ECEN 4013
Design of Engineering Systems

Agenda

Project 1 Questions
4024 Materials
New Sprint
Schmitt Triggers

Project 1

- Questions?

- It is now the first week of Sprint 2.

ECEN 4024 Materials

Throughout the semester I will provide presentation videos and slides for teams in 4024 so that you can get a feel for what is expected of you. Also, it helps to have knowledge of the projects because some of them are multi-semester, and you might find yourself

New Sprint

New Sprint

All completed stories will be moved to the "done" section of the backlog. Stories not finished will be moved to the next sprint.

New Sprint

New Sprint

Schmitt Trigger

Basic Op amp Comparator

If $V_{IN} > V_{REF}$ then $V_{OUT} = +V_{CC}$
If $V_{IN} < V_{REF}$ then $V_{OUT} = -V_{CC}$
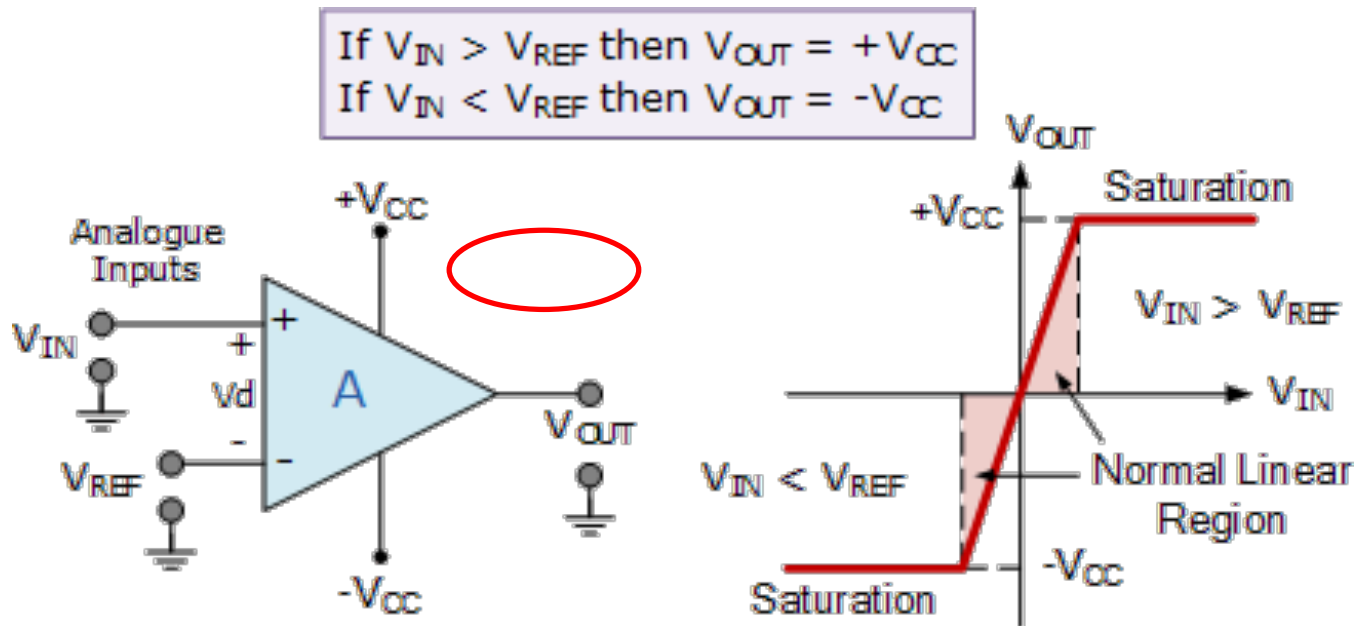
What happens at the decision boundary?

