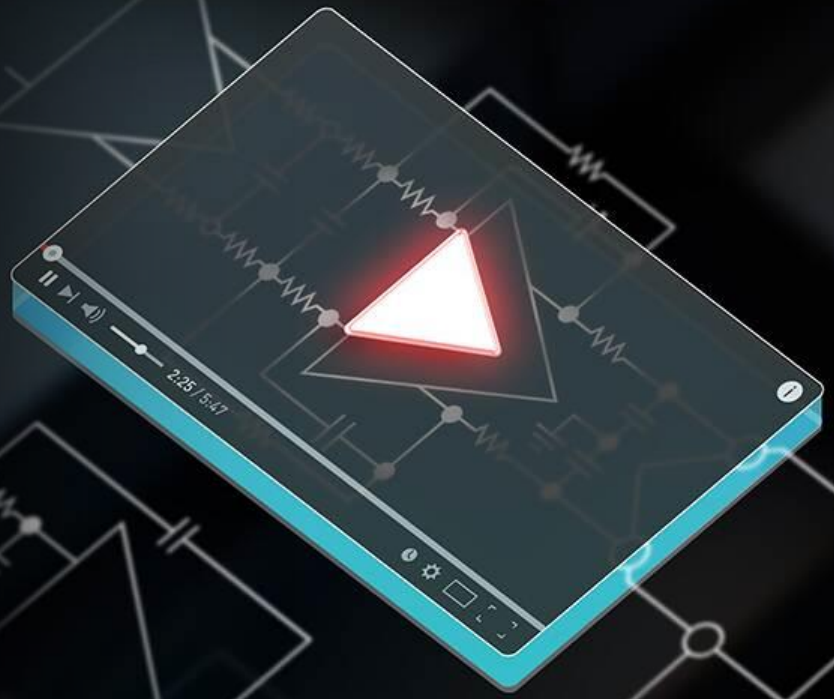
TI Precision Labs Seminar

Comparator applications



Philip Siu

Applications Engineer

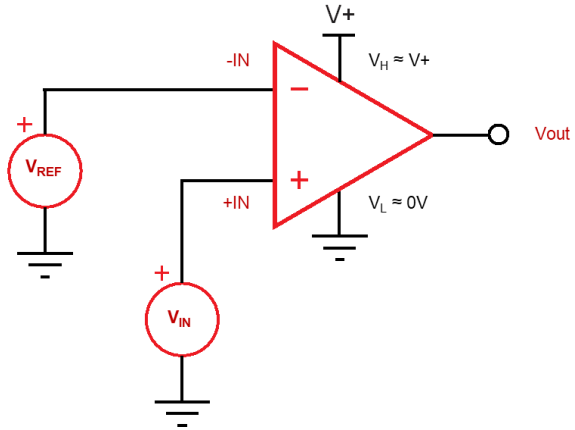
Philip Siu

Role/Title:	Applications Engineer LVAC (Low Voltage Amplifiers and Comparators)
Experience:	1 Year
Education:	BS Electrical Engineering, University of California, San Diego MS Electrical Engineering, University of California, San Diego

Agenda

- Comparator differentiation from amplifiers
- Comparator specifications
  - Output types
  - DC specifications
  - AC specifications
- Applications/use cases
  - TI Comparator features
- TI Comparator Webpage

Comparators…

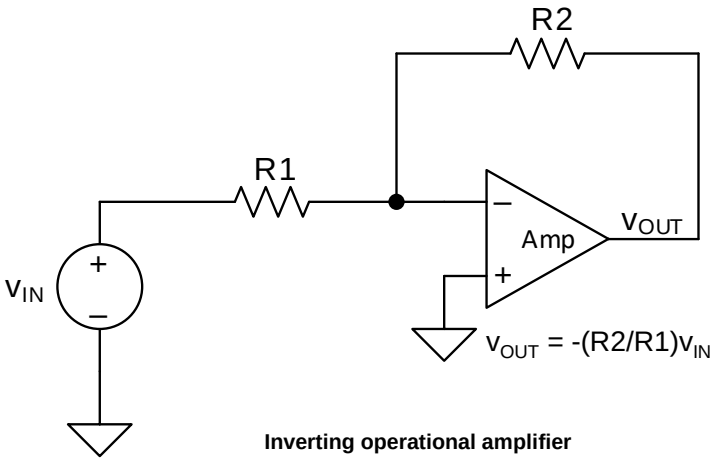


Input	Output
$V_{IN} > V_{REF}$	**HIGH (1)**
$V_{IN} < V_{REF}$	**LOW (0)**
$V_{IN} = V_{REF}$	**UNDEF (Determined by Vos)**

Amplifiers and Comparator differences

Amplifiers

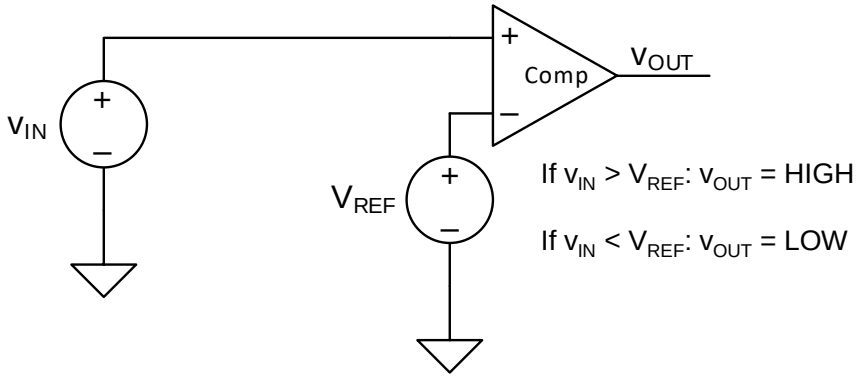
- Amplifiers operate with **negative** feedback with a “virtual” short across inputs
- Analog input, **analog** output



Inverting operational amplifier

Comparators

- Comparators operate in open-loop or with **positive** feedback (hysteresis)
- Inputs can be independent and be volts apart
- Analog input, **digital** output

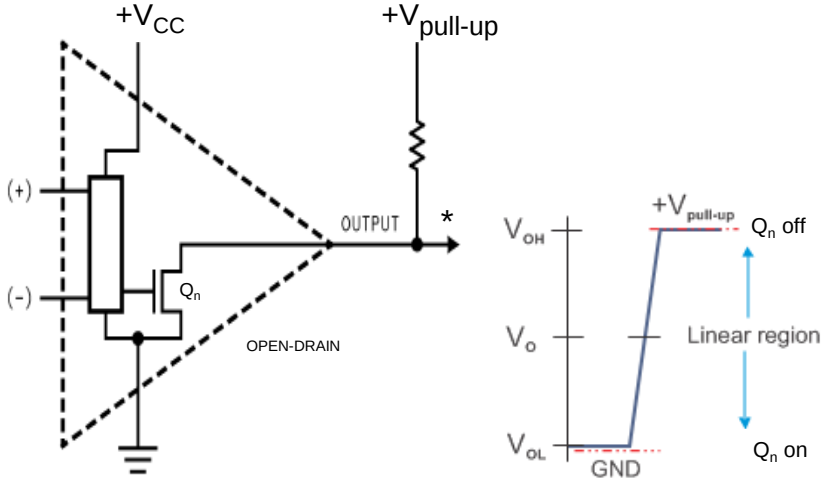


Non-inverting comparator

Comparator output types

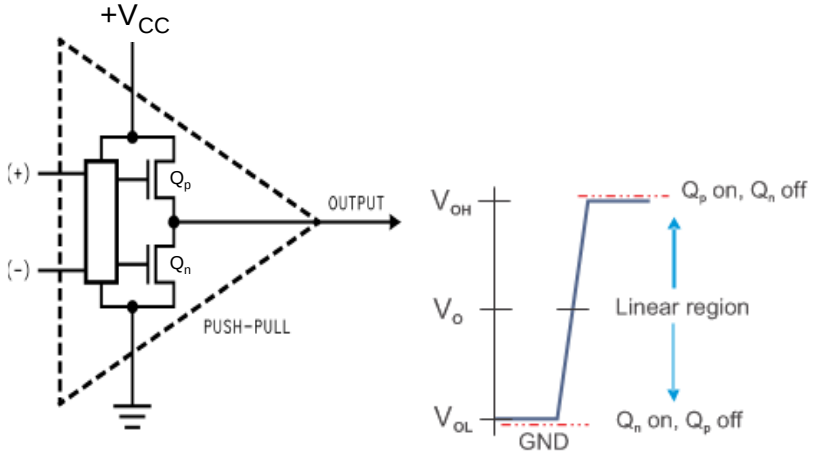
Open-drain/open-collector output

Requires pull-up resistor – level shifting or wired-OR output apps



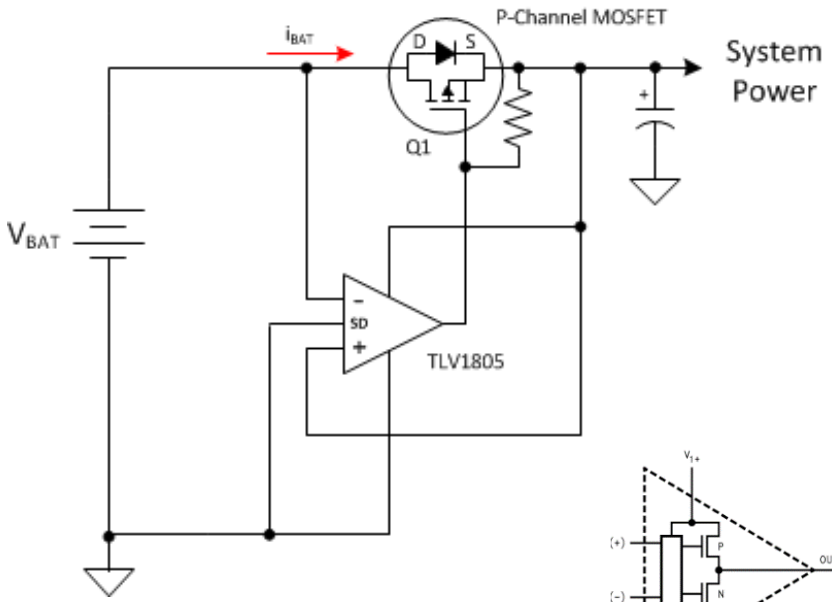
Push-pull (also called R-R or Totem Pole) **output**

No pull-up resistor required – strong output drive and symmetrical rise and fall times



Output type usage examples

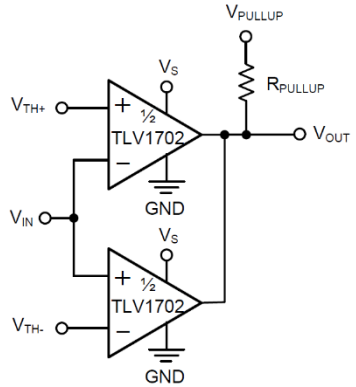
Push-pull output

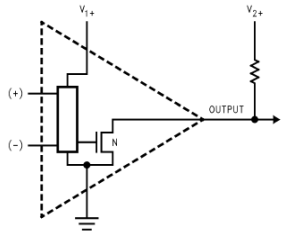


Common in high-speed devices!

Open drain output

Output OR'ing

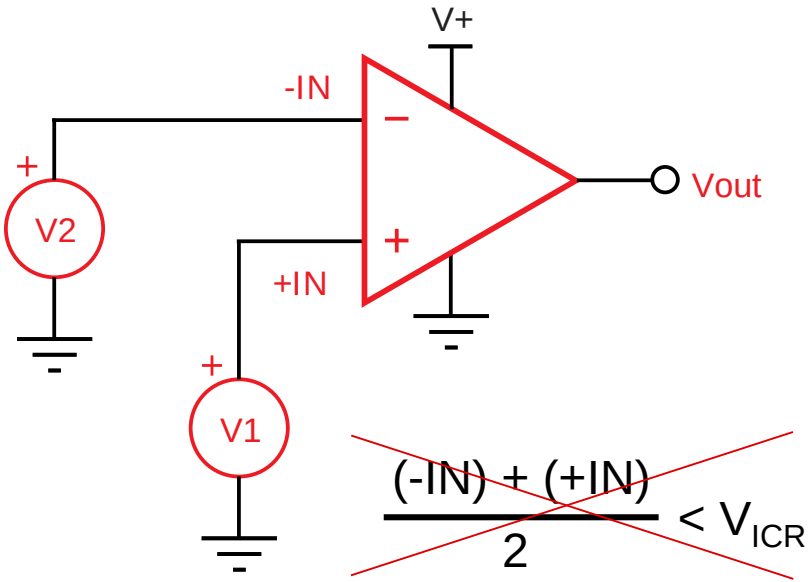




Level shifting

Comparator DC parameters - common mode range

- Common mode voltage is commonly defined as “the average of the two input voltages”
  - Only true for operational amplifiers under negative feedback
  - Not true for comparators
- Input common mode voltage range specification is **per input**
- If one input is within V_{ICR} and the other input is above V_{ICR}, the output will be correct but the comparator may not meet full datasheet specs
- If both inputs are above V_{ICR}, **the output may be INCORRECT!!!!**

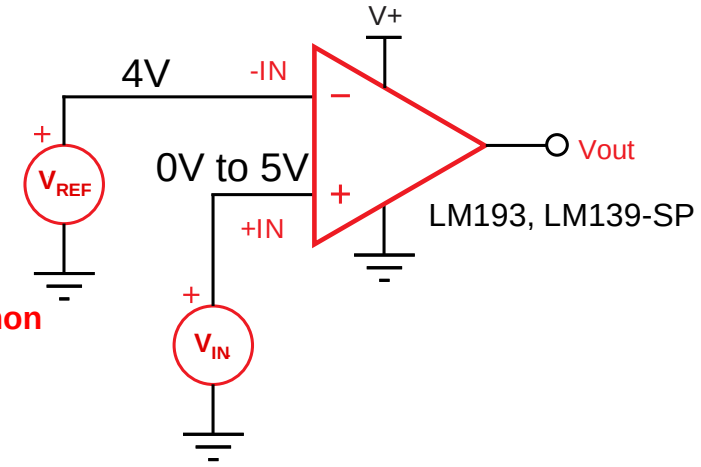


Common Mode Range Considerations

Example: V+ = 5V for Non-RRI Comparator

Valid common mode input voltage range is 0 to 3V

Should we use this comparator for this V_{REF} and V_{IN}?
No
Why?
As V_{IN} rises above 3V, BOTH inputs are above the input common mode voltage range and the output may be INCORRECT!



