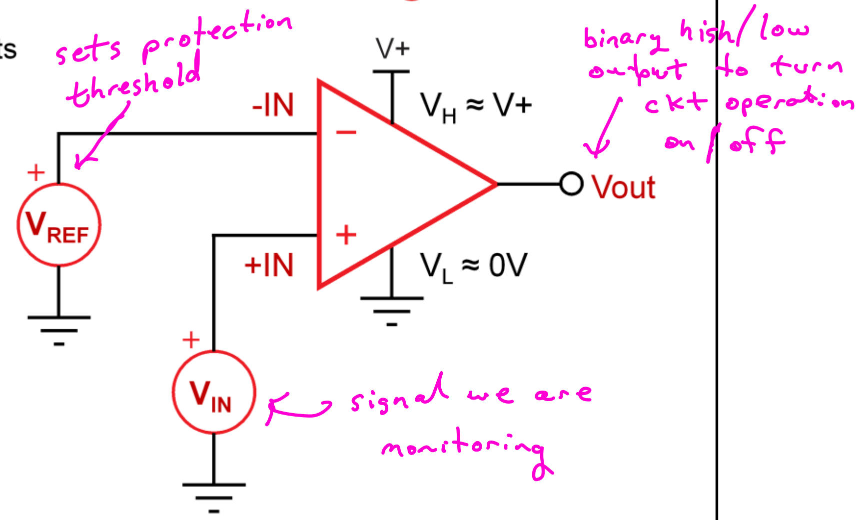
useful for protection

The Comparator Function – Non-inverting

V_{IN} and V_{REF} applied to +IN and -IN inputs
- V_{IN} = input signal
- V_{REF} = reference signal
- may have both dc and ac components

Vout can be one of two levels
- V_H = HIGH (1)
- V_L = LOW (0)

Input	Output
$V_{IN} > V_{REF}$	**HIGH (1)**
$V_{IN} < V_{REF}$	**LOW (0)**



Texas Instruments 2

Let's begin by introducing the basic functionality of a comparator. Similar to a standard op amp, a comparator has two inputs, one output, and two power supply pins. From a schematic perspective it looks the same as an op amp, although its intended function is quite different.

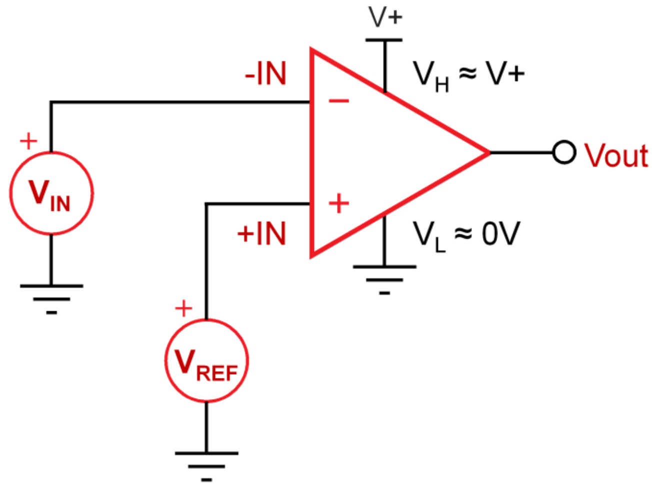
A comparator gets its name because it **compares** the voltages applied to its inputs and sets its output voltage based on the input levels. One input is considered to be the primary input signal, or VIN, and the other input is considered to be the reference signal VREF. These inputs may have both dc and ac components. The output voltage Vout can be set to one of two levels; a high level or logic 1, or a low level or logic 0. VH, the output high level, approaches V+, the positive power supply voltage. VL, the output low level, approaches 0V or ground, or the negative supply in dual supply configurations.

The comparator shown on this slide is configured for non-inverting operation. In this condition, VIN, the input signal, is connected to the non-inverting input +IN, and VREF, the reference signal, is connected to the inverting input –IN. If VIN > VREF, the comparator output goes high. If VIN < VREF, the output goes low.

