Electronics

Logic Gates: Open Collector Output

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Totem pole outputs

Open collector outputs
Open Collector Advantages
CMOS outputs

Output circuit
Output equivalent circuit
Equivalent circuit; output low
Equivalent circuit; output high
Totem pole outputs

- Two transistors
- Only one on at one time
Totem pole outputs

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TTL Totem Pole Output Equivalent Circuit

\[ V_{cc} \]

Transistor acts like a switch

Output is a voltage divider
TTL Totem Pole Output Equivalent Circuit

\[ V_{cc} \rightarrow V_{out} \rightarrow \text{Transistor acts like a switch} \]

Output is a voltage divider.
TTL Totem Pole Output Equivalent Circuit

Transistor acts like a switch
TTL Totem Pole Output Equivalent Circuit

- Transistor acts like a switch
- Output is a voltage divider
Totem pole outputs; output low

- Upper transistor **OFF** (open switch)
- Lower transistor **ON** (closed switch)
Totem pole outputs; output high

- Upper transistor **ON** (closed switch)
- Lower transistor **OFF** (open switch)

*The voltage at the output will depend on the current drawn because of the resistor.*
Open collector outputs
Open collector outputs

\[ V_{out} \]
Open collector outputs

- Single transistor; ON or OFF

\[ V_{out} \]
Open collector outputs

- Single transistor; **ON** or **OFF**
Open collector output equivalent circuit

Output is either grounded or floating. An external pull-up resistor is required to produce a high output.
Open collector output equivalent circuit

An external pull-up resistor is required to produce a high output.
Open collector output equivalent circuit

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\[ V_{out} \]
Open collector output equivalent circuit

- Output is either grounded or *floating*
- An external pull-up resistor is required to produce a high output
Open Collector Output Equivalent Circuit (Output Low)
Open Collector Output Equivalent Circuit (Output Low)

Inside chip

$V_{supply}$

$V_{out}$

Transistor ON (closed switch)

$V_{out}$ pulled to GROUND

Current into gate
Open Collector Output Equivalent Circuit (Output Low)

- **$V_{supply}$**
- **$V_{out}$**
- Inside chip
- Transistor **ON** (closed switch)
Open Collector Output Equivalent Circuit (Output Low)

- Transistor ON (closed switch)
- $V_{out}$ pulled to GROUND
Open Collector Output Equivalent Circuit (Output Low)

- Transistor **ON** (closed switch)
- $V_{out}$ pulled to GROUND
- Current into gate
Open Collector Output Equivalent Circuit (Output High)

- Transistor OFF (open switch)
- $V_{out}$ pulled to $V_{supply}$
- Current from supply
Why use open collector gates?
Why use open collector gates?

- More current
Why use open collector gates?

- More current
- Mixing logic families
Why use open collector gates?

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- Wired ANDing of outputs
Why use open collector gates?

- More current
- Mixing logic families
- Wired ANDing of outputs
- Bidirectional communication
More current

A TTL gate can source 0.4 mA. A TTL gate can sink 16 mA. A TTL open collector gate can source 0 mA. A TTL open collector gate can sink 16 mA. Note: $I_{OH}$ for open-collector gate?
More current

- A TTL gate can source 0.4 mA.
More current

- A TTL gate can *source* 0.4 mA.
- A TTL gate can *sink* 16 mA.

Note: $I_{OH}$ for open-collector gate?
More current

- A TTL gate can *source* 0.4 mA.
- A TTL gate can *sink* 16 mA.
- A TTL open collector gate can *source*?
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More current

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- A TTL open collector gate can *source* ?
- A TTL open collector gate can *sink* 16 mA.

**Note:** $I_{OH}$ for open-collector gate?

Look at the sign given for $I_{OH}$, and consider what that means.
Mixing logic families

- Totem pole outputs
- Open collector outputs
- Open Collector Advantages
- CMOS outputs

More current

Mixing logic families

Wire ANDing of outputs

Bidirectional communication

Pull-up Resistor Calculations

V_{OH} for TTL is 2.4V.

V_{IH} for 4.5V HC (MOS) is 3.15V.

V_{IH} for 6V HC (CMOS) is 4.20V.

Examples

- TTL open collector output can feed into 5V HC (CMOS) if the output is pulled up to 5V. (But V_{cc} is still 5V!)
Mixing logic families

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**Examples**

TTL open collector output can feed into 5V HC(CMOS) *if* the output is pulled up to 5V. (But $V_{cc}$ is still 5V!)
Totem pole outputs tied together
Totem pole outputs tied together
Totem pole outputs tied together

Which gate will win?
Totem pole outputs tied together

Which gate will win? (Think about current limits.)
Wire ANDing of outputs
Wire ANDing of outputs

\[ V_{supply} \]

\[ V_{out} \]
Wire ANDing of outputs

No gate is grounded, so output is pulled high.
Wire ANDing of outputs

One gate is grounded, so output is low.
Wire ANDing of outputs

One gate is grounded, so output is low.
Bidirectional communication

If two (or more) devices are connected to the same open collector signal, then the signal can be an input or an output for both.
Bidirectional communication

If two (or more) devices are connected to the same open collector signal, then the signal can be an input or an output for both.
Pull-up Resistor Calculations

How do you calculate the pull-up resistor value?

When the output is low, the gate must be able to sink the current from the pull-up resistor and anything else connected. This will produce a minimum value for the resistor.

