IN 277 Notes 6
Comparators
Positive Feedback and Hysteresis
RC Square Wave Oscillators

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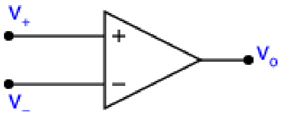
October 28, 2025

Operational Amplifier as a Comparator



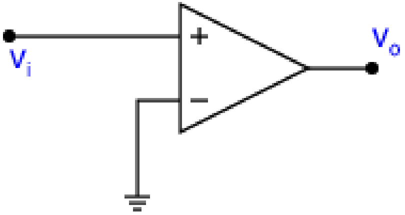
$$v_o = \begin{cases} V_{\mathrm{OH}} & v_+ > v_-, \\ V_{\mathrm{OL}} & v_+ < v_-. \end{cases} \tag{1}$$

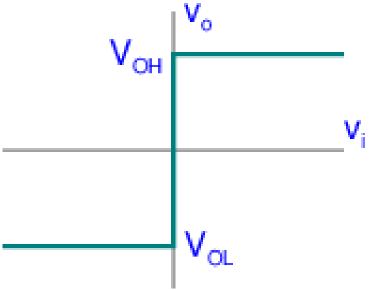
Uses: Waveform shaping, Analogue to Digital Conversion, ...

Comparator

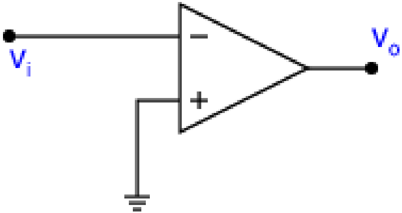
- Not all operational amplifiers are suitable for use as comparators.
- The inputs may have special diode protection making it unsuitable for use as a comparator. Example: OP07
- Comparator ICs (Example: LM339)

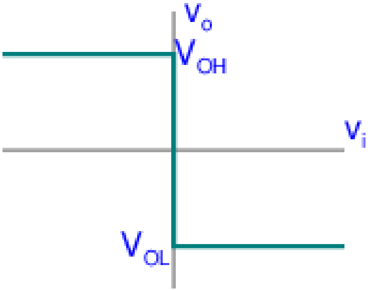
Positive Comparator



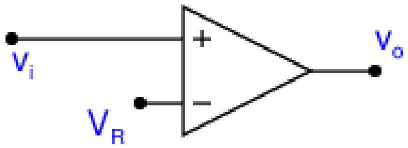


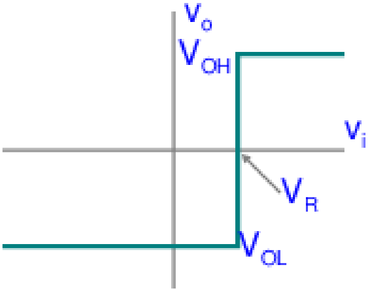
Negative Comparator



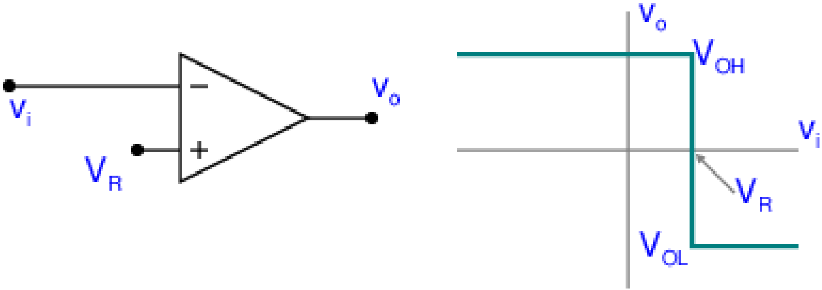


Positive Comparator with Shift

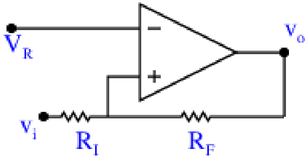


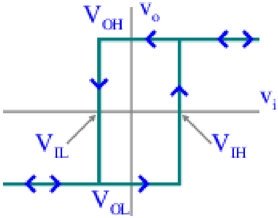


Negative Comparator with Shift



Positive Comparator with Hysteresis





$$V_{\mathrm{IH}} = \left(1 + \frac{R_I}{R_F}\right) V_R - \frac{R_I}{R_F} V_{\mathrm{OL}}. \tag{2}$$

$$V_{\mathrm{IL}} = \left(1 + \frac{R_I}{R_F}\right) V_R - \frac{R_I}{R_F} V_{\mathrm{OH}}. \tag{3}$$

Derivation follows.

