LECTURE 360 – CHARACTERIZATION OF COMPARATORS
(READING: AH – 439-444)

Objective

The objective of this presentation is:

1.) Introduction to the comparator

2.) Characterization of the comparator

Outline

- Static characterization
- Dynamic characterization
- Summary

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What is a Comparator?

The comparator is essentially a 1-bit analog-digital converter.

Input is analog

Output is digital

Types of comparators:

1.) Open-loop (op amps without compensation)

2.) Regenerative (use of positive feedback - latches)

3.) Combination of open-loop and regenerative comparators

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Circuit Symbol for a Comparator

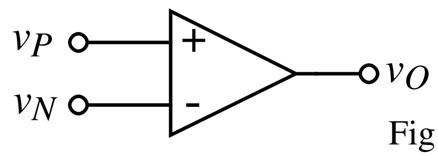


Fig. 8.1-1

Static Characteristics

- Gain
- Output high and low states
- Input resolution
- Offset
- Noise

Dynamic Characteristics

- Propagation delay
- Slew rate

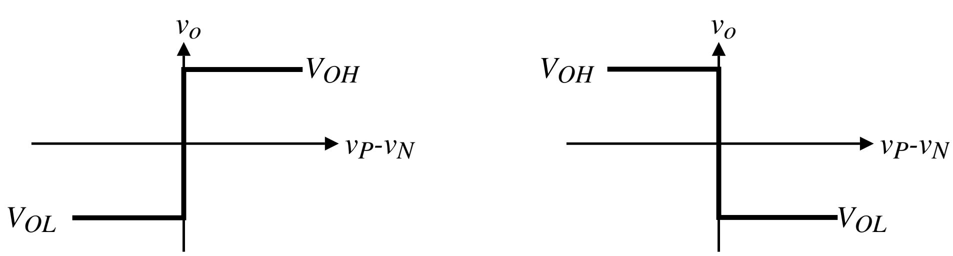
Noninverting and Inverting Comparators

The comparator output is binary with the two-level outputs defined as,

V_{OH} = the high output of the comparator

V_{OL} = the low level output of the comparator

Voltage transfer function of an Noninverting and Inverting Comparator:



Noninverting Comparator

Inverting Comparator

Fig. 8.1-2A

Static Characteristics - Zero-order Model for a Comparator

Voltage transfer function curve:

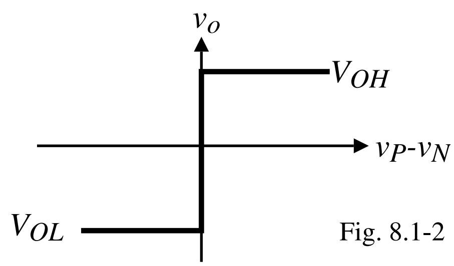
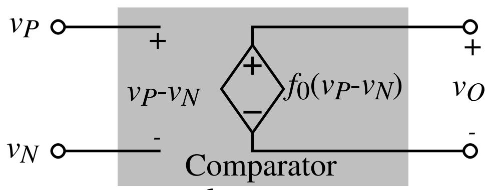


Fig. 8.1-2

Model:



$$f_0(v_P\text{-}v_N) = \begin{cases} V_{OH} \text{ for } (v_P\text{-}v_N) > 0 \\ V_{OL} \text{ for } (v_P\text{-}v_N) < 0 \end{cases}$$

Fig. 8.1-3

$$\text{Gain} = A_v = \lim_{\Delta V \to 0} \frac{V_{OH}\text{-}V_{OL}}{\Delta V}$$ where ΔV is the input voltage change

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Static Characteristics - First-Order Model for a Comparator

Voltage transfer curve:

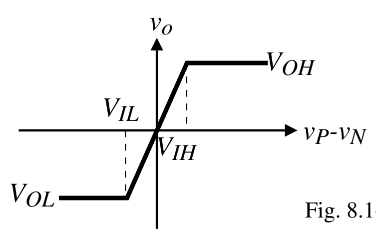


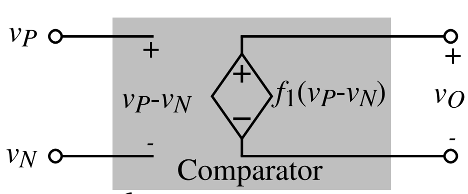
Fig. 8.1-4

where for a noninverting comparator,

V_{IH} = smallest input voltage at which the output voltage is V_{OH}

V_{IL} = largest input voltage at which the output voltage is V_{OL}

Model:



The voltage gain is $A_v = \dfrac{V_{OH} - V_{OL}}{V_{IH} - V_{IL}}$

$$f_1(v_P\text{-}v_N) = \begin{cases} V_{OH} \text{ for } (v_P\text{-}v_N) > V_{IH} \\ A_v(v_P\text{-}v_N) \text{ for } V_{IL} < (v_P\text{-}v_N) < V_{IH} \\ V_{OL} \text{ for } (v_P\text{-}v_N) < V_{IL} \end{cases}$$

Fig. 8.1-5

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Static Characteristics - First-Order Model including Input Offset Voltage

Voltage transfer curve:

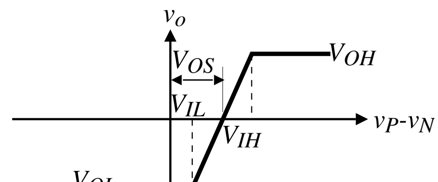

Fig. 8.1-6

V_{OS} = the input voltage necessary to make the output equal $\frac{V_{OH}+V_{OL}}{2}$ when $v_P = v_N$.

Model:

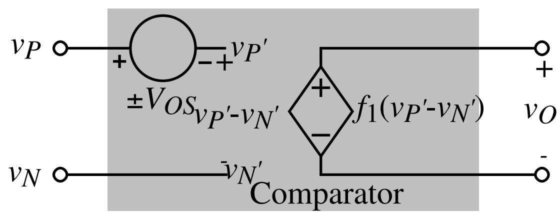

Fig. 8.1-7

Other aspects of the model:

ICMR = input common mode voltage range (all transistors remain in saturation)

R_{in} = input differential resistance

R_{icm} = common mode input resistance

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Static Characteristics - Comparator Noise

Noise of a comparator is modeled as if the comparator were biased in the transition region.

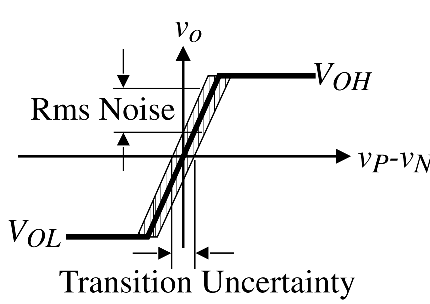

Fig. 8.1-8

Noise leads to an uncertainty in the transition region which causes jitter or phase noise.

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Dynamic Characteristics - Propagation Time Delay

Rising propagation delay time:

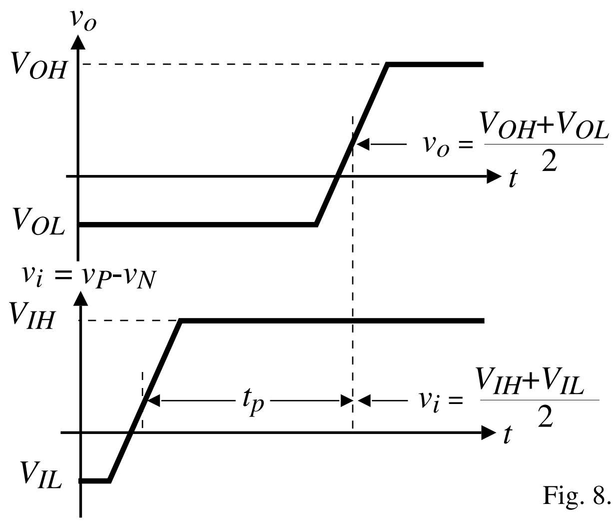

Fig. 8.1-9

$$\text{Propagation delay time} = \frac{\text{Rising propagation delay time} + \text{Falling propagation delay time}}{2}$$

Dynamic Characteristics - Single-Pole Response

Model:

$$A_v(s) = \frac{A_v(0)}{\frac{s}{\omega_c}+1} = \frac{A_v(0)}{s\tau_c+1}$$

where

$A_v(0)$ = dc voltage gain of the comparator

$\omega_c = \frac{1}{\tau_c}$ = -3dB frequency of the comparator or the magnitude of the pole

Step Response:

$$v_O(t) = A_v(0)\,[1 - e^{-t/\tau_c}]V_{in}$$

where

V_{in} = the magnitude of the step input.

