Experiment

Study of integrator, differentiator and phase shift oscillator using OPAMP (IC-741)

Objectives

1. To study OPAMP as an integrator
2. To study OPAMP as a differentiator
3. To study OPAMP as a phase shift oscillator

Components/equipment required

1. OPAMP IC 741
2. D.C. power supply
3. Resistors
4. Digital multi-meter
5. Connecting wires
6. Breadboard
7. Function generator
8. Digital storage oscilloscope

Contents

1 To study OP-AMP as an integrator

1.1 Theory

We have seen how an operational amplifier can be used as part of a positive or negative feedback amplifier or as an adder or subtractor type circuit using pure resistors in both the input and the feedback loop. But what if we were to change the purely Resistive (R_F) feedback element of an inverting amplifier to that of a reactive element, such as a Capacitor, . We now have a resistor and capacitor combination forming an Network across the operational amplifier as shown below.

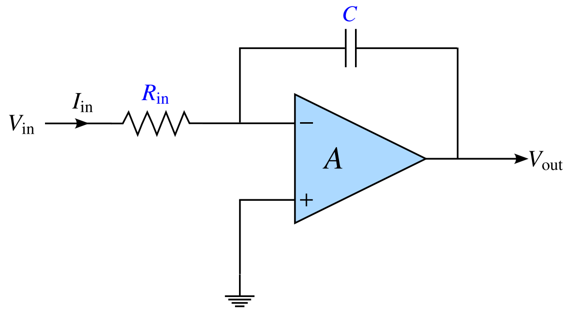

Figure 1: OP-AMP as an integrator.

The integrator amplifier performs the mathematical operation of integration, that is, we can cause the output to respond to changes in the input voltage over time and the integrator amplifier produces a voltage output which is proportional to that of its input voltage with respect to time. In other words, the magnitude of the output signal is determined by the length of time a voltage is present at its input as the current through the feedback loop charges or discharges the capacitor.

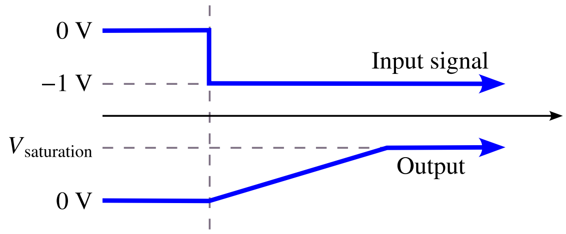

Figure 2: Output waveform in an OPAMP integrator.

When a voltage, V_{in} is firstly applied to the input of an integrating amplifier, the uncharged capacitor C has very little resistance and acts a bit like a short circuit (voltage follower circuit) giving an overall gain of less than 1, thus resulting in zero output. As the feedback capacitor C begins to charge up, the ratio of Z_F/R_{in} increases producing an output voltage that continues to increase until the capacitor is fully charged. At this point the ratio of feedback capacitor to input resistor (Z_F/R_{in}) is infinite resulting in infinite gain and the output of the amplifier goes into saturation as shown in the diagram. (Saturation is when the output voltage of the amplifier swings heavily to one voltage supply rail or the other with no control in between).

Since the node voltage of the integrating op-amp at its inverting input terminal is zero, the current I_{in} flowing through the input resistor is given as:

$$I_{\text{in}} = \frac{V_{\text{in}}}{R_{\text{in}}}$$

The current flowing through the feedback capacitor is given as:

$$I_{\text{in}} = C\frac{dV_{\text{out}}}{dt}$$

Assuming that the input impedance of the OP-AMP is infinite (ideal OP-AMP), no current flows into the OP-AMP terminal. Therefore, the nodal equation at the inverting input terminal is given as:

$$\frac{V_{\text{in}}}{R_{\text{in}}} = C\frac{dV_{\text{out}}}{dt} = 0$$

From which we have an ideal voltage output for the Integrator Amplifier as:

$$V_{\text{out}} = -\frac{1}{R_{\text{in}}C} = \int V_{\text{in}}dt = -\frac{V_{in}}{j\omega R_{in}C}$$

where $j\omega = 2\pi f$ and the output voltage is a constant times the integral of the input voltage with respect to time. The minus sign $(-)$ indicates a $180°$ phase shift because the input signal is connected directly to the inverting input terminal of the OP-AMP.