V_{IH} Formula: Positive Comparator with Hysteresis

$$v_+ = \frac{R_F}{R_F + R_I} v_i + \frac{R_I}{R_F + R_I} v_o.$$

For this value to be more than $v_- = V_R$, even when $v_o = V_{\mathrm{OL}}$, it is required that

$$\frac{R_F}{R_F + R_I} v_i + \frac{R_I}{R_F + R_I} V_{\mathrm{OL}} > V_R.$$

$$\Rightarrow v_i + \frac{R_F + R_I}{R_F} \frac{R_I}{R_F + R_I} V_{\mathrm{OL}} > \frac{R_F + R_I}{R_F} V_R.$$

$$\Rightarrow v_i + \frac{R_I}{R_F} V_{\mathrm{OL}} > (1 + R_I/R_F) V_R.$$

$$\Rightarrow v_i > (1 + R_I/R_F) V_R - \frac{R_I}{R_F} V_{\mathrm{OL}} = V_{\mathrm{IH}}.$$

V_{IL} Formula: Positive Comparator with Hysteresis

$$v_+ = \frac{R_F}{R_F + R_I} v_i + \frac{R_I}{R_F + R_I} v_o.$$

For this value to be less than $v_- = V_R$, even when $v_o = V_{\mathrm{OH}}$, it is required that

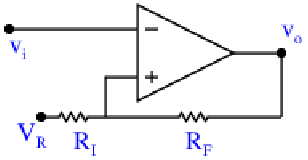
$$\frac{R_F}{R_F + R_I} v_i + \frac{R_I}{R_F + R_I} V_{\mathrm{OH}} < V_R.$$

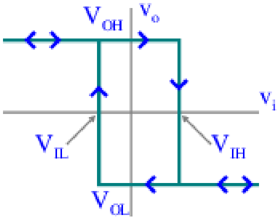
$$\Rightarrow v_i + \frac{R_F + R_I}{R_F} \frac{R_I}{R_F + R_I} V_{\mathrm{OH}} < \frac{R_F + R_I}{R_F} V_R.$$

$$\Rightarrow v_i + \frac{R_I}{R_F} V_{\mathrm{OH}} < (1 + R_I/R_F) V_R.$$

$$\Rightarrow v_i < (1 + R_I/R_F) V_R - \frac{R_I}{R_F} V_{\mathrm{OH}} = V_{\mathrm{IL}}.$$

Negative Comparator with Hysteresis





$$V_{\mathrm{IH}} = \frac{R_F}{R_F + R_I} V_R + \frac{R_I}{R_F + R_I} V_{\mathrm{OH}}. \tag{4}$$

$$V_{\mathrm{IL}} = \frac{R_F}{R_F + R_I} V_R + \frac{R_I}{R_F + R_I} V_{\mathrm{OL}}. \tag{5}$$

Derivation follows.

Derivation: Negative Comparator with Hysteresis

$$v_+ = \frac{R_F}{R_F + R_I} V_R + \frac{R_I}{R_F + R_I} v_o.$$

For $v_i = v_-$ to be more than v_+, even when $v_o = V_{\mathrm{OH}}$, it is required that

$$v_i > \frac{R_F}{R_F + R_I} V_R + \frac{R_I}{R_F + R_I} V_{\mathrm{OH}} = V_{\mathrm{IH}}.$$

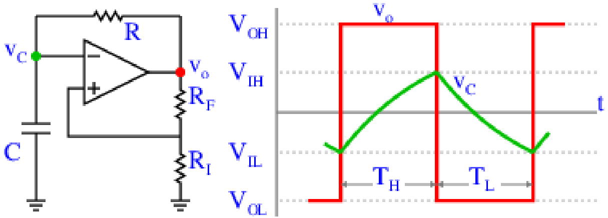
For $v_i = v_-$ to be less than v_+, even when $v_o = V_{\mathrm{OL}}$, it is required that

$$v_i < \frac{R_F}{R_F + R_I} V_R + \frac{R_I}{R_F + R_I} V_{\mathrm{OL}} = V_{\mathrm{IL}}.$$

