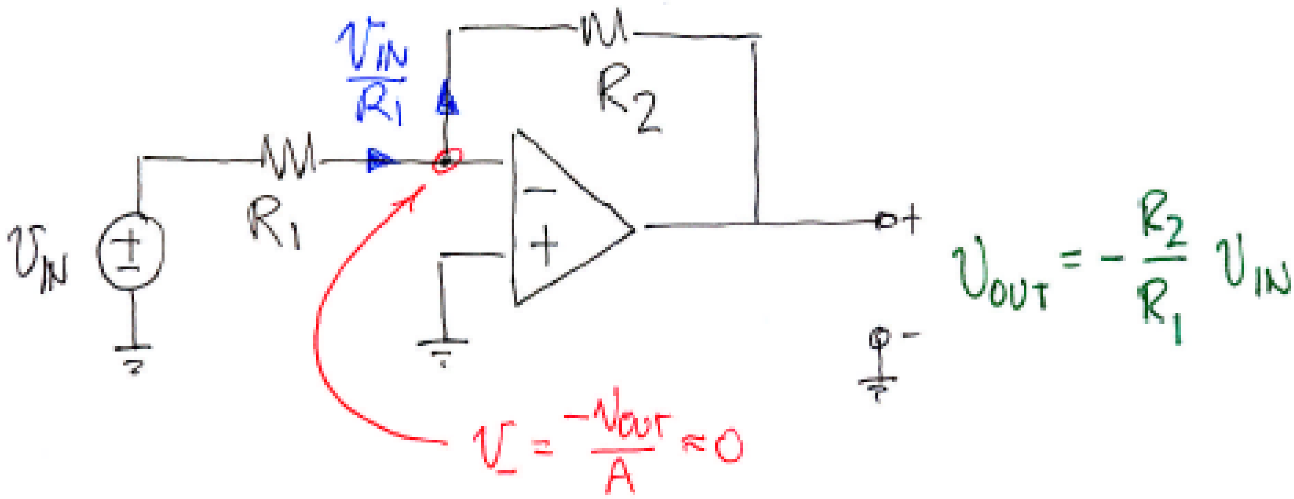
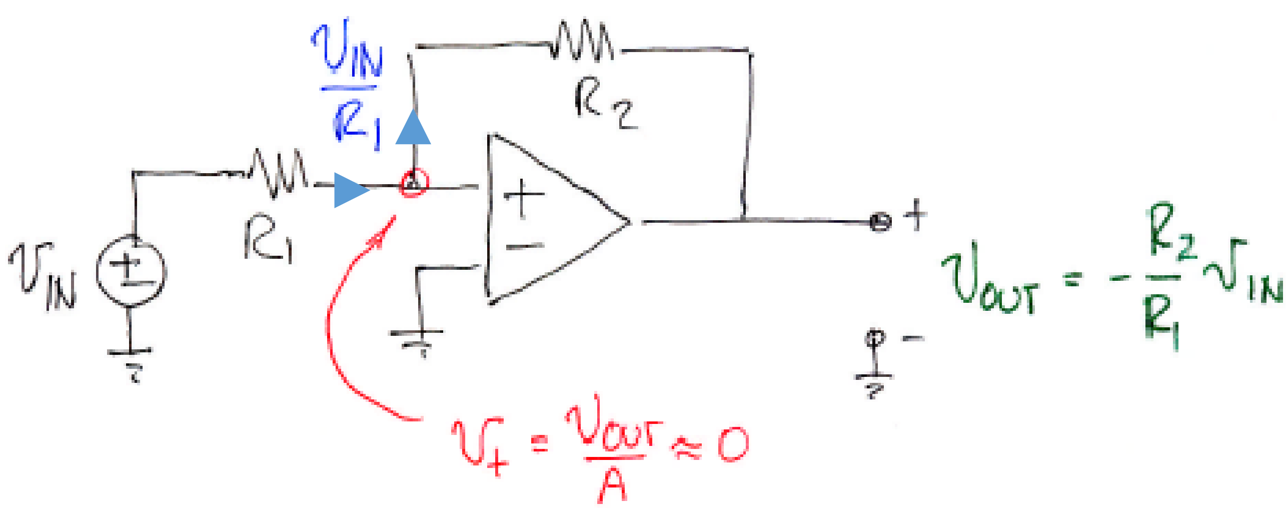
6.002 - Lecture 14

