Group No:

Experiment-02

Study of Op-Amp: Inverting Summing Amplifier, Schmitt Trigger

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To investigate the use of Op-Amp as Inverting Summing Amplifier and Schmitt Trigger

Equipments

1. Op-Amp (uA741)
2. Resistance ($100k\Omega$)
3. POT ($100k\Omega$)
4. DC power supply
5. Function Generator
6. Trainer Board
7. Breadboard
8. Chords and Wire
9. Digital Multimeter
10. Oscilloscope

Background Theory

Inverting Summing Amplifier

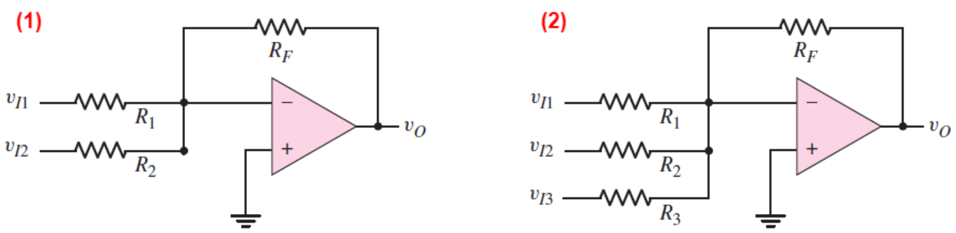


Figure 1: Inverting Summing Amplifier (1) with 2-inputs (2) with 3-inputs

Op-Amps can be used to do weighted summation of multiple input voltages. Figure-1 shows inverting summing amplifier circuits that can do this. The weight of each input voltage during the summing operation can be controlled by the resistances. The circuit does weighted summation and inverts the result at the output. The following equation shows the relationship between the input and output of a 2-input inverting summing amplifier.

$$v_O = -(\frac{R_F}{R_1} \times v_{I1} + \frac{R_F}{R_2} \times v_{I2}); \texttt{ where, gain for } v_{I1} = -\frac{R_F}{R_1}, \texttt{ gain for } v_{I2} = -\frac{R_F}{R_2}$$

We can extend it to as many inputs as we want and the equation will change accordingly. Let's say, we need to add another input v_{I3}. Then the equation will look like this:

$$v_O = -(\frac{R_F}{R_1} \times v_{I1} + \frac{R_F}{R_2} \times v_{I2} + \frac{R_F}{R_3} \times v_{I3})$$

$$\texttt{where, gain for } v_{I1} = -\frac{R_F}{R_1}, \texttt{ gain for } v_{I2} = -\frac{R_F}{R_2}, \texttt{ gain for } v_{I3} = -\frac{R_F}{R_3}$$

Schmitt Trigger

A Schmitt trigger is a type of comparator circuit that compares an input voltage to a set of threshold values and switches its output based on the comparison. The circuit has two different threshold values, one for switching the output high and one for switching it low. This makes the Schmitt trigger useful in applications where noise or rapid voltage changes need to be filtered out and only clean digital signals are desired. The Schmitt trigger is widely used in digital electronics.

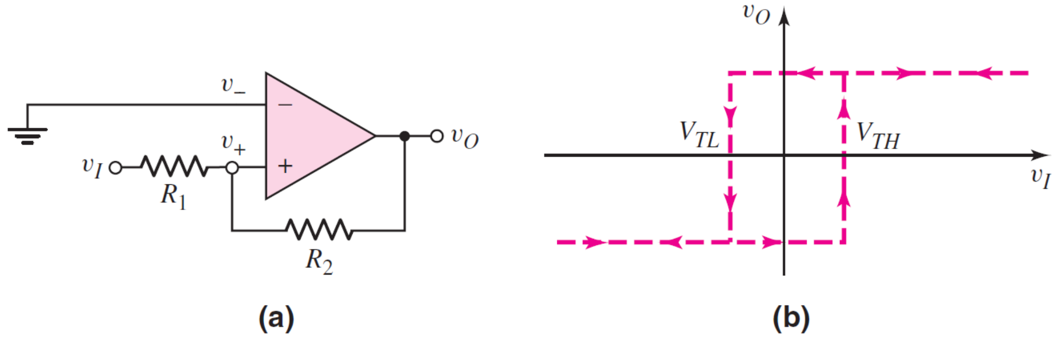


Figure 2: (a) Non-inverting Schmitt trigger circuit and (b) voltage transfer characteristics