Uses of Comparators with Hysteresis

- Noise immunity
- Many line receiver ICs such as MC 1489 have built-in hysteresis to combat noise.
- Oscillators

Oscillator A

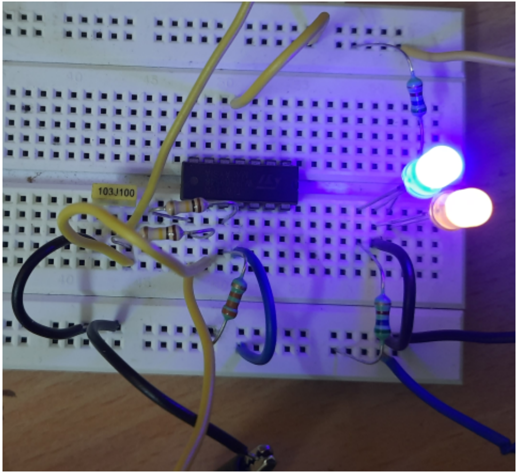


$$T_H = RC \ln \frac{V_{\mathrm{OH}} - V_{\mathrm{IL}}}{V_{\mathrm{OH}} - V_{\mathrm{IH}}}. \tag{6}$$

$$T_L = RC \ln \frac{V_{\mathrm{IH}} - V_{\mathrm{OL}}}{V_{\mathrm{IL}} - V_{\mathrm{OL}}}. \tag{7}$$

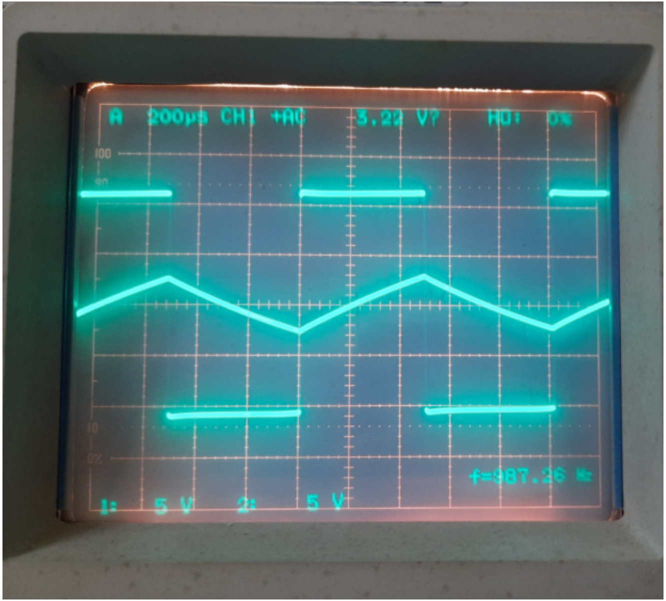
Here, $V_{\mathrm{IH}} = \frac{R_I}{R_F+R_I} V_{\mathrm{OH}}$, and $V_{\mathrm{IL}} = \frac{R_I}{R_F+R_I} V_{\mathrm{OL}}$. These were obtained by setting $V_R = 0$ in the expressions given for the negative comparator with hysteresis.

Implementation: Oscillator A

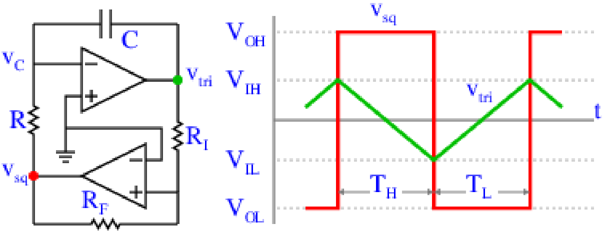


Uses $R_F = 100\,\mathrm{k}\Omega$, $R_I = 33\,\mathrm{k}\Omega$, $R = 100\,\mathrm{k}\Omega$, and $C = 10\,\mathrm{nF}$.
IC: TL084, Supply: ± 12 V.

