National Aviation University

Department of Electronics, Robotics, Monitoring and IoT Technologies

Course: “Analog and Digital Instrumentation”

Experiment 3

“Phase Shift RC Oscillator”

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OBJECTIVES

1. To study phase shift in RC circuits.
2. To study RC phase shift oscillator based on inverting op-amp.
3. To implement RC phase shift oscillator using solderless breadboard and discrete electronic components.
3. To simulate RC phase shift oscillator based on inverting op-amp using MULTISIM software.

THEORY

RC phase shift oscillator is a sinusoidal oscillator used to produce sustained well shaped sine wave oscillations. It is used for different applications such as local oscillator for synchronous receivers, musical instruments, study purposes etc. The main part of an RC phase shift oscillator is an op amp inverting amplifier with its output fed back into its input using a regenerative feedback RC filter network, hence the name RC phase shift oscillator.

In an RC oscillator circuit the input is shifted 180° through the amplifier stage and 180° again through a second inverting stage giving us “180° + 180° = 360°” of phase shift which is effectively the same as 0° thereby giving us the required positive feedback. In other words, the phase shift of the feedback loop should be “0”.

In a Resistance-Capacitance oscillator or simply an RC oscillator, we make use of the fact that a phase shift occurs between the input to a RC network and the output from the same network by using RC elements in the feedback branch, as shown in Fig. 1.

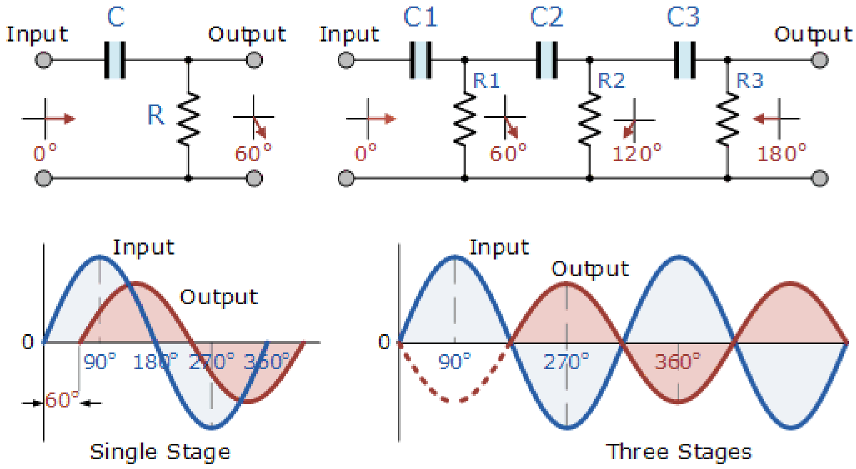


Fig. 1. Phase shift in RC circuits

The circuit on the left shows a single Resistor-Capacitor Network whose output voltage "leads" the input voltage by some angle less than 90°. An ideal single-pole RC circuit would produce a phase shift of exactly 90°, and because 180° of phase shift is required for oscillation, at least two single-poles must be used in an RC oscillator design.

However in reality it is difficult to obtain exactly 90° of phase shift so more stages are used. The amount of actual phase shift in the circuit depends upon the values of the resistor and the capacitor, and the chosen frequency of oscillations with the phase angle (Φ) being given as:

$$X_C = \frac{1}{2\pi fC},\ Z = \sqrt{R^2 + (X_C)^2},\ \Phi = \tan^{-1}\left(\frac{X_C}{R}\right)$$

In our simple example above, the values of R and C have been chosen so that at the required frequency the output voltage leads the input voltage by an angle of about 60°. Then the phase angle between each successive RC section increases by another 60° giving a phase difference between the input and output of 180° (3 x 60°) as shown by the following vector diagram.

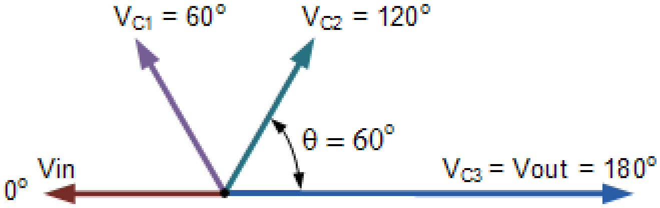


Fig. 2. Vector diagram

Then by connecting together three such RC networks in series we can produce a total phase shift in the circuit of 180° at the chosen frequency and this forms the bases of a "phase shift oscillator" otherwise known as a RC oscillator circuit.

We know that in an amplifier circuit either using a **bipolar transistor** or an **operational amplifier**, it will produce a phase-shift of 180° between its input and output. If a three-stage RC phase-shift network is connected between this input and output of the amplifier, the total phase shift necessary for regenerative feedback will become 3 x 60° + 180° = 360° as shown in Fig. 3.

