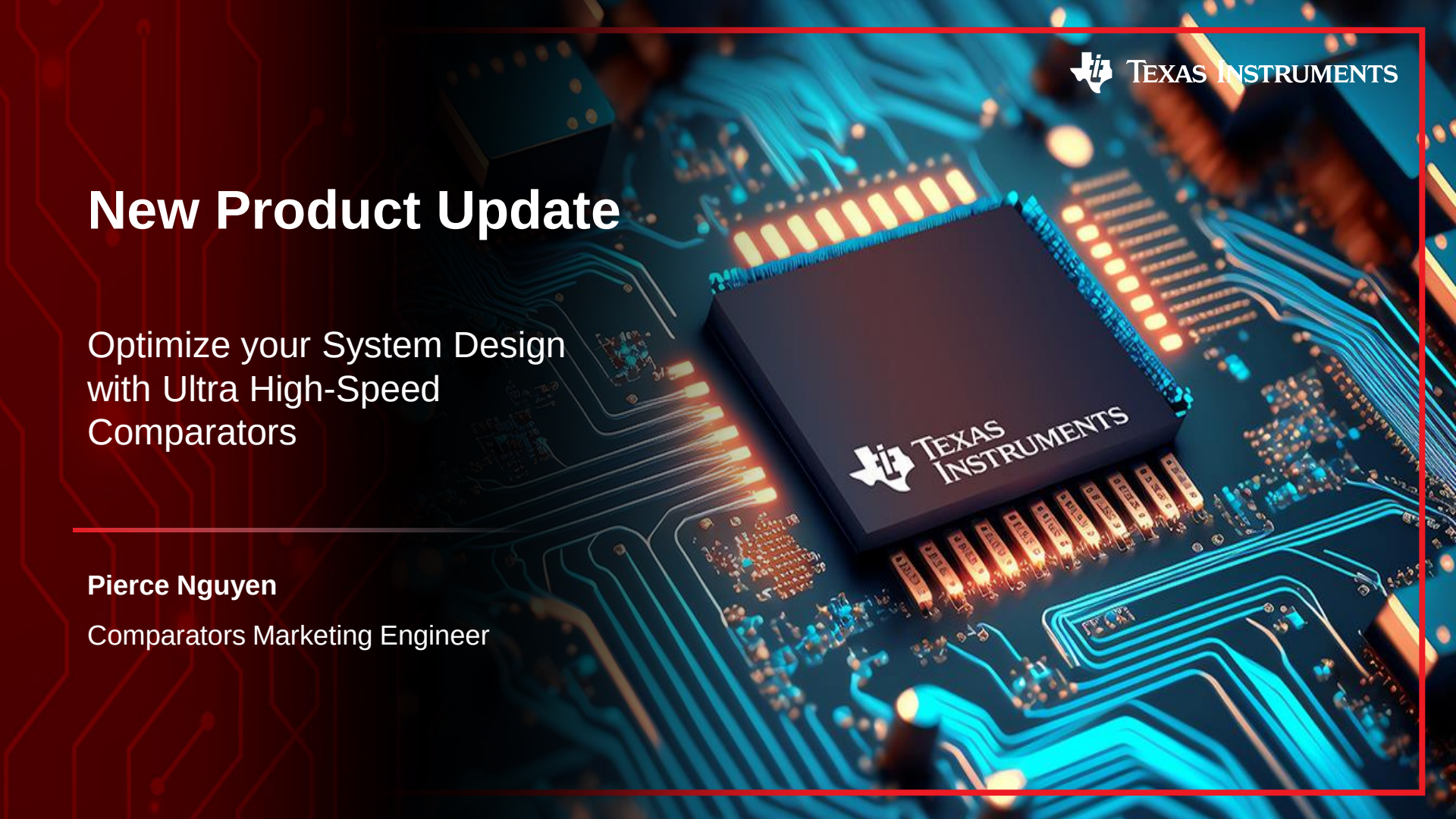
New Product Update

Optimize your System Design with Ultra High-Speed Comparators



Pierce Nguyen

Comparators Marketing Engineer

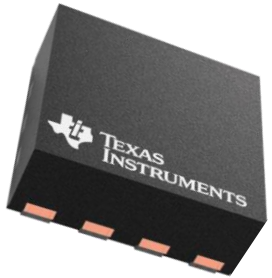
Agenda

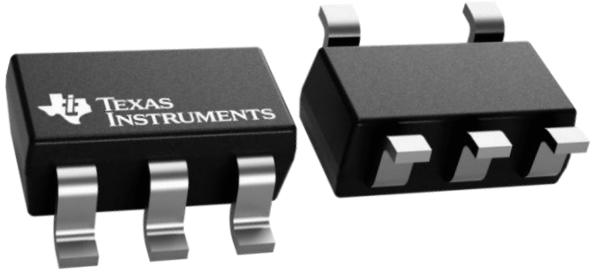
- Introduction to Typical Comparator Specs
- Response time
    - DC-DC, OBC, and Traction Inverter
- Overdrive Dispersion
    - Lidar Receiver
- Minimum Pulse Width
    - Lidar Receiver
- Channel-to-channel skew (matching)
    - Laser Driver
    - GANfet Driver
    - Lidar Receiver
- Toggle Frequency
    - Oscilloscope
- Output Type
- Special Features – Hysteresis

Where are comparators used?

Typical “housekeeping” applications:

- Overcurrent detection
- Overvoltage protection
- Undervoltage protection
- Zero-cross detection
- Temperature detection
- Level shifting





New frontier – High speed comparators

End equipment examples

- Lidar transceivers
- DC-DC converters
- Inverters
- Position sensors
- Rangefinders
- Oscilloscopes
- Optical modules
- Automated test equipment

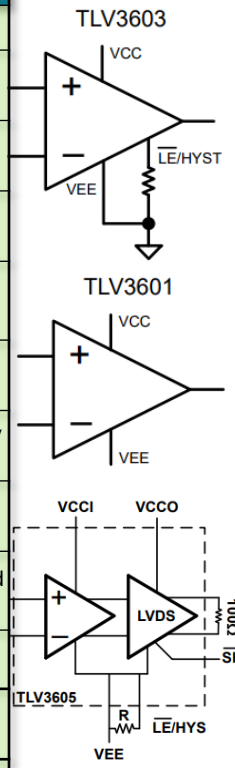
Applications

- Signal buffering
- Signal translation
- Level translation
- High-precision timing
- Trigger functionality
- PWM modulation
- Clock buffering
- High-speed fault detection