Schmitt Trigger

- Why are Schmitt Triggers used?
  - The hysteresis loop is beneficial. There are two thresholds, a low to high and a high to low. This effectively reduces noise in the stage where you are very close to your decision line
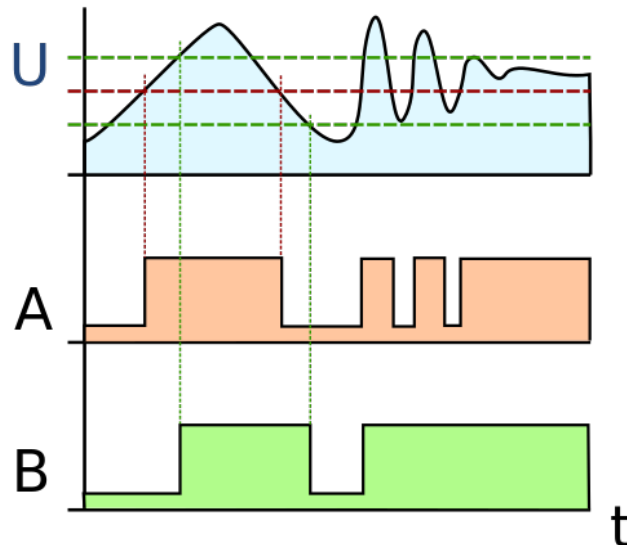
Schmitt Trigger
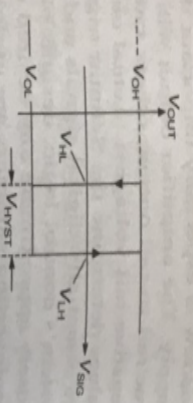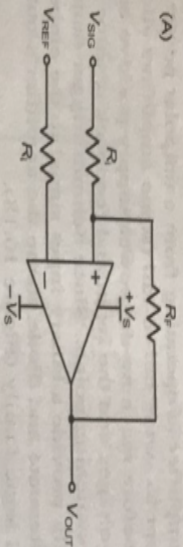
(A)

$$V_{LH} = V_{REF}\left(\frac{R_i + R_F}{R_F}\right) - \left(\frac{R_i}{R_F}\right)V_{OL}$$

$$V_{HL} = V_{REF}\left(\frac{R_i + R_F}{R_F}\right) - \left(\frac{R_i}{R_F}\right)V_{OH}$$

$$V_{HYST} = V_{LH} - V_{HL} = \left(\frac{R_i}{R_F}\right)(V_{OH} - V_{OL})$$

(B)
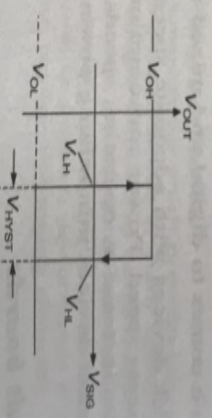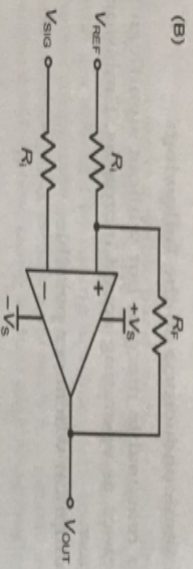
$$V_{HL} = \frac{1}{R_i + R_F}(R_F V_{REF} + R_i V_{OH})$$

$$V_{LH} = \frac{1}{R_i + R_F}(R_F V_{REF} + R_i V_{OL})$$

$$V_{HYST} = V_{HL} - V_{LH} = \frac{R_i}{R_i + R_F}(V_{OH} - V_{OL})$$

Figure 10.18: (A) and (B): Schmitt-trigger implementations.

In (A), the reference voltage is applied to the inverting input, whereas in (B) the reference voltage is applied to the noninverting input. Notice the effect of output voltage on the switching voltages. This effect is especially pronounced when a unipolar power supply is used and $-V_s = 0$.

Derivation of Schmitt trigger relationships – form A

A Schmitt trigger has two possible output states and two switching points – one when the input signal is low and going high, the other when the input signal is high and going low.

The circuit is clearly nonlinear, but analysis can be done using techniques of conventional linear op amp analysis.

Derivation of Schmitt trigger relationships – form A

There are two inputs: the signal input and a voltage reference input.

The voltage reference is the approximate middle of the switching hysteresis loop.

*** The reference voltage will be the center of the loop if using a bipolar supply and an amplifier with rail-to-rail outputs.

Derivation of Schmitt trigger relationships – form A

$$V_{LH} = V_{REF}\left(\frac{R_i + R_F}{R_F}\right) - \left(\frac{R_i}{R_F}\right)V_{OL}$$

$$V_{HL} = V_{REF}\left(\frac{R_i + R_F}{R_F}\right) - \left(\frac{R_i}{R_F}\right)V_{OH}$$

