Application Report

When to Use High-Speed Comparators or ADCs for Distance Measurements in Optical Time-of-Flight Systems

ABSTRACT

- This document details how optical Time-of-Flight (ToF) measurements are made with ADCs and discrete comparators and when to use a comparator in a Time-of-Flight system.
- ADC's are best for complex measurements while comparators are used to calculate simple measurements including the distance between the receiver and target object.
- Two key comparator specifications to keep in mind when using comparators in Time-of-Flight systems are minimum pulse width and input overdrive dispersion.

Table of Contents

List of Figures

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1 Introduction

Time-of-Flight is regarded as a very accurate distance mapping technology that has been used for over a century. ToF systems can be found in a wide variety of products, from proximity sensors, drone vision, machine vision, to automotive ADAS LiDAR systems. As seen with this system variety, ToF technology can calculate distances from just a few millimeters to several meters, have different field of views, power requirements, solution sizes, and different resolutions depending on the components used within the system. While there are different mediums to calculate distance in a ToF system such as ultrasonic or radar, this tech note will focus primarily on optical ToF systems.

2 How ToF Measurements are Calculated

Optical ToF systems consist of a light transmitter and receiver. The emitter is typically an LED or a laser diode that sends short analog light pulses which reflect off a target. When this pulse is sent, this is typically denoted as the “Start Event”. The reflected light from the target is returned to the receiver, generally a photodiode combined with a TIA to convert the photonic energy into electrical current. Since the speed at which light travels through a given medium is constant, the distance to the target can be calculated by measuring the time delay between when the initial light pulse is sent, to when it is reflected and received back.

Using light waves allows for reliable detection of fast-moving objects, and performs well in ambient light conditions. Likewise, measurements can be calibrated for temperature, humidity, and air pressure. Once the reflected light has returned back to the receiver, this is denoted as the “Stop Event”. The time difference between the start and stop event is used to determine the distance to the object; the propagation delays of all devices within the system are then de-skewed out of this time difference. What is left is the time it took for the light pulse to have a full round trip cycle from when the initial pulse is sent and received back. Dividing this value by two gives the time it takes for the light to reach just the target object. The equation for distance can then be defined as:

$$d=(c*t)/2, \tag{1}$$

where

d is distance,

c is the speed of light (3x10^8),

t is the time difference between the start and stop event.