LM193, LM139-SP (non RRI)

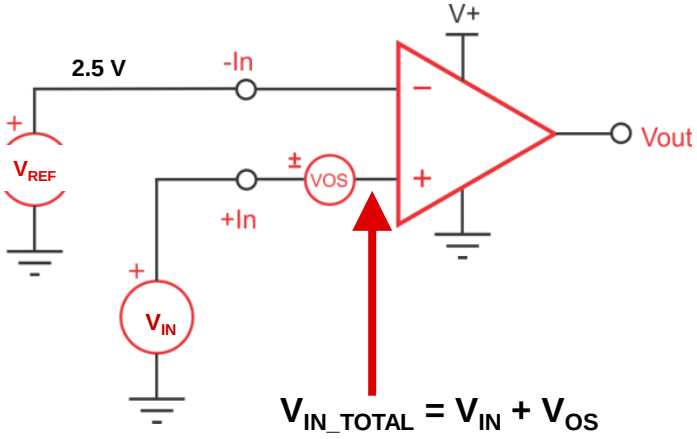
V_{ICR}	Common-mode input-voltage range (3)		25°C	0 to V_{CC} – 1.5	V
			Full range	0 to V_{CC} – 2	

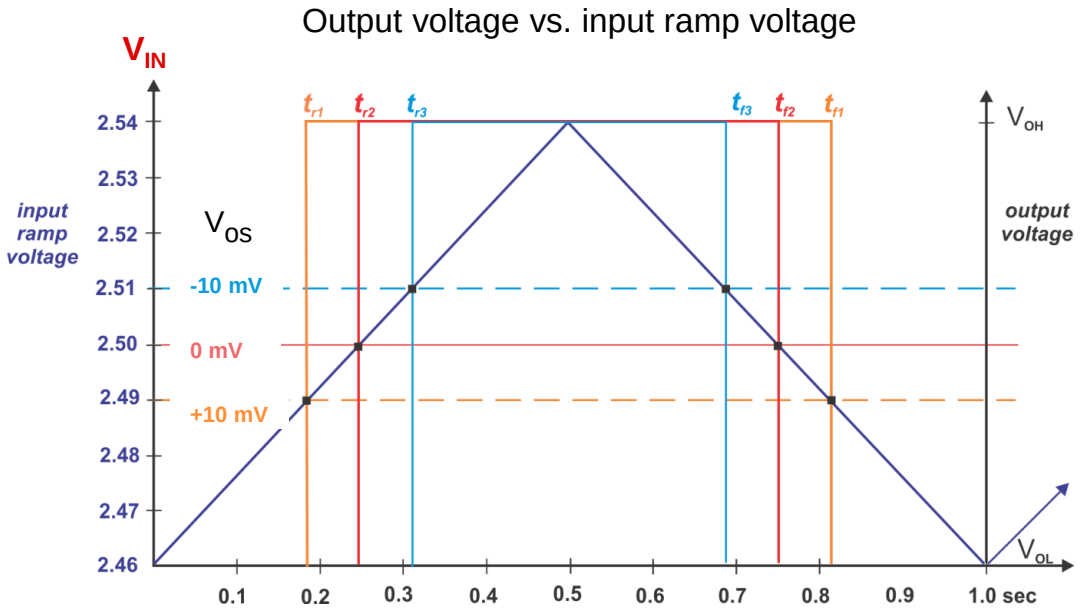
TLV1704-SEP, TLV4Hx90-SEP (RRI) – better for low voltage systems

INPUT VOLTAGE RANGE					
V_{CM}	Common-mode voltage range	T_A = –55°C to 125°C	(V–)	(V+)	V

Technical article: Solving top comparator challenges: Violating input common-mode range

Comparator DC parameters – offset voltage (V_{OS})



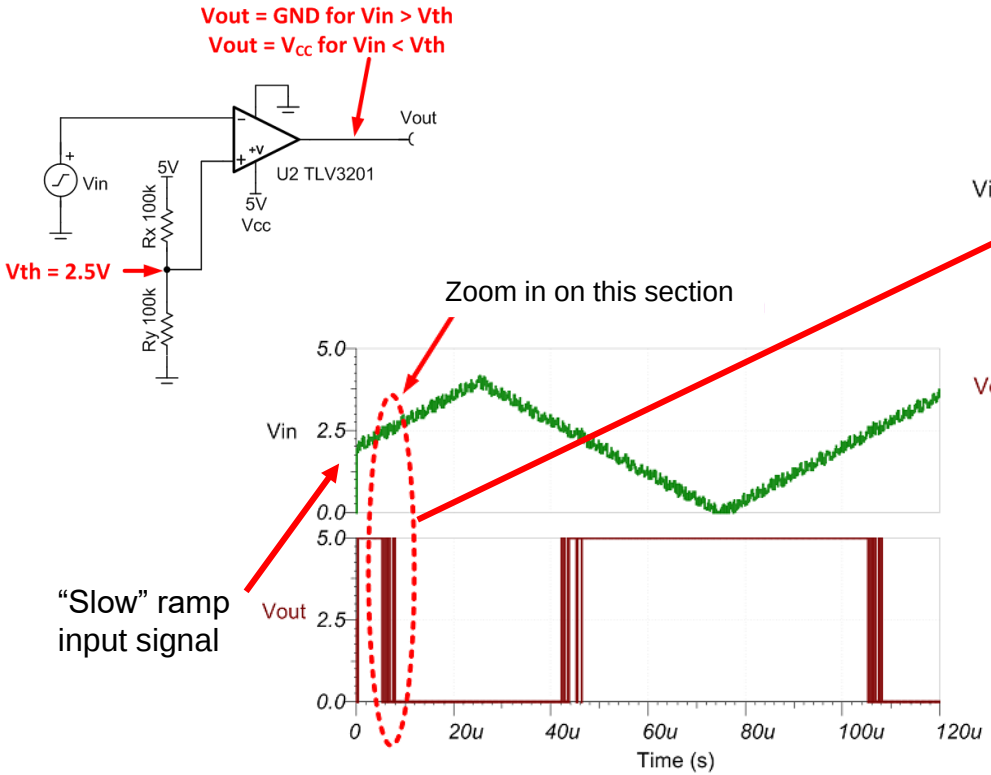


The maximum V_{OS} of a comparator ranges from about **±0.5 mV** up to **±15 mV**

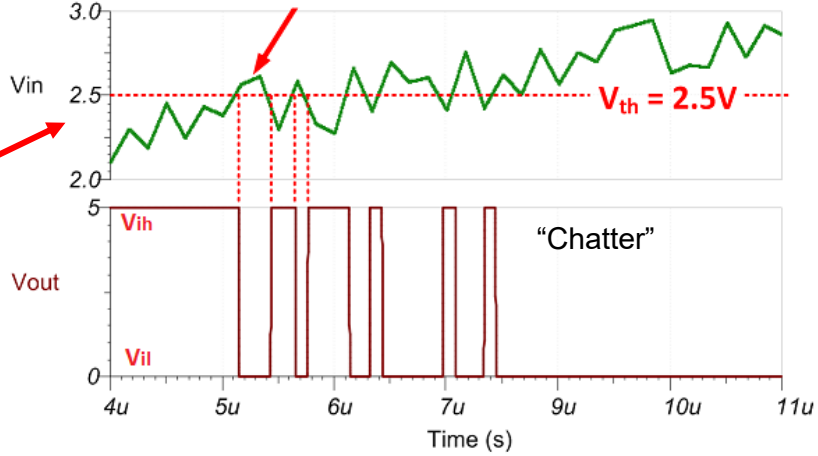
- Offset appears in series with positive input.
- "Suppresses" actual input signal

Example application: Zero crossing detection using comparator circuit

Noise effect on comparator output – “chatter”



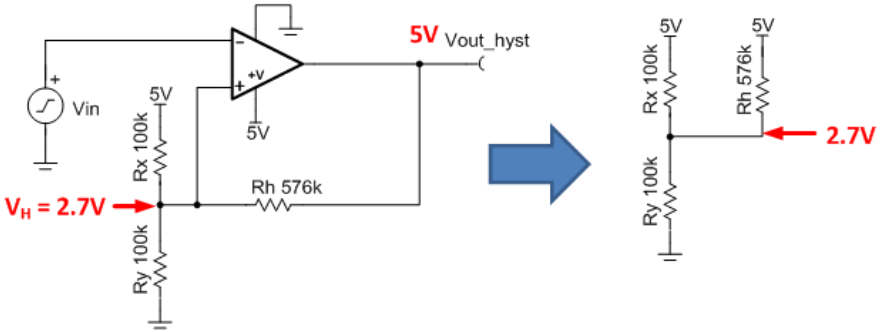
Vout momentarily transitions from Vih to Vil as Vin crosses above the 2.5V Vth level



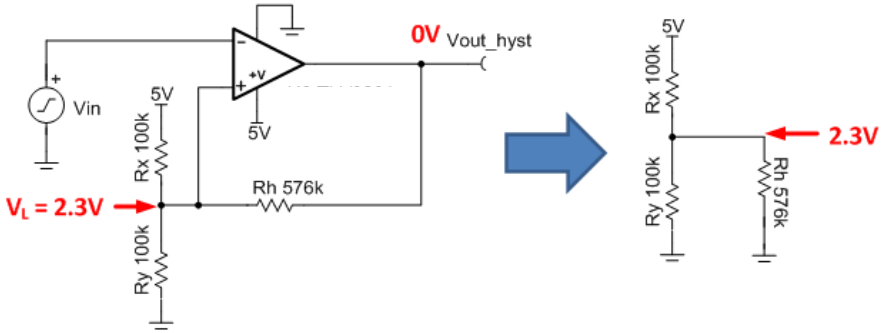
Comparator output rapidly changes state near the threshold point in response to the noise peaks.