$$V_{HYST} = V_{LH} - V_{HL} = \left(\frac{R_i}{R_F}\right)(V_{OH} - V_{OL})$$
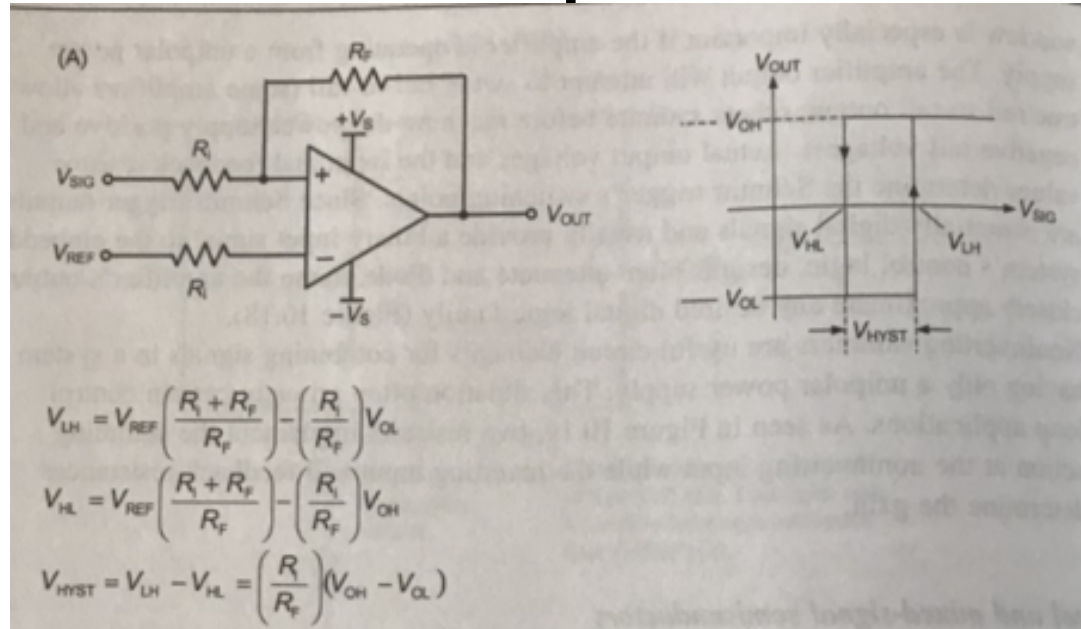
The input signal is assumed to be approaching the threshold from the left – that is, negative and going positive.

Derivation of Schmitt trigger relationships – form A

The amplifier will saturate positive when the noninverting input voltage exceeds the reference voltage present at the inverting input.

The amplifier will saturate negative when the reference voltage at the inverting input exceeds the voltage at the noninverting input.

Derivation of Schmitt trigger relationships – form A

Analysis of the two conditions and input node voltages are how we obtain the equations defining the switching points and the hysteresis window.

R_F

R_I

V_{IN} —/\/\/—

$+V_S$

V_{REF} —/\/\/—

R_I

$-V_S$

V_{OL}
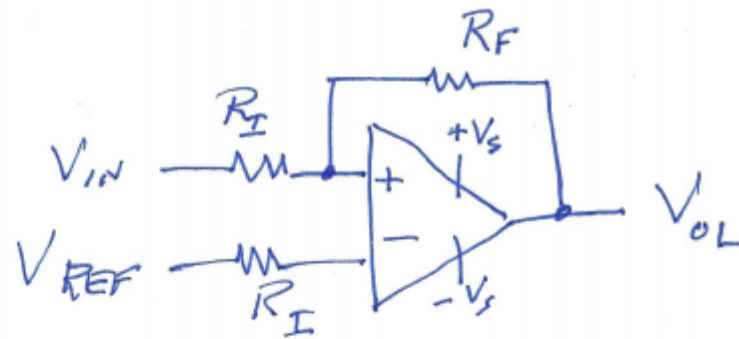
ASSUME

(1) $V_{IN} << V_{REF}$, SO THE AMPLIFIER OUTPUT IS SATURATED LOW AT V_{OL}.

$$V_{OL} \simeq -V_S$$

(2) WE INCREASE V_{IN} UNTIL THE AMPLIFIER OUTPUT SATURATES HIGH AT $V_{OH} \simeq +V_S$.

(3) WHAT IS THE LOW-HIGH TRANSITION VOLTAGE V_{LH}?

V_{OH}

0

V_{OL}

V_{LH}

$V_{IN} \rightarrow$
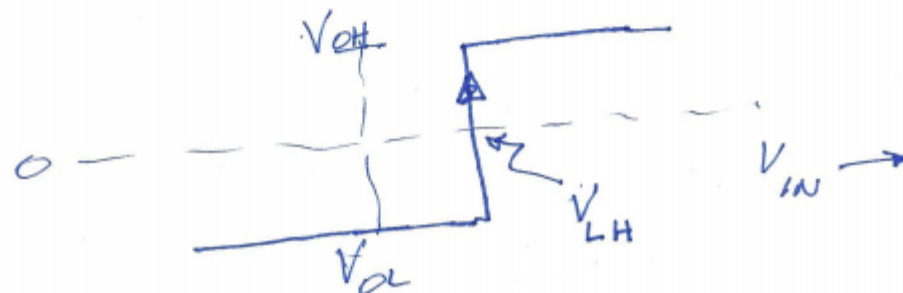
Schmitt trigger – form A

