LAST TIME:

OP AMP CIRCUITS USING THE "GOLDEN RULES" (CH. 29)
  * INVERTING AMP
  * INVERTING ADDER
  * NON-INVERTING ADDER
  * SUBTRACTOR

TODAY:

OP AMP CIRCUITS WITHOUT NEGATIVE FEEDBACK (CH. 34)
  * HOW TO ANALYZE THEM
  * COMPARATOR
  * SCHMIDT TRIGGER
RECALL THE "GOLDEN RULES"

I. \( V_+ = V_- \)

**Assumptions:**
- \( \infty \) "Open Loop" Gain, A
- 0 Offset Voltage
- 0 Offset Feedback
- Active Mode (Output Voltage "Between the Rails")

II. \( n_+ = n_- = 0 \)

**Assumptions:**
- Input Impedance > Impedance of CIRCUITS connected to the inputs.

WE NOW CONSIDER CIRCUITS without NEGATIVE FEEDBACK.

INSTEAD OF RULE I, WE USE THE OPEN LOOP GAIN EQUATION:

\[
V_{\text{OUT}} = A (V_+ - V_- - V_{\text{OFFSET}})
\]

- Very often, we ignore \( V_{\text{OFFSET}} \).
- If the Op Amp is "Ideal", \( V_{\text{OFFSET}} = 0 \), \( A \rightarrow \infty \), so

\[
V_{\text{OUT}} = \begin{cases} 
V_H, & V_+ > V_- \\
V_L, & V_+ < V_- 
\end{cases}
\]

**OP AMP used as a Comparator**

To make YES or NO DECISIONS.

IN REAL APPLICATIONS, YOU SHOULD LOOK AT GAIN & OFFSET OF THE DEVICE TO ENSURE IT WILL WORK FOR YOUR APPLICATION:

\[
\frac{V_H - V_L}{\Delta V} = A
\]
COMPARATOR EXAMPLE

Design a comparator circuit that switches "on" when $V_{in} > 5V$. Your power supply is $\pm 10V$, no ground provided!

![Comparator Circuit Diagram]

Q: What if we wanted the circuit to turn "off" for $V_{in} > 5V$ ("on" for $V_{in} < 5V$)?

A:

![Comparator Circuit Diagram]
COMPARATOR EXAMPLE

DESIGN CRITERIA:

- Assume water R << 1MΩ
- Keep the water at the desired level.
- Don’t electrocute the fish!
- Use single-ended supply (+6V and ground only)

POSSIBLE ISSUES:

- Leakage thru motor when V_{out} = V_L > 0
  \[ \rightarrow \text{solve using D1 (assumes V_L < 0.6V)} \]
- Frequent on-off switching — could wear out the pump motor!
  \[ \rightarrow \text{what we need is hysteresis, which can be provided by a Schmitt trigger...} \]

NOTE: Special purpose comparators are manufactured with modest gain and high slew rate (fast response time).
**Schmitt Trigger**  (Inverting type, as in Faissler, fig 34-5a)

![Schmitt Trigger Diagram](image)

Looks like a non-inverting amplifier, but the polarity of the op amp is switched, so the feedback is positive.

Analyzing the node at \( V_+ \),

\[
\frac{V_b - V_+}{R_2} + \frac{V_{out} - V_+}{R_1} = 0 \quad \Rightarrow \quad V_+ = \frac{R_1 V_b + R_2 V_{out}}{R_1 + R_2}
\]

Assume \( A \to \infty \) and \( V_{offset} = 0 \).

**Case I**: \( V_+ > V_- \) \( \Rightarrow \) \( V_{out} = V_H \)

So \( V_- < V_+ \) \( \Rightarrow \) \( V_- = \frac{R_1 V_b + R_2 V_H}{R_1 + R_2} \)

**Case II**: \( V_+ < V_- \) \( \Rightarrow \) \( V_{out} = V_L \)

\( V_- > V_+ \) \( \Rightarrow \) \( V_- = \frac{R_1 V_b + R_2 V_L}{R_1 + R_2} \)

Let

\[
V_{+H} = \frac{R_1 V_b + R_2 V_H}{R_1 + R_2}
\]

\[
V_{+L} = \frac{R_1 V_b + R_2 V_L}{R_1 + R_2}
\]

Since \( V_H > V_L \), \( V_{+H} > V_{+L} \).

- Increasing \( V_{in} \) past \( V_{+H} \) causes \( V_{out} \to V_H \).
- Decreasing \( V_{in} \) past \( V_{+L} \) causes \( V_{out} \to V_L \).

*Note: Choice of \( V_0 \) can make \( V_{+H} \) and \( V_{+L} \) both + or −, or they can straddle the origin as drawn above.*
Q: How could the Schmitt trigger be used to decrease the number of on-off cycles for the water pump?

A: Need a water sensor that gives different values for different depths. For example:

\[ V_- = \begin{cases} 
0V, & h \leq \text{low} \\
3V, & \text{low} < h < \text{high} \\
6V, & h \geq \text{high} 
\end{cases} \]

Now, set up Schmitt thresholds \( V_{+L} \), \( V_{+H} \) such that

\[ 0 < V_{+L} < 3V, \]
\[ 3V < V_{+H} < 6V. \]

Result:

\( V_- < V_{+L} \Rightarrow h \leq \text{low} \Rightarrow \text{pump on} \)
\( V_- > V_{+H} \Rightarrow h \geq \text{high} \Rightarrow \text{pump off} \)

Now, set up Schmitt thresholds \( V_{+L}, V_{+H} \) such that

\[ 0 < V_{+L} < 3V, \]
\[ 3V < V_{+H} < 6V. \]

Result:

\( V_- < V_{+L} \Rightarrow h \leq \text{low} \Rightarrow \text{pump on} \)
\( V_- > V_{+H} \Rightarrow h \geq \text{high} \Rightarrow \text{pump off} \)