{1}{2\pi f C R}\right)$$

The phase shift between the input and the base of the transistor is $3\phi_1$ and the value of $\phi_1$ is between 0° and 90°. The transistor amplifier inverts the signal as well as amplifying the signal. Inversion corresponds to a phase shift of 180°. Therefore the total phase shift from the input to the amplifier to the output is $\phi_{total} = 3\phi_1 + 180°$. The output will then be in phase with the input but shifted by one period when $\phi_1 = 60°$, that is for a frequency $f_0 = \frac{1}{2\sqrt{3}\pi CR}$. (See Unit 13.)

Now remove the signal generator from the input and loop the output back to the input as shown in Figure 53.2.

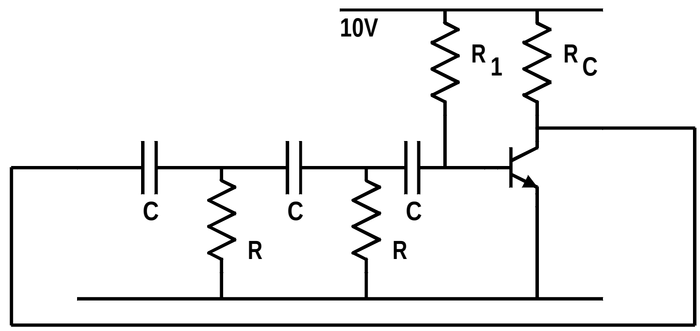


Figure 53.2: Phase shift oscillator.

If the loop gain is greater than 1, that is if the gain of the transistor amplifier more than compensates for the attenuation in the three $CR$ filters, then any very small signal (noise) in the circuit at frequency $f_0 = \frac{1}{2\sqrt{3}\pi CR}$ will be amplified and phase shifted by 360° as it propagates around the loop with the result that the amplitude of a signal at frequency $f_0$ will grow with each loop traversal and the circuit will break into oscillation at frequency $f_0$. The amplitudes of the oscillations grow until they are limited by the power supply voltage. Since the only frequency satisfying the condition is $f_0 = \frac{1}{2\sqrt{3}\pi CR}$ we then have a sinusoidal function generator.

Here we have employed positive feedback to cause the circuit to go into oscillation. When the internal construction of a 741 op-amp was discussed in Units 35 and 49, it was pointed out that the capacitor included in the op-amp gave stability. The function of the internal capacitor in the 741 op-amp is to form a filter and prevent the phase shift ever reaching 180° and therefore prevent the 741 op-amp from going into unwanted oscillation due to positive feedback resulting from stray external capacitances coupling signal from the output back to the input.

If the circuit shown in Figure 53.2 is constructed and the output waveform is examined with an oscilloscope it will be found that the waveform is distorted from a sinusoidal waveform as is shown in Figure 53.3.

The reason for this distortion is that the transistor amplifier ceases to be fully linear when large signals are present. The solution to this nonlinearity distortion problem is to introduce a feedback mechanism which reduces the gain of the amplifier if the output amplitude becomes too large. This is called amplitude stabilization.

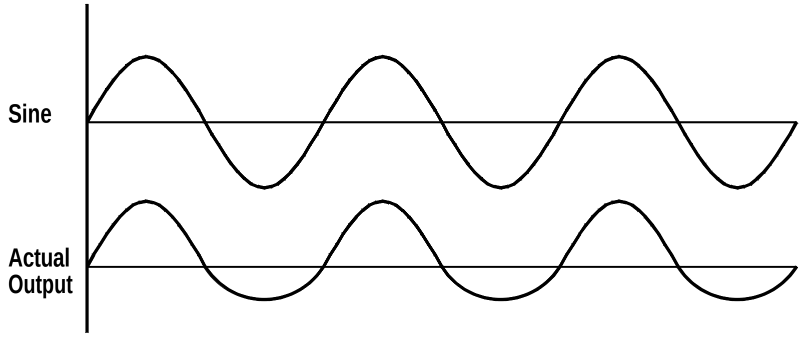


Figure 53.3: Distortion due to saturation nonlinearity.