Schmitt trigger uses positive feedback mechanism and it's threshold voltages depend on the output voltage. Figure-2 shows a non-inverting schmitt trigger circuit and it's transfer characteristics. In the circuit, we choose the value of the resistances in such a way that, $R_2 = pR_1$.

In a comparator, $v_O = V_s^+$ when $v_+ > v_-$, $v_O = V_s^-$ when $v_- > v_+$ and v_O transitions from V_s^+ to V_s^- when $v_+ = v_-$. We need to get the value of v_I for which this transition occurs. Now in this schmitt trigger circuit,

$$I_{R1} = I_{R2}$$
$$\implies \frac{v_I - v_+}{R_1} = \frac{v_+ - v_O}{R_2}$$
$$\implies \frac{v_I - v_+}{R_1} = \frac{v_+ - v_O}{pR_1}$$
$$\implies v_+(1 + \frac{1}{p}) = v_I + \frac{v_O}{p}$$

In this circuit, $v_- = 0$. So, if at any moment, v_- becomes equal to v_+, we can write,

$$v_+ = 0$$
$$\implies v_+(1 + \frac{1}{p}) = 0$$
$$\implies v_I + \frac{v_O}{p} = 0$$
$$\implies v_I = -\frac{v_O}{p}$$

We can conclude that, $v_+ = v_-$ for $v_I = -\frac{v_O}{p}$, which gives us the transition point. If we carefully observe the equation, we see that it depends on v_O. So, we get 2 transition points,

$$v_I = \frac{-V_S^+}{p}, \quad \texttt{when initially } v_O = V_S^+$$

$$v_I = \frac{-V_S^-}{p}, \quad \texttt{when initially } v_O = V_S^-$$

We can say that, these 2 transition points are 2 thresholds where the schmitt trigger changes it's output from V_S^+ to V_S^- or from V_S^- to V_S^+. We call them Lower Threshold, V_{LH} and Higher Threshold, V_{TH} respectively. Now, we can write v_+ as a function of v_I and v_O. Using superposition, we get,

$$v_+ = \left(\frac{R_2}{R_1 + R_2}\right) v_I + \left(\frac{R_1}{R_1 + R_2}\right) v_O$$

If v_I is negative, and the output is in its low state, then $v_O = V_S^-$ (assumed to be negative), v_+ is negative, and the output remains in V_S^-. Transition voltage $v_I = V_{TH}$ occurs when $v_+ = 0$ and $v_O = V_S^-$, we get,

$$R_2 V_{TH} + R_1 V_S^- = 0$$

$$\implies V_{TH} = -\left(\frac{R_1}{R_2}\right) V_S^-$$

Since V_S^- is negative, V_{TH} is positive. If we let $v_I = V_{TH} + \delta$, where δ is a small positive voltage, the input voltage is just greater than the transition/threshold voltage and we get,

$$v_+ = \left(\frac{R_2}{R_1 + R_2}\right)(V_{TH} + \delta) + \left(\frac{R_1}{R_1 + R_2}\right) V_S^-$$

$$\implies v_+ = \left(\frac{R_2}{R_1 + R_2}\right)\left(\frac{-R_1}{R_2}\right) V_S^- + \left(\frac{R_2}{R_1 + R_2}\right)\delta + \left(\frac{R_1}{R_1 + R_2}\right) V_S^-$$

$$\implies v_+ = \left(\frac{R_2}{R_1 + R_2}\right)\delta > 0$$

When $v_+ > 0$, the output switches to V_S^+.