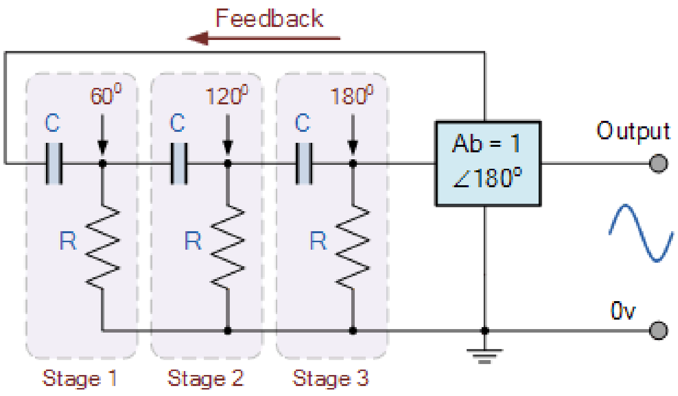


Fig. 3. Schematic diagram of RC phase shift oscillator

The three RC stages are cascaded together to get the required slope for a stable oscillation frequency. The feedback loop phase shift is -180^o when the phase shift of each stage is -60^o. This occurs when $\omega = 2\pi f = 1.732/RC$ as (tan 60^o = 1.732). Then to achieve the required phase shift in an RC oscillator circuit is to use multiple RC phase-shifting networks such as the circuit in Fig. 4.

The op amp is connected as inverting amplifier hence the total phase shift around the loop will be 360 degrees.

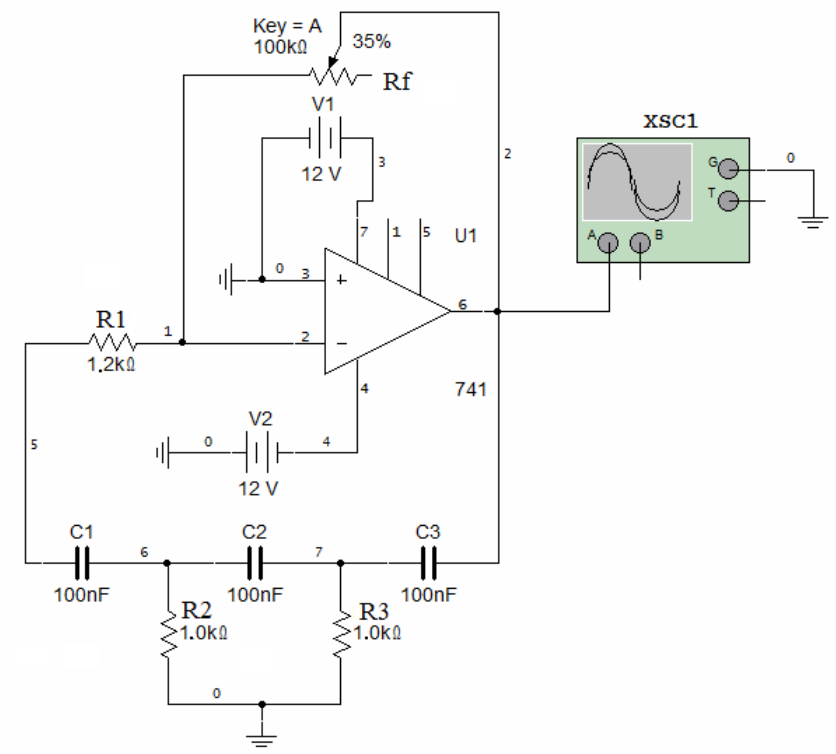


Fig. 4. Basic circuit of RC phase shift oscillator

The basic RC Oscillator which is also known as a **Phase-shift Oscillator**, produces a sine wave output signal using regenerative feedback obtained from the resistor-capacitor combination. This regenerative feedback from the RC network is due to the ability of the capacitor to store an electric charge, (similar to the LC tank circuit).

This resistor-capacitor feedback network can be connected as shown above to produce a leading phase shift (phase advance network) or interchanged to produce a lagging phase shift (phase retard network) the outcome is still the same as the sine wave oscillations only occur at the frequency at which the overall phase-shift is 360^o.

By varying one or more of the resistors or capacitors in the phase-shift network, the frequency can be varied and generally this is done by keeping the resistors the same and using a 3-ganged variable capacitor.