Stability

- Static Equilibria
- Pos/Neg Feedback
- Dynamics & Stability
- Comparators
- Schmitt Trigger
- Relaxation Oscillator

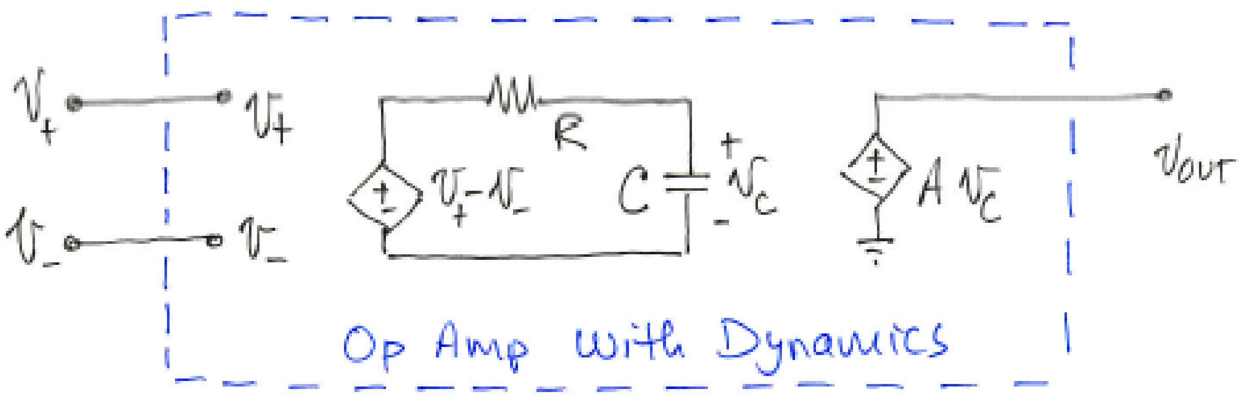
Equilibria



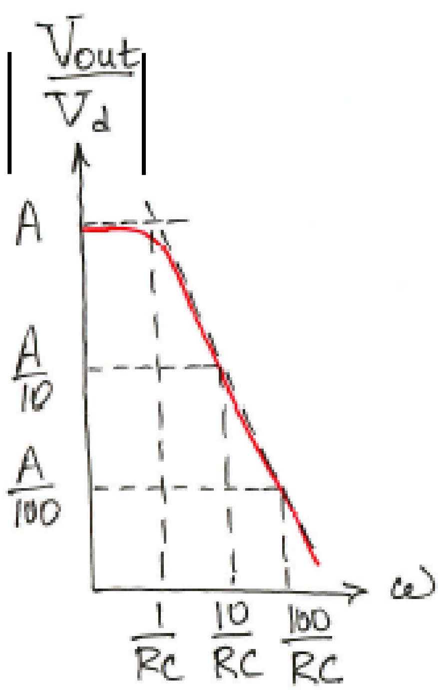


Do these two circuits really behave in the same way?