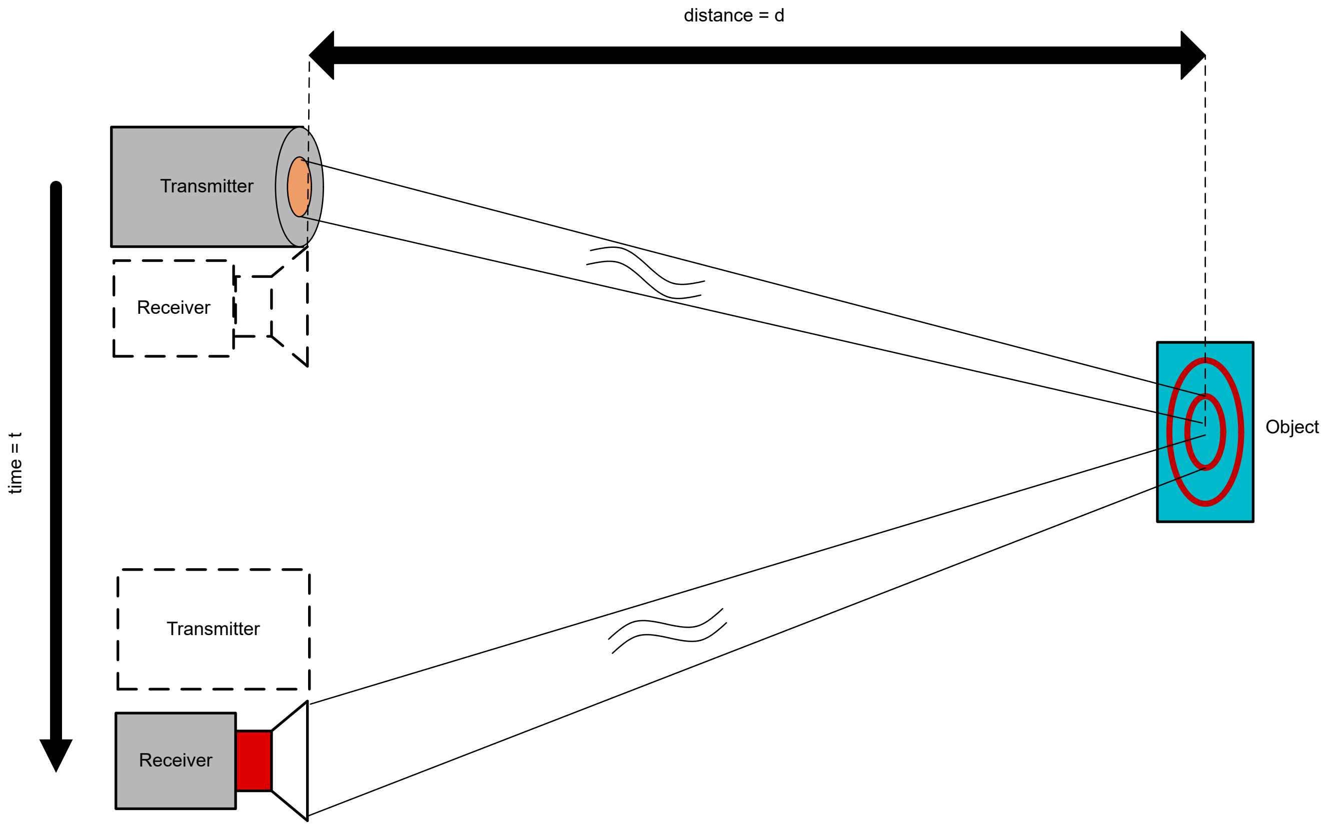

Figure 2-1. Time-of-Flight Concept

An example of a ToF system is shown in Figure 2-2 . The system uses a laser diode as the stimulus to the target object. Once the laser driver reaches the target and gets reflected back, transimpedance amplifiers are then used to convert the photodiode current into a voltage. From here, either a high-speed comparator or an ADC is used to capture data and send downstream to another device such as an FPGA or a high end DSP for computation of the ToF measurement.

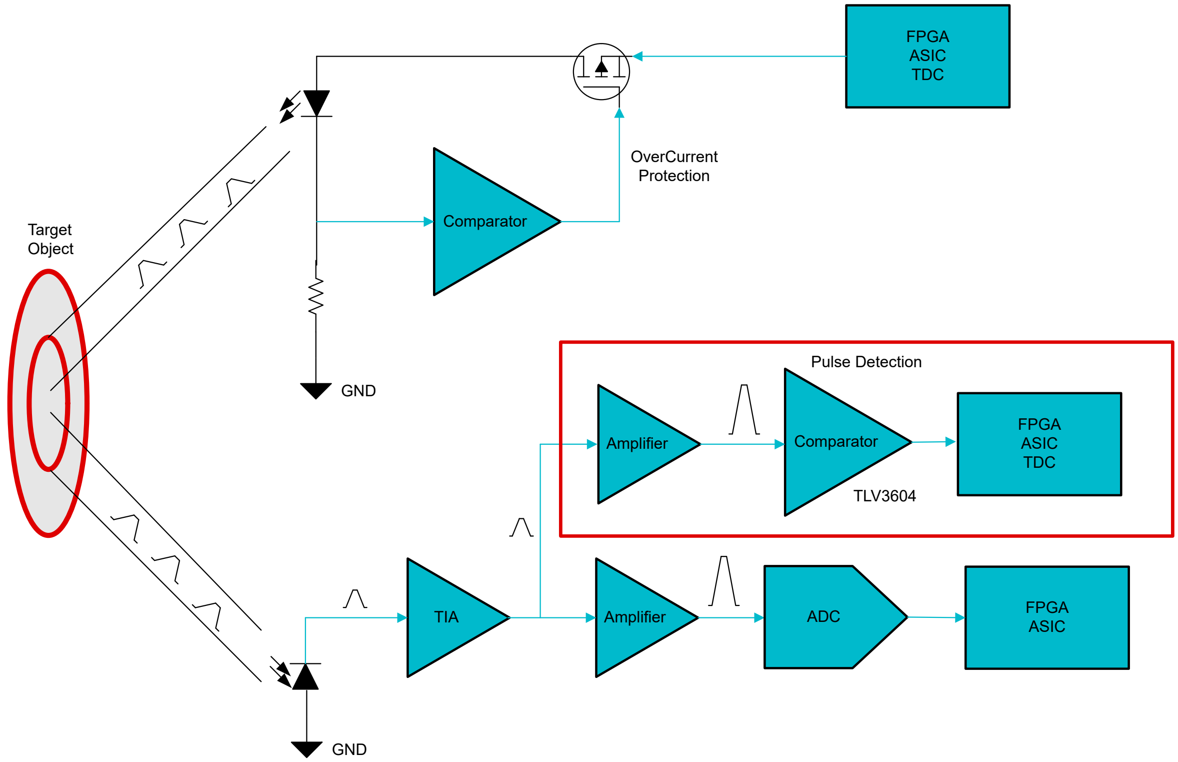

Figure 2-2. Time-of-Flight Concept Diagram

Although many of the components upstream from a comparator or ADC in the receiver path of the ToF system are the same, the way in which it measures distance can be quite different. With a comparator, one of the inputs is tied to a reference voltage. The light pulse expected in the reflection from the target object is then measured and compared to this reference voltage. If the reflected light pulse crosses the reference threshold, the distance to that object can be measured. The comparator will output high denoting the “Stop Event”, and downstream devices can compute the distance to the target from this trigger.