1.2 Circuit diagram

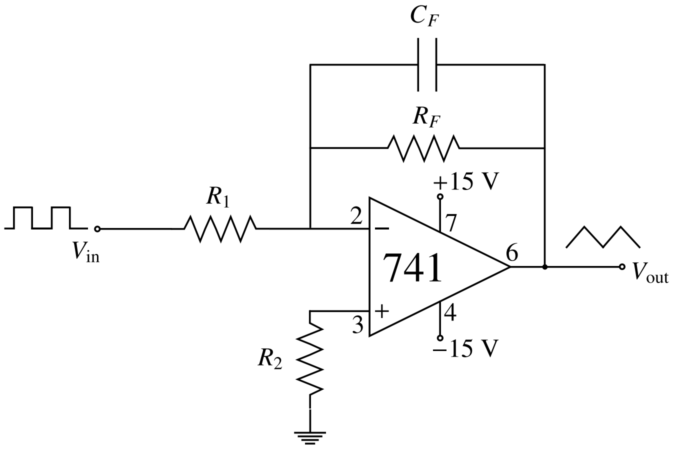

Figure 3: Circuit diagram of an integrator.

1.3 Procedure

In this practical integrator circuit, R_F is connected parallel with C_F. R_F discharges left over charges present in the capacitor before the next pulse being applied and limits the gain of the circuit at low frequencies, which is infinite at DC. R_2 is known as offset minimizing resistor (ROM) which reduces output offset voltage due to input bias current.

1. Assemble the circuit as shown in circuit diagram choosing $R_1, R_2 = 10$ kΩ each, $R_F = 100$ kΩ, and $C_1 = 0.1$ µF. Use 0 to ±15 V terminal output to provide supply to the IC.
2. Feed a square wave input of required amplitude from the function generator, which is set at 1 kHz frequency.
3. Feed both the input and output signals to an oscilloscope. The output should be a triangular wave

1.4 Observations

Paste the various input and corresponding output waveforms here

Observation	**Waveform**
Input	
Output	

1.5 Discussion

Discuss your observations

1.5.1 Precautions

2 To study OPAMP as a differentiator

2.1 Theory

The basic differentiator amplifier circuit is the exact opposite to that of the Integrator operational amplifier circuit. Here, the position of the capacitor and resistor have been reversed and now the Capacitor, C is connected to the input terminal of the inverting amplifier while the resistor, R_F forms the negative feedback element across the operational amplifier. This circuit performs the mathematical operation of **Differentiation**, i.e. it produces a voltage output which is proportional to rate-of-change of the input voltage and the current flowing through the capacitor. In other words, the faster or larger the change to the input voltage signal, the greater the input current, the greater will be the output voltage change in response becoming more of a "spike" in shape.

As with the integrator circuit, we have a resistor and capacitor forming an RC Network across the operational amplifier and the reactance (X_C) of the capacitor plays a major role in the performance of a differentiator amplifier.

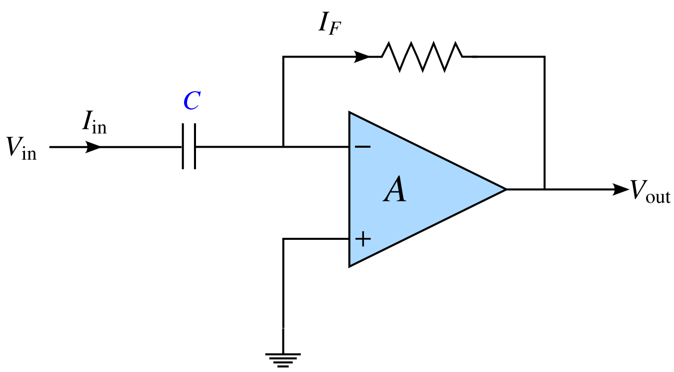

Figure 4: OPAMP as a differentitator.