In order to implement amplitude stabilization we need a device whose resistance changes smoothly as the current in the device increases. The simplest and cheapest such device is a small, low wattage filament bulb such as a T1-3 mm, 5 V, 50 mA bulb. When the current through the bulb increases, the filament heats up and the resistance of the filament also increases to $R_B = \frac{5\,\mathrm{V}}{50\,\mathrm{mA}} = 100\,\Omega$ when the bulb is at operating voltage. When the bulb is cold the resistance is typically about $9\,\Omega$. The thermal capacity of the filament is such that its resistance remains at the higher value from one half cycle to the next for frequencies above about 10 Hz.

Consider the operation of the potential divider circuit at the output of the circuit in Figure 53.4.

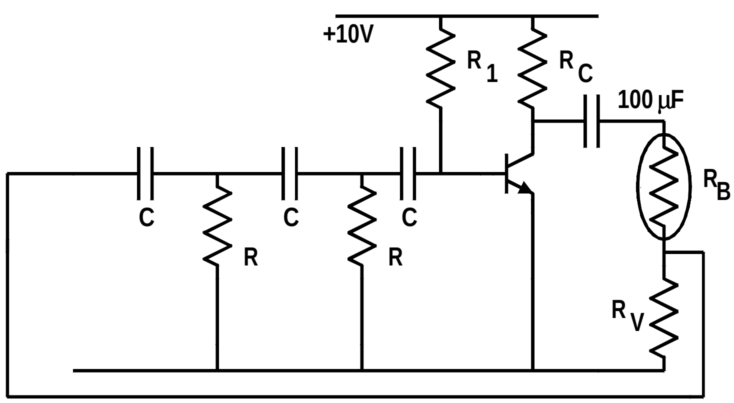


Figure 53.4: Amplitude stabilization by control of feedback.

The potential divider comprising the bulb, which has a resistance $R_B$, and $R_V$ allows a fraction of the output sinusoidal signal given by $\frac{R_V}{R_B+R_V}$ to be fed back. $R_V$ is adjusted so that the oscillator just oscillates with a clean sinusoidal waveform. If the oscillation amplitude grows then the voltage across the potential divider increases, the bulb heats owing to the increased current through the bulb and the resistance of the bulb $R_B$ increases so that the positive feedback fraction given by $\frac{R_V}{R_B+R_V}$ decreases tending to reduce the amplitude of oscillation. The amplitude of the oscillation is thus regulated at one stable value which can be chosen to keep the amplifier operating in the linear region and keep a sinusoidal output waveform.

The same principles of positive feedback and amplitude stabilization can be employed in a Wein bridge oscillator which has a more readily adjustable frequency of operation and is therefore more suitable for use as a laboratory sinusoidal signal generator.

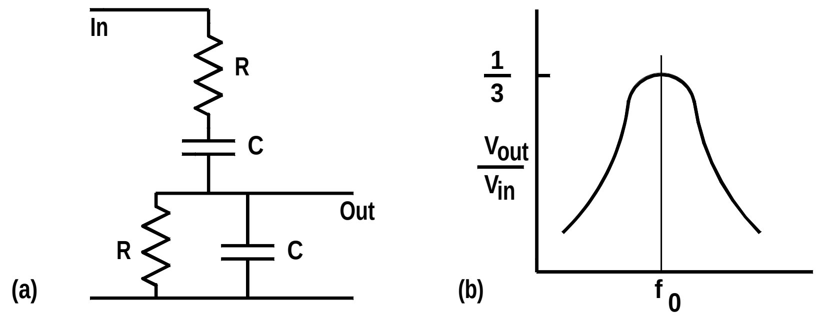


Figure 53.5: Wein bridge and response.

First consider a Wein bridge as shown in Figure 53.5 (a). This is a band pass filter which has a response curve as shown in Figure 53.5 (b). The frequency at the peak of the pass band is $f_0 = \frac{1}{2\pi RC}$.