Key specs of high speed comparators

Superior Spec

Specifications	TLV3601/2	TLV3603	TLV3604/06	TLV3605/07	TLV3801/11/02	How contribute to your system
Channel count	1/2	1	1/2	1/2	1/2	Matching across channels
Power supply range	2.4V – 5.5V	2.4V – 5.5V	2.4V – 5.5V	2.4V – 5.5V	2.7 – 5.25V	Can use 2.5V, 3.3V and 5V supply rails
Propagation delay	2.5ns	2.5ns	800ps	800ps	225ps	Increases accuracy of measurement
Toggle frequency	325MHz	325MHz	1.45GHz	1.45GHz	3GHz	Can detect pulses in systems with high frequency signals
tPD overdrive dispersion	600ps	600ps	350ps	350ps	5ps	Increases measurement precision by reducing variability in prop. delay for different overdrive voltages
Min pulse width	1ns	1ns	800ps	800ps	240ps	Allows for detection of rapid pulses or voltage spikes
Input offset max	5mV	5mV	5mV	5mV	5 mV	Lower offset improves detection sensitivity and accuracy of threshold detection
Input common mode	Rail-to-Rail	Rail-to-Rail	Rail-to-Rail	Rail-to-Rail	1.5V to Vcc	Increases signal detection range, allowing flexibility for voltage swings
Features	3mV hysteresis, rail-to-rail	Adjustable hysteresis, latch, rail-to-rail	No hysteresis, rail-to-rail	Adjustable hysteresis, latch, rail-to-rail	2mV hysteresis, split-supply	Allows for configurable noise immunity and reduces chatter in noisy environments
IQ/channel typ	4.9mA	6mA	12.5mA	12.5mA	20mA/16mA	Lower power generates less thermal heat, improving device performance
Output structure	Push-pull	Push-pull	LVDS	LVDS	LVDS	Enables receiver flexibility with either single-ended or differential output
Package	SC-70-5, SOT-23-5 / VSSOP-8	SC-70-6	SC70-6	QFN-12	WF-DFN (DSG) / WCSP (YBG)	Small-size package is ideal in space-constrained Lidar applications



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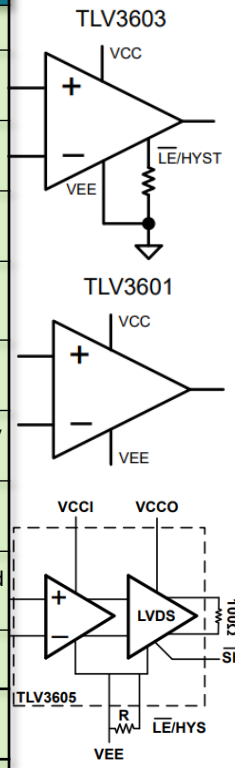

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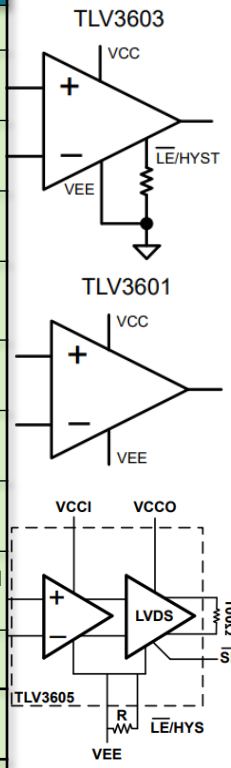

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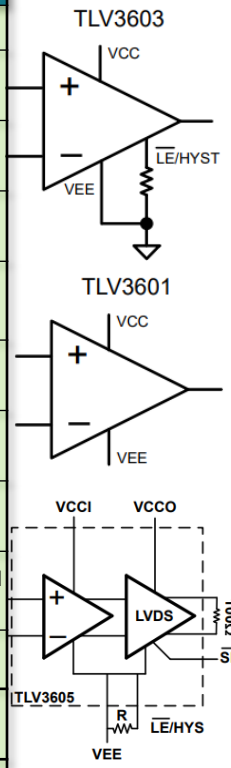

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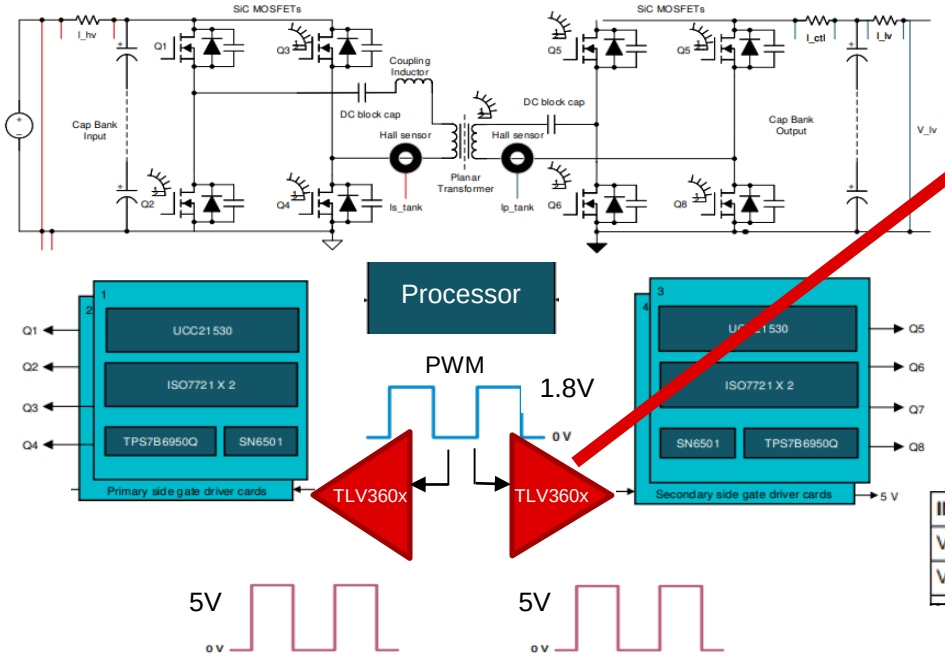
Propagation delay example #1: High-speed buffer & level shift

End equipment: DC/DC converters, traction inverter, EV charging stations

Systems needs to buffer and/or level shift 1.8V high-speed PWM outputs of FPGA and high-speed MCU's to single-ended 5V levels to meet compatibility of isolated gate drivers. The design is beneficial where higher switching frequencies, inductor (coil) weight, galvanic isolation, high-voltage conversion ratio, and reliability are critical factors.