USE VOLTAGE DIVIDER AT NON-INVERTING INPUT

R_F

R_I

V_{IN}

V_{REF} R_I

V_{OL}

V_{REF}

INPUT

V_{LH}

R_I

V_{REF}

R_F

V_{OL}

OUTPUT IS LOW –
WHEN WILL IT GO
HIGH?
THAT IS V_{LH}?

WHEN + INPUT
EQUALS V_{REF}
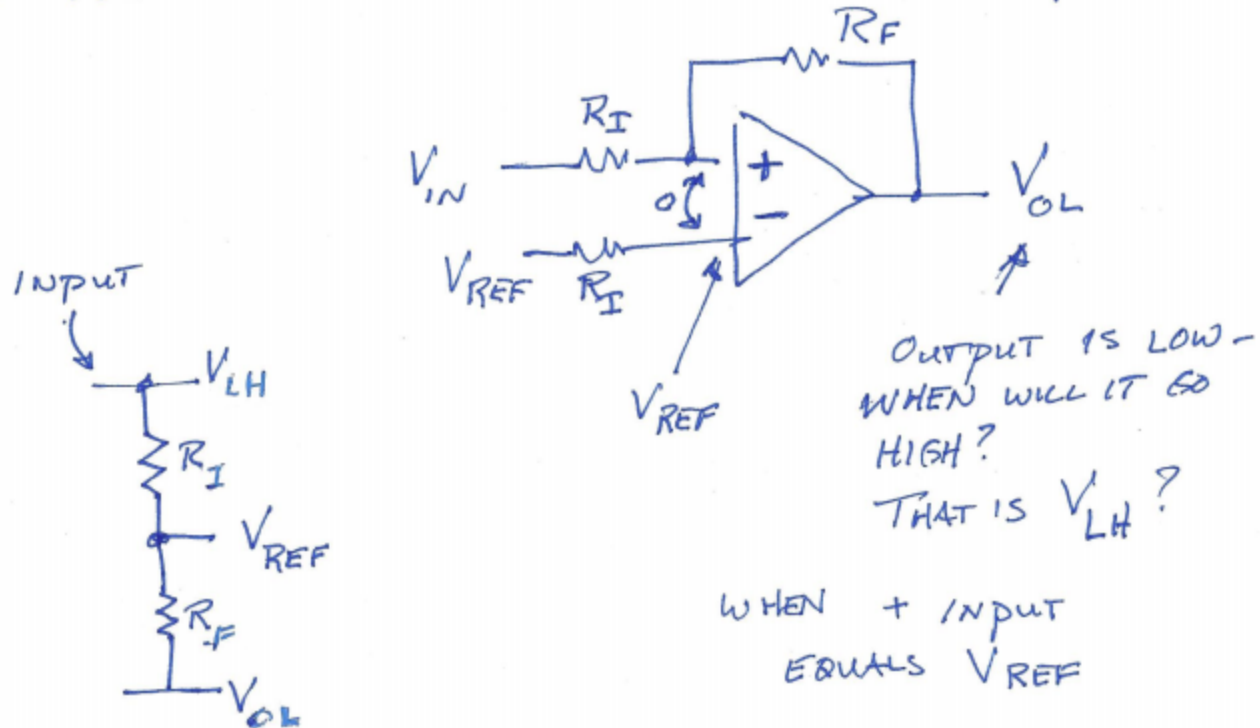
Schmitt trigger – form A

$$V_{REF} = V_{OL} + \left(\frac{R_F}{R_I + R_F} \right) \left(V_{LH} - V_{OL} \right)$$

$$= V_{OL} \left(1 - \frac{R_F}{R_I + R_F} \right) + \left(\frac{R_F}{R_I + R_F} \right) V_{LH}$$

$$= \left(\frac{R_I}{R_I + R_F} \right) V_{OL} + \left(\frac{R_F}{R_I + R_F} \right) V_{LH}$$

$$V_{LH} = \left(\frac{R_I + R_F}{R_F} \right) \left[V_{REF} - \left(\frac{R_I}{R_I + R_F} \right) V_{OL} \right]$$

Schmitt trigger – form A

Solve for V_{LH}:

$$V_{LH} = \left(\frac{R_I + R_F}{R_F}\right) V_{REF} - \left(\frac{R_I}{R_F}\right) V_{OL}$$