Since the node voltage of the operational amplifier at its inverting input terminal is zero, the current, flowing through the capacitor will be given as:

$$I_{in} = I_F \text{ and } I_F = -\frac{V_{out}}{R_F}$$

The charge on the capacitor = Capacitance × Voltage across the capacitor

$$Q = C \times V_{in}$$

The rate of change of this charge is

$$\frac{dQ}{dt} = C\frac{dV_{in}}{dt}$$

But is the capacitor current

$$I_{in} = C\frac{dV_{in}}{dt} = I_F$$

From which we have an ideal voltage output for the Differentiator Amplifier is given as:

$$V_{\text{out}} = -R_F C \frac{dV_{\text{in}}}{dt}$$

Therefore, the output voltage V_{out} is a constant $-R_F C$ times the derivative of the input voltage V_{in} with respect to time. The minus sign indicates a 180° phase shift because the input signal is connected to the inverting input terminal of the operational amplifier.

If we apply a constantly changing signal such as a Square-wave, Triangular or Sine-wave type signal to the input of a differentiator amplifier circuit the resultant output signal will be changed and whose final shape is dependent upon the RC time constant of the Resistor/Capacitor combination.

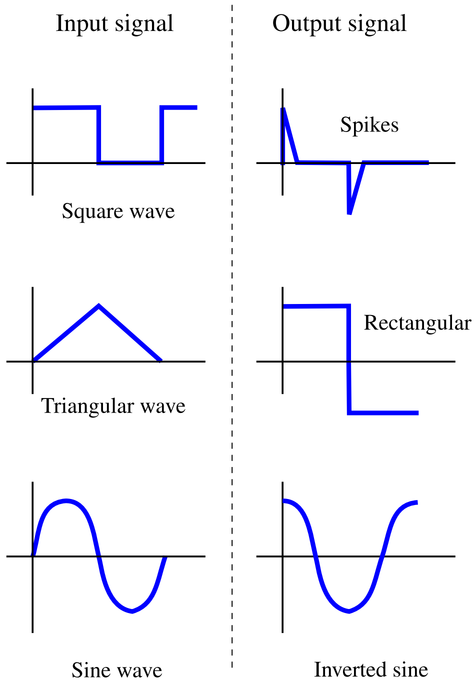

Figure 5: Output waveforms in a OP-AMP differentiator.

2.2 Circuit diagram

2.3 Procedure

For the practical differentiator, is added in parallel to to control the gain and a small resistance at the input in series with Cin drops the noise at the input. is known as offset minimizing resistor (ROM) which reduces output offset voltage due to input bias current.

1. Assemble the circuit as shown in circuit diagram choosing $R_1, R_2 = 1$ kΩ each, $R_F = 10$ kΩ, $C_{\text{in}} = 0.1$ μF and $C_F = 0.01$ μF. Use 0 to ±15 V terminal output to provide supply to the IC.

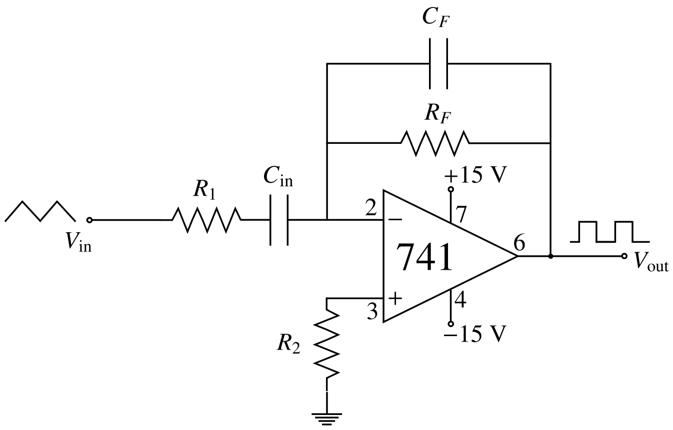

Figure 6: Circuit diagram of an integrator.

2. Feed a triangular input signal of required amplitude from the function generator, which is set at 1 kHz frequency.

3. Feed both the input and output signals to an oscilloscope and save. The output should be approximately a square wave.

4. Check the output waveform with sine and square waves as inputs and save.

2.4 Observations

Paste the various input and corresponding output waveforms here

Observation	Waveform		
Input	**Triangular**	**Sine**	**Square**
Output			

2.5 Discussion

Discuss your observations

2.6 Precautions

3 To study OPAMP as a Phase Shift oscillator

3.1 Theory

The main principle of oscillator is positive feedback. Block diagram of oscillator is shown in figure 7.