Dynamic Characteristics - Propagation Time Delay

The rising propagation time delay for a single-pole comparator is:

$$\frac{V_{OH}-V_{OL}}{2} = A_v(0)\,[1 - e^{-t_p/\tau_c}]V_{in} \quad \rightarrow \quad t_p = \tau_c \ln\left[\frac{1}{1 - \frac{V_{OH}-V_{OL}}{2A_v(0)V_{in}}}\right]$$

Define the minimum input voltage to the comparator as,

$$V_{in}(\min) = \frac{V_{OH}-V_{OL}}{A_v(0)} \quad \rightarrow \quad t_p = \tau_c \ln\left[\frac{1}{1-\frac{V_{in}(\min)}{2V_{in}}}\right]$$

Define k as the ratio of the input step voltage, V_{in}, to the minimum input voltage, $V_{in}(\min)$,

$$k = \frac{V_{in}}{V_{in}(\min)} \quad \rightarrow \quad t_p = \tau_c \ln\left[\frac{2k}{2k-1}\right]$$

Thus, if $k = 1$, $t_p = 0.693\tau_c$.

Illustration:

Obviously, the more overdrive applied to the input, the smaller the propagation delay time.

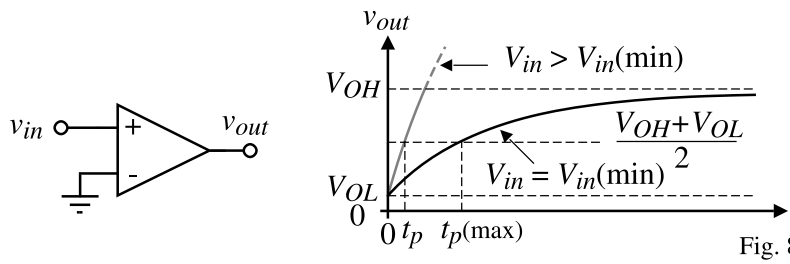

Fig. 8.1-10

Dynamic Characteristics - Slew Rate of a Comparator

If the rate of rise or fall of a comparator becomes large, the dynamics may be limited by the slew rate.

Slew rate comes from the relationship,

$$i = C\frac{dv}{dt}$$

where i is the current through a capacitor and v is the voltage across it.

If the current becomes limited, then the voltage rate becomes limited.

Therefore for a comparator that is slew rate limited we have,

$$t_p = \Delta T = \frac{\Delta V}{SR} = \frac{V_{OH}-V_{OL}}{2\cdot SR}$$

where

SR = slew rate of the comparator.

Example 1 - Propagation Delay Time of a Comparator

Find the propagation delay time of an open loop comparator that has a dominant pole at 10^3 radians/sec, a dc gain of 10^4, a slew rate of 1V/μs, and a binary output voltage swing of 1V. Assume the applied input voltage is 10mV.

Solution

The input resolution for this comparator is $1\text{V}/10^4$ or 0.1mV. Therefore, the 10mV input is 100 times larger than v_{in}(min) giving a k of 100. Therefore, we get

$$t_p = \frac{1}{10^3}\, ln\left(\frac{2\cdot 100}{2\cdot 100\text{-}1}\right) = 10^{-3}\, ln\left(\frac{200}{199}\right) = 5.01\mu\text{s}$$

For slew rate considerations, we get

$$t_p = \frac{1}{2\cdot 1\text{x}10^6} = 0.5\mu\text{s}$$

Therefore, the propagation delay time for this case is the larger or 5.01μs.

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SUMMARY

- A comparator is a one-bit ADC
- Comparators can be noninverting or inverting
- Types of comparators include:
  - Open-loop
  - Regenerative
  - Open-loop and regenerative
- Static Characteristics
  - Gain
  - Output high and low states
  - Input resolution
  - Offset
  - Noise
- Dynamic Characteristics
  - Propagation delay
  - Slew rate

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