Block 23 — Comparator Circuits

Student Group

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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

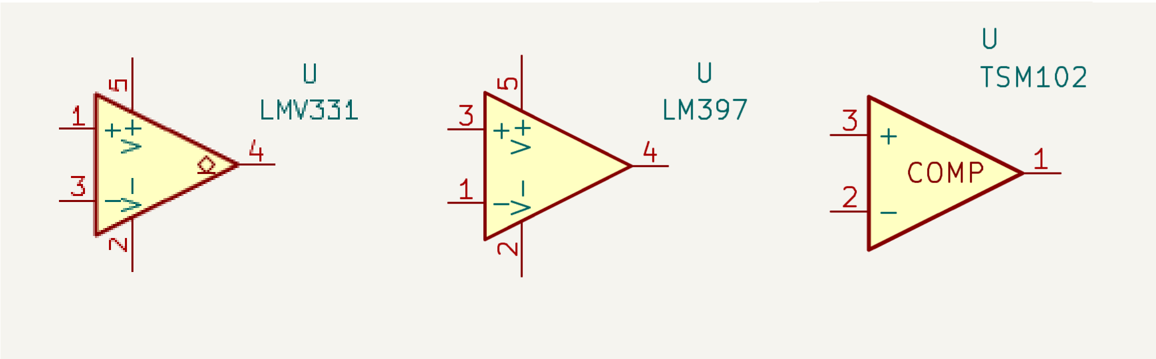
Comparator

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 $u_{\rm p}$ and the inverting input $u_{\rm n}$. They result in the differential voltage $u_{\rm d} = u_{\rm p} - u_{\rm n}$.

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 ◇ on the output.
   For these type, a **pull-up resistor** is needed to have a readable output in case of $u_{\rm d}>0$.
   $$u_{\rm O,OC}= \biggl\{ \begin{array}{l} &&\text{undefined} &&\text{for} &&u_{\rm d}>0 \\ &&U_{\rm sat, min} &&\text{for} &&u_{\rm d}<0 \end{array}$$
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.
   $$u_{\rm O, PP}= \biggl\{ \begin{array}{l} &&U_{\rm sat, max} &&\text{for} &&u_{\rm d}>0\\ &&U_{\rm sat, min} &&\text{for} &&u_{\rm d}<0 \end{array}$$

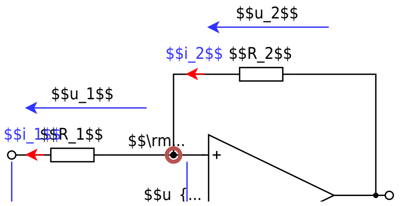
Similar to the operational amplifier, the situation $u_{\rm d}=0$ is important.
This time, $u_{\rm d}=0$ is not automatically reached, but it is the "turning point" for changing the output value.

The values of the output voltages $U_{\rm sat, min}$ (and $U_{\rm sat, max}$, when defined) are given by the voltage supply of the comparator,
In the first simulation they are set unipolar to $U_{\rm sat, min}=0 ~\rm V$ and $U_{\rm sat, max}=5 ~\rm V$.

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** ($R_{\rm I}=0$, $R_{\rm O}\rightarrow \infty$, $A_{\rm D}\rightarrow \infty$) also apply here.

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

$$ u_{\rm D}=0 \quad \rightarrow \quad u_{\rm O} \text{ changes its state} $$

At the “turning point” with $u_{\rm D}=0$, the input and output voltages are equal to the voltages over the resistances.
However, the signs have to be considered (when $u_{\rm O}$ is positive, $u_{\rm i}$ has to be negative for $u_{\rm D}=0$): $$ u_1 = - u_{\rm I} \\ u_2 = u_{\rm O} $$

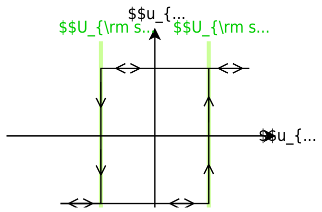
Then, the currents i_1 and i_2 are given by $$ i_1 = - {{u_{\rm I}}\over{R_1}} \\ i_2 = {{u_{\rm O}}\over{R_2}} $$

And therefore, this “turning point” is given by $$ u_{\rm I} = - {{R_1}\over{R_2}} \cdot u_{\rm O} $$

These “turning points” are called **threshold**.
The upper threshold $U_{\rm sh,u}$ and the lower threshhold $U_{\rm sh,l}$ are given by $$ \boxed{ U_{\rm sh,u} = + {{R_1}\over{R_2}} \cdot u_{\rm O} \\ U_{\rm sh,l} = - {{R_1}\over{R_2}} \cdot u_{\rm O} } $$

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