High speed comparators

TLV3601/2/3:

- Single and dual channel options
- **2.5ns propagation delay**
- **325MHz toggle frequency**
- **24ps channel-to-channel tpd skew**
- Externally adjustable hysteresis on TLV3603

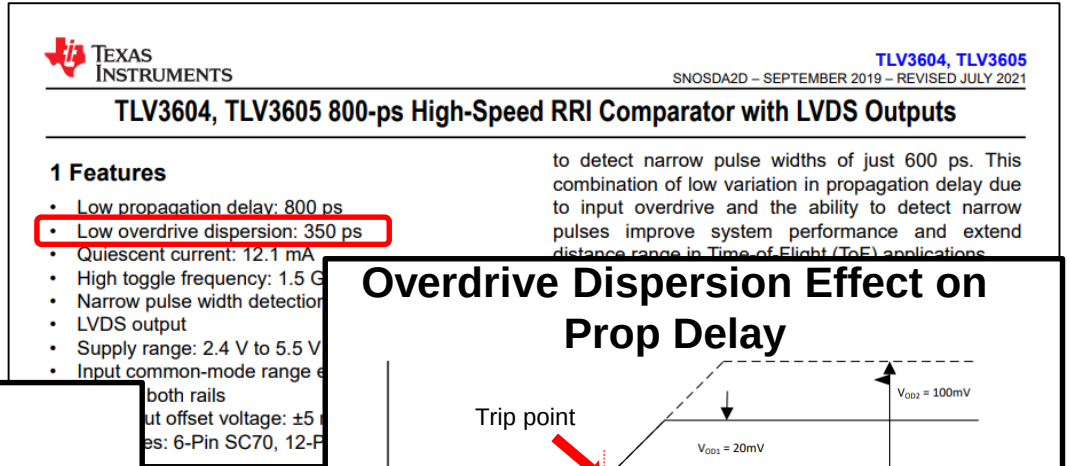
- *Capable of converting 1.8V FPGA output without impacting signal integrity*
- *Rail-to-Rail inputs allow flexible switching threshold making it good to recover attenuated or distorted waveforms*
- *Variable hysteresis makes the system more immune to system noise*

INA, INB, AND EN /					
V_{INxH} , V_{ENH}	Input High Threshold Voltage		2	2.3	V
V_{INxL} , V_{ENH}	Input Low Threshold Voltage	0.8	1		

What is t_{PD} overdrive dispersion?

Overdrive dispersion: change in prop delay as a function of change in overdrive voltage

Lower dispersion enables more precision by enabling smaller change in prop. delay for different overdrive voltages



Texas Instruments

TLV3604, TLV3605

SNOSDA2D – SEPTEMBER 2019 – REVISED JULY 2021

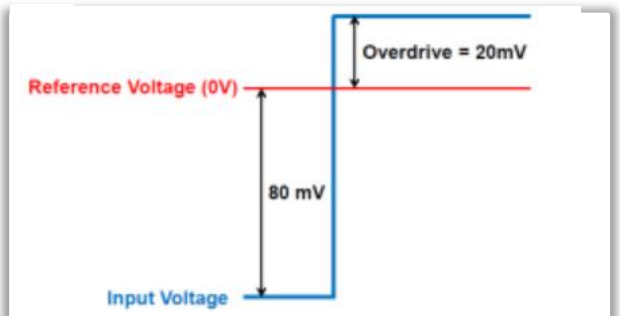
TLV3604, TLV3605 800-ps High-Speed RRI Comparator with LVDS Outputs

1 Features

- Low propagation delay: 800 ps
- Low overdrive dispersion: 350 ps
- Quiescent current: 12.1 mA
- High toggle frequency: 1.5 G
- Narrow pulse width detectior
- LVDS output
- Supply range: 2.4 V to 5.5 V
- Input common-mode range e
- both rails
- ut offset voltage: ±5
- es: 6-Pin SC70, 12-P

to detect narrow pulse widths of just 600 ps. This combination of low variation in propagation delay due to input overdrive and the ability to detect narrow pulses improve system performance and extend distance range in Time-of-Flight (ToF) applications

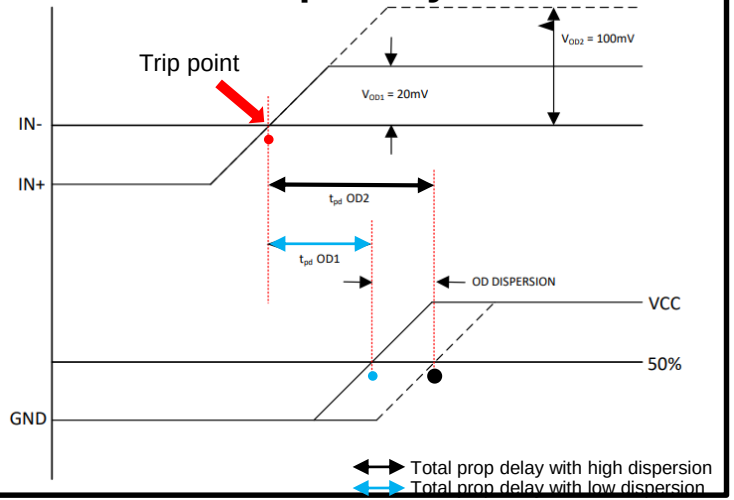
Input Overdrive Voltage



100mVpp input step with 20mV overdrive

Overdrive is defined as the amount of the differential input voltage *exceeding* the reference voltage

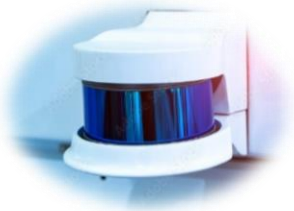
Overdrive Dispersion Effect on Prop Delay