The Comparator Function – Inverting

Switch the input and reference signals to use the comparator in an inverting configuration

- V_{IN} applied to **–IN**
- V_{REF} applied to **+IN**

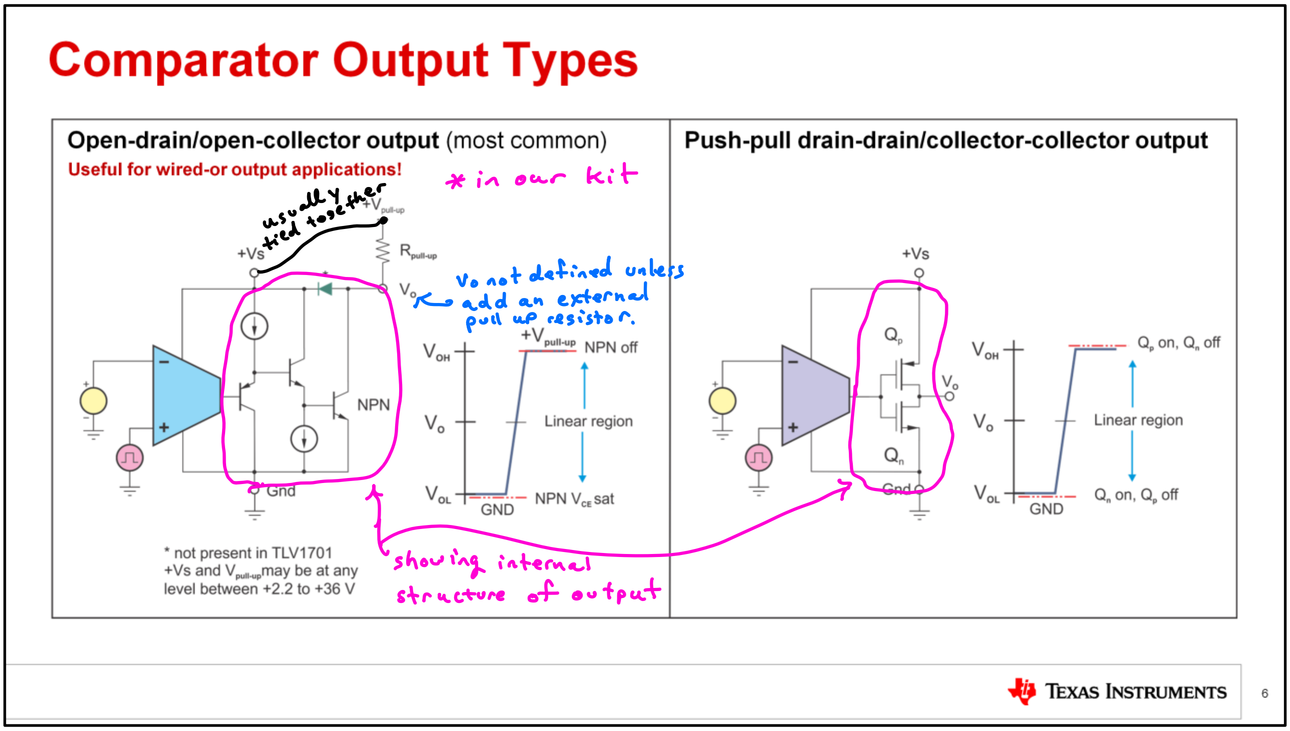


Input	Output
$V_{IN} > V_{REF}$	**LOW (0)**
$V_{IN} < V_{REF}$	**HIGH (1)**

reversed logic

TEXAS INSTRUMENTS 3

A comparator can also be used in an inverting configuration. In this condition, VIN, the input signal, is connected to the **inverting** input –IN, and VREF, the reference signal, is connected to the **non-inverting** input +IN. Because of the change in how we've defined our input signals, the output behavior can be considered inverted. Now if VIN > VREF, the comparator output goes **low**, and if VIN < VREF, the output goes **high**.