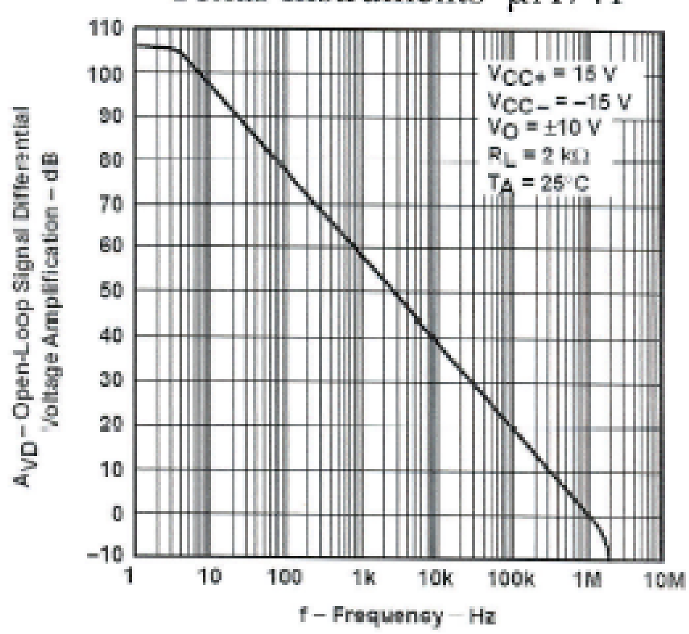
Op Amp Dynamics



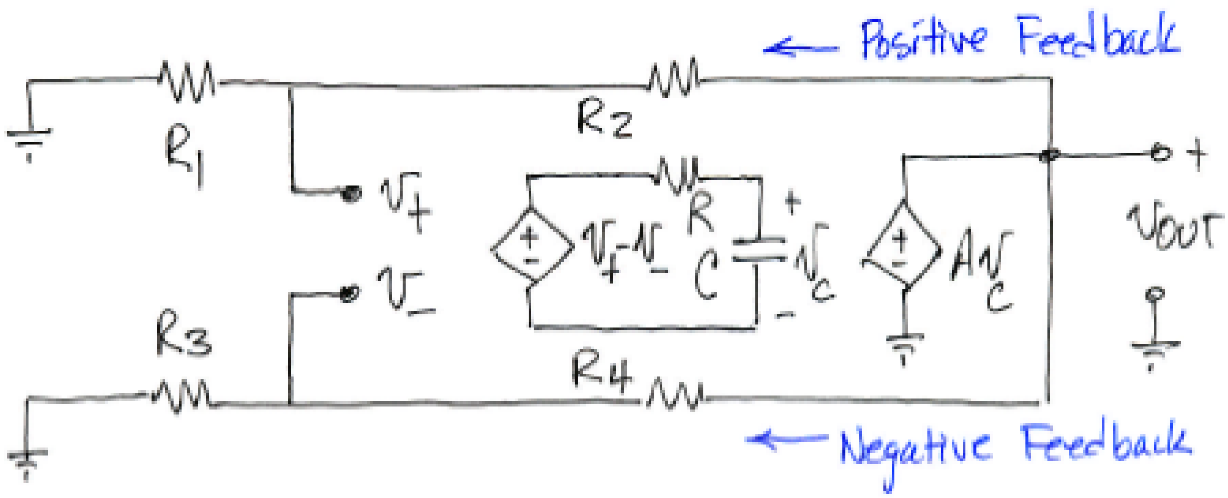
$$v_+ - v_- \equiv v_D \rightarrow V_d e^{j\omega t} \quad \Rightarrow \quad v_{out} \rightarrow \frac{A V_d}{1 + j\omega RC} e^{j\omega t}$$



Texas Instruments μA741



Amplifier Dynamics I



$$v_{out} = A\, v_c$$

$$RC \frac{dv_c}{dt} + v_c = v_+ - v_-$$

$$v^+ = \frac{R_1}{R_1 + R_2} v_{out} \equiv \overset{+}{\delta}\, v_{out} \quad \text{(Positive Feedback)}$$

$$v^- = \frac{R_3}{R_3 + R_4} v_{out} \equiv \bar{\delta}\, v_{out} \quad \text{(Negative Feedback)}$$

Small as $A \to \infty$

$$\frac{RC}{A} \frac{dv_{out}}{dt} + \left[\frac{1}{A} + \bar{\delta} - \overset{+}{\delta} \right] v_{out} = 0$$