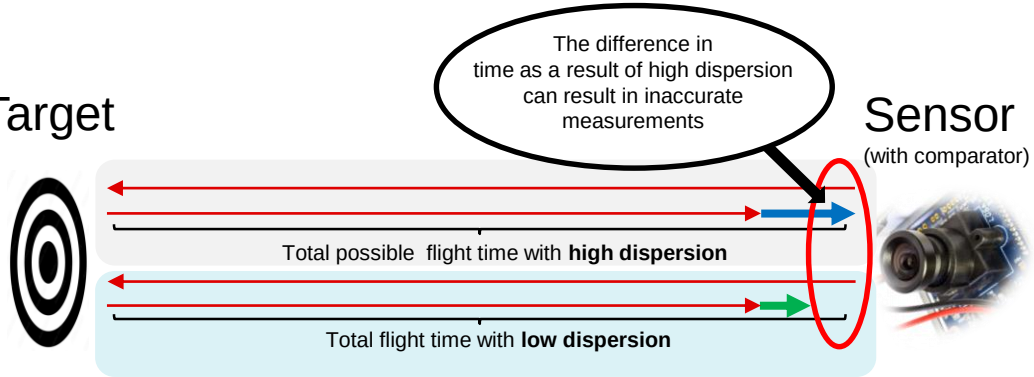
Texas Instruments

t_{PD} overdrive dispersion customer example #1: ADAS lidar receiver

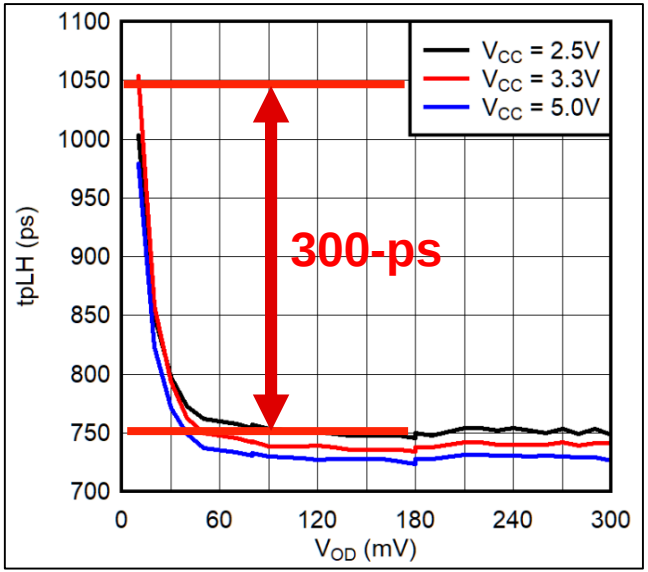
Ex: Laser scanner equipment
- $\Delta d = 1/2 * c * \Delta t \rightarrow$
- 0.5*3E8m/s***300-ps** = **4.5-cm error**



Customer requires the best precision when making their measurement, requiring the lowest Vod Dispersion spec possible to capture the right data



Improving precision to **receive consistent pulse flight time** requires detection components with **low overdrive voltage dispersion**, minimizing any differences in sensed flight time, *even for widely different* amplitudes of returned pulse



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What is 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

TLV3604, TLV3605 800-ps High-Speed RRI Comparator with LVDS Outputs

1 Features

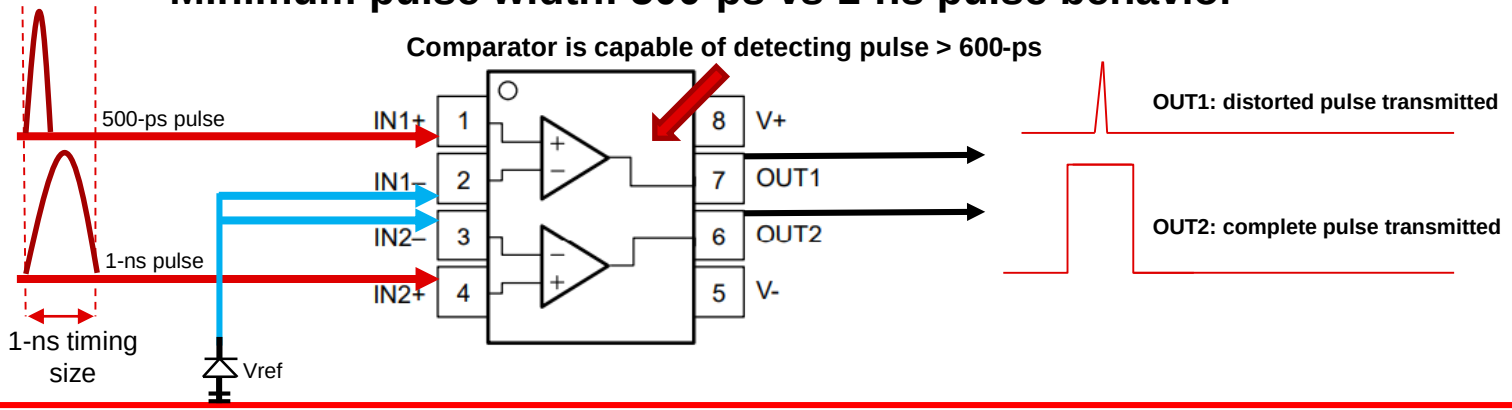
- Low propagation delay: 800 ps
- Low overdrive dispersion: 350 ps
- Quiescent current: 12.1 mA
- High toggle frequency: 1.5 GHz / 3.0 Gbps
- Narrow pulse width detection capability: 600 ps
- LVDS output
- Supply range: 2.4 V to 5.5 V
- Input common-mode range extends 200 mV beyond both rails
- Low input offset voltage: ±5 mV

to detect narrow pulse widths of just 600 ps. This combination of low variation in propagation delay due to input overdrive and the ability to detect narrow pulses improve system performance and extend distance range in Time-of-Flight (ToF) applications.