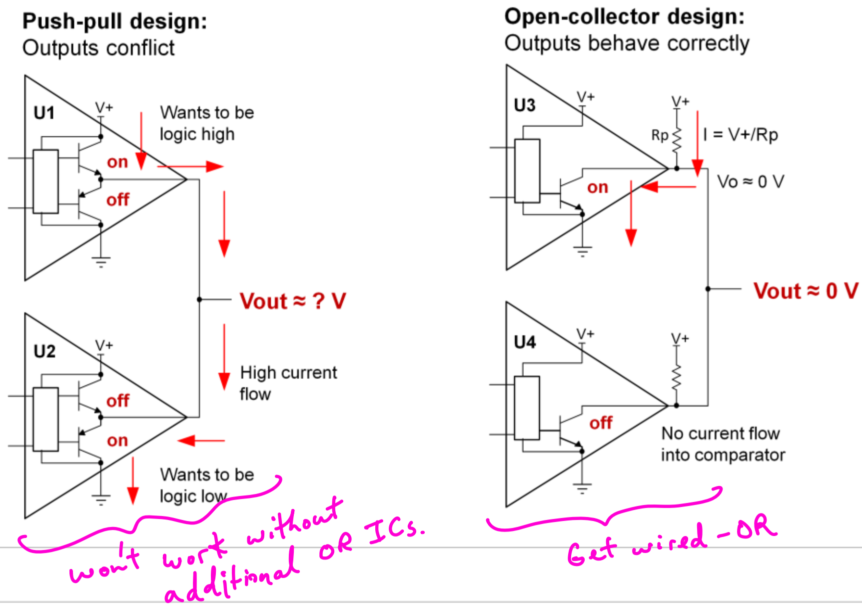


Comparators are divided into two main types, based on the design of their output stage. These two types are called open-drain (or open-collector), and push-pull (also known as drain-drain, or collector-collector). Open-collector and collector-collector comparators are built with bipolar transistors, while open-drain and drain-drain comparators are built with FETs.

The comparator on the left and the LM139 example from the previous slide have an open-collector output, with an output stage consisting of a single NPN bipolar transistor. When this transistor is on, it actively sinks current from collector to emitter and pulls the output voltage Vo down very close to GND or 0V. How close the output can swing to ground depends on the collector-to-emitter saturation voltage. When the transistor is off, its collector looks like high impedance and has essentially no effect on the output voltage. In this case, a small amount of current is sourced from V+ through the pull-up resistor and Vo rises to VOH, or logic 1. Without this pull-up resistor, Vo could float to an unknown state.

Push-pull comparators, on the other hand, have an output stage consisting of a pair of output transistors. Either the upper or lower transistor in the pair turns on and actively sources or sinks current in order to drive the output high or low as needed. In the example on the right, the P-channel upper FET turns on to source current and **push** the output high, while the N-channel lower FET turns on to sink current and **pull** the output low. No pull-up resistor is required for this type of comparator.

Wired-or Configuration



Open-collector (or open-drain) truth table

U3	U4	Output
OFF	OFF	**HIGH**
OFF	ON	**LOW**
ON	OFF	**LOW**
ON	ON	**LOW**

A commonly-desired function of comparators is to generate a logical **OR**, where an output is logic **LOW** when either of its two inputs is **ON**. This functional block is commonly implemented by wiring the outputs of two comparators together. However, care must be taken to use the right type of comparator, as we'll discuss.

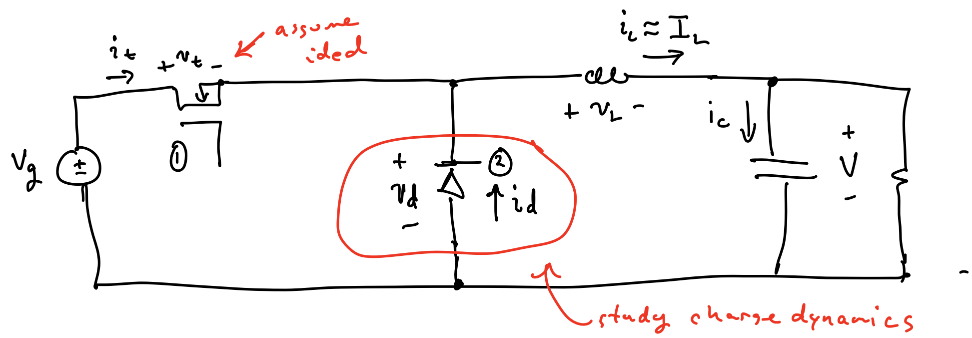
Let's first consider the circuit on the left, with two push-pull devices whose outputs are tied together. Remember, a push-pull comparator actively sources or sinks current to push or pull its output voltage high or low. You may already see the problem with this circuit configuration, but let's analyze the different possibilities of its operation.