NOW FIND HIGH-LOW TRANSITION LEVEL V_{HL}
WHEN OUTPUT IS HIGH (V_{OH}) AND V_{IN} IS
DECREASING

USE SAME VOLTAGE DIVIDER ANALYSIS
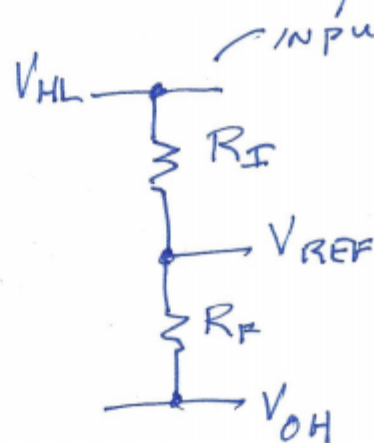
$$V_{REF} = V_{OH} + \frac{R_F}{R_I + R_F}\left(V_{HL} - V_{OH}\right)$$

Schmitt trigger – form A

$$V_{REF} = V_{OH}\left(1 - \frac{R_F}{R_I + R_F}\right) + V_{HL}\left(\frac{R_F}{R_I + R_F}\right)$$

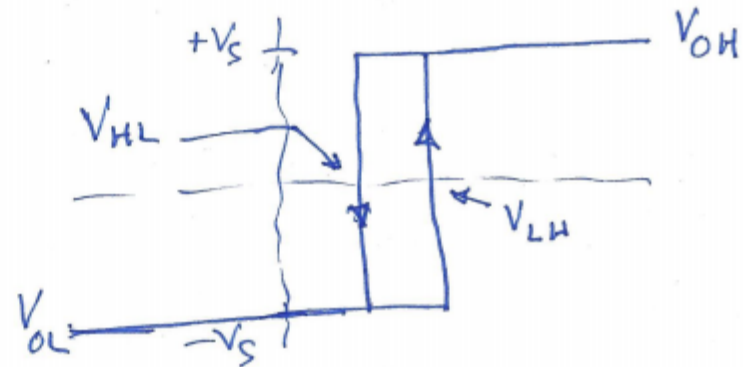$$= \left(\frac{R_I}{R_I + R_F}\right)V_{OH} + \left(\frac{R_F}{R_I + R_F}\right)V_{HL}$$

SOLVE FOR V_{HL} AS BEFORE!

$$\boxed{V_{HL} = \left(\frac{R_I + R_F}{R_F}\right)V_{REF} - \left(\frac{R_I}{R_F}\right)V_{OH}}$$

Now FIND HYSTERESIS!

LET $V_{HYST} = V_{LH} - V_{HL}$

$$V_{HYST} = \left[\left(\frac{R_I + R_F}{R_F} \right) V_{REF} - \left(\frac{R_F}{R_I} \right) V_{OL} \right]$$

$\leftarrow V_{LH}$

$$- \left[\left(\frac{R_I + R_F}{R_F} \right) V_{REF} - \left(\frac{R_F}{R_I} \right) V_{OH} \right]$$

$\leftarrow V_{HL}$

$$\boxed{V_{HYST} = \frac{R_I}{R_F} \left(V_{OH} - V_{OL} \right)}$$

Schmitt trigger – form A

Things to notice:

Resistor ratio of RI to RF is a large part of the hysteresis, but not all of it.

If RI = 10 K and RF = 10 M, the hysteresis is 0.1% of the voltage difference between VOH and VOL.

Schmitt trigger – form A

VOH and VOL will equal the supply voltages only if the amplifier has rail-to-rail output. If not, you must use specified amplifier saturated output voltages.

Schmitt trigger – form A

These results are perfectly general. If the amplifier has a unipolar supply, then VOH and VOL will equal the positive supply voltage and zero Volts, respectively (if rail-to-rail output).

The reference voltage will be in the center of the hysteresis window only if VOH and VOL are equal in magnitude and opposite in sign.

Schmitt trigger – form A

Suggestions:

1) Assume outputs
2) Set Vref at anticipated midpoint of the hysteresis window.
3) Select RI and RF based on anticipated output voltages and desired hysteresis window
4) Vary Vref slightly to position the hysteresis window where you want it.

Derivation of Schmitt trigger relationships – form B

Reversing the input and reference voltages in the same structure gives the designer the flexibility to change the output switching and possibly eliminate the need for an additional inverter.

The analytical process is the same. The results are deceptively similar, but the two results are not the same.

Questions?