The Low-Voltage-Differential-Signal (LVDS) output of the TLV3604 and TLV3605 also helps increase data throughput and optimizes power consumption. The complementary outputs reduce EMI by suppressing common mode noise on each output. The LVDS output is designed to drive and interface directly with

PulseWidth	Minimum allowed input pulse width	$V_{OVERDRIVE}$ = $V_{UNDERDRIVE}$ = 50mV PW_{OUT} = 90% of PW_{IN}	600	ps

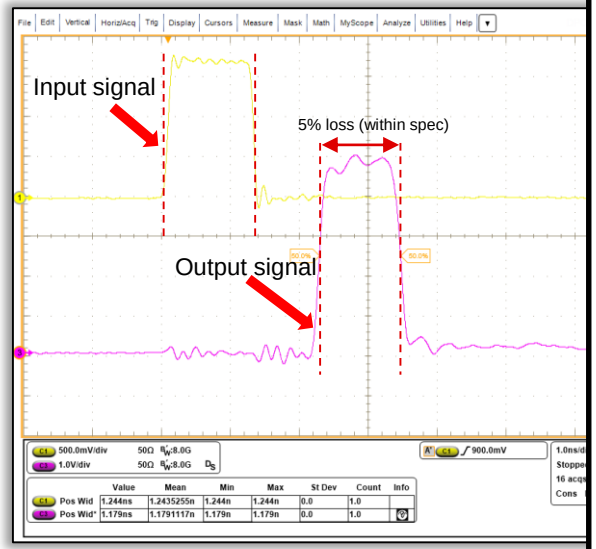
Minimum pulse width: 500-ps vs 1-ns pulse behavior



Minimum pulse customer example #1: Lidar receiver

Ex: Lidar receiver
detection of long-range, high-amplitude pulse

- Enables detection at greater distance (increases lidar range)

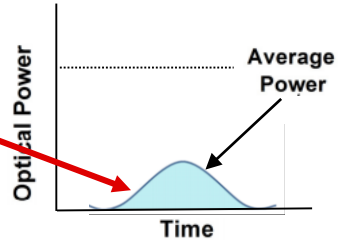


Minimum pulse width:

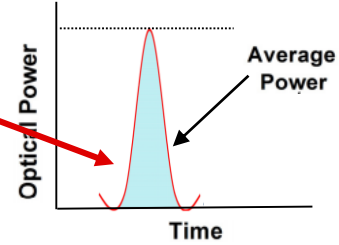
TLV3601: 1.25-ns
TLV3604: 600-ps – 2x improvement
TLV3801: 240-ps – **5x** improvement

Ultra-low minimum pulse width detection capability allows for **shorter pulses at higher power**, enabling **increased detection range**

(A) Wide pulse with average power shown as area under the curve



(B) Narrowing the pulse yields **same average power, but at high amplitude**

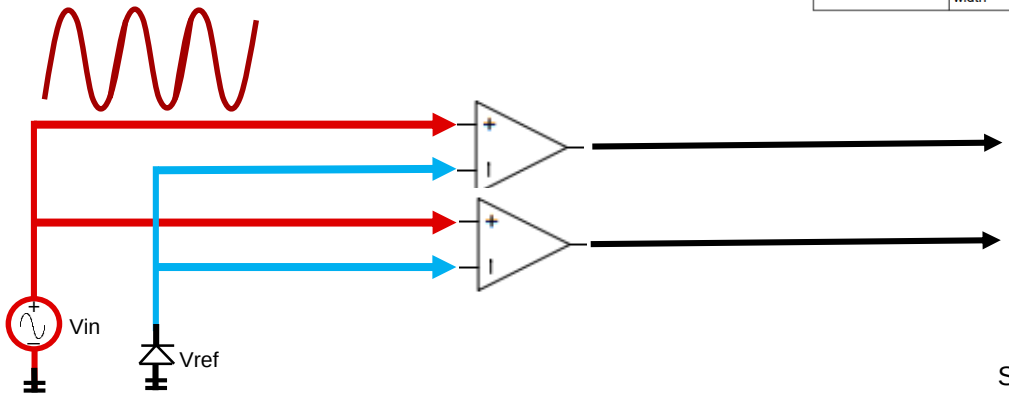


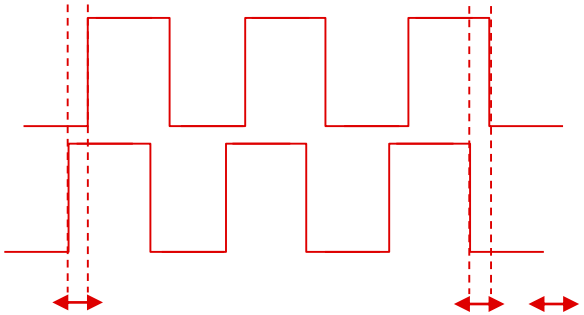
What is t_{PD} channel-to-channel skew (matching)?

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} or output low reaches 10% of V_{CC} - V_{EE}	325		MHz
PulseWidth	Minimum allowed input pulse width	$V_{OVERDRIVE}$ = $V_{UNDERDRIVE}$ = 50mV PW_{OUT} = 90% of PW_{IN}	1.25		ns

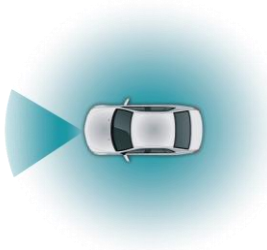
Overdrive dispersion effect on prop delay





Skew causing timing differences in output signal

Skew customer example #1: Lidar transmitter

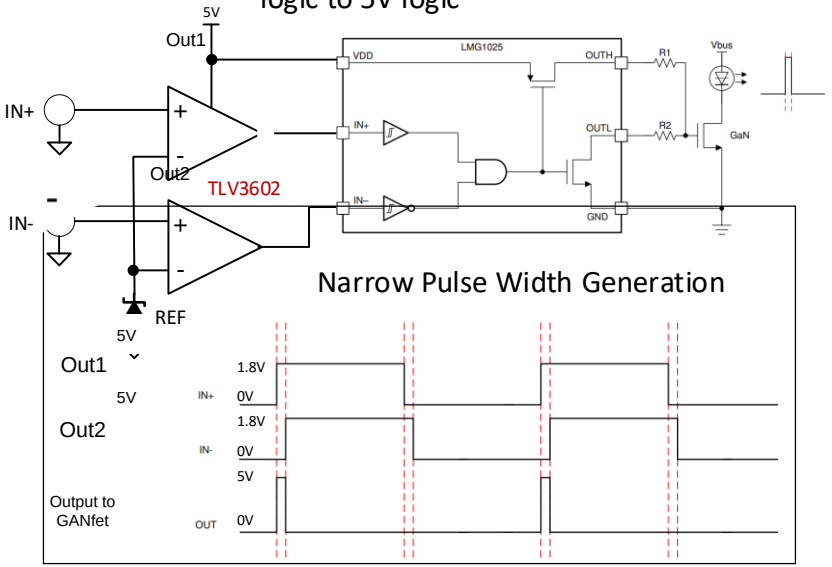


Ex: Laser driver for GANfet

Customer requires ultra-low skew spec, from well-matched propagation delay to enable narrow pulse width generation; this is best achieve when comparators are connected to the same substrate