Output: Oscillator A



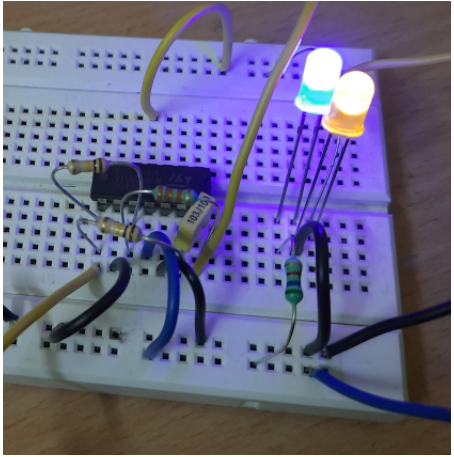
Oscillator B



$$T_H = RC\frac{V_{\mathrm{IH}} - V_{\mathrm{IL}}}{V_{\mathrm{OH}}}. \tag{8}$$

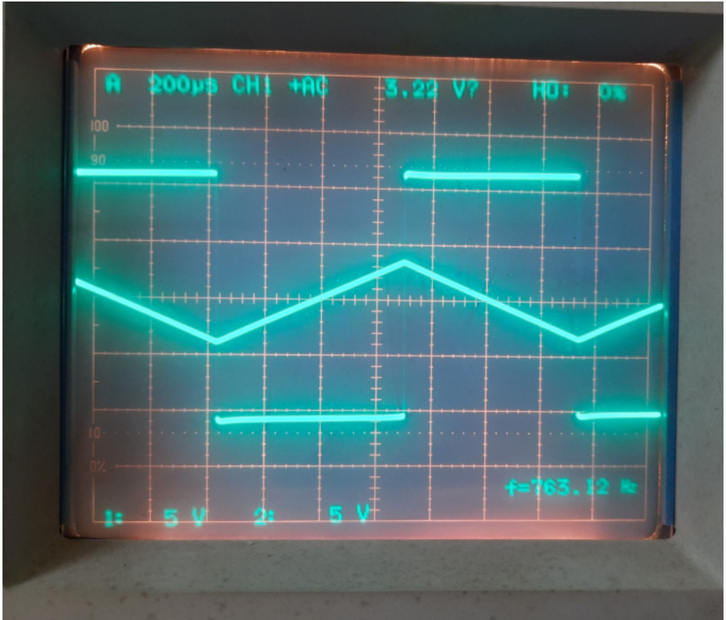
$$T_L = RC\frac{V_{\mathrm{IH}} - V_{\mathrm{IL}}}{-V_{\mathrm{OL}}}. \tag{9}$$

Here, $V_{\mathrm{IH}} = -\frac{R_I}{R_F}V_{\mathrm{OL}}$, and $V_{\mathrm{IL}} = -\frac{R_I}{R_F}V_{\mathrm{OH}}$. These were obtained by setting $V_R = 0$ in the expressions given for the positive comparator with hysteresis.
This oscillator has both square wave and triangle wave outputs.



Uses $R_F = 100\,\mathrm{k}\Omega$, $R_I = 33\,\mathrm{k}\Omega$, $R = 100\,\mathrm{k}\Omega$, and $C = 10\,\mathrm{nF}$.
IC: TL084, Supply: ± 12 V.

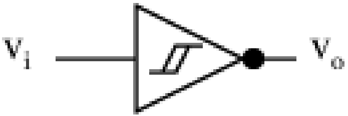
Output: Oscillator B



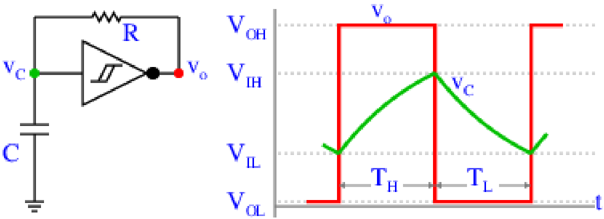
Schmitt Trigger Inverter

- Logic inverter designed to have hysteresis
- Improves noise immunity
- Frequently used in interfacing
- Examples: 74LS14, 74HC14, 74HCT14
- Can be used for making an RC oscillator
- Similar to Oscillator A