Reducing noise sensitivity with hysteresis

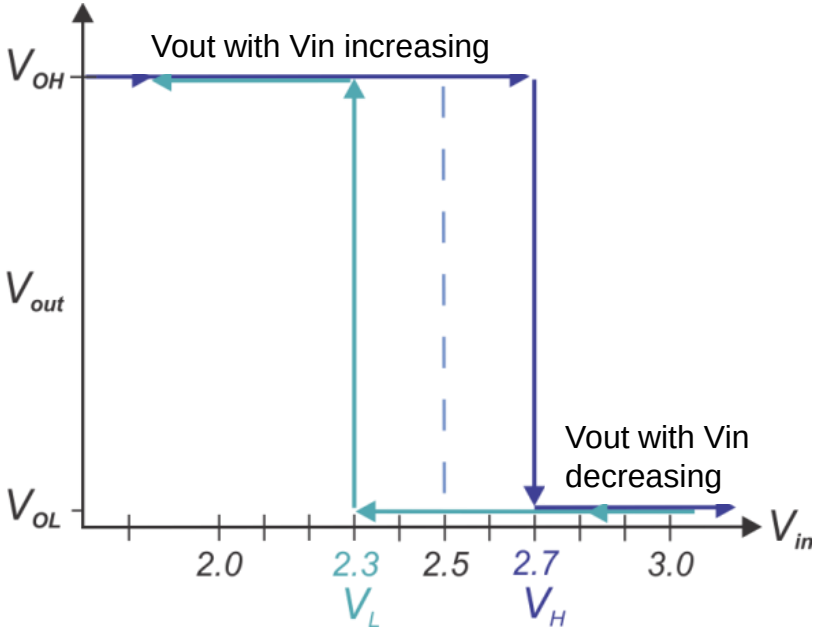
Vin > 2.7V causes Vout to transition to 0V



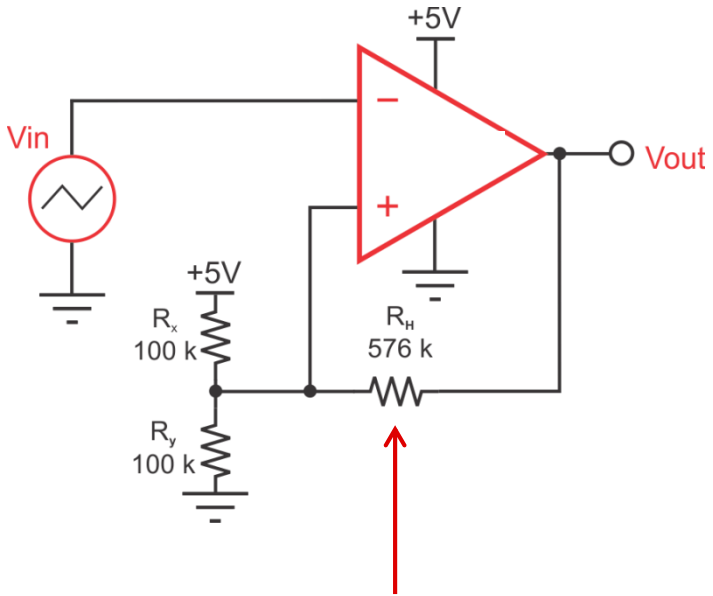
Vin < 2.3 V causes Vout to transition to 5 V



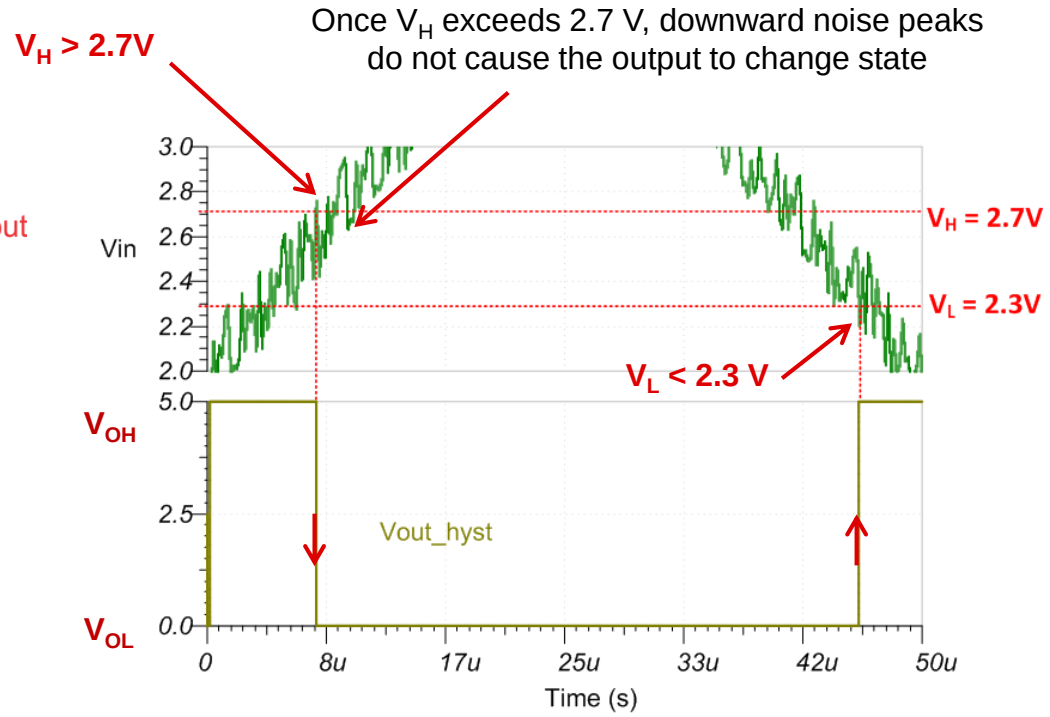
Vout vs Vin with 400 mV of hysteresis



Reducing noise sensitivity with hysteresis



Positive feedback or “hysteresis”



Some comparators have internal hysteresis

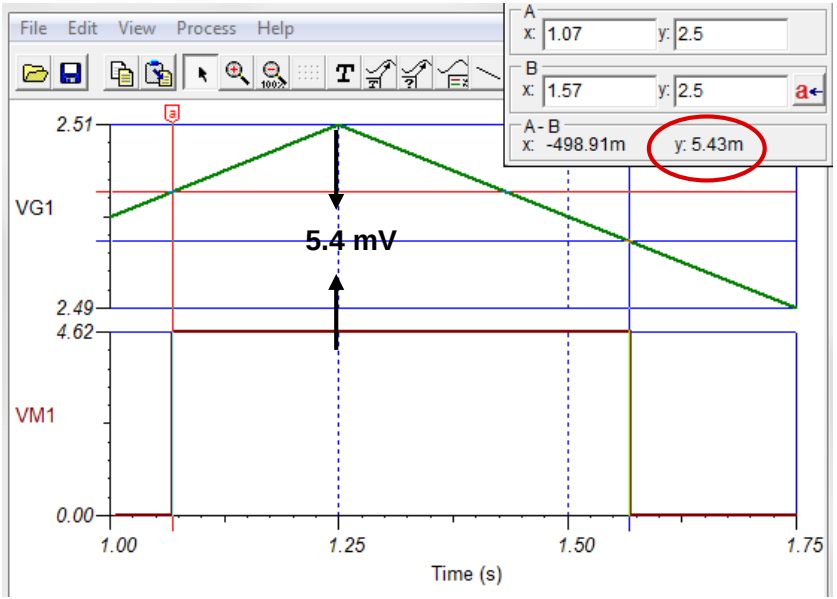
TI comparators with internal (built-in) hysteresis:

- **TLV3501** – 4.5 ns, V_{HYST} 5.4 mV typ.
- **TLV3601/2/5** – 2.5 ns, V_{HYST} 3 mV typ.
- **TLV3603** – 2.5 ns, resistor programmable V_{HYST} up to 60 mV.
- **TLV38x1** – 225ps, V_{HYST} 2 mV typ.
- **TLV40x1** – 450 ns V_{HYST} 20 mV typ.
- **TLV701/2x** – 3 us, V_{HYST} 6.5 mV typ.

External hysteresis can still be applied

- Total hysteresis = Internal hysteresis + External hysteresis

TLV3501 simulation model with built-in hysteresis



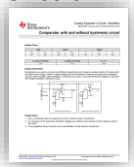
Chatter and hysteresis resources

Technical article: Solving Top Comparator Challenges: Chatter

Circuit Cookbook → SBOA313: Non-Inverting Comparator with Hysteresis

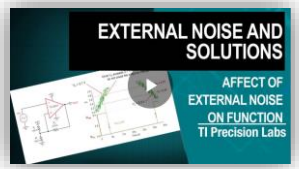
TI training video: How to Add External Hysteresis to a High Speed LVDS Comparator

Application note → SBOA219A: Comparator with and without Hysteresis Circuit

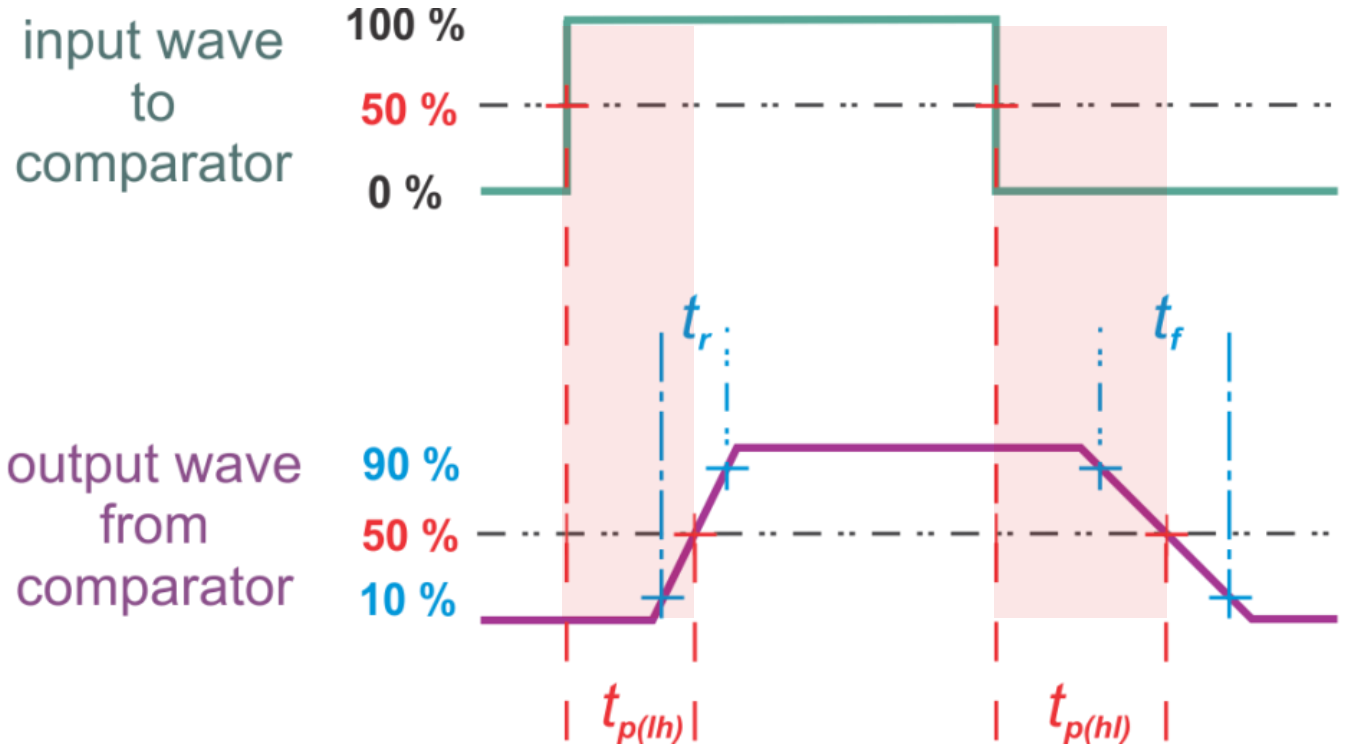


Circuit Cookbook → SNOA997: Inverting Comparator with Hysteresis

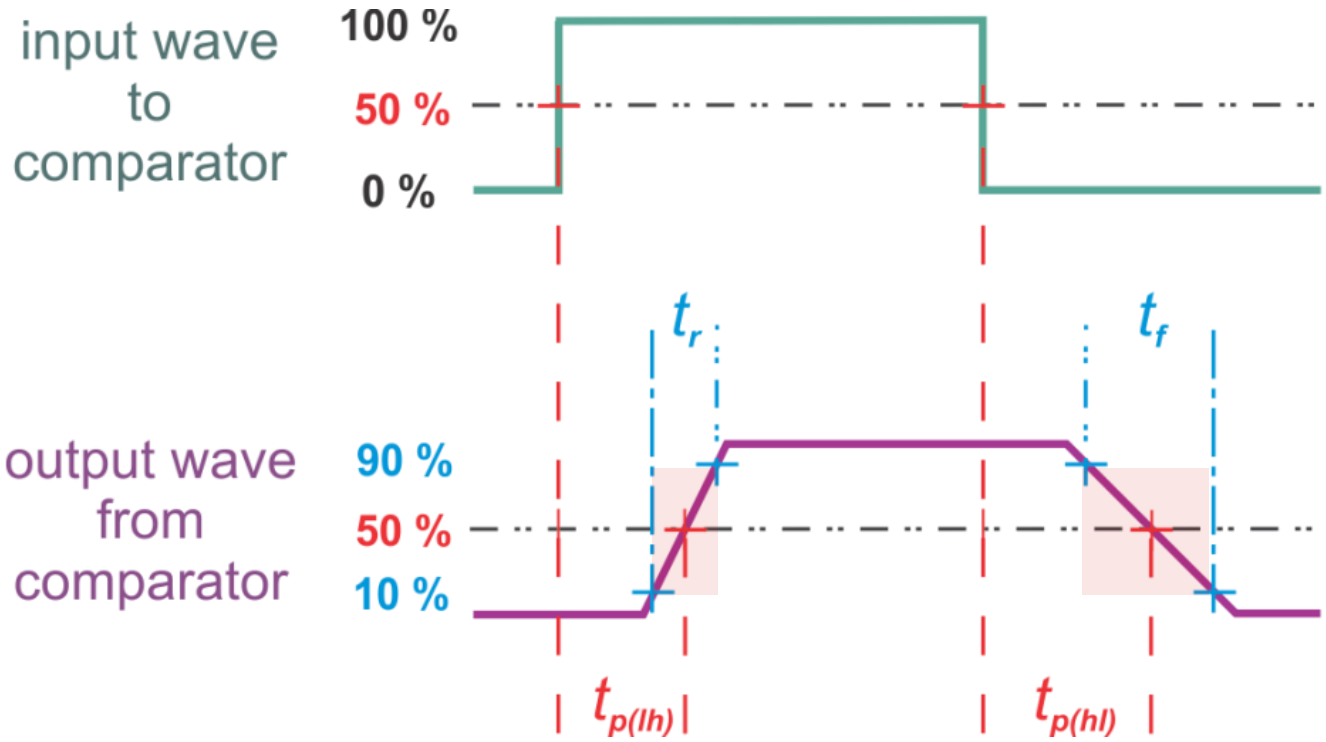
TI training video: How to Solve Comparator Noise Problems with Hysteresis