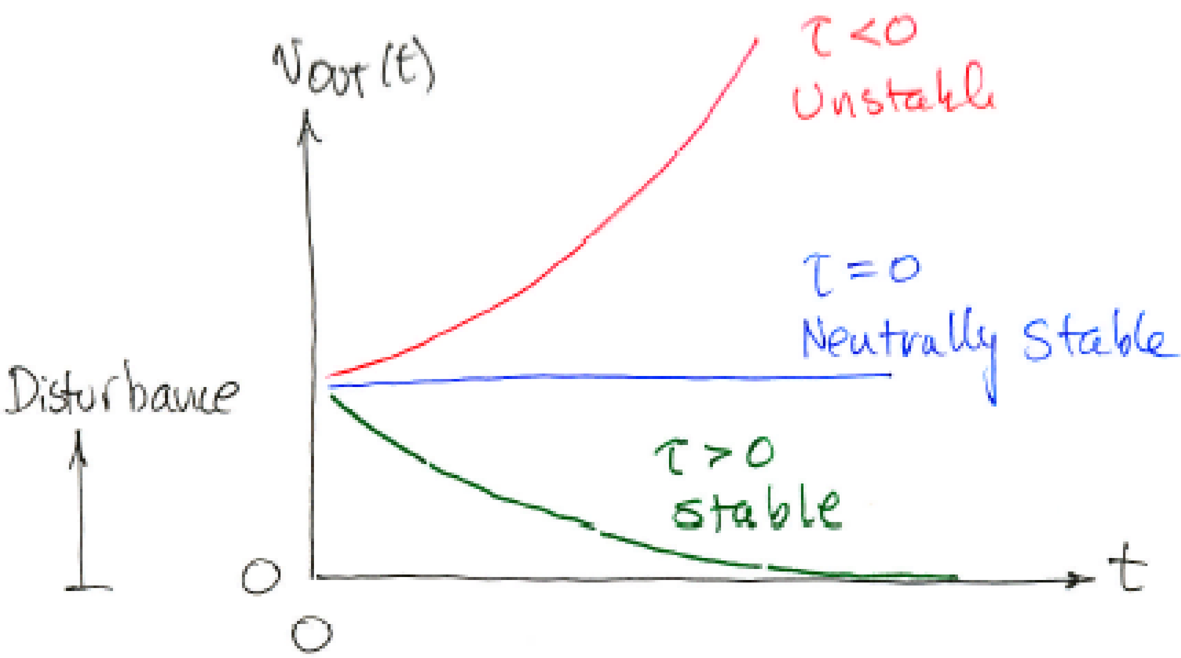
$$\frac{dv_{out}}{dt} + \frac{A(\bar{\delta} - \overset{+}{\delta})}{RC} v_{out} = 0$$

Amplifier Dynamics II

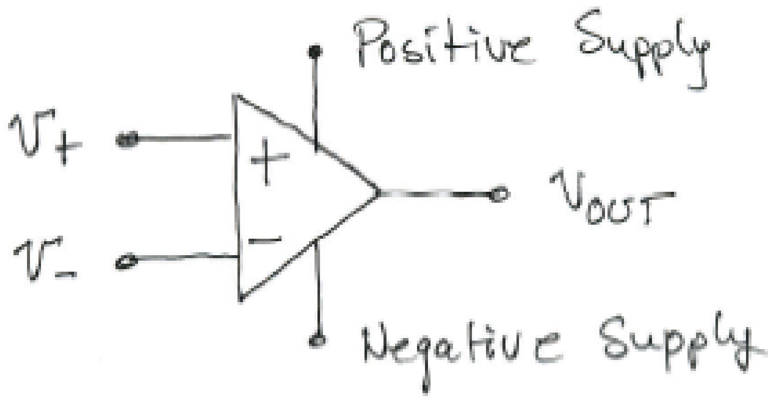
$$\frac{dV_{out}}{dt} + \frac{1}{\tau} V_{out} = 0 \qquad \tau = \frac{RC}{A(\gamma^- - \gamma^+)}$$