Symbol: Schmitt Trigger Inverter



RC Oscillator using an inverting Schmitt Trigger

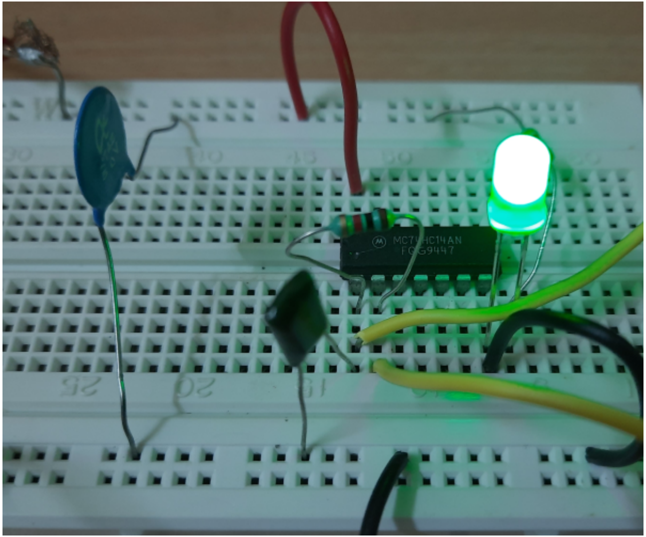


$$T_H = RC \ln \frac{V_{\mathrm{OH}} - V_{\mathrm{IL}}}{V_{\mathrm{OH}} - V_{\mathrm{IH}}}. \qquad (10)$$

$$T_L = RC \ln \frac{V_{\mathrm{IH}} - V_{\mathrm{OL}}}{V_{\mathrm{IL}} - V_{\mathrm{OL}}}. \qquad (11)$$

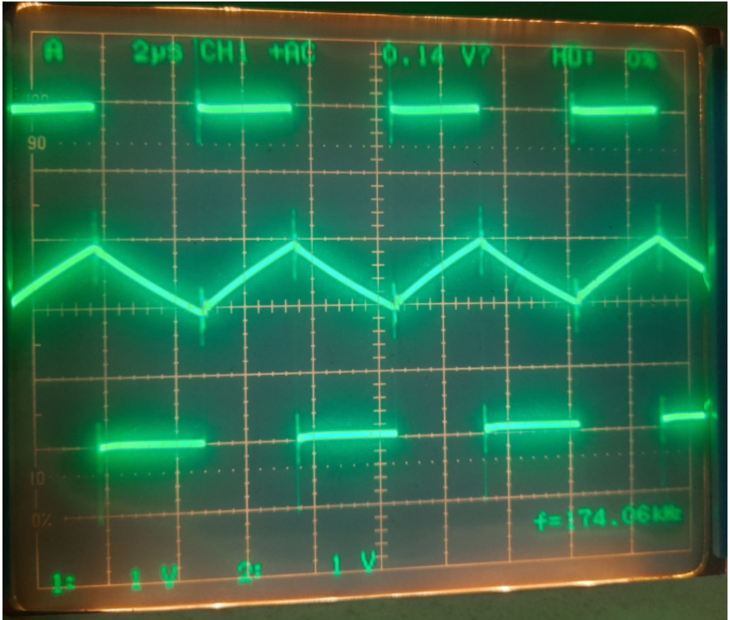
V_{OH}, V_{OL}, V_{IH}, and V_{IL} are to be obtained from IC data sheet or measured.
For CMOS gates, $V_{\mathrm{OH}} = V_{\mathrm{DD}}$, $V_{\mathrm{OL}} = 0$.
Many oscillators used in digital systems are of this type.

Implementation: 74HC14 RC Oscillator



Uses $R = 1\,\mathrm{k}\Omega$, and $C = 6.8\,\mathrm{nF}$.

Output: 74HC14 RC Oscillator



Calculation: 74HC14 RC Oscillator

From the output display, $V_{\mathrm{OH}} = 5\,\mathrm{V}$, $V_{\mathrm{OL}} = 0\,\mathrm{V}$, $V_{\mathrm{IH}} = 3\,\mathrm{V}$, $V_{\mathrm{IL}} = 2\,\mathrm{V}$.
Using $R = 1\,\mathrm{k}\Omega$, and $C = 6.8\,\mathrm{nF}$ we get $T_H = 2.7572\,\mu\mathrm{s}$, and $T_L = 2.7572\,\mu\mathrm{s}$.
Calculated period $T = T_H + T_L = 5.5143\,\mu\mathrm{s}$.
Calculated frequency $f = 1/T = 181.35\,\mathrm{kHz}$.
The measured frequency (as seen on the screen) is 174.06 kHz.