High speed **1.8V** Logic

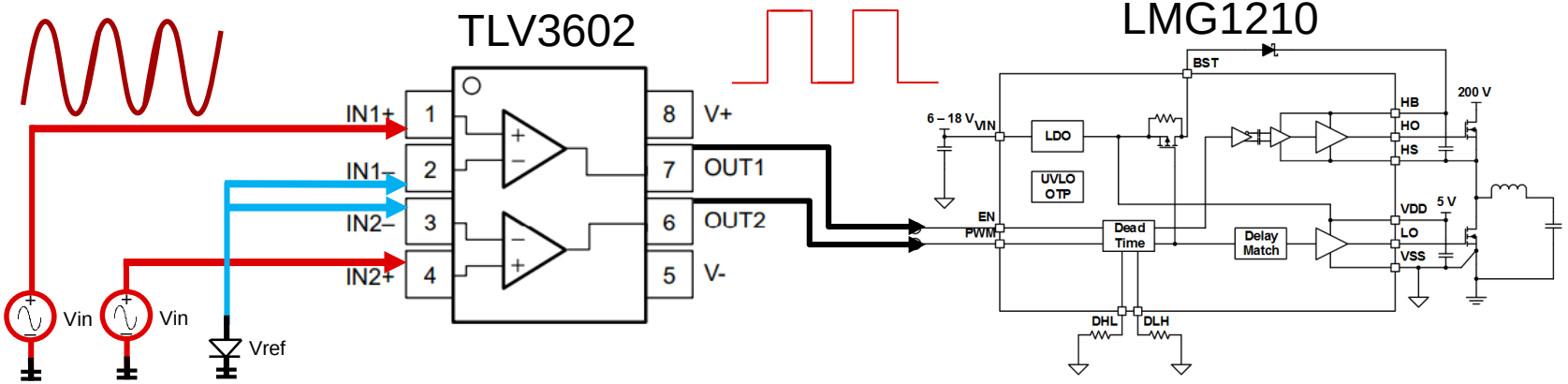
Level shift from 1.8V logic to 5V logic



LMG1025-Q1 Automotive Low Side GaN and MOSFET Driver For High Frequency and Narrow Pulse Applications

		MIN	TYP	MAX	UNIT
Input DC Characteristics					
V_{IH}	IN+, IN- high threshold	1.7		2.6	V
V_{IL}	IN+, IN- low threshold	1.1		1.8	V

Skew customer example #2: GANfet driver



Ex: Precise motor driver
driving the FET driver for motor control

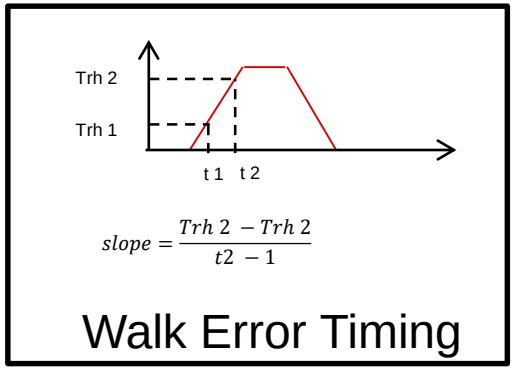
System alternates pulses from high and low side, with very little time between switching. Comparator must have low skew to ensure short circuits across the FETs do not occur and precise timing is maintained

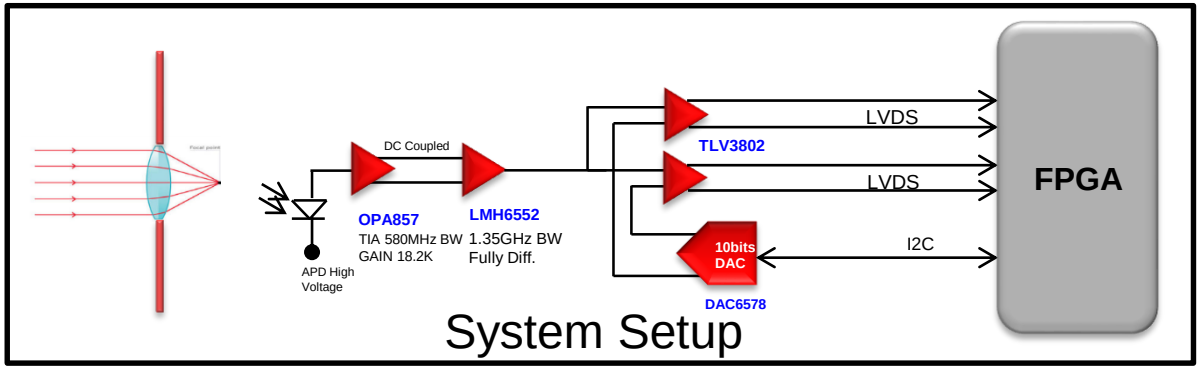
High speed comparators

TLV3602: 5V dual channel, high-speed

- 2.5ns propagation delay
- 24ps channel-to-channel propagation delay skew
- 325MHz toggle frequency
- 600ps overdrive dispersion
- 1.25ns narrow pulse width detection