In order to construct an oscillator we require that the loop gain be greater than 1. The attenuation at the peak of the Wein bridge response is $\frac{1}{3}$ and therefore the gain of the amplifier must be at least 3 for oscillation to take place or more than 3 when amplitude stabilization is employed.

The circuit in Figure 53.6 shows how the op-amp is set up with a Wein bridge. The output from the op-amp is fed back through the bridge with the output of the bridge going to the noninverting positive feedback input to the op-amp in order to give oscillation. The resistor, $R_1$, and the bulb resistor initially give very small amounts of negative feedback which allows the oscillator to start oscillating. The bulb resistance at this time is low because there is no current through the bulb at the start.

As the oscillation grows, the bulb heats up and the fraction of the output that is fed back to the inverting input or negative feedback input to the op-amp increases until an amplitude of oscillation is reached when the bulb is at a temperature which gives a loop gain of 1 and a clean sinusoidal signal is obtained at the output. The loop gain is less than 1 at other frequencies

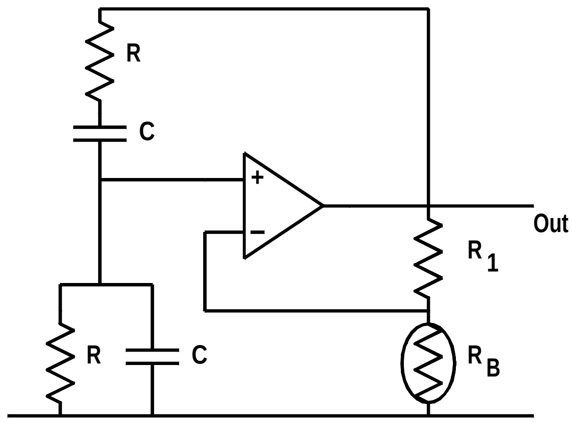


Figure 53.6: Wein bridge oscillator.

and therefore other Fourier components will not be present in the waveform thus giving a pure sinusoidal waveform.

Continuous frequency control by a factor of 10 is obtained by using a twin ganged potentiometer for the two Wein bridge resistors. Decade changes of frequency are obtained by switching in pairs of capacitors with a multiple pole switch. A potentiometer on the output allows the output voltage amplitude from the unit to be varied from 0 V to about 10 V.

## 53.1 Examples

53.1 Design a transistor phase shift oscillator for a fixed frequency of 300 Hz.

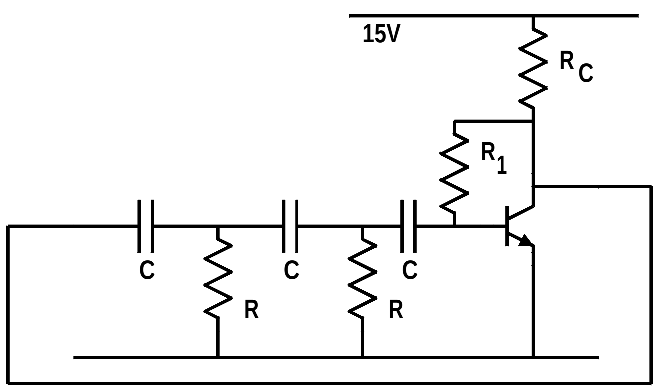


Figure 53.7: Example 53.1.

A suitable circuit is shown in Figure 53.7.

First set up the DC bias for the transistor. A reasonable value for a typical BC109 ($\beta = 300$) transistor amplifier would be $R_C = 4.7\,\mathrm{k}\Omega$.

We then require $V_C \approx 9\,\text{V}$ so:

$$I_C = \frac{15 - 9}{4700} = 1.28\,\text{mA}$$

$$\text{Then} \quad I_B = \frac{0.00128}{300} = 4.2\,\mu\text{A}$$

$$\text{which gives} \quad R_B = \frac{9\,\text{V} - 0.7\,\text{V}}{4.2\,\mu\text{A}} = 1.9\,\text{M}\Omega$$

Given $f_0 = 300\,\text{Hz}$ then:

$$300 \times 2\pi \times \sqrt{3}CR = 1$$

If we take $C = 0.1\,\mu\text{F}$ we get $R = 3064\,\Omega$.