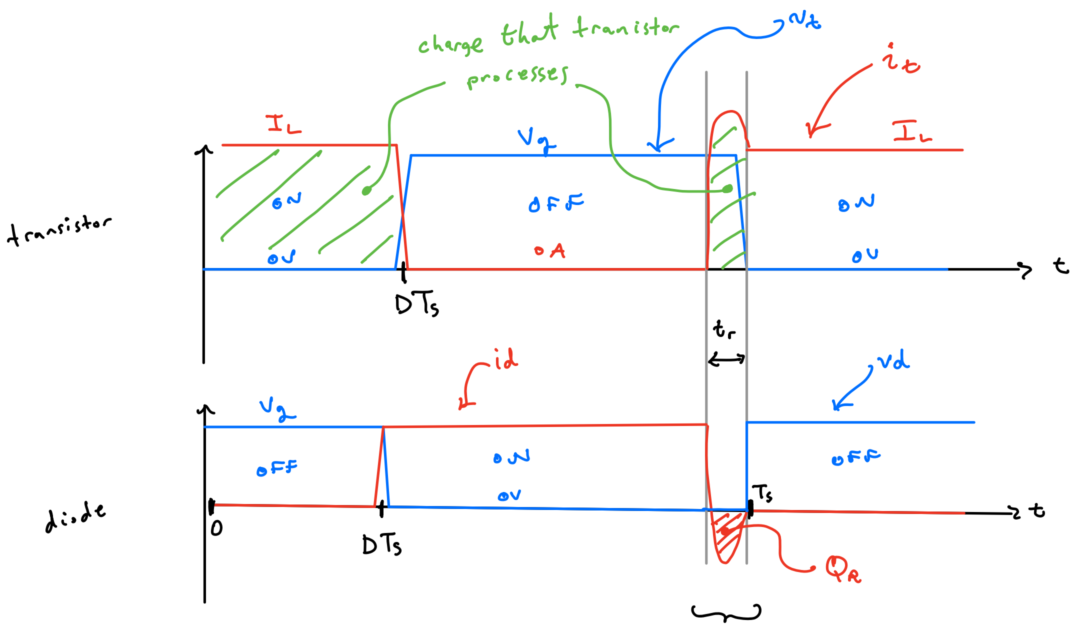
In the case where the outputs of both comparators are **high**, the **top** transistor in each push-pull output stage turns on and the output is driven **high**. Similarly, if both outputs are **low** then the **bottom** transistors in each comparator turn on and the output is driven **low**. The **problem** arises when the two comparators try to drive the output to different states – in this case, there is a conflict as each comparator tries to source or sink current to force the output to a different voltage. This creates a high current condition and drives the output to some indeterminate state which is neither high nor low. As you might imagine, this condition is undesirable and can even damage the devices. For this reason, push-pull comparators should never be connected together in this way.

On the other hand, open-collector or open-drain comparators work perfectly with this approach. Remember that the output stage of an open-collector or open-drain comparator is built with a single transistor that pulls the output low when it turns on, and looks like a high impedance when it turns off. Now, no matter which combination of high or low is present on each output, the output will safely be driven to a known state. If both outputs are low, both output transistors are **ON** and pull the overall output down to approximately 0V. If both outputs are high, both transistors are **OFF** and act like a high impedance, allowing the output to be pulled up to logic high through the pullup resistors. If one output is high and one output is low, the low state will dominate as the transistor which is ON can sink much more current to pull the output low than the pull-up resistor can provide to drive the output high. You can check the truth table on the right for the logical behavior in all four possible input states. As you can see, this is equivalent to a logic OR function.

This implementation of a logical OR with comparators is commonly called the **wired-or configuration**.

— Reverse Recovery Circuit Example





- turn off transition of diode
- need to extract Q_R to re-establish depletion region.