An ADC meanwhile, samples the analog signal at a high frequency and digitizes the signal to bits. These bits contain amplitude and timing information to send downstream to a processing device where not only distance can be calculated, but other useful measurements such as color or material type can be determined as well, based off the reflectivity or amplitude of the reflected pulse.

There are several benefits of choosing either a comparator or an ADC to capture ToF data, but choosing the correct device comes from the system needs and exactly what data needs to be captured. If more than just distance is required to be calculated, than an ADC in the receiver path would be an appropriate choice. However, if just a distance measurement to the target object is needed, than a comparator would be a more practical and cost effective solution.

Although using a comparator in the receiver path limits the system to only measuring the distance to an object, using a comparator greatly simplifies the signal chain, as there is no need for a high end signal processing device in the backend. This greatly improves the robustness of the system as it is typically much easier to integrate a comparator into the receiver path, rather than an ADC which requires more complex devices to be tested and integrated into the system. A Simple TDC or an FPGA and MCU combination is all that is needed downstream to calculate the ToF distance measurement. As mentioned previously, distance can simply be calculated with the equation

$$d = (c*t)/2 \quad (2)$$

This results in cost savings in multiple ways: a smaller solution size, a lower cost receiver chip, and lower cost in external components and downstream processing devices.

3 Importance of Comparator's Minimum Pulse Width Detection Capability

Generally, the laser driver in a ToF system is required to operate under a specific wattage so that if any human comes between the transmitter and target option, the laser will not damage their retina or skin. Below are two images depicting the wave in the transmitter side.

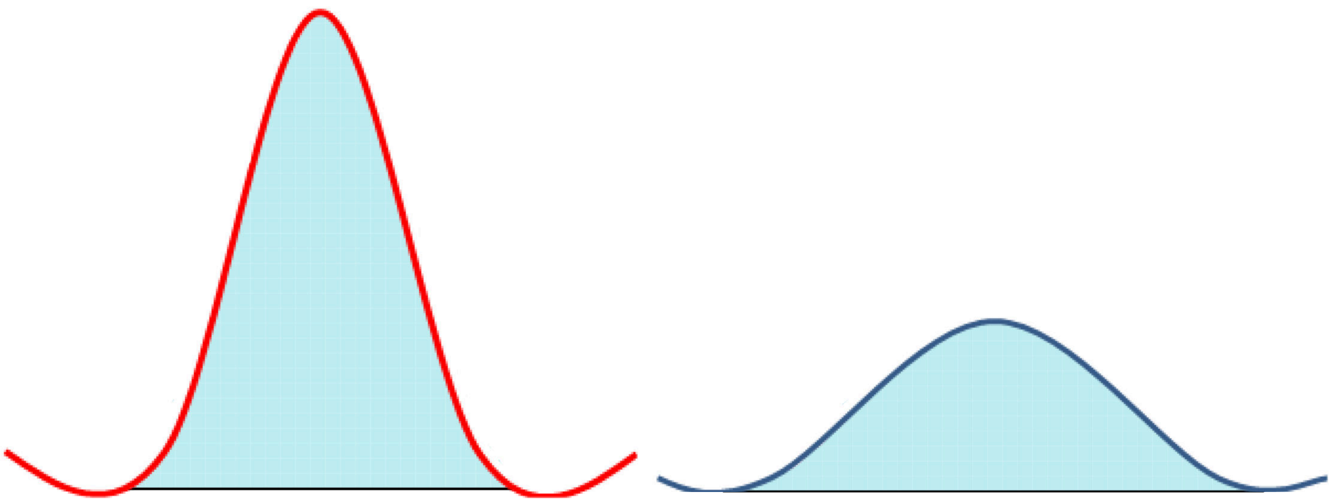

Figure 3-1. Examples of ToF Transmitted Pulses

Although the pulse widths of the two images are different, the area under the curve of both images is the same – depicting that they have the same wattage use. The image on the left with the narrower pulse width is used to detect a target object several meters further than the image on the right. The image with the wider pulse would be used to detect an object at a shorter distance. To detect objects further away from the ToF System while operating under the same power requirements, the receiver needs to have the capability to detect narrower pulse widths.

For ADC's, this translates to the amount of samples per second the ADC can measure. If the ADC does not have a high enough sampling rate and the reflected pulse is too narrow, the ADC will not be able to accurately digitize the data to bits to calculate the distance to the target object. The same will happen if using a comparator that cannot detect the reflected pulse width. In fact, the comparator may not respond to the signal at all and a distance measurement might not be calculated.

ADC's with a sample rate equivalent to a comparator's minimum pulse width detection capabilities will be much more expensive to both purchase and incorporate into a ToF system. However the decision to use one over the other should still mostly depend on if more than just distance is needed to be calculated in a ToF system. If a decision has been made to use a comparator as a receiver in the ToF system, than selecting a comparator with better minimum pulse width capabilities will result in being able to measure a target object at a further distance.

3.1 Importance of Comparator's Input Overdrive Dispersion

One more important spec to pay attention to when using a