53.2 Design a Wein bridge oscillator for a fixed frequency of oscillation of 2000 Hz using the circuit in Figure 53.6.

The essential equation is $f_0 = \frac{1}{2\pi CR}$.

Assume a reasonable value $C = 0.1\,\mu\text{F}$, which gives $R = \frac{1}{2\pi f_0 C} = 796\,\Omega$.

Determine the value of $R_B$ and then choose $R_1$ to get a loop gain of 1; that is, set the gain to at least:

$$A_V = 1 + \frac{R_1}{R_B} = 3$$

## 53.2 Problems

53.1 Show that the phase shift $\phi = 60°$ in a $CR$ circuit when $\sqrt{3} = \frac{1}{2\pi fCR}$.

53.2 Sketch the voltage waveforms, showing the amplitude and phase, which you would expect to observe at the top of each of the resistors in the feedback $CR$ network and at the base of the transistor in Figure 53.7.

53.3 Show that the centre of the band pass of the Wein filter in Figure 53.5 (a) is at a frequency $f_0 = \frac{1}{2\pi RC}$. Also show that the attenuation at this frequency is $\frac{1}{3}$ or $-9.5\,\text{dB}$. (Review Problem 15.8.)

53.4 Design a transistor phase shift oscillator for a fixed frequency of 1500 Hz.

53.5 Design a Wein bridge oscillator for a fixed frequency of 700 Hz. Justify your choice of component values.

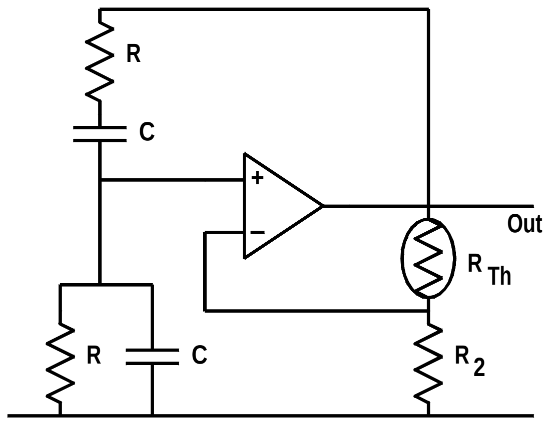


Figure 53.8: Problem 53.6.

53.6 Design a Wein bridge oscillator for a fixed frequency of oscillation of 1300 Hz using the circuit in Figure 53.8. Note that the type RA53 thermistor, $R_{Th}$, has a resistance of 5 kΩ at 20°C decreasing to 80 Ω at about 90°C.

53.7 The gain or sensitivity of the controller in a control loop, such as that shown in Figure 41.2, is gradually increased until the control loop oscillates with a periodic time, $T$. By how much does the gain of the controller have to be reduced so that the amplitudes of successive peaks resulting from a process disturbance are in the ratio of 4:1? What is the shortest time in which such a control loop can correct for a sudden disturbance?

53.8 In the circuit shown in Figure 53.9, the collector load is a resonant $LC$ circuit. Calculate the frequency at which the gain will be a maximum. The secondary winding couples a fraction of the output signal back to the base. Under what circumstances will positive feedback occur? What will be the frequency of oscillation of the circuit? Under what circumstances will the output waveform be sinusoidal?

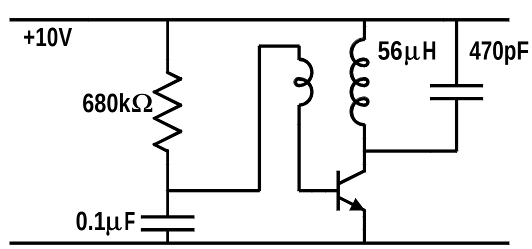


Figure 53.9: Problem 53.8.