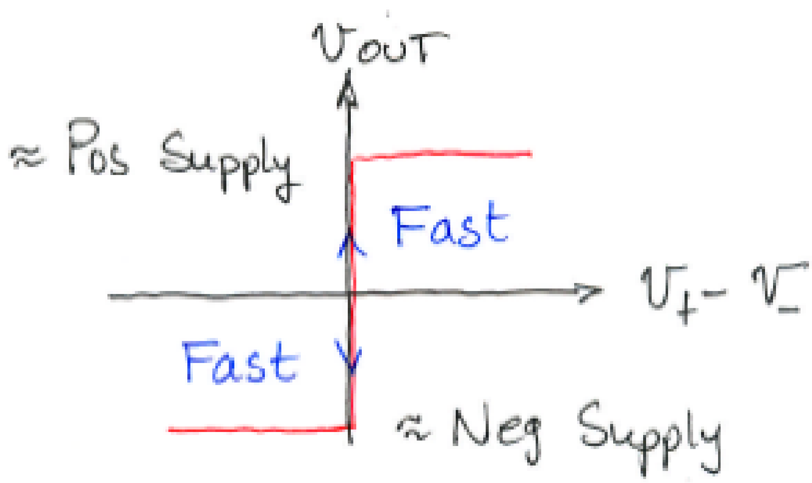
$$V_{out}(t) = V_{out}(0)\, e^{-t/\tau}$$

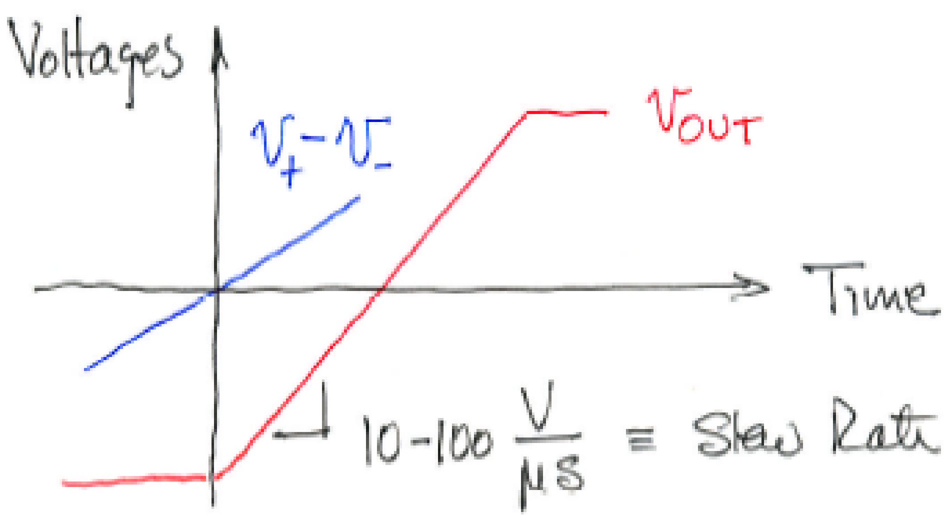
$$\tau \begin{cases} >0 & \gamma^- > \gamma^+ \quad \text{Negative Feedback} \\ =0 & \gamma^- = \gamma^+ \quad \text{Neutral Feedback} \\ <0 & \gamma^- < \gamma^+ \quad \text{Positive Feedback} \end{cases}$$



Comparators

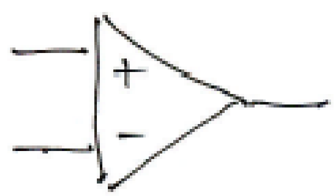






Op Amp ↔ Comparator I

In 6.002, the device



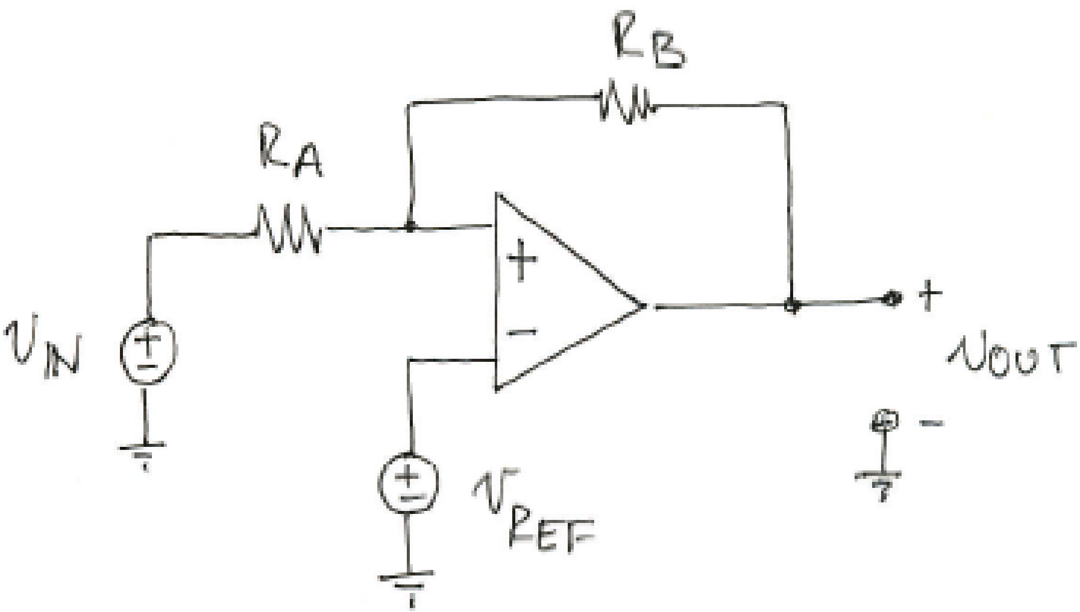
represents an amplifier, usually having ideal properties. It can be used in both negative-feedback amplification (Op-Amp) applications, and positive-feedback comparison (Comparator) applications.

Op Amp ↔ Comparator II

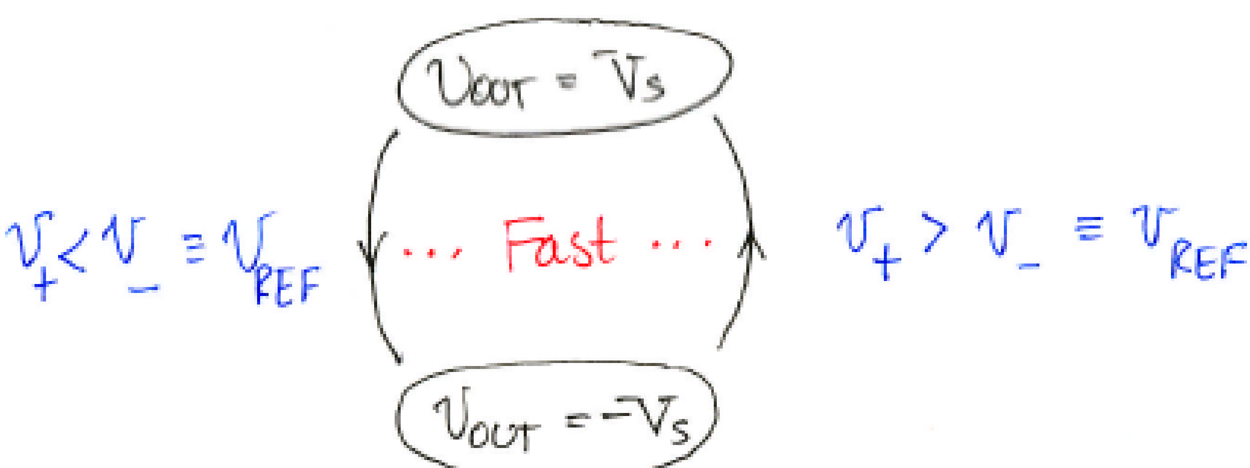
Op-Amp ⇒ Designed to be largely linear, and for use in negative feedback applications. Implemented with a few high-gain stages having modest bandwidth.

Comparators ⇒ Designed to be very fast, and for use in open-loop applications or with positive feedback. Often implemented with many very fast stages having modest gain. May employ positive feedback for high-speed.

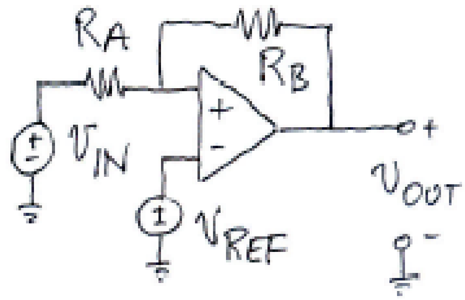
Schmitt Trigger I



Could interchange roles of v_{IN} and v_{REF}.



Schmitt Trigger II



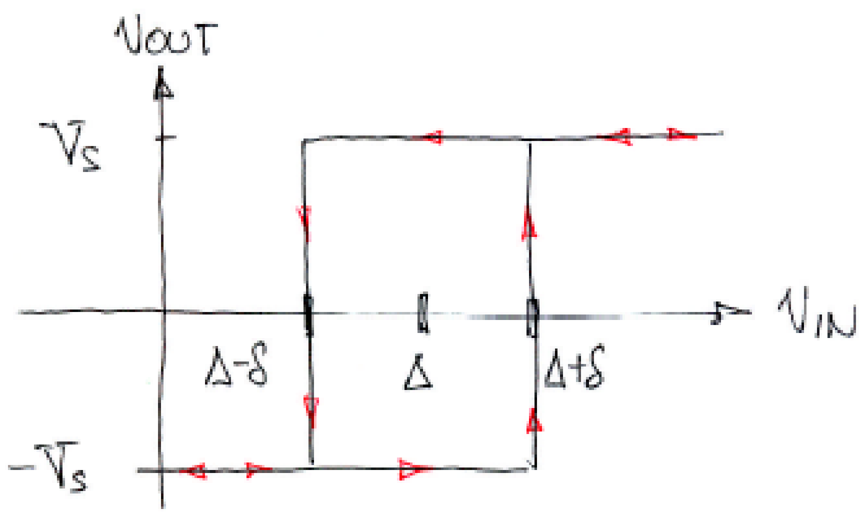
$-\bar{V}_S \rightarrow +\bar{V}_S$ Transition:

$$v_{OUT}\frac{R_A}{R_A+R_B} + v_{IN}\frac{R_B}{R_A+R_B} > v_{REF} \Rightarrow v_{IN} > \frac{R_A+R_B}{R_B} v_{REF} + \frac{R_A}{R_B}\bar{V}_S$$

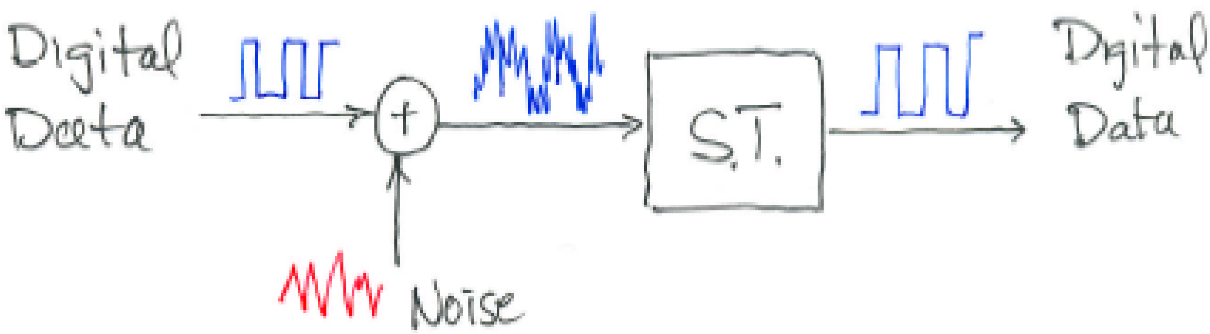
$$\Delta \pm \delta$$

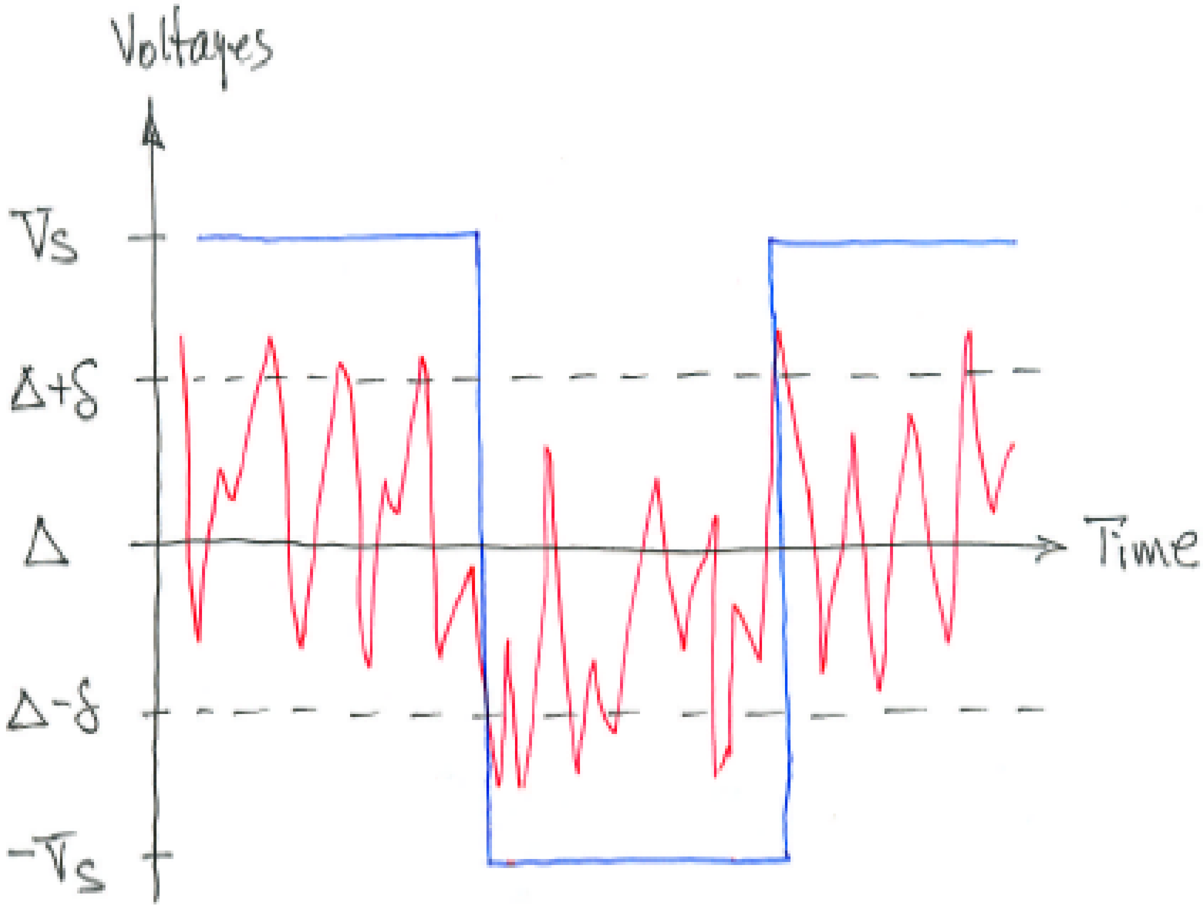
$+\bar{V}_S \rightarrow -\bar{V}_S$ Transition:

$$v_{OUT}\frac{R_A}{R_A+R_B} + v_{IN}\frac{R_B}{R_A+R_B} < v_{REF} \Rightarrow v_{IN} < \frac{R_A+R_B}{R_B} v_{REF} - \frac{R_A}{R_B}\bar{V}_S$$



Schmitt Trigger Application





Oscillator