Last few lectures:

OP AMP CIRCUITS USING THE "GOLDEN RULES" (CH. 29)

- INVERTING AMP
- INVERTING ADDER
- NON-INVERTING ADDER
- SUBTRACTOR
- Current source
- Current (transimpedance) amplifier

TODAY!

All these examples used negative feedback!

OP AMP CIRCUITS WITHOUT NEGATIVE FEEDBACK (CH. 34)

- HOW TO ANALYZE THEM
- COMPARATOR
- SCHMITT TRIGGER

RECALL THE "GOLDEN RULES"

I. $V_+ = V_-$

ASSUMPTIONS: ∞ "OPEN LOOP" GAIN, A
0 OFFSET VOLTAGE
NEGATIVE FEEDBACK
ACTIVE MODE (OUTPUT VOLTAGE "BETWEEN THE RAILS")

II. $i_+ = i_- = 0$

ASSUMPTIONS: INPUT IMPEDANCE >> IMPEDANCE OF CIRCUITS CONNECTED TO THE INPUTS.

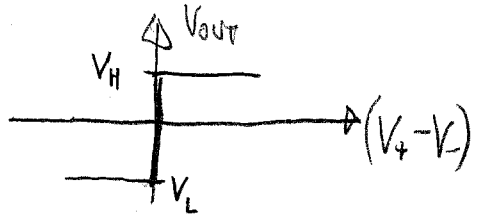
WE NOW CONSIDER CIRCUITS <u>WITHOUT NEGATIVE FEEDBACK</u>.

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

$$V_{OUT} = A(V_+ - V_- - V_{OFFSET})$$

- VERY OFTEN, WE IGNORE V_{OFFSET}.
- IF THE OP AMP IS "IDEAL", $V_{OFFSET} = 0$, $A \to \infty$, SO

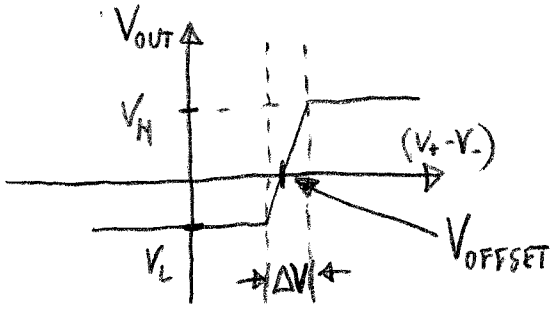
$$V_{OUT} = \begin{cases} V_H, & V_+ > V_- \\ V_L, & V_+ < V_- \end{cases}$$



OP AMP USED AS A <u>COMPARATOR</u>

TO MAKE <u>YES OR NO DECISIONS.</u>

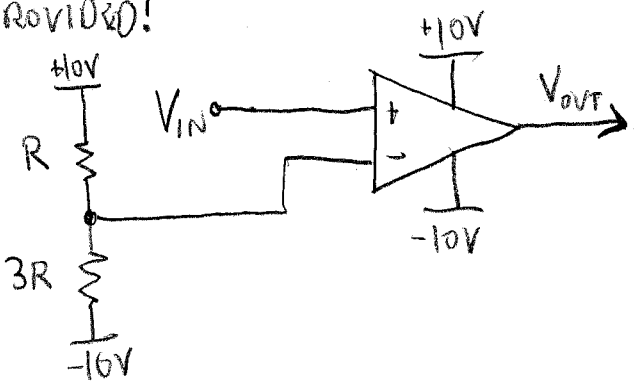
IN REAL APPLICATIONS, YOU SHOULD LOOK AT GAIN & OFFSET OF THE DEVICE TO ENSURE IT WILL WORK FOR YOUR APPLICATION:



$$\frac{V_H - V_L}{\Delta V} = A$$

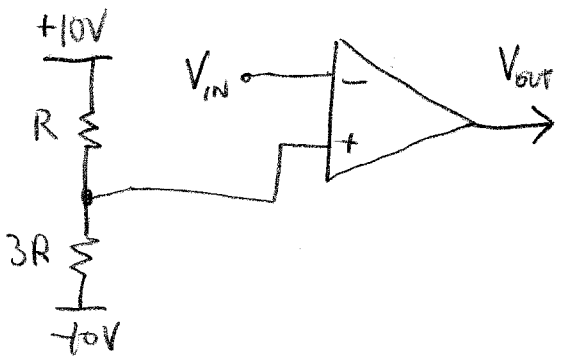
COMPARATOR EXAMPLE

DESIGN A COMPARATOR CIRCUIT THAT SWITCHES "ON" WHEN $V_{IN} > 5V$. YOUR POWER SUPPLY IS $\pm 10V$, NO GROUND PROVIDED!

