

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
- SCHMITT TRIGGER

SHARP

RECALL THE "GOLDEN RULES"

I.  $V_+ = V_-$

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

II.  $i_+ = i_- = 0$

- ASSUMPTIONS: INPUT IMPEDANCE  $\gg$  IMPEDANCE OF  
 CIRCUITS CONNECTED TO THE INPUTS.

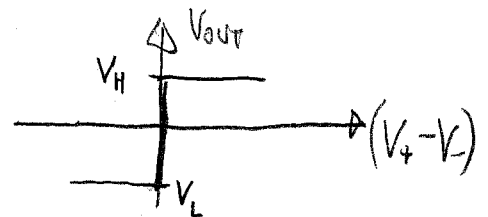
WE NOW CONSIDER CIRCUITS WITHOUT NEGATIVE FEEDBACK.

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

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

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

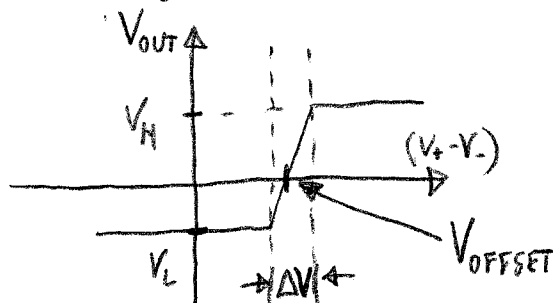
$$V_{OUT} = \begin{cases} V_H, & V_+ > V_- \\ V_L, & V_+ < V_- \end{cases}$$



★ OP AMP USED AS A COMPARATOR

TO MAKE YES OR NO DECISIONS.

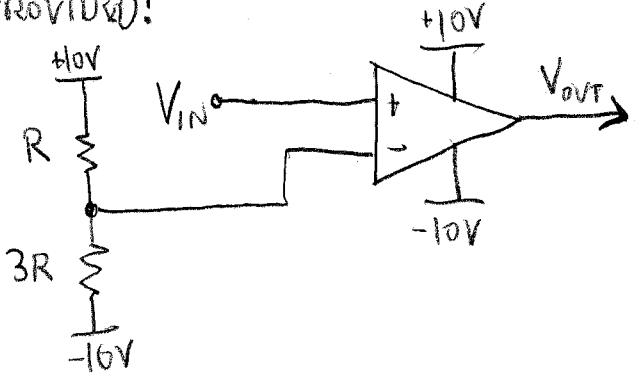
IN REAL APPLICATIONS, YOU SHOULD LOOK AT GAIN & OFFSET OF THE DEVICE TO ENSURE IT WILL WORK FOR YOUR APPLICATION:



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

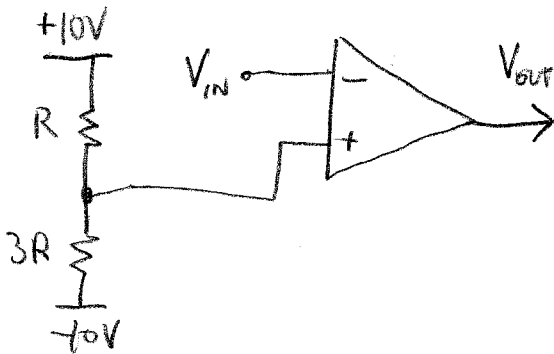
### COMPARATOR EXAMPLE

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



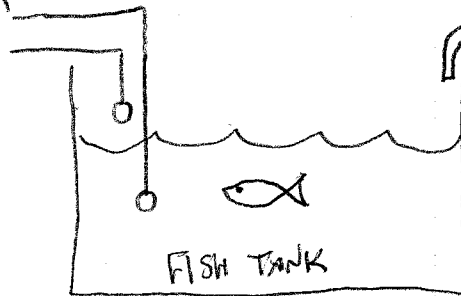
Q: WHAT IF WE WANTED THE CIRCUIT TO TURN "OFF" FOR  $V_{IN} > 5V$  ("ON" FOR  $V_{IN} < 5V$ ) ?

A:

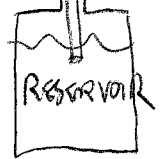


# COMPARATOR EXAMPLE

CONDUCTIVITY  
PROBE

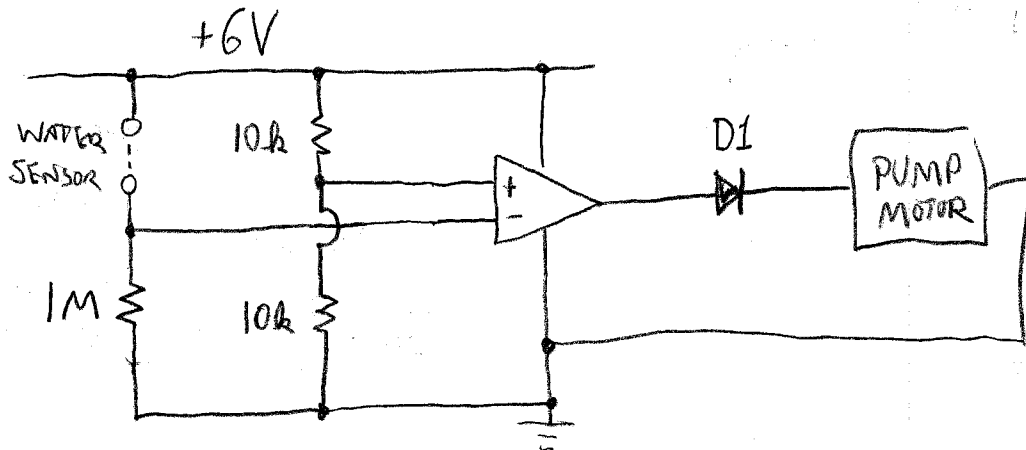


ELECTRIC  
WATER  
PUMP



## DESIGN CRITERIA:

- ASSUME WATER  $R \ll 1M\Omega$
- KEEP THE WATER AT THE DESIRED LEVEL.
- DONT ELECTROCUTE THE FISH!
- USE SINGLE-ENDED SUPPLY (+6V AND GROUND ONLY)

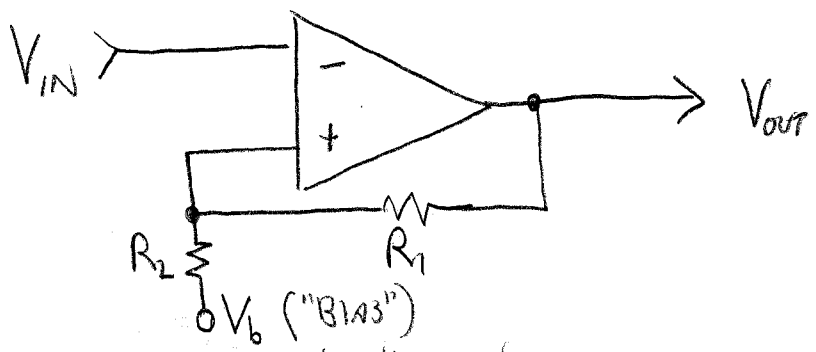


## POSSIBLE ISSUES:

- 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  $V_+$

$$\frac{V_b - V_+}{R_2} + \frac{V_{out} - V_+}{R_1} = 0 \Rightarrow V_+ = \frac{R_1 V_b + R_2 V_{out}}{R_1 + R_2}$$

ASSUME  $A \rightarrow \infty$  AND  $V_{offset} = 0$ .

CASE I:  $V_+ > V_- \Rightarrow V_{out} = V_H$

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

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

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

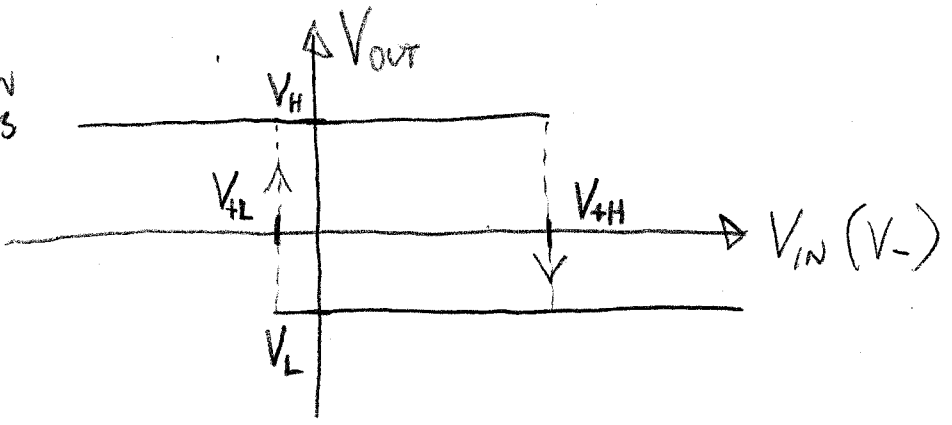
LET

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

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

SINCE  $V_H > V_L$ ,  
 $V_{+H} > V_{+L}$ .

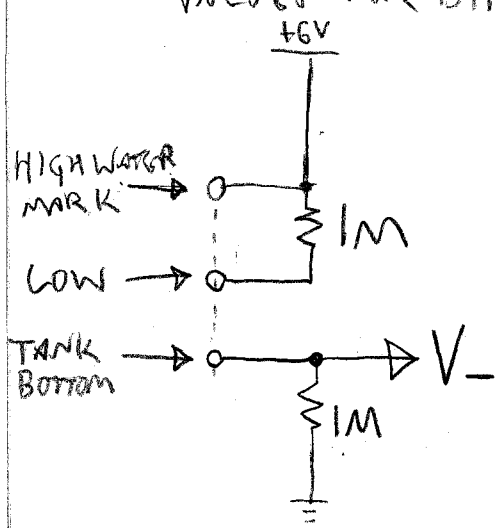
- INCREASING  $V_{in}$  PAST  $V_{+H}$  CAUSES  $V_{out} \rightarrow V_H$ .
- DECREASING  $V_{in}$  PAST  $V_{+L}$  CAUSES  $V_{out} \rightarrow V_L$ .



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

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