Comparator AC parameters - propagation delay

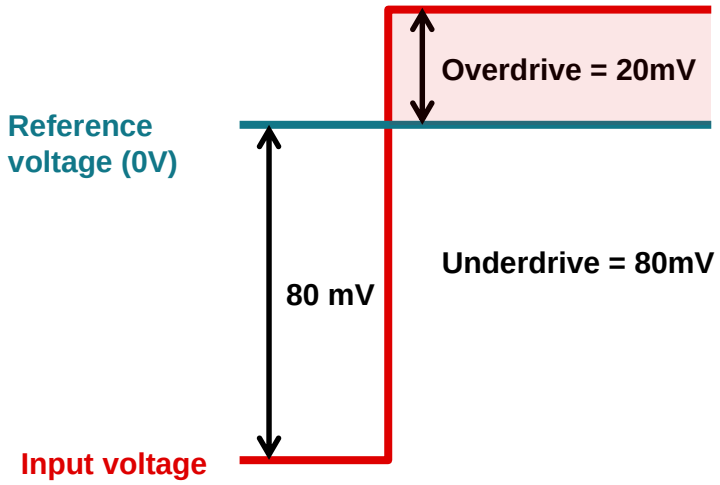


Comparator AC parameters - rise and fall time



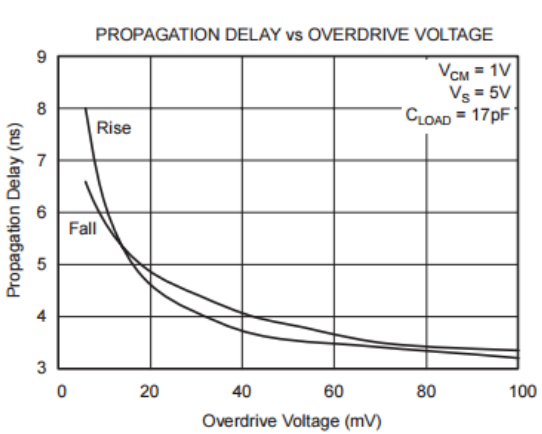
Comparator AC parameters - input overdrive

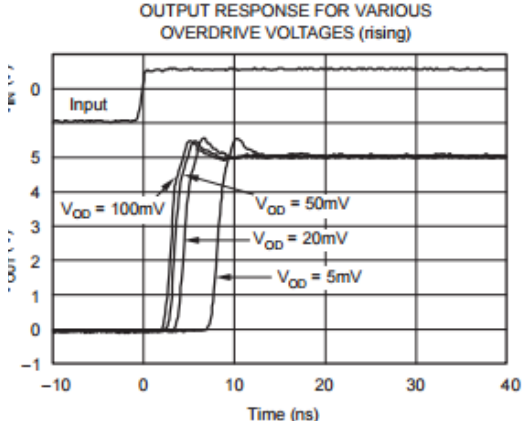
- A commonly misunderstood specification
- Overdrive is not the total change in input voltage
- Overdrive is defined as the amount of differential input voltage exceeding the reference voltage



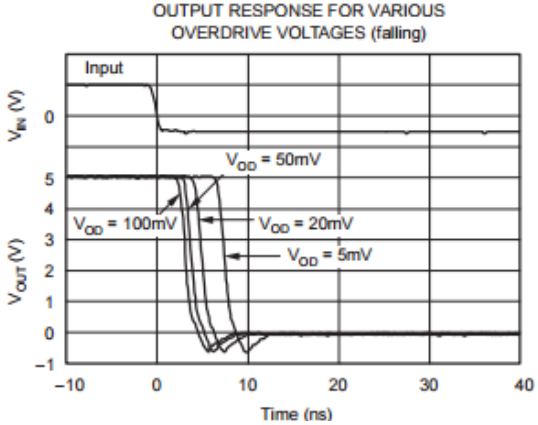
Example:
100mVpp input step with 20mV overdrive

Input overdrive influences propagation delay

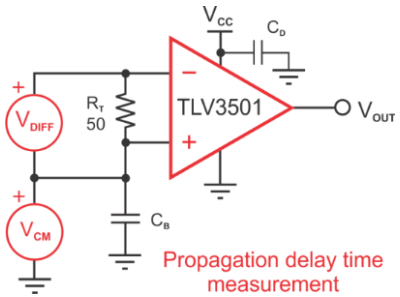




Prop delay $t_{P(LH)}$



Prop delay $t_{P(HL)}$

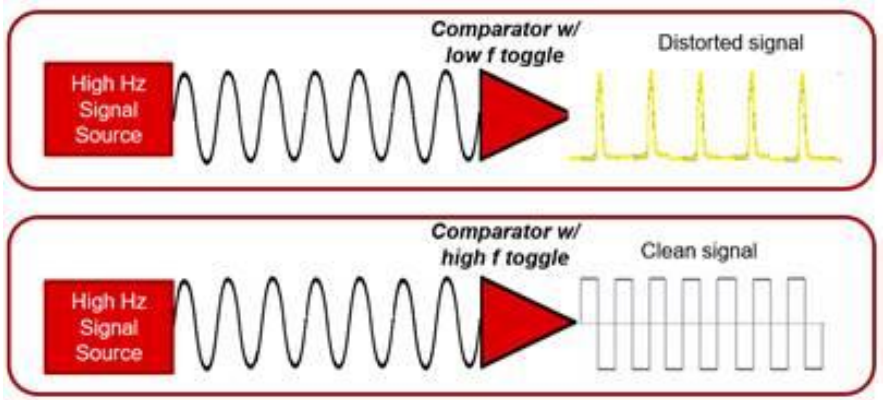


Temp	Overdrive	Typical	Maximum
25°C	5 mV	7.5 ns	10 ns
-40°C to 85°C			12 ns
25°C	20 mV	4.5 ns	6.4 ns
-40°C to 85C			7 ns

Propagation delay t_{PD} , ΔVin = 100 mV

Comparator AC parameters - maximum toggle frequency

- Maximum switching frequency of the comparator
- Overall “speed” of a comparator
- Rule of thumb:
  - Ftoggle_max = 1 / (tr + TPLH + TPHL + tf)
  - Does not account for output fidelity
- Do not try to “push” the speed of the comparator
  - Output can distort or “shrink”
  - Variation over process / lot / temperature
  - Chance of missing pulses
  - Better to use a faster comparator



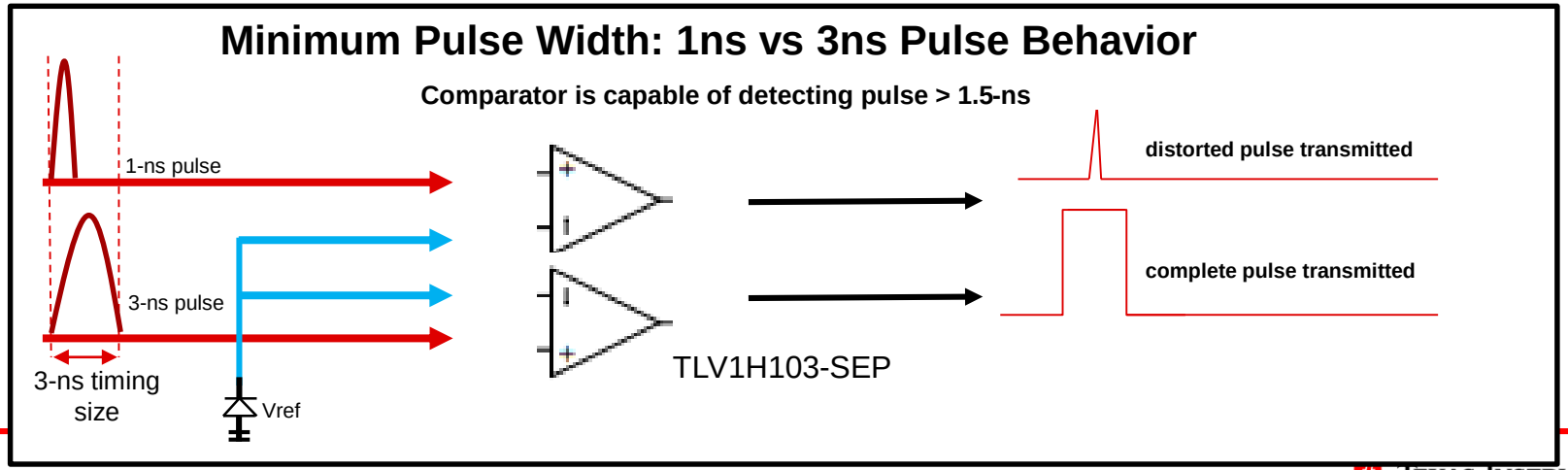
f_{TOGGLE}	Input toggle frequency	V_{IN} = 200 mV_{PP} Sine Wave, When output high reaches 90% of V_{CC} - V_{EE} or output low reaches 10% of V_{CC} - V_{EE}	325	MHz

Comparator AC parameters – minimum pulse width

Minimum pulse width: smallest pulse size (measured in seconds) that will produce a high output state on the comparator

A pulse that is too narrow will not be detected, as the pulses will disappear before the comparator can transition its output

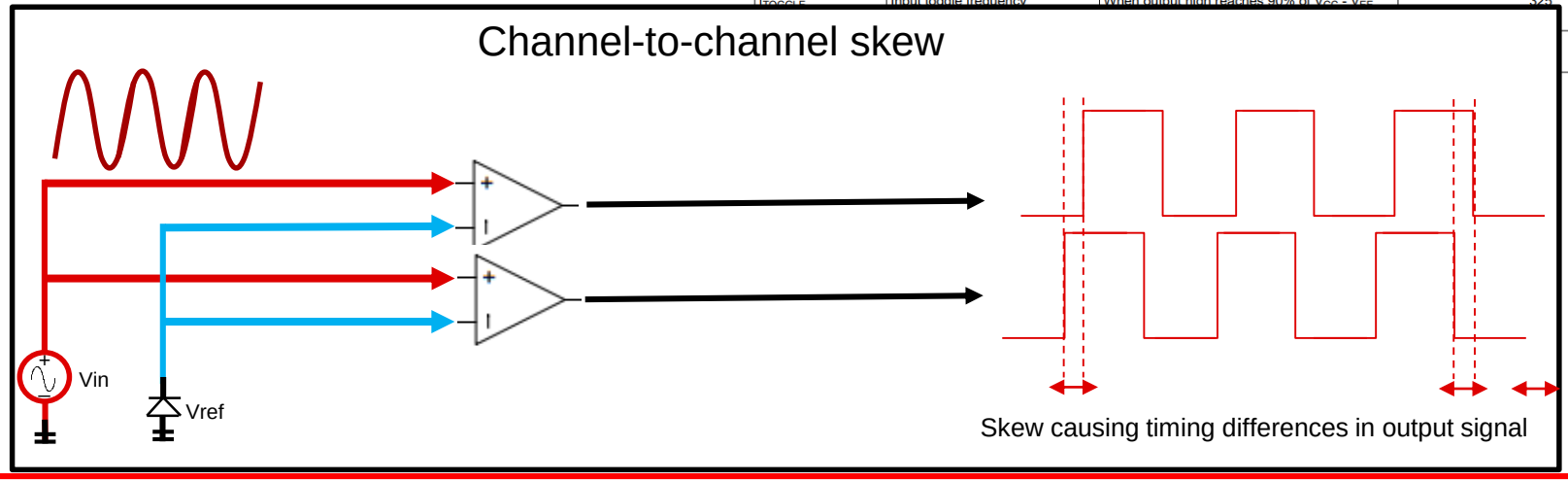
PulseWidth	Minimum allowed input pulse width	$V_{OVERDRIVE}$ = $V_{UNDERDRIVE}$ = 50mV PW_{OUT} = 90% of PW_{IN}	1.5	ns



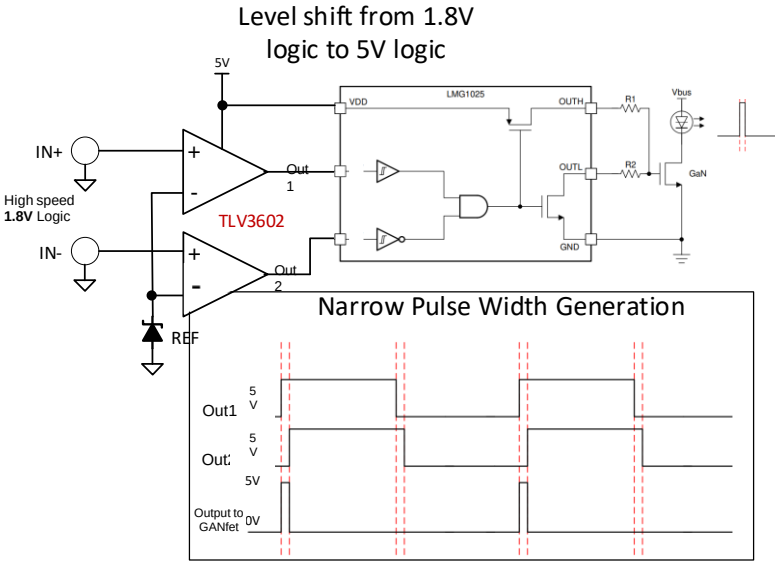
Comparator AC parameters – t_{PD} Channel-to-channel Skew (matching)

Channel-to-channel skew (often called “matching”) refers to the **variation in response time between two or more channels** when receiving the same input signal

AC Characteristics					
t_{PD}	Propagation delay	$V_{OVERDRIVE}$ = $V_{UNDERDRIVE}$ = 50mV	2.5	3.5(1)	ns
t_{PD}	Propagation delay	$V_{OVERDRIVE}$ = $V_{UNDERDRIVE}$ = 50mV T_A = –40°C to +125°C		4.5(1)	ns
Δt_{PD} (TLV3602 only)	Channel-to-channel propagation delay skew(2)	V_{CM} = V_{CC}/2, $V_{OVERDRIVE}$ = $V_{UNDERDRIVE}$ = 50mV, 50 MHz Squarewave	24		ps
$t_{CM\_DISPERSION}$	Common dispersion	V_{CM} varied from V_{EE} to V_{CC}	80		ps
$t_{OD\_DISPERSION}$	Overdrive dispersion	Overdrive varied from 10 mV to 125 mV	600		ps
$t_{UD\_DISPERSION}$	Underdrive dispersion	Underdrive varied from 10mV to 125 mV	330		ps
t_R	Rise time	10% to 90%	0.75		ns
t_F	Fall time	90% to 10%	0.75		ns
t_{JITTER}	RMS Jitter	V_{IN} = 100mV$_{P-P}$, f_{IN} = 100MHz, Jitter BW = 10Hz – 50MHz	4		ps
f_{TOGGLE}	Input toggle frequency	V_{IN} = 200 mV$_{PP}$ Sine Wave, When output high reaches 90% of V_{CC} - V_{EE}	325		MHz
					ns



Minimum Ch-Ch Skew Applications



Well-matched prop delay minimizes timing error and enables generation of precision narrow pulses for GaN FET Driver

Comparator applications/use cases

Power supply monitoring

Comparator usage cases

Under-voltage detection:

Devices such as the MCU need to know when the power supply reaches a nominal operating voltage to ensure proper operation. Standard comparators are frequently used because a reference voltage is already available in the system, otherwise comparators with an integrated REF can be used for higher precision and lower power consumption.

System Care Abouts:

- Low Offset | Low Power | Low Operating Voltage

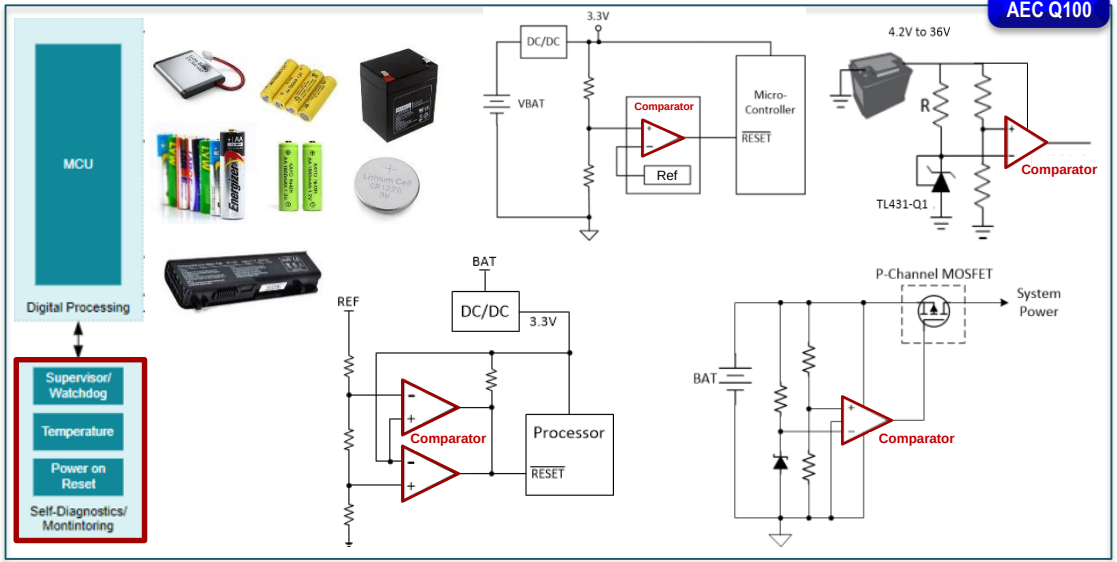
Over-voltage detection:

High voltage sources are resistor divided down and compared against a reference voltage to protect the system. Protection is provided by disabling the power source or disconnecting the system from the source. If powered by the source that is being monitored, the comparator's max operating voltage must be greater than the highest supply voltage.

System Care Abouts:

- Low Offset | Propagation Delay | Max Operating Voltage

Standard comparators	Precision comparators
Q100 **LM2903B** → Standard DUAL comparator; best price guaranteed	Q100 **TLV90XX** → 100ns, 16uA
Q100 **TLV1805** → 40V operation with push-pull output stage is well-suited to drive a MOSFET switch	Q100 **TLV301X / TLV40XX** → Integrated 1% REF
	Q100 **TLV170X** → 36V operation with IQ of 55uA and low offset;
	Q100 **TLV70XX** → Power sensitive applications



Benefits:

- Integrated reference saves board space and reduces BOM count
- Push-pull output eliminates the need for a pull-up resistor, thus saving power and decreasing the time it takes to switch off or alert the system of undervoltage/overvoltage conditions
- Inverting/non-inverting options allow for more flexibility in design

Want to learn more? Check out these links:

- Overvoltage Protection with Comparator Circuit
- Non-Inverting Comparator with Hysteresis Circuit
- High-Side Inverting Comparator with Hysteresis Circuit
- Analog Engineers Cookbook: Op Amps & Comparators

Current Sense

Comparator usage cases

Bi-directional current sense of the motor:

When the shunt resistor is placed in series with a phase lead of a motor, the current sensing requirement is bi-directional. A current sense amplifier will bias its output at mid-supply and a window comparator will alert the system if the current ever goes outside the desired range.

System Care Abouts:

- Low Offset | Propagation Delay | Output Configuration

High-side & low-side current sensing

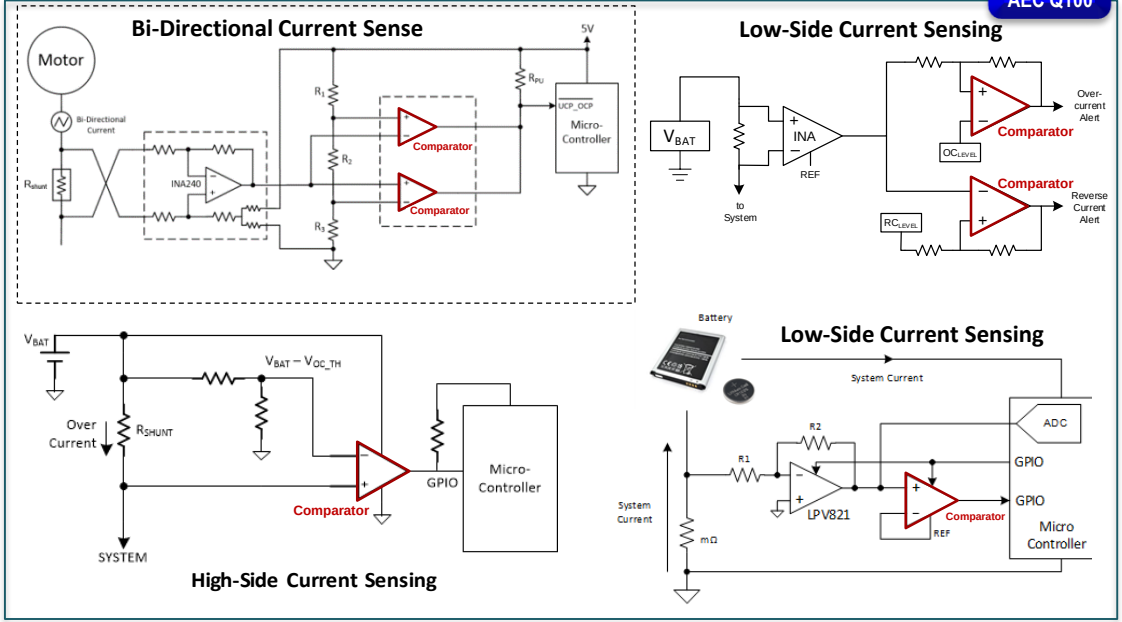
High and low side current sensing have current flowing in one direction. The voltage across the shunt can be directly monitored by a comparator or a current sense amplifier can be used when higher precision is required. An alert signal is generated by the comparator when an over-current event occurs.

System Care Abouts:

- Low Offset | Propagation Delay | Input Common Mode Range

High-voltage current sensing	Highspeed current sensing
Q100 **LM2903B** → Standard dual comparator	Q100 **TLV90XX** → 16µA, 100ns delay, best for low power application in bi-directional current sensing
Q100 **TLV170x** → 36V operation with IQ of 55uA and RRI; best for low power application in high-side current sensing	Q100 **TLV320X** → 40ns delay, 40uA supply current for high speed OC alert
Q100 **TLV1805** → 40V operation with push-pull output stage is well-suited to drive a MOSFET switch.	• **TLV360X** → 800-ps prop delay, 350-ps overdrive dispersion
	Q100 **TL331B/2903B** → 2.5mv offset voltage, 2V to 36V supply range, 1µs prop delay

AEC Q100



Benefits:

- Low offset increases accuracy of current detection
- Low propagation delay allows the comparator to send a fast alert signal
- Simplifies design and monitors hardware

Want to learn more? Check out these links:

- Bidirectional Current Sensing with a Window Comparator Circuit
- Analog Engineers Cookbook: Op Amps & Comparators
- High-side Current Sensing with Comparator Circuit
- Precision Over-Current Latch Circuit
- High-Side Fast-response Over-Current Detection Circuit

Temperature Detection

AEC Q100

Comparator usage cases

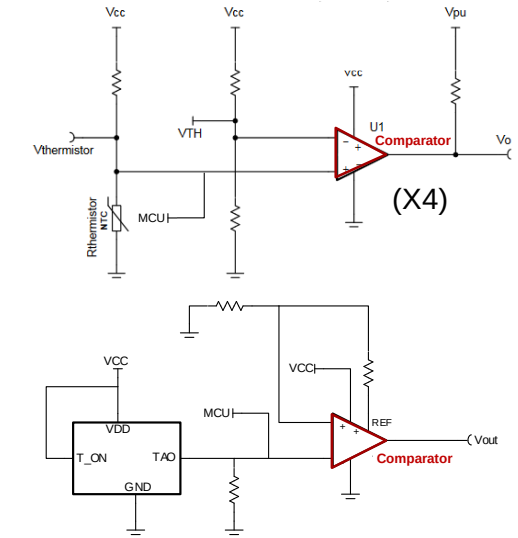
Detect when system reaches critical temperature:

Over-temperature detection is required to protect systems from excessive temperatures during operation; note that no fixed reference is required with integrated reference comparator solution.

System care about:

- Low quiescent current
- Low input offset voltage
- Integrated hysteresis
- Rail-to-rail inputs
- Multichannel options for measuring multiple temperatures
- Known startup condition

Standard	Specialized
Q100 **TLV703X/4X** → Nanopower, best when need low power in high-side current sensing, 0.8 mm × 0.8 mm, Q100 **TL331B/TL391B** → operating voltage up to 36V, Low input offset	Q100 **TLV3011/TLV3012**→ Power on Reset circuit, Externally available precision 1.2V reference, ±1% accuracy • **TLV4031R1**→ Power on Reset circuit, precision 1.2V reference, ±1% accuracy, 0.73 mm × 0.73 mm size package



Benefits:

- Offers analog backup protection when placed in parallel with microcontroller
- Hysteresis and low V_{OS} eliminate false output transitions for slow temperature transitions
- Rail to rail inputs allow for monitoring temperature over a wider range
- In the presence of a POR circuit, the output is in a known state during startup

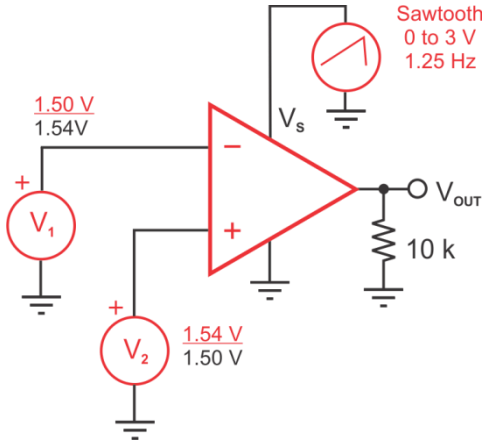
Want to learn more? Check out these links:

- Thermal Switch with a Comparator
- Analog Engineers Cookbook: Op Amps & Comparators

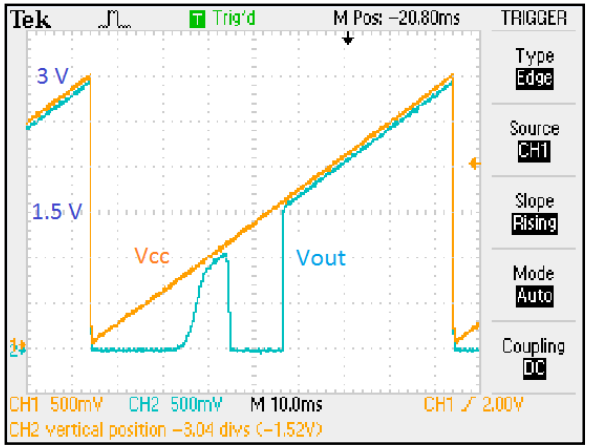
Comparator Special Features

- Known Startup Condition (Power on Reset Circuit)
- Fail-safe Inputs
- Integrated references
- 65V Comparator with Integrated Reference
- Reverse battery protection
- Over-the-rail operation – transient voltage protection up to 40V
- Split-supply input operation with ground reference outputs
- Hysteresis pin
- Self-Latching Comparator

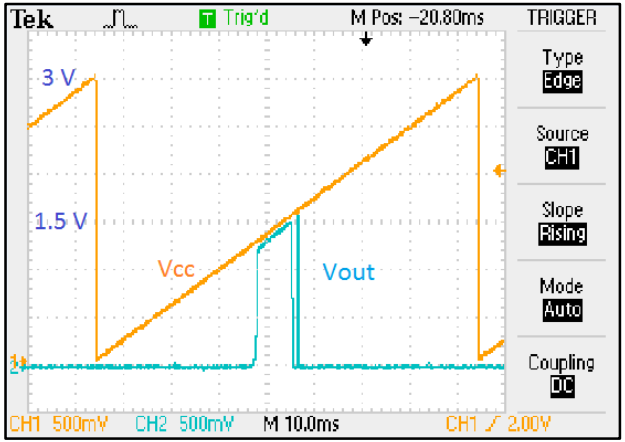
Start-up output state uncertainty



V_1 = 1.50V, V_2 = 1.54V
(Output should be high)



V_1 = 1.54V, V_2 = 1.50V
(Output should be low)

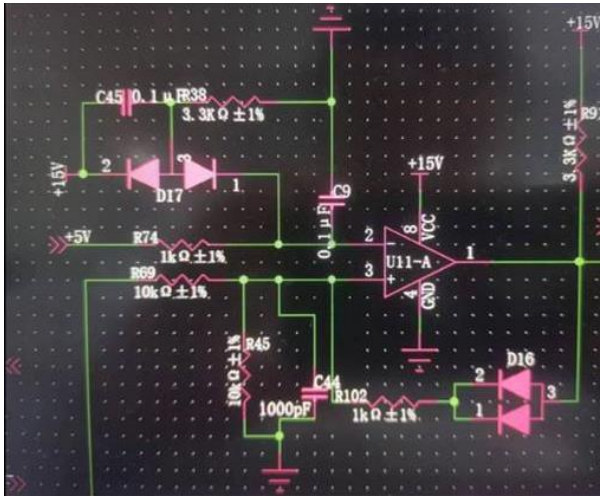


The comparator output flips state as it is powering up.
This is a common behavior for comparators.

Examples where Known Start-up is needed

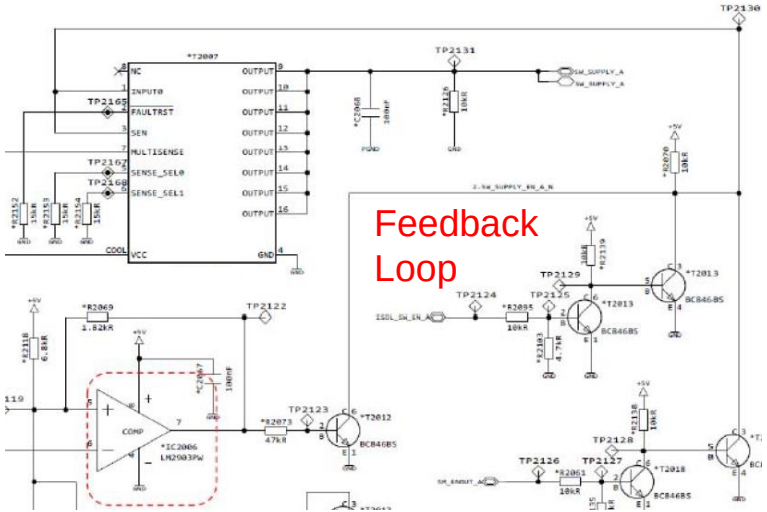
Latching output circuits

- Latches HIGH, so needs to start logic LOW
- Remains latched until power is cycled



Feedback loops

- Needs to start LOW, otherwise system is never ENABLED



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AEC Q100

Known Start-Up Conditions

Power-on-Reset (POR)

Feature Highlight

Problem: Start-up uncertainty creates a false state on start

In *Figure A*, output should be logic high, but upon start-up, the output toggles between high and low before stabilizing at logic high. In *Figure B*, output should be logic low, but the output briefly transitions to logic high before stabilizing at logic low. This transition between a high and low state can cause the premature activation of the circuit

Solution: Integrated Power-On-Reset (POR) Circuity

The integrated POR circuit forces the comparator output to a known state during start-up until the supply reaches the minimum supply value.

Feature Facts:

- Integrated POR circuitry will be designed into most new TI comparators

Comparators with POR

	I_Q	V_{OS}	t_{PD}	Supply Range
Q100 TLV3601/2/3	6mA	5mV	2.5ns	2.4V to 5.5V
Q100 TLV181X/2X	7µA		400ns	2.4V to 40V
Q100 TLV1805	135µA	500µV	250ns	3.3V to 40V
Q100 TLV701X/2X	5µA	8mV	260ns	1.6V to 6.5V
Q100 TLV703X/4X	315nA	8mV	3µS	1.6V to 6.5V
TLV40X1	2µA	-	360ns	1.6V to 5.5V
Q100 TLV185X/6X	560nA		30µs	1.8V t0 40V

Without POR

IN+ > IN-

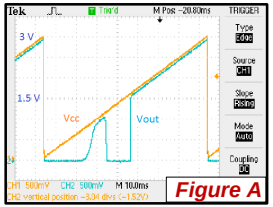


Figure A

*IN- > IN+

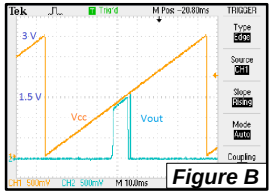


Figure B

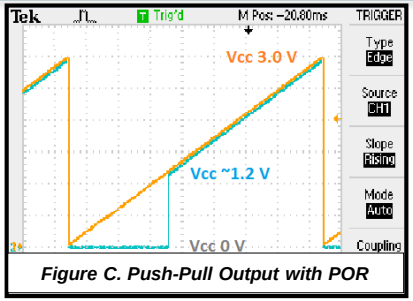


Figure C. Push-Pull Output with POR

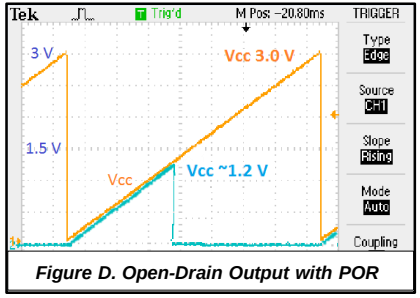


Figure D. Open-Drain Output with POR

For a Push-Pull comparator, the output is held low until the minimum operating voltage is reached

*IN+ > IN-

For an open-drain comparator, the output follows the supply until the minimum operating voltage is reached

*IN- > IN+

Benefits:

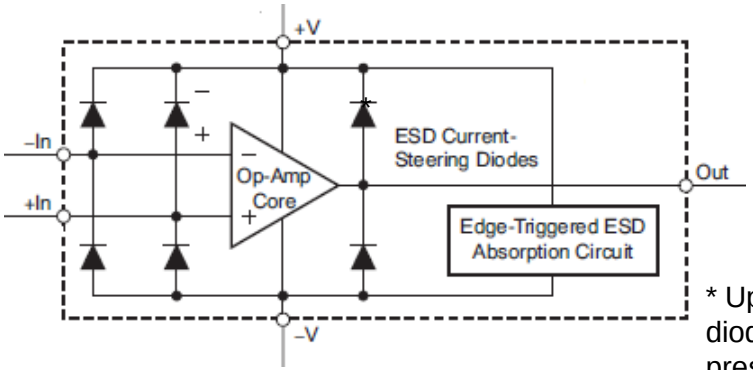
- Allows the comparator to consistently remain in a known state (POR state or reflective of input)
- Minimizes impact of brownout conditions by protecting against an accidental change in state
- Avoid false output conditions

Want to learn more? Check out these links:

- How to Solve Comparator Startup Uncertainty with POR
- [FAQ] How Power on Reset Comparators Simplify Designs

Input voltages beyond VCC

- Common question: *“What if I expect the input voltage to exceed the rails?”*
- Most low-voltage and CMOS devices have conventional ESD clamping diodes to supplies
- Diodes will clamp to supply when input exceeds supply by >500mV
- ESD diodes are not designed for continuous power dissipation



Conventional ESD Protection

* Upper output ESD diode may not be present on Open Collector Outputs

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Integrated Fail-Safe Inputs

AEC Q100

Feature Highlight

Problem: Input pins are dependent on power supply

Designing with input pins that are dependent on the power supply can lead to system damages in cases where the power supply ramps down faster than the input supply or during start-up where the input supply ramps faster than the output supply.

Solution: Make input pins independent of power supply

By giving the input pins their own absolute maximum ratings independent of the power supply, users can have more flexibility in designing without worrying about damage to the input pins.

System Care Abouts:

- High Input Impedance in absence of supply
- Input signal can go well beyond the supply voltage of the comparator as defined by Absolute Maximum Table

	I_Q	t_{PD}	Supply Range
Q100 LM393LV/LM339LV	25µA	600ns	1.65V to 5.5V
Q100 TLV902x/3x	16µA	100ns	1.65V to 5.5V
TLV701X/2X	5µA	260ns	1.6V to 6.5V
Q100 TLV703X/4X	315nA	3µS	1.6V to 6.5V
Q100 TLV185X/6X	560nA	30us	1.8V to 40V

Want to learn more? Check out these links:

- [FAQ] How to the apply inputs before powering the supply of my comparator?

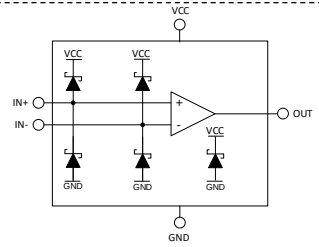
Without Fail-Safe Inputs

Absolute Maximum Ratings

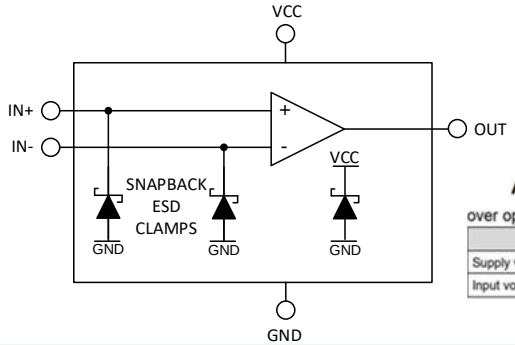
over operating free-air temperature range (unless otherwise noted)(1)

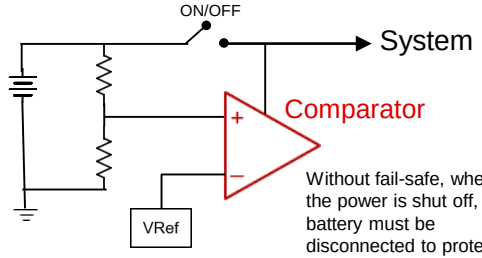
		MIN	MAX	UNIT
Voltage	Supply voltage		7	V
	Signal input pins(2)	–0.5	(VCC) + 0.5	

*Input limited by VCC



With Fail-Safe Inputs





Without fail-safe, when the power is shut off, the battery must be disconnected to protect the comparator.

Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

	MIN	MAX	UNIT
Supply voltage: V_S = (V+) – (V–)	–0.3	40	V
Input voltage (IN) from (V–) (2)	–0.3	40	V

*Input independent of VCC

Benefits:

- Don't have to disconnect monitored signal from comparator input when powering down
- Eliminates power supply sequencing concern

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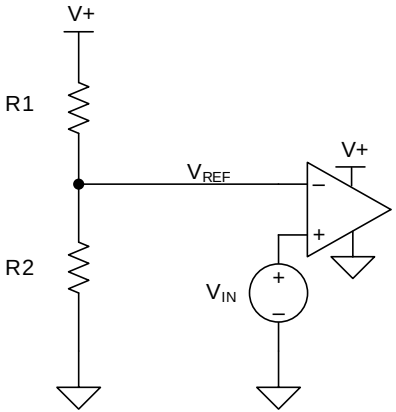
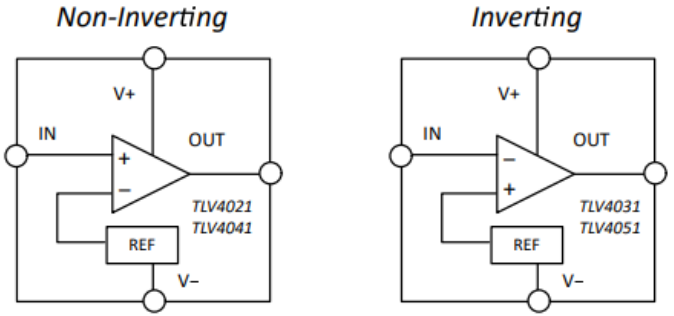
Texas Instruments

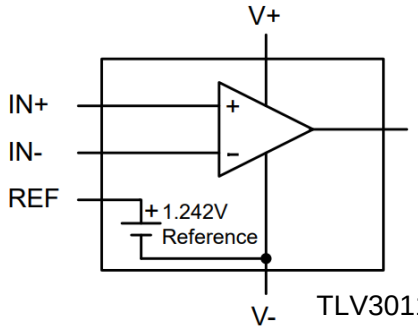
Integrated Reference



$V_{REF} = R2/(R1+R2)V+$

V_{REF} here is sensitive to the power supply and variations in the resistors.





TLV3011B/TLV3012B

Benefits:

- **V_{REF}** is more precise and insensitive to variations in power supply
- Lower BOM count due to not needing resistive divider to create **V_{REF}**

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TLV192x: 65V Comparator

Single and Dual Channel with Integrated REF

In Production

AEC Q100 Planned

Features

Specifications:

- Propagation Delay: **1 us**
- Input Offset Voltage: 3 mV (max @ 25C)
- Output Type: Open-Drain, 5.5V max

Key performance:

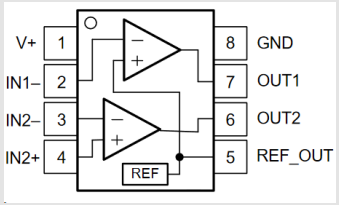
- Supply Range: **4.5V to 65V**
- Input range **Up to 65V**
- Quiescent Current: 20 uA

Additional Features:

- **65V Fail Safe Inputs**
- Externally Available Int. Ref: **2.5V, 1.75%**
- Package Options: Dual: WSON-8, SOIC-8
  Single: WSON-8

Applications/EE

- PELV/SELV voltage monitoring
- Power loss dual UV detection
- DC-DC Conversion protection
- 24V Industrial Backplane voltage monitoring

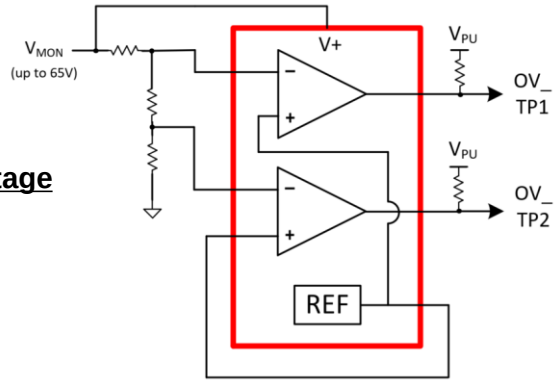


Benefits

- Wide supply range and low quiescent current offers low power performance for **PELV/SELV** voltage supplies
- 65V inputs eliminates concern for HV shorts or opens in divider network
- Externally available reference allows for health checks and design flexibility

Common Functionality

Dual Over-Voltage Application



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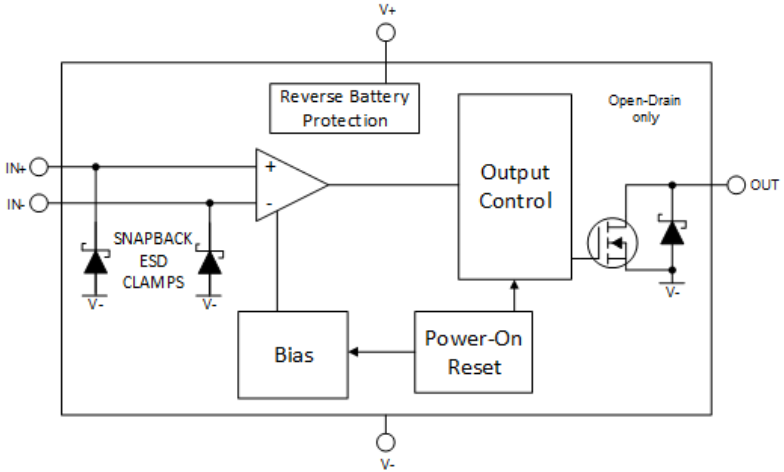
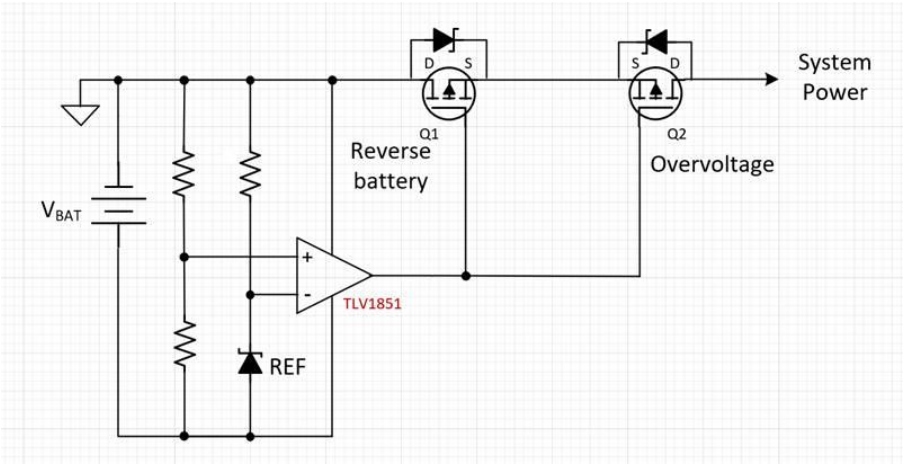
Texas Instruments

TLV185x/6x Reverse Battery Protection Feature

The TLV185x/6x devices have an internal reverse battery protection feature that prevents damage to the comparator in the event of improper battery installation to the supply pins. This protection feature works up to 40 V.



TLV185x/6x Internal Block Diagram

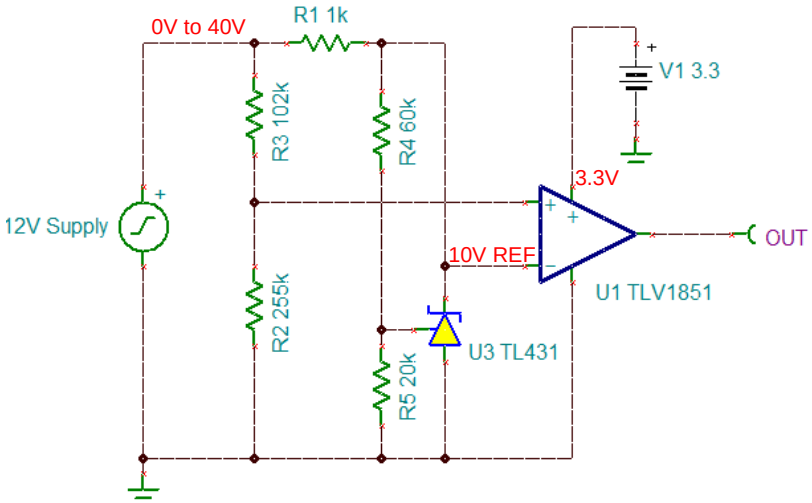


Reverse Battery + Overvoltage Protection Scheme

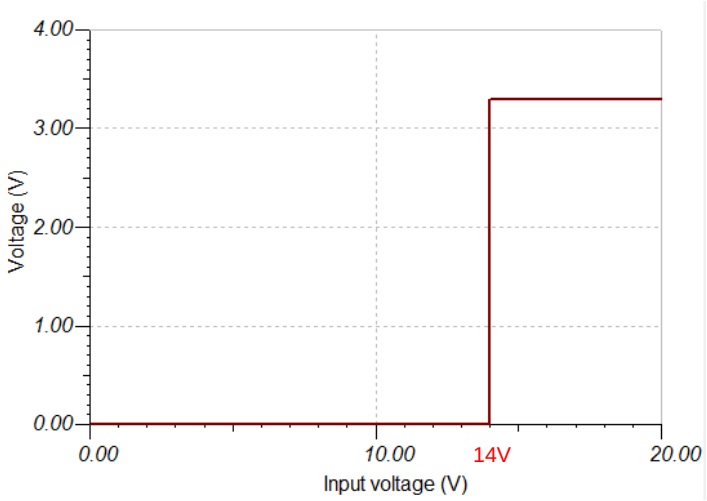
- *This feature can be used to prevent damage to the overall system in the event of reverse battery and overvoltage conditions*

TLV185x/6x Over-the-rail Inputs

The TLV185x/6x devices have a unique input stage that allows the input common mode range to extend from 0V to 40V, independent of the supply voltage. Operation at low supply voltages does not limit the range of the input voltages that can be compared.



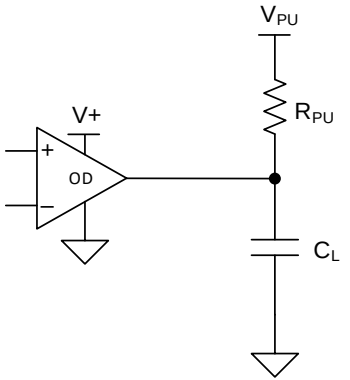
Overvoltage Protection Scheme using Over-the-rail



- *"Over-the-rail" allows the comparator to monitor high voltages on the inputs while operating at low supply voltages (i.e, monitor a 12V battery for overvoltage conditions while powering the comparator at 3.3V)*

Separate input and output supplies
(maintain GND referenced outputs)

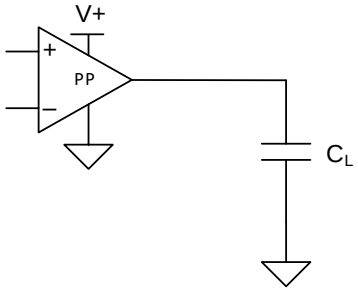
Open-drain comparator



Benefit:
Output high voltage can be a voltage V_{PU} different from V+

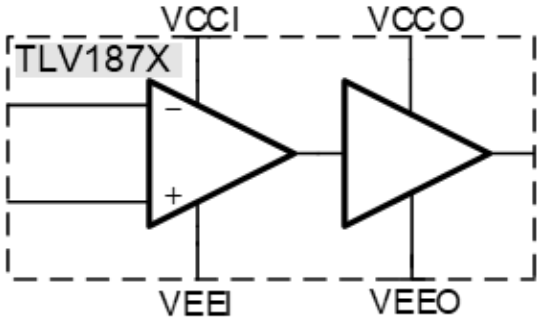
Disadvantage:
Asymmetrical propagation delay (t_{plh} dependent on $R_{PU}C_L$ time constant)

Push-pull comparator



Benefit:
Symmetrical propagation delay ($t_{plh} = t_{phl}$)

Disadvantage:
Output high voltage is pulled to V+



Benefits:

- Symmetrical propagation delay ($t_{plh} = t_{phl}$)
- Ability to level shift with separate input and output supplies

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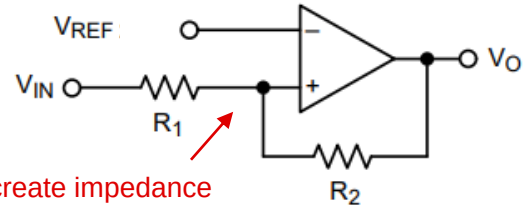
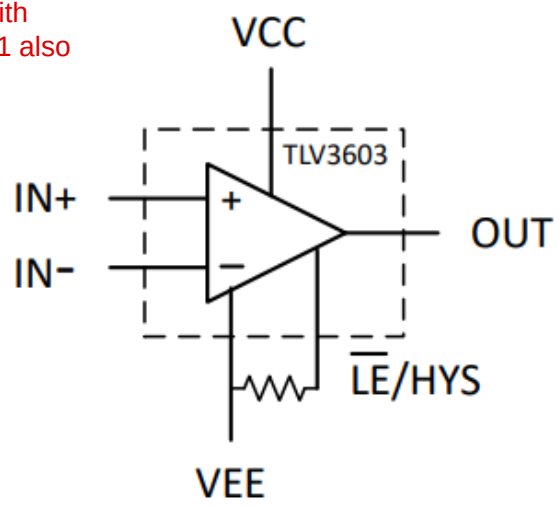
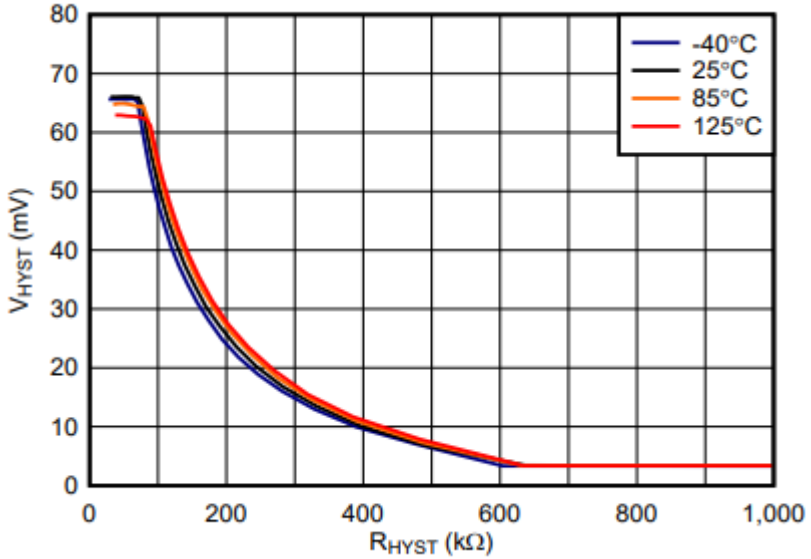
Hysteresis pin

(eliminates need for external feedback (R_2) and input resistor (R_1))



R1 & R2 create impedance mismatch and filtering with parasitic capacitance; R1 also acts as a load for VIN





Back to features list

TLV903xL

5.5V Single, Dual Channel High Speed Comparator Family

In Production

AEC Q100 Planned

Features

Specifications:

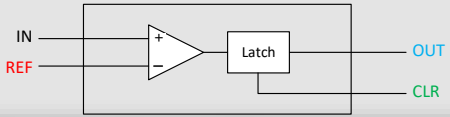
- Propagation Delay **100ns**
- Input Offset Voltage: 2mV (max @ 25C)
- I_Q/CH: 20uA
- Supply range: 1.65V to 5.5V

Key performance:

- **Self-latch**
- CLR Logic level **1.8V**
- CLR to Output Delay 40ns
- Output Short-Circuit Current 100mA

Additional Features:

- R2R Inputs
- Known Start-up Conditions
- Package Options:



Single: SC706, WSON6

Dual: VSSOP10, X2QFN10

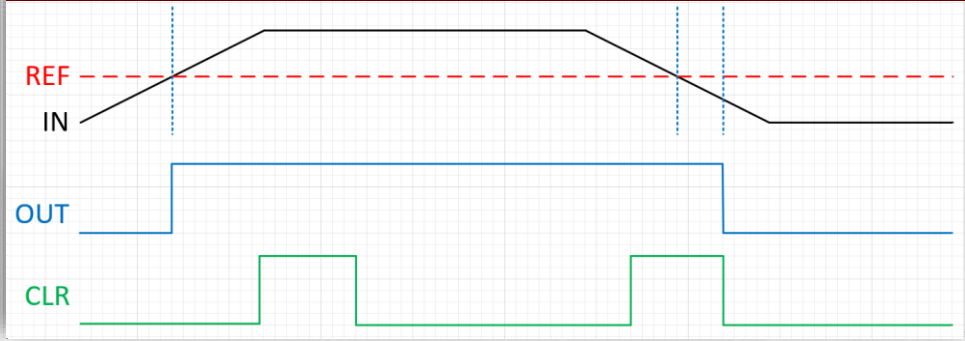
Applications/EE

- Overcurrent detection
- Reverse current sense
- Undervoltage detection
- HEV/EV
- Grid Infrastructure
- Power Delivery

Benefits

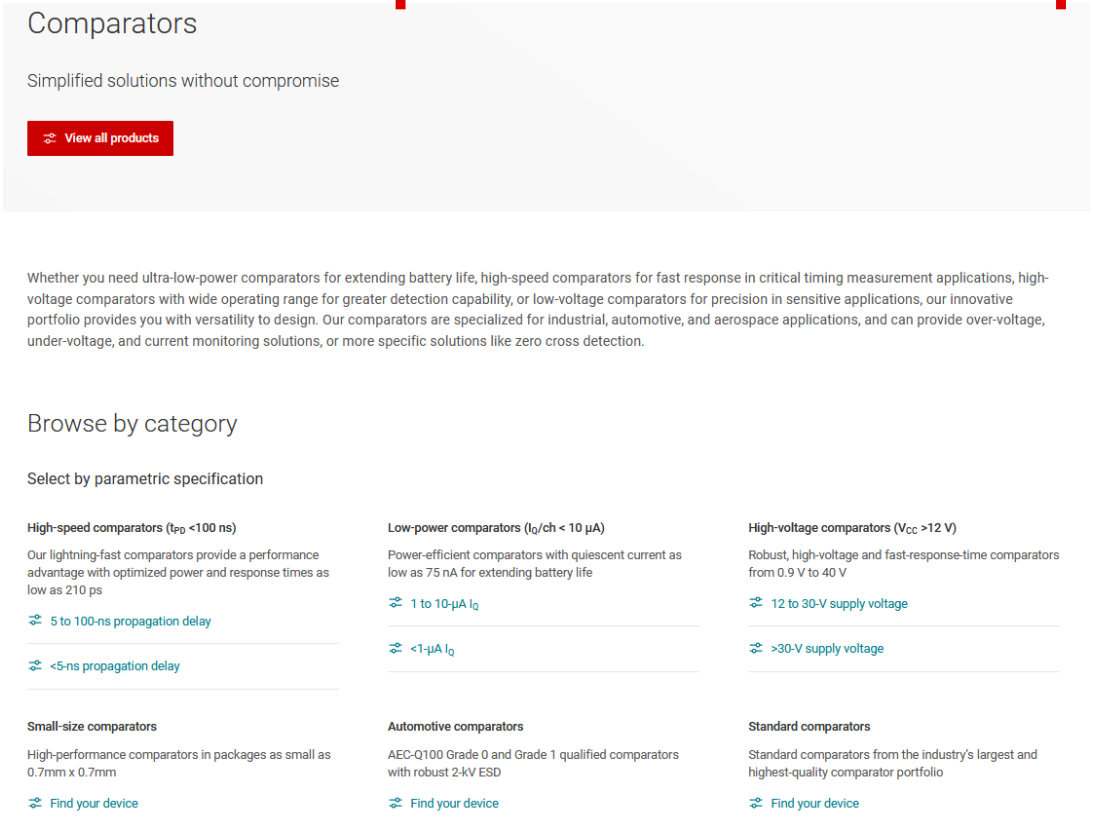
- Simplify design by reducing component count with integrated self-latch
- Low propagation delay allows for a fast response to signals crossing voltage thresholds
- Push-pull output type allows latching on low to high transition, requiring no pull-up resistor
- Low power usage is ideal for constant monitoring applications, while low offset enables better accuracy for sensitive voltage sensing

Push-Pull Functionality



Texas Instruments

Comparators web portal – ti.com/comparators



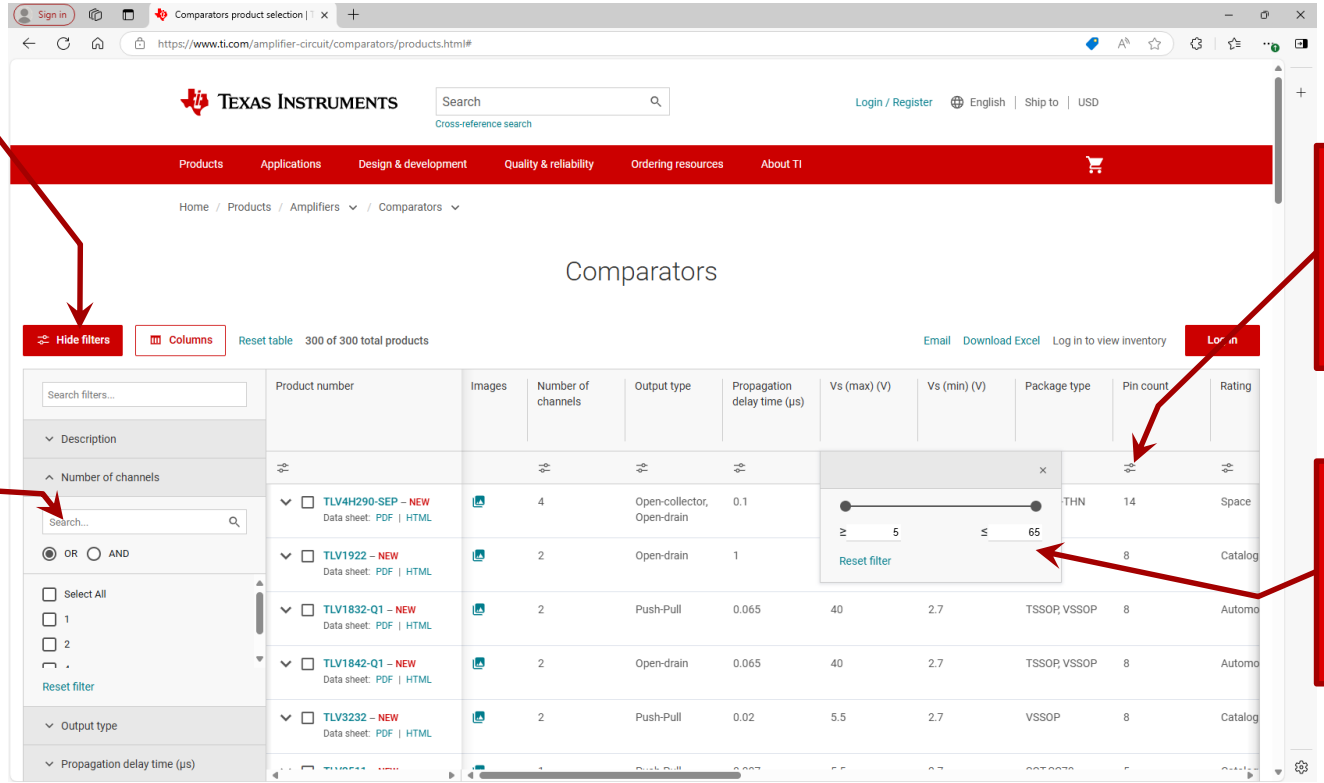
Comparators all products – ti.com/comparators

Click here for parametric filters

Selectable filters for more detailed search

Sliders for each specification can be activated here

Configure slider to refine each specification

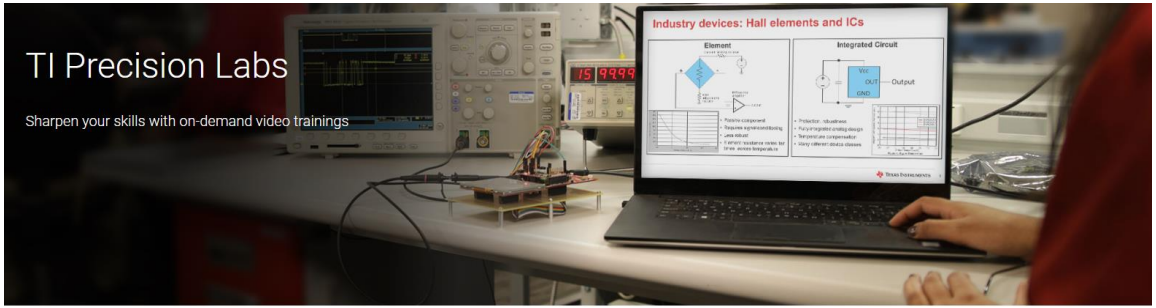


Questions?

To find more technical resources on comparators and search for products, visit **ti.com/comparators**.

Learn more

Check out **TI.com/PrecisionLabs**



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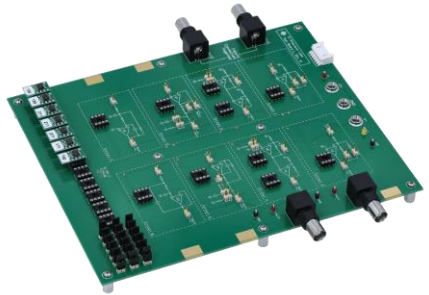

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