Skew customer example #3: Lidar receiver

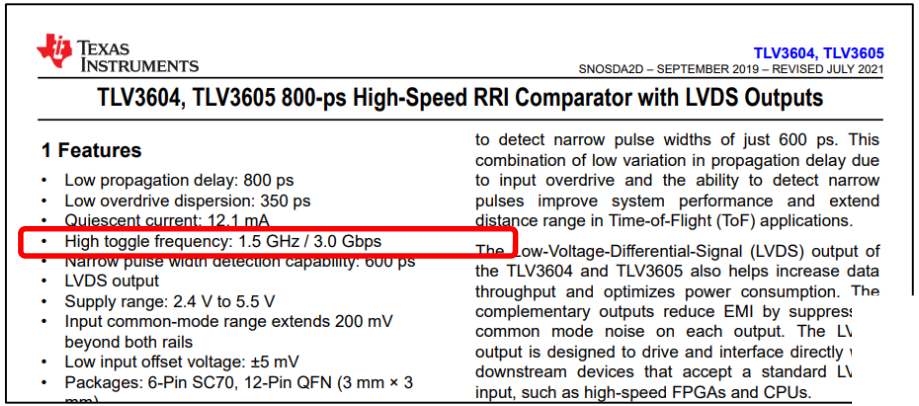




Specifications	Channel count	Power supply range	Propagation delay	tPD overdrive dispersion	Min pulse width	Skew	Output structure
TLV3602	2	2.4V – 5.5V	2.5ns	600ps	1ns	24ps	Push-pull
TLV3606/7	2	2.4V – 5.5V	800ps	350ps	600ps	10-ps	LVDS
TLV3802	2	2.7~4.2V	225ps	5ps	240ps	5-ps	LVDS

The returning pulse, by using two different threshold (Trh1 and Trh 2), will generate two triggers. The FPGA, by measuring the time difference and knowing Trh1 and Trh2, can determine the slope. The slope brings information on the reflecting property of the material, thus the walk error can be compensated.

What is toggle frequency?



Texas Instruments

TLV3604, TLV3605

SNOSDA2D – SEPTEMBER 2019 – REVISED JULY 2021

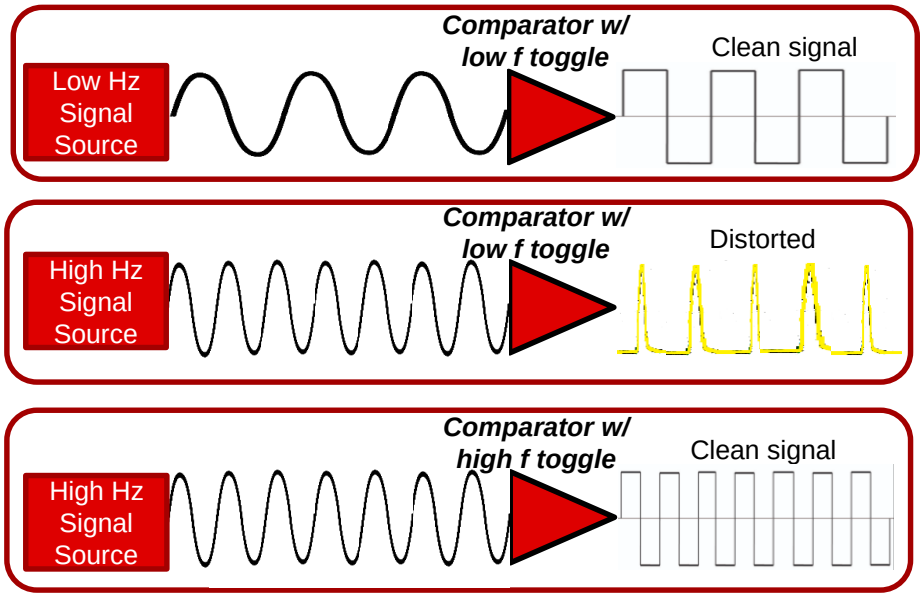
TLV3604, TLV3605 800-ps High-Speed RRI Comparator with LVDS Outputs

1 Features

- Low propagation delay: 800 ps
- Low overdrive dispersion: 350 ps
- Quiescent current: 12.1 mA
- High toggle frequency: 1.5 GHz / 3.0 Gbps
- Narrow pulse width detection capability: 600 ps
- LVDS output
- Supply range: 2.4 V to 5.5 V
- Input common-mode range extends 200 mV beyond both rails
- Low input offset voltage: ±5 mV
- Packages: 6-Pin SC70, 12-Pin QFN (3 mm × 3 mm)

to detect narrow pulse widths of just 600 ps. This combination of low variation in propagation delay due to input overdrive and the ability to detect narrow pulses improve system performance and extend distance range in Time-of-Flight (ToF) applications.

The Low-Voltage-Differential-Signal (LVDS) output of the TLV3604 and TLV3605 also helps increase data throughput and optimizes power consumption. The complementary outputs reduce EMI by suppress common mode noise on each output. The LV output is designed to drive and interface directly downstream devices that accept a standard LV input, such as high-speed FPGAs and CPUs.



Toggle frequency: the rate at which the comparator can switch from output low to output high

It ensures that a signal with a very high frequency can maintain each rise and fall without any information loss at the comparator output

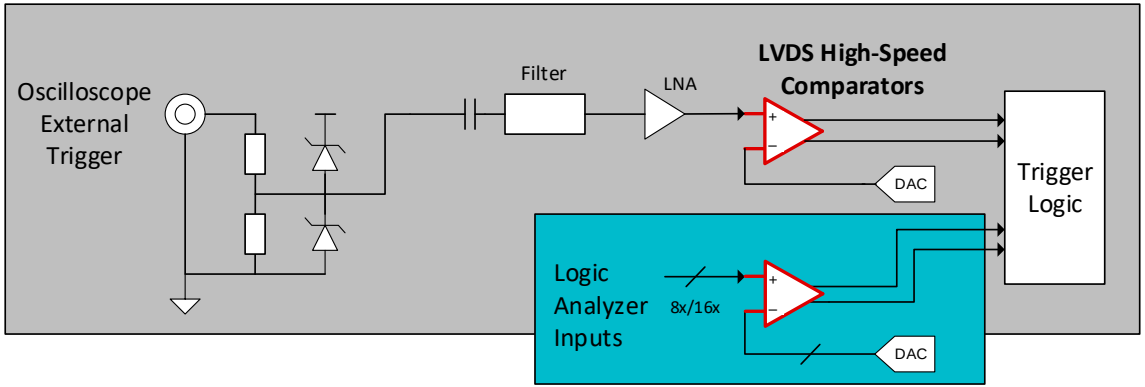
Toggle frequency customer example #1: T&M

Ex: Logic Analyzer
detection and triggering of high-frequency signal

In analyzer applications, the input signal can fall within a broad frequency spectrum, necessitating a wide input bandwidth detection capability; it is critical to detect when a voltage spike occurs

Comparator bandwidth:

TLV3601: 325-MHz
TLV3604: 1.5-GHz – 4x improvement
TLV3801: 3.0-GHz – **9x** improvement



How does output type benefit high-speed comparators?