If all the resistors, R and the capacitors, C in the phase shift network are equal in value, then the frequency of oscillations produced by the RC oscillator is given as:

$$f_0 = 1 \big/ 2\pi RC\sqrt{2 \cdot N}$$

where f_0 is the output frequency in Hertz
R is the resistance in Ohms
C is the capacitance in Farads
N is the number of RC stages (N = 3).

RC oscillators are stable and provide a well-shaped sine wave output with the frequency being proportional to 1/RC and therefore, a wider frequency range is possible when using a variable capacitor. However, RC oscillators are restricted to frequency applications because of their bandwidth limitations to produce the desired phase shift at high frequencies.

Example. A 3-stage RC phase shift oscillator is required to produce an oscillation frequency of 650 Hz. If 100 nF capacitors are used in the feedback circuit, calculate the value of the frequency determining resistors and the value of the feedback resistor required to sustain oscillations.

The standard equation given for the phase shift RC Oscillator is:

$$f_0 = 1 \big/ 2\pi RC\sqrt{2 \cdot N}$$

The circuit is to be a 3-stage RC oscillator which will therefore consist of three resistors and three 100 nF capacitors. As the frequency of oscillation is given as 650 Hz, the values of the resistors are calculated as:

$$: f_0 = 650\,Hz = \frac{1}{2\pi \cdot R \cdot 100 \cdot 10^{-9}\sqrt{2 \cdot 3}}$$

$$R = \frac{1}{2\pi\sqrt{6}\cdot 650\cdot 100\cdot 10^{-9}} = 1\mathrm{k}\Omega$$

Attenuation offered by the feedback RC network is 1/29, so the gain **A_V** of inverting amplifier should be equal to 29 in order to sustain oscillations. The resistive value of R_1 we select to be 1.2 kΩ, therefore the value of the op-amps feedback resistor **R_f** is calculated as:

$$A_V = -R_f / R_1 = -29 \Rightarrow R_f = -A_V \cdot R_1 = 35\mathrm{k}\Omega$$

Use a 100 kΩ potentiometer and adjust its value to obtain a non-distorted sinusoidal output on the oscilloscope screen.

The simulated by RC oscillator waveform is shown in Fig. 5.

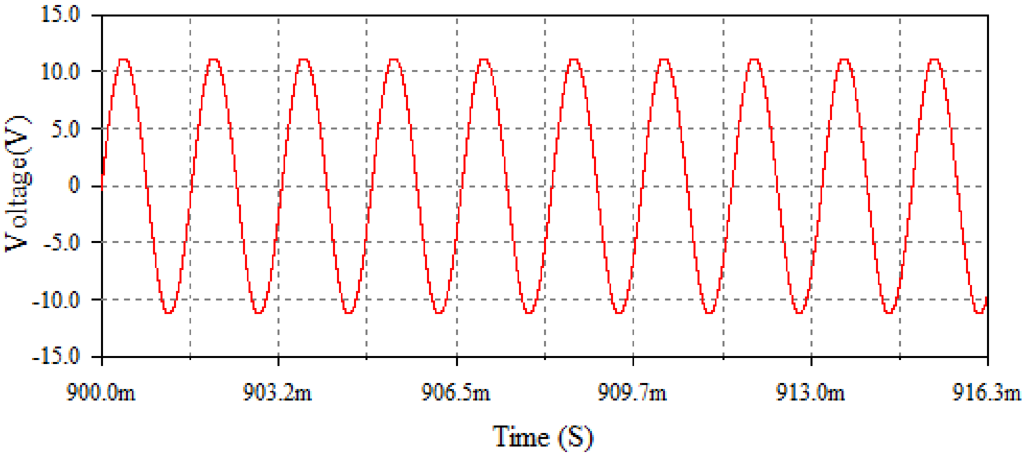
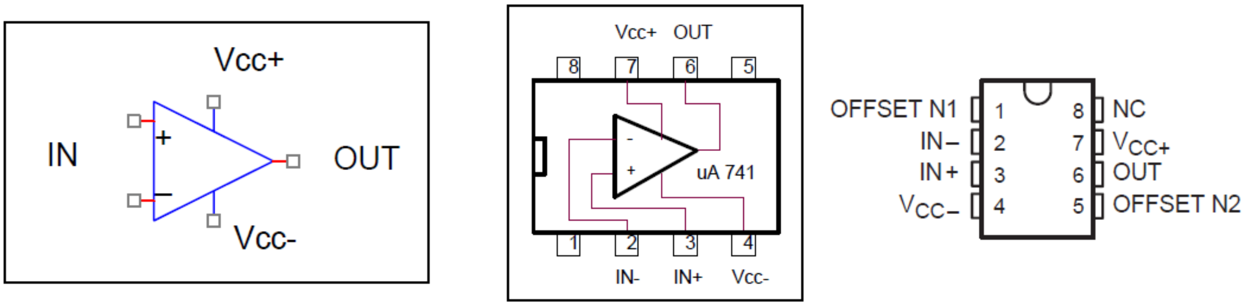


Fig. 5. Simulated RC oscillator output voltage

PIN DIAGRAM OF UA741 OPERATIONAL AMPLIFIER

The circuit symbol for an op-amp is shown in Fig. 6(a). The pin connections for the 8 pin DIP package UA741 op-amp are given in Fig. 6(b).

