

# Block 23 — Comparator Circuits

## Student Group

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# Block 23 — Comparator Circuits

## Learning objectives

After this 90-minute block, you can

- ...

## Preparation at Home

Well, again

- read through the present chapter and write down anything you did not understand.
- Also here, there are some clips for more clarification under 'Embedded resources' (check the text above/below, sometimes only part of the clip is interesting).

For checking your understanding please do the following exercises:

- ...

## 90-minute plan

1. Warm-up (x min):
  1. ....
2. Core concepts & derivations (x min):
  1. ...
3. Practice (x min): ...
4. Wrap-up (x min): Summary box; common pitfalls checklist.

## Conceptual overview

1. ...

## Core content

### Comparator

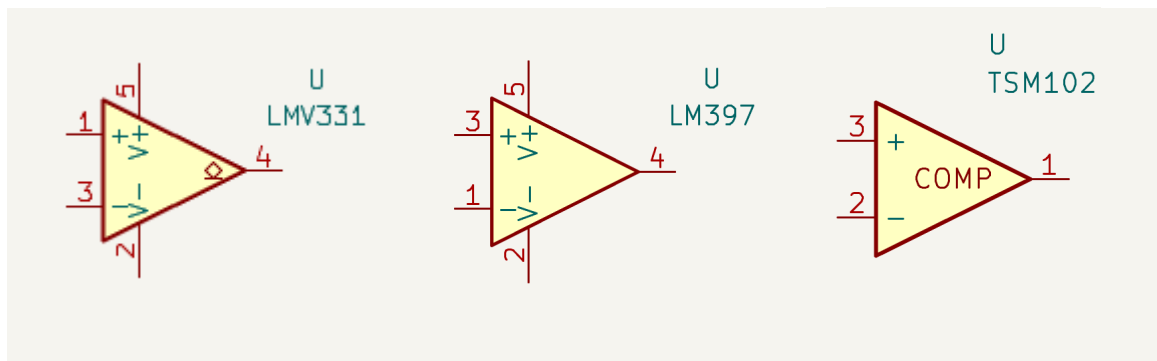
Up to now we focussed on operational amplifier, which is only usable in a closed-loop setup. However, it also as a “special brother”, the **comparator**.

The differences form the comparator in contrast to the operational amplifier are:

1. It is **only used in positive feedback**. It should never be used in negative feedback.
2. It is optimized for **fast switching**

3. It only outputs **in saturation**, which means it only has two possible outputs, see details below.

The symbol is related to the op-amps triangular shape - often the exact same symbol is used.



We again have two inputs: The non-inverting input  $u_{\text{p}}$  and the inverting input  $u_{\text{m}}$ . They result in the differential voltage  $u_{\text{d}} = u_{\text{p}} - u_{\text{m}}$ .

So, but what is the output, now? For this, it helps to have a look onto the simulation below.

There are two types of comparators:

1. **comparators with open-collector output:**

This type outputs the minimum value, when the non-inverted input is bigger than the inverted one.

Otherwise, the output is **high-ohmic** or **undefined**.

This is sometimes shown by a diamond shape  $\diamond$  on the output.

For these type, a **pull-up resistor** is needed to have a readable output in case of  $u_{\text{d}} > 0$ .

$$u_{\text{O, OC}} = \begin{cases} \text{undefined} & \text{for } u_{\text{d}} > 0 \\ U_{\text{sat, min}} & \text{for } u_{\text{d}} < 0 \end{cases}$$

2. **comparators with push-pull output:**

This type outputs the minimum value, when the non-inverted input is bigger than the inverted one.

Otherwise, it outputs the maximum value.

$$u_{\text{O, PP}} = \begin{cases} U_{\text{sat, max}} & \text{for } u_{\text{d}} > 0 \\ U_{\text{sat, min}} & \text{for } u_{\text{d}} < 0 \end{cases}$$

Similar to the operational amplifier, the situation  $u_{\text{d}} = 0$  is important.

This time,  $u_{\text{d}} = 0$  is not automatically reached, but it is the “turning point” for changing the output value.