When the output is high, the current through the pull-up resistor must be high enough for whatever is connected to it. This will produce a maximum value for the resistor.
Pull-up Resistor Calculations

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Pull-up Resistor Calculations

How do you calculate the pull-up resistor value?

- When the output is low, the gate must be able to sink the current from the pull-up resistor and anything else connected. This will produce a minimum value for the resistor.
- When the output is high, the current through the pull-up resistor must be high enough for whatever is connected to it. This will produce a maximum value for the resistor.
Pull-up Resistor; output low

Calculating $R_{min}$
Pull-up Resistor; output low

Calculating $R_{min}$

When the output is low, $R_{min} = (V_{cc} - V_{OL}) / (I_{OL})$
Pull-up Resistor; output low

**Calculating** $R_{min}$

![Diagram of pull-up resistor](image)

When the output is low, $R_{min} = (V_{cc} - V_{OL}) / (I_{OL})$

(If $R$ were smaller, the output couldn’t be kept low.)
Pull-up Resistor; output low

Calculating $R_{min}$

If another gate follows, then the output has to sink from both the resistor and the gate input, so the current through $R$ must be REDUCED.
Pull-up Resistor; output low

Calculating $R_{min}$

When the output is low, $R_{min} = (V_{cc} - V_{OL}) / (I_{OL} - I_{IL})$

(Current through $R$ is reduced by $I_{IL}$.)
Pull-up Resistor; output low

Calculating $R_{\text{min}}$

When the output is low, $R_{\text{min}} = \frac{(V_{cc} - V_{OL})}{(I_{OL} - I_{IL})}$
Pull-up Resistor; output low

Calculating $R_{min}$

When the output is low, $R_{min} = (V_{cc} - V_{OL}) / (I_{OL} - I_{IL})$

Another gate with a wired-OR output won’t change the current through $R$, since its output is floating.
Pull-up Resistor; output low

Calculating $R_{min}$

When the output is low, $R_{min} = (V_{cc} - V_{OL}) / (I_{OL} - 2 \times I_{IL})$
Pull-up Resistor; output low

**Calculating** $R_{min}$

When the output is low, $R_{min} = (V_{cc} - V_{OL}) / (I_{OL} - 2 \times I_{IL})$
Pull-up Resistor; output low

Calculating $R_{min}$

When the output is low, $R_{min} = (V_{cc} - V_{OL}) / (I_{OL} - 3 \times I_{IL})$
Pull-up Resistor; output low

Calculating $R_{min}$

When the output is low, $R_{min} = (V_{cc} - V_{OL}) / (I_{OL} - N \times I_{IL})$
Pull-up Resistor; output high

Calculating $R_{max}$
Pull-up Resistor; output high

Calculating $R_{max}$

When the output is high, $R_{max} = (V_{cc} - V_{OH}) / (I_{OH})$
Pull-up Resistor; output high

Calculating $R_{max}$

When the output is high, $R_{max} = \frac{(V_{cc} - V_{OH})}{I_{OH}}$

(If $R$ were bigger, $V_{OH}$ wouldn’t be guaranteed.)
Pull-up Resistor; output high

Calculating $R_{\text{max}}$

If another gate follows, then the current has to pull *both* the resistor *and* the gate input HIGH, so the current through $R$ must be **INCREASED**.
Pull-up Resistor; output high

Calculating $R_{max}$

When the output is high, $R_{max} = \frac{V_{cc} - V_{OH}}{(I_{OH} + I_{IH})}$

(Current through $R$ is increased by $I_{IH}$.)
Pull-up Resistor; output high

Calculating $R_{max}$

Another gate with a wired-OR output will also need to be pulled HIGH, so the current must be INCREASED.
Pull-up Resistor; output high

Calculating $R_{\text{max}}$

When the output is high,

$$R_{\text{max}} = (V_{cc} - V_{OH}) / (2 \times I_{OH} + I_{IH})$$
Pull-up Resistor; output high

Calculating $R_{\text{max}}$

When the output is high,

$$R_{\text{max}} = \frac{V_{cc} - V_{OH}}{2 \times I_{OH} + 2 \times I_{IH}}$$
Pull-up Resistor; output high

Calculating $R_{\text{max}}$

When the output is high,

$$R_{\text{max}} = \frac{(V_{cc} - V_{OH})}{(3 \times I_{OH} + 2 \times I_{IH})}$$
Pull-up Resistor; output high

Calculating $R_{\text{max}}$

When the output is high,

$$R_{\text{max}} = (V_{cc} - V_{OH}) / (3 \times I_{OH} + 3 \times I_{IH})$$
Pull-up Resistor; output high

Calculating $R_{\text{max}}$

When the output is high,

$$R_{\text{max}} = \frac{(V_{cc} - V_{OH})}{(M \times I_{OH} + N \times I_{IH})}$$
So, to summarize:
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\[ R_{\text{min}} = \frac{(V_{cc} - V_{OL})}{(I_{OL} - N \times I_{IL})} \]
So, to summarize:

\[ R_{\text{min}} = \frac{(V_{cc} - V_{OL})}{(I_{OL} - N \times I_{IL})} \]

\[ R_{\text{max}} = \frac{(V_{cc} - V_{OH})}{(M \times I_{OH} + N \times I_{IH})} \]
CMOS output

CMOS Output circuit

Two transistors
Only one on at one time
CMOS output

![CMOS Output Circuit Diagram](image)

- **$V_{DD}$**
- **$V_{out}$**

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\[ V_{out} \]
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