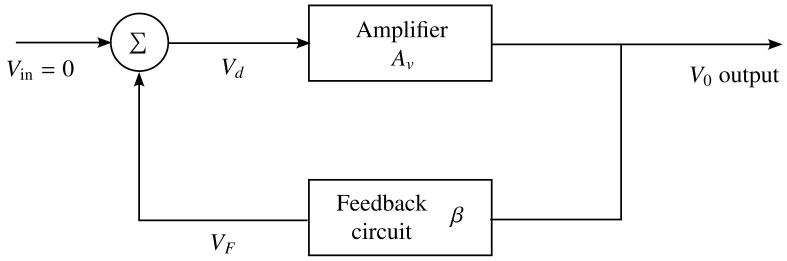

Figure 7: Block diagram of the Phase Shift Amplifier using OPAMP.

In the block diagram,

$$V_d = V_F + V_{in}$$
$$V_{out} = A_v V_d \text{ and } V_F = \beta V_{out}$$

Using these relations, following equation can be obtained:

$$\frac{V_{out}}{V_{in}} = \frac{A_v}{1 - A_v\beta}$$

When $A_v\beta = 1, A_F = \infty = V_{out}/V_{in}$. This will happen only when $V_{in} = 0$. That is, we get a signal at output without any input. The condition $A_v\beta = 1$ is known as the Barkhausen condition.

Barkhausen condition gives two requirements for oscillation:

1. The magnitude of the loop gain must be equal to 1 ($|A_v\beta| = 1$)
2. The total phase shift of the loop gain $\angle A_v\beta = 0°$ or $360°$

3.2 Phase shift Oscillator

Figure 8 gives the circuit diagram for a phase shift oscillator, which consists of an OP-AMP as the amplifying stage and three RC cascaded networks as the feedback circuit. The OP-AMP used in this oscillator is in inverting mode, output is 180° phase shifted. To feedback the output to input, additional 180° is achieved by the RC network. The frequency of oscillation is given by,

$$f_C = \frac{1}{2\pi\sqrt{6}RC}$$

and at this frequency gain must be at least 29. That is $R_F/R_1 \geq 29$. Feedback circuit with network gives 180° phase shift but decreases the output voltage by a factor of 29. That is $\beta = 1/29$. For the oscillations, $A_v\beta = 1$. Therefore, gain should be at least 29.

3.3 Circuit diagram

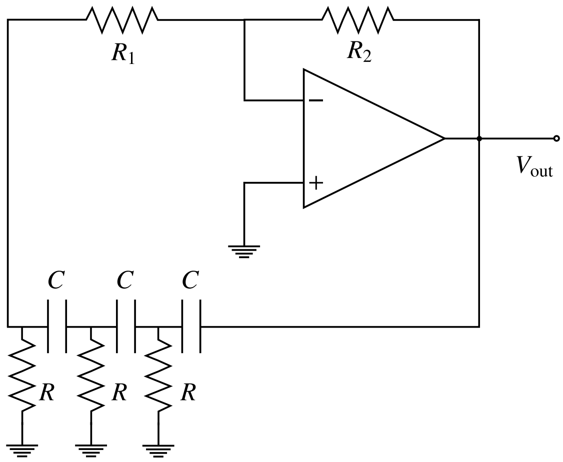

Figure 8: Circuit diagram of Phase Shift Amplifier using OPAMP.

3.4 Procedure

1. Choose $R_F = 100$ kΩ, $R_1 = 2$ kΩ, $C = 0.1$ µF, $R = 1$ kΩ and construct a phase shift oscillator.
2. Determine the oscillating frequency using oscilloscope and compare with calculated oscillation frequency.
3. Experimentally determine the minimum gain required to sustain oscillations by varying the gain in the circuit. Obtain Lissajous figure (circle) with X-Y mode of the oscilloscope and estimate oscillating frequency. Try to make the circuit for some other oscillating frequency by choosing components appropriately.

3.5 Observations

$$R_1 = \_\_\_\_\_\_, R_2 = \_\_\_\_\_\_, C = \_\_\_\_\_\_$$

$$\text{Max gain (calculated)} = \_\_\_\_\_\_, -\frac{R_F}{R_1} = \_\_\_\_\_\_, f_C = \frac{1}{2\pi\sqrt{6}RC} = \_\_\_\_\_\_$$

3.6 Discussions

Discuss your results.

3.7 Precautions