- Transistor current has mirrored shape since

$$i_t(t) + i_d(t) = i_L \approx \underbrace{I_L}_{\text{constant}}$$

Lecture # 13 10/27/21

↳ Make up lecture for canceled class on $\underbrace{\text{10/29/21 Friday}}$ → no class

Last time

- RR loss of diodes

Today

- Continue RR loss modeling → get equiv ckt.
- Lab materials
  ↳ using comparators for protection

- Apply balance eqns to analyze.

$$\langle v_L \rangle = 0 = D(V_g - V) + \underbrace{(1-D)}_{D'}(-V)$$

$$= DV_g - V$$

$$\langle i_c \rangle = 0 = I_L - \frac{V}{R}$$

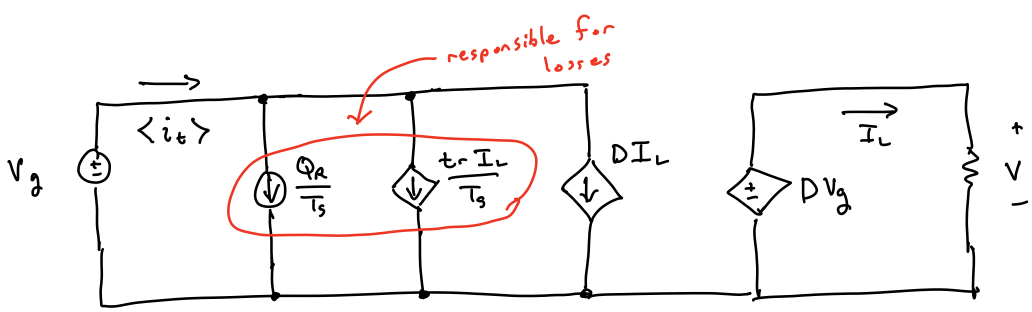
... New part of analysis. Look @ avg transistor current:

$$\langle i_t \rangle = \frac{\text{Area}}{T_s}$$

$$= \frac{I_L D T_s + I_L t_r + Q_R}{T_s}$$

$$= D I_L + \frac{t_r I_L}{T_s} + \frac{Q_R}{T}$$

Draw equiv ckt model ?



$\underbrace{\qquad\qquad}_{\text{redraw as xfmr}}$

Analyze efficiency

$$\boxed{P_{\substack{diode\\loss}} = V_g\left(\frac{Q_R}{T_s} + \frac{t_r I_L}{T_s}\right) = \text{losses circled above}}$$

note this power, due to diode reverse recovery, is actually dissipated in the transistor.

look @ η

$$P_{out} = V I_L \ , \qquad P_{in} = V_g\left(\frac{Q_R}{T_s} + \frac{t_r I_L}{T_s} + D I_L\right)$$

(*) recall $I_L = \frac{V}{R}$, $V = DV_g$, $T_s = \frac{1}{f_s}$

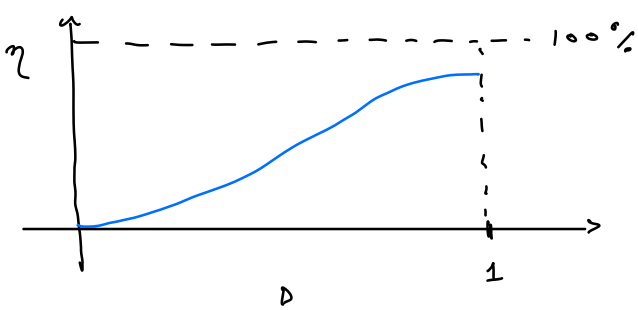
$$\eta = \frac{P_{out}}{P_{in}} = \frac{V I_L}{V_g\left(\frac{Q_R}{T_s} + \frac{t_r I_L}{T_s} + D I_L\right)}$$

- Substitute (*) relations & do some algebra

...

$$= \frac{1}{1 + f_s\left(\frac{t_r}{D} + \frac{Q_R R}{D^2 V_g}\right)}$$

- note that f_s is in denom.
- higher f_s, lowers η



curve w reverse recovery losses only

- Diff diode types

  - "standard recovery" → low freq only (60 Hz, etc)

  - "Fast/ultrafast recovery"
    ↳ lower t_r & Q_R

  - "Schottky diodes"
    ↳ has a unique type of physical construction
    ↳ high performance (low t_r & Q_R) but typically limited to low voltages only ($< 100V$)