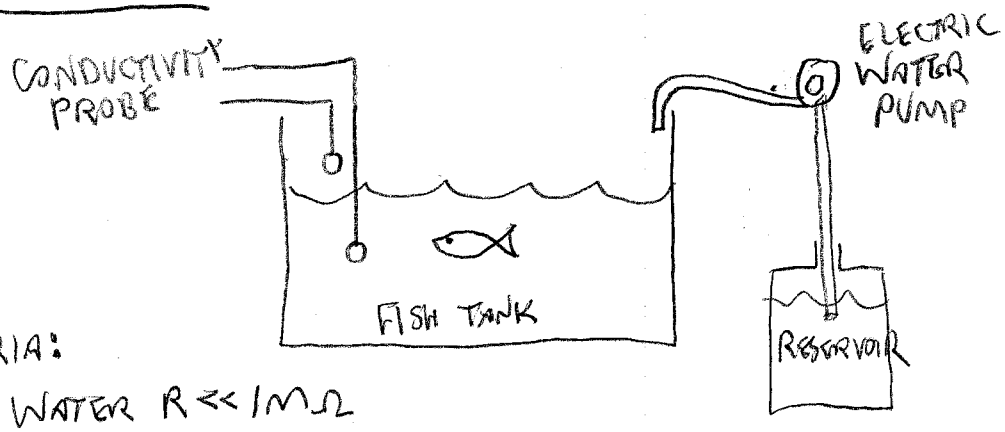


Q: WHAT IF WE WANTED THE CIRCUIT TO TURN "OFF" FOR $V_{IN} > 5V$ ("ON" FOR $V_{IN} < 5V$)?

A:

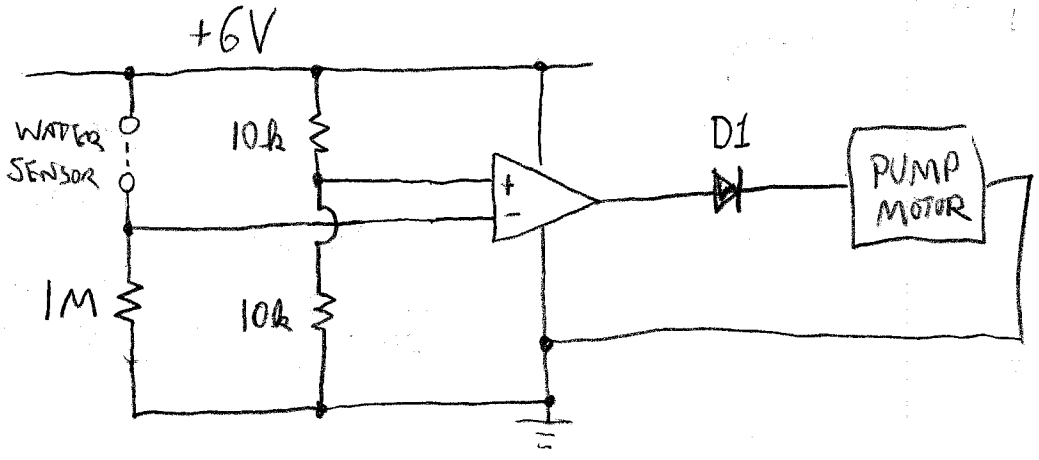


COMPARATOR EXAMPLE



DESIGN CRITERIA:

- ASSUME WATER $R \ll 1M\Omega$
- KEEP THE WATER AT THE DESIRED LEVEL.
- DON'T ELECTROCUTE THE FISH!
- USE SINGLE-ENDED SUPPLY (+6V AND GROUND ONLY)

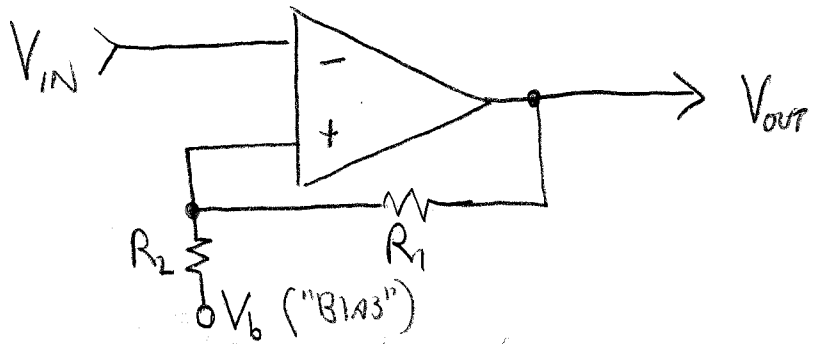


POSSIBLE ISSUES:

- LEAKAGE THRU MOTOR WHEN $V_{OUT} = V_L > 0$
  → SOLVE USING D1 (ASSUMES $V_L < 0.6V$)
- FREQUENT ON-OFF SWITCHING — COULD WEAR OUT THE PUMP MOTOR!
  → 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)



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 $\boxed{V_- < V_+ = \frac{R_1 V_b + R_2 V_H}{R_1 + R_2}}$

CASE II: $V_+ < V_- \Rightarrow V_{OUT} = V_L$,

$\boxed{V_- > V_+ = \frac{R_1 V_b + R_2 V_L}{R_1 + R_2}}$

LET

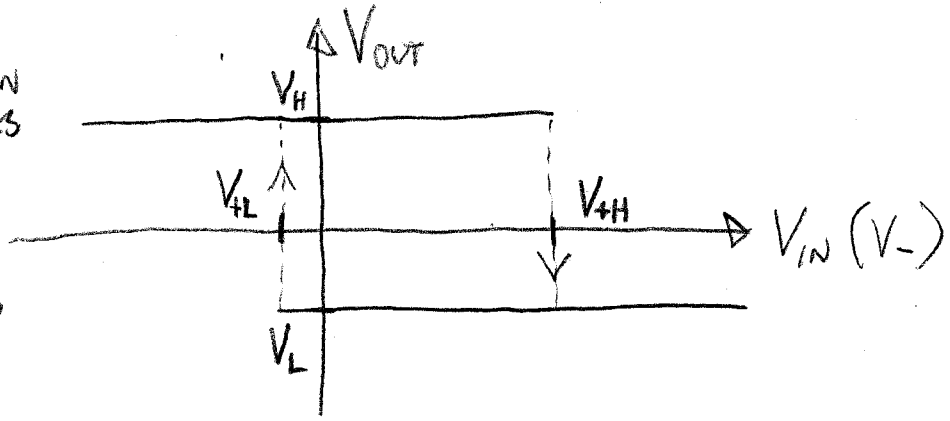
$V_{+H} \equiv \frac{R_1 V_b + R_2 V_H}{R_1 + R_2}$

$V_{+L} \equiv \frac{R_1 V_b + R_2 V_L}{R_1 + R_2}$

SINCE $V_H > V_L$,

$V_{+H} > V_{+L}$.

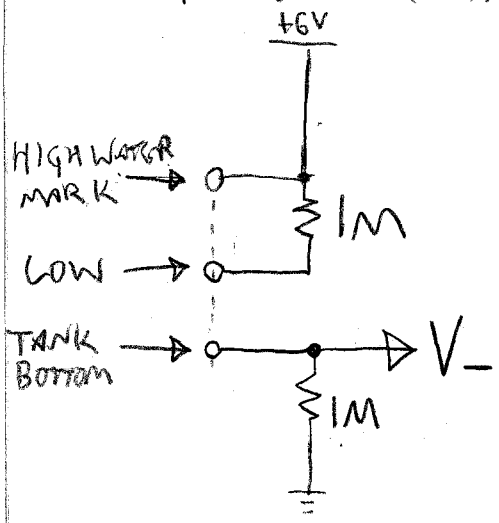
- INCREASING V_{IN} PAST V_{+H} CAUSES $V_{OUT} \to V_H$.
- DECREASING V_{IN} PAST V_{+L} CAUSES $V_{OUT} \to V_L$.



NOTE: CHOICE OF V_b 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_{+H}, V_{+L} SUCH THAT

$$0 < V_{+L} < 3V,$$

$$3V < V_{+H} < 6V$$

RESULT: $V_- < V_{+L} \Rightarrow h \leq \text{LOW} \Rightarrow$ PUMP ON

$V_- > V_{+H} \Rightarrow h \geq \text{HIGH} \Rightarrow$ PUMP OFF