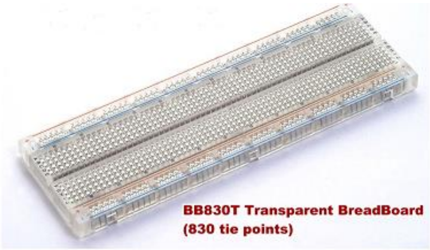


(a) (b)

Fig. 6. Symbol for a basic op-amp (a), the UA741 op-amp package (b)

EQUIPMENT

1. Digital multimeter UT33B
2. Solderless breadboard BB830T
3. Oscilloscope HAMEG HMO1024
4. Power Supply +12V, 0, -12V
5. Resistors: 1.2 kΩ, 2×1.0 kΩ,
6. Potentiometer: 100 kΩ
7. Capacitors 3x100nF
8. UA741 (УД708) op-amp



PROCEDURE

The pin connections for the 8 pin DIP package UA741 (УД708) op-amp are given in Fig. 1. Throughout this experiment use the external DC Power Supply Unit with **+12V**, **0**, **-12V** jacks. The initial location of the UA741 chip and connections to +12V, 0, -12V terminals of the power supply are shown in Fig. 7.

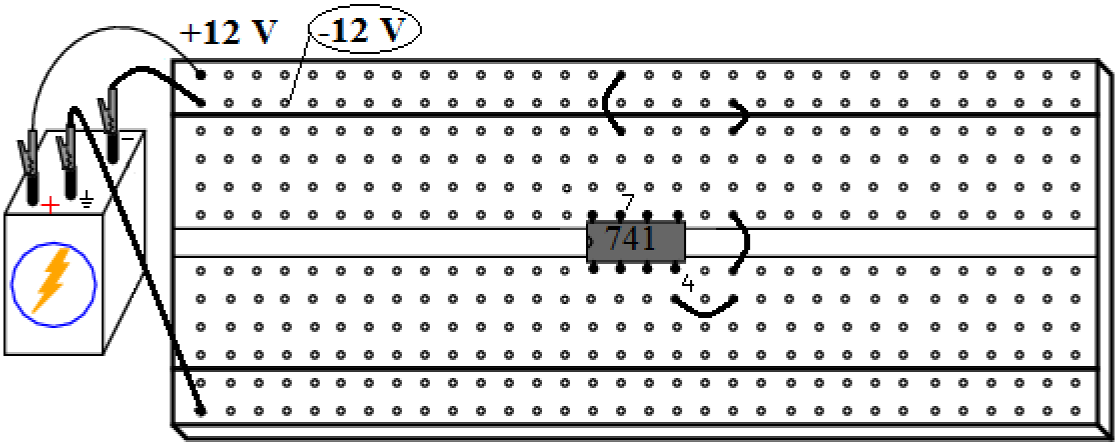


Fig. 7. Initial location of UA741 chip on the solderless breadboard

To use the Power Supply Unit:

• Turn the Power Supply ON. This will set both positive and negative power sources respectively to **+12V** and **–12V**. Measure these voltages with digital multemeter.

• Turn the Power Supply OFF before connecting to the circuits.

• Connect the **+12V** terminal of the Power Supply to the pin 7 of your circuit as shown in Fig. 4. Connect the **-12V** terminal of the Power Supply to the pin 4 of your circuit as shown in Fig. 4. Connect the **COM** terminal of the Power Supply to the ground of your circuit as shown in Fig. 4.

Procedure steps

1. Build the circuit of Fig. 4 using an 8-pin uA741 (УД708) op-amp with Rf = 100 kΩ (potentiometer), R1 = 1.2 kΩ, R2 = R3 = 1 kΩ, and C1 = C2 = 100 nF.
2. To achieve undistorted waveform on the oscilloscope screen, adjust 100 kΩ potentiometer.
3. Measure the amplitude of the output signal V_{out}.
4. Draw (make a photograph of) the oscillator output waveform.

REFERENCE

1. A.S. Sedra and K.S. Smith, “Microelectronic circuits”, 5th ed., New York: Oxford University Press, 2004, 1283 p.