The lower threshold voltage $v_I = V_{TL}$ occurs when $v_+ = 0$ and $v_O = V_S^+$. We can write,

$$R_2 V_{TL} + R_1 V_S^+ = 0$$

$$\implies V_{TL} = -\left(\frac{R_1}{R_2}\right) V_S^+$$

Since $V_S^+ > 0$, then $V_{TL} < 0$. The complete voltage transfer characteristics are shown in Figure-2(b).

Schmitt Trigger Circuits with Applied Reference Voltage

Both V_{TH} and V_{TL} can be shifted in either a positive or negative direction by applying a reference voltage in the schmitt trigger circuit. The following circuit demonstrates this phenomenon.

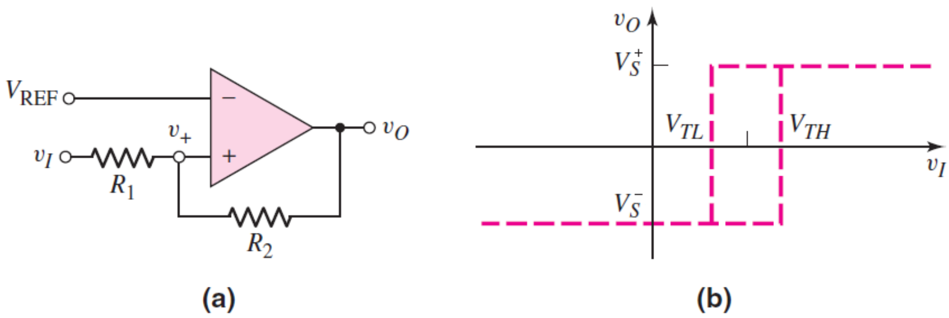


Figure 3: (a) Non-inverting Schmitt trigger circuit with applied reference voltage and (b) voltage transfer characteristics

If we analyze this circuit like the previous one, for transition we get,

$$v_+ = v_- = V_{REF}$$

$$\implies v_+(1 + \frac{1}{p}) = V_{REF}(1 + \frac{1}{p})$$

$$\implies v_I + \frac{v_O}{p} = V_{REF}(1 + \frac{1}{p})$$

When initially, $v_O = V_S^-$,

$$v_I + \frac{V_S^-}{p} = V_{REF}(1 + \frac{1}{p})$$

$$\implies v_I = V_{TH} = V_{REF}(1 + \frac{1}{p}) - \frac{V_S^-}{p}$$

When initially, $v_O = V_S^+$,

$$v_I + \frac{V_S^+}{p} = V_{REF}(1 + \frac{1}{p})$$

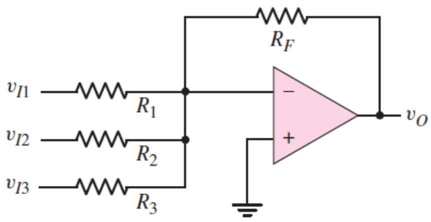
$$\implies v_I = V_{TL} = V_{REF}(1 + \frac{1}{p}) - \frac{V_S^+}{p}$$

In this circuit, we will use $V_{REF} = 2.5$ V, $V_S^+ = 5$ V and $V_S^- = 0$ V. So we get,

$$V_{TH} = 2.5 + \frac{2.5}{p} \quad \text{and} \quad V_{TL} = 2.5 - \frac{2.5}{p}$$

So, changing the ratio of $p = R_2/R_1$ will let us choose our desired value of V_{TH} and V_{TL}.

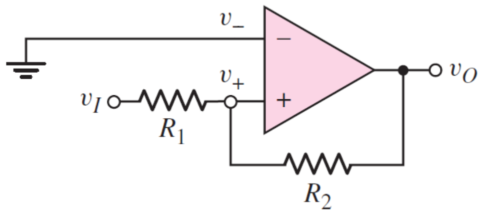
Task-01: Inverting Summing Amplifier



Procedure

1. Construct the circuit with 3-inputs where the supply voltage $+V_S$ and $-V_S$ should be +8 V and -8 V respectively. Use the Trainer board for the supply voltages.
2. Use the DC Power Supply for $v_{I1} = 0.5$ V, $v_{I2} = 1$ V and the Trainer Board for $v_{I3} = 5$ V.
3. Use $R_1 = 100$ kΩ, $R_2 = 100$ kΩ, $R_3 = 100$ kΩ and $R_F = 100$ kΩ.
4. Use the digital multimeter to measure the output voltage and write down the values according to the data sheet.

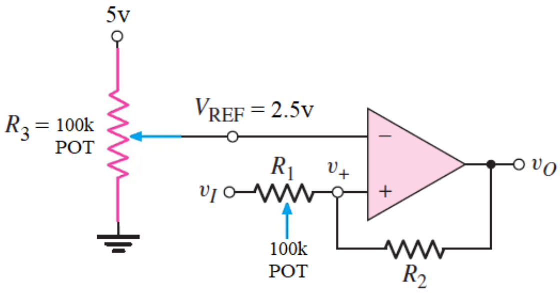
Task-02: Schmitt Trigger



Procedure

1. Construct the circuit where the supply voltage $+V_S$ and $-V_S$ should be +5 V and -5 V respectively. Use the Trainer board for the supply voltages.
2. Use a 100 kΩ POT for R_1. Use $R_2 = 100$ kΩ.
3. Use the Function Generator to generate $v_I = 8$ V (p-p) 1 KHz.
4. Connect the Ch-1 and Ch-2 of the oscilloscope to v_I and v_O respectively.
5. Change the value of R1 (as it is a POT) and observe the output voltage and write down the values according to the data sheet.

Task-03: Schmitt Trigger with Applied Reference Voltage



Procedure

1. Construct the circuit where the supply voltage $+V_S$ and $-V_S$ should be +5 V and 0 V respectively. Use the Trainer board for the supply voltages. Use a 100 kΩ POT for R_1 and R_3. Use R_2 = 100 kΩ.
2. Use the Function Generator to generate v_I = 8 V (p-p) 1 KHz and connect the Ch-1 and Ch-2 of the oscilloscope to v_I and v_O respectively.
3. Change the value of R_3 (as it is a POT) so that V_{REF} = 2.5 V (use multimeter).
4. Change the value of R_1 (as it is a POT) and observe the output voltage and write down the values according to the data sheet.

Task-04: Report

1. Cover page [include course code, course title, name, student ID, group, semester, date of performance, date of submission]
2. Attach the signed Data Sheet.
3. Add a brief Discussion at the end of the report.

Data Sheet

Task-01:

from multimeter, v_{I1} =
from multimeter, v_{I2} =
from multimeter, v_{I3} =
Output Amplitude from equation, $v_O = -(\frac{R_F}{R_1} \times v_{I1} + \frac{R_F}{R_2} \times v_{I2} + \frac{R_F}{R_3} \times v_{I3}) =$
Output Amplitude from multimeter, v_O =

Task-02:

R_1	**From Equation,** $V_{TH} = -\left(\frac{R_1}{R_2}\right) V_S^-$	**From Oscilloscope,** V_{TH}	**From Equation,** $V_{TL} = -\left(\frac{R_1}{R_2}\right) V_S^+$	**From Oscilloscope,** V_{TL}
25 kΩ				
50 kΩ				

Task-03:

R_1	$p = R_2/R_1$	**From Equation,** $V_{TH} = 2.5 + \frac{2.5}{p}$	**From Oscilloscope,** V_{TH}	**From Equation,** $V_{TL} = 2.5 - \frac{2.5}{p}$	**From Oscilloscope,** V_{TL}
25 kΩ					
50 kΩ					