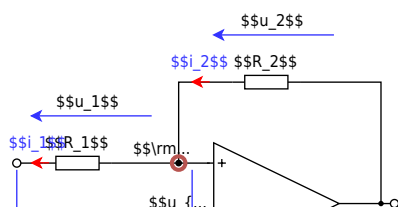
The values of the output voltages  $U_{\text{sat, min}}$  (and  $U_{\text{sat, max}}$ , when defined) are given by the voltage supply of the comparator,

In the first simulation they are set unipolar to  $U_{\text{sat, min}} = 0 \text{ ~V}$  and  $U_{\text{sat, max}} = 5 \text{ ~V}$ .

### Non-inverting Schmitt Trigger

Based on the comparator, we can try to setup a “op-amp like” circuitry. However, we have to take care, that we use a positive feedback.

The most important circuit is similar to the inverting amplifier, but with positive feedback is it the **non-inverting Schmitt trigger**.



The **golden rules** ( $R_{in} = 0$ ,  $R_{out} \rightarrow \infty$ ,  $A_D \rightarrow \infty$ ) also apply here.

Therefore, the currents through the resistors  $R_1$  and  $R_2$  are the same:  $i_1 = i_2$  (given, that  $R_{out} \rightarrow \infty$ ).

$$u_D = 0 \quad \rightarrow \quad u_O \quad \text{changes its state}$$

At the “turning point” with  $u_D = 0$ , the input and output voltages are equal to the voltages over the resistances.

However, the signs have to be considered (when  $u_O$  is positive,  $u_i$  has to be negative for  $u_D = 0$ ):  $u_1 = -u_i \quad \wedge \quad u_2 = u_O$

Then, the currents  $i_1$  and  $i_2$  are given by  $i_1 = -\frac{u_i}{R_1} \quad \wedge \quad i_2 = \frac{u_O}{R_2}$

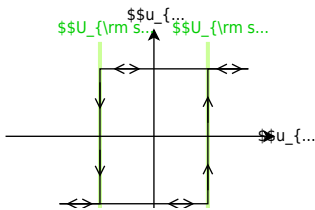
And therefore, this “turning point” is given by  $u_i = -\frac{R_1}{R_2} \cdot u_O$

These “turning points” are called **threshold**.

The upper threshold  $U_{sh,u}$  and the lower threshold  $U_{sh,l}$  are given by  $\boxed{U_{sh,u} = +\frac{R_1}{R_2} \cdot u_O \quad \wedge \quad U_{sh,l} = -\frac{R_1}{R_2} \cdot u_O}$

The shown “switching effect” is called **hysteresis**.

The curve is called **hysteresis loop** and shows the switching at the upper and lower threshold.



## Applications

### Bang-Bang Control

See [Bang-bang\\_control](#)

### De-Noise

### Analog-to-Digital Converter (ADC)

## Common pitfalls

- ...

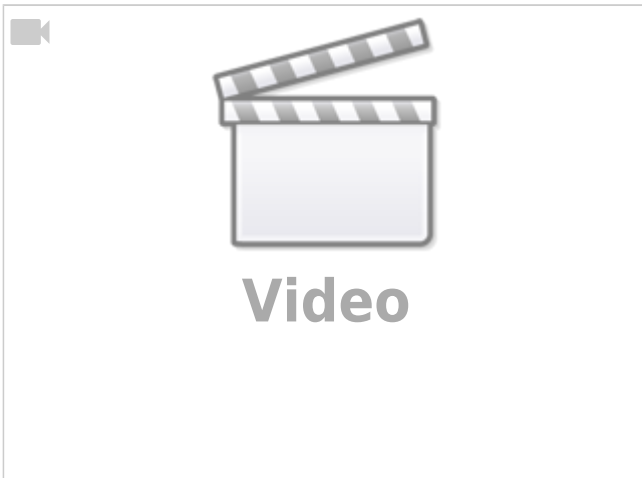
## Exercises

### Worked examples

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## Embedded resources

Longer tutorial on Schmitt trigger



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