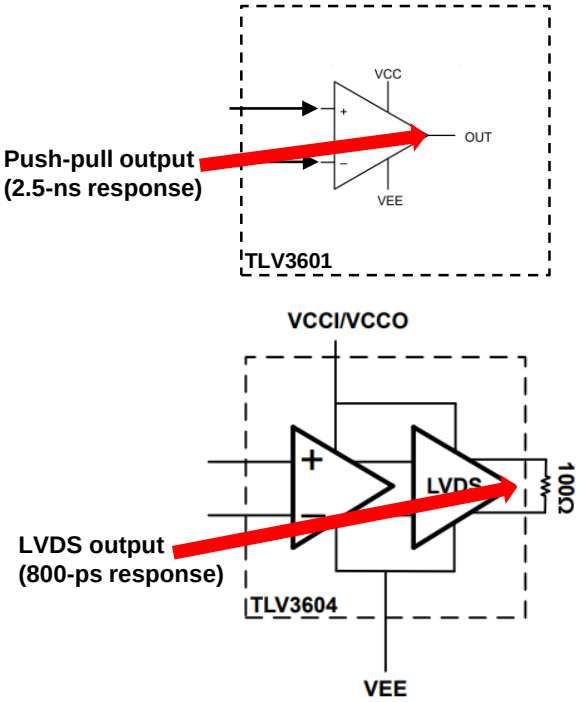
2.5-ns TLV3601/2: One of the fastest push-pull comparator out today. Why is that?

Push-pull outputs have limited range when it comes to increasing responsiveness, and consume too much power to be feasible under 2-ns

$$\mathrm{I} = \mathrm{C}\frac{dv}{dt} \rightarrow \frac{dv}{dt} = \frac{I}{C};\ greater\ \frac{dv}{dt}\ requires\ increased\ I$$

LVDS can circumvent this because of the differential outputs, allowing sub-nanosecond responses. Further benefits are faster transmission speeds and **noise immunity** (common mode noise disappears)

Even LVDS can have speed limitations, necessitating CML output type to achieve under 200-ps response



Key specs of high speed comparators

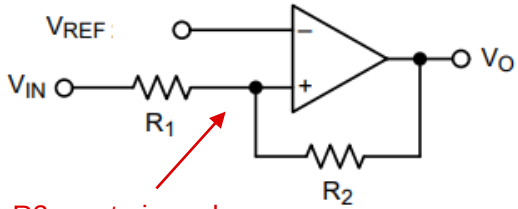
Superior Spec	

Specifications	TLV3601/2	TLV3603	TLV3604/6	TLV3605/7	TLV3801/11/02	How contribute to your system
Channel count	1/2	1	1/2	1/2	1/2	Matching across channels
Propagation delay	2.5ns	2.5ns	800ps	800ps	225ps	Increases accuracy of measurement
Toggle frequency	325MHz	325MHz	1.45GHz	1.45GHz	3GHz	Can detect pulses in systems with high frequency signals
tPD overdrive dispersion	600ps	600ps	350ps	350ps	5ps	Increases measurement precision by reducing variability in prop. delay for different overdrive voltages
Min pulse width	1ns	1ns	800ps	800ps	240ps	Allows for detection of rapid pulses or voltage spikes
Features	3mV hysteresis, rail-to-rail	Adjustable hysteresis, latch, rail-to-rail	No hysteresis, rail-to-rail	Adjustable hysteresis, latch, rail-to-rail	2mV hysteresis, split-supply	Allows for configurable noise immunity and reduces chatter in noisy environments
Output structure	Push-pull	Push-pull	LVDS	LVDS	LVDS	Enables receiver flexibility with either single-ended or differential output

How do features benefit high-speed comparators?

Hysteresis (integrated, adjustable):

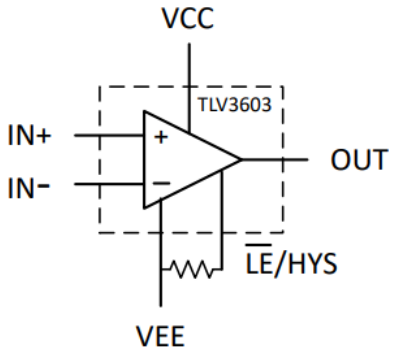
Function: **disables chatter** from affecting the output when input signal is in close proximity to threshold and avoids overwhelming system with unnecessary information



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

Size: using integrated hysteresis instead of externally implemented **saves board space**, eliminating the resistor network

Design optimization: in high-speed BiCMOS process, **bias currents** for inputs are high, ensuring that any effort to implement external hysteresis results in large Vos. This can also add parasitics that may affect the prop delay



Additional features for high-speed comparators

Latch: allows comparator to latch and hold its state until it is manually reset, particularly useful for busy MCUs

Split-supply: offers customizable design to accept inputs from signals oscillating at 0V or below, mimics rail-to-rail behavior

Rail-to-rail: wide input supply

Getting started

You can start evaluating this device leveraging the following:

Content type	Content title	Link to content or more details
Product folder	TLV3802 Product Folder	https://www.ti.com/product/TLV3802
	TLV3607 Product Folder	https://www.ti.com/product/TLV3607
Customer training series or webinar session	Ultra-High Speed comparators overview	https://www.ti.com/video/6342337386112
Technical blog content or white paper	How to Improve Accuracy W/ High-Speed Comparators in LIDAR and Proximity Sensing	https://www.ti.com/lit/pdf/snoaa86
	Improving the Performance of Test and Measurement Equipment with High-Speed Comp	https://www.ti.com/lit/pdf/snot030
	Enhancing Accuracy and Narrow Pulse Detection in Automotive and Industrial LiDAR	https://www.ti.com/lit/pdf/snot029
	Measuring Rise and Fall Times in Automated Test Equipment With High-Speed Comparators	https://www.ti.com/lit/po/snot035
Development tool or evaluation kit	TLV3802 Evaluation Module	https://www.ti.com/tool/TLV3802EVM
	TLV3607 Evaluation Module	https://www.ti.com/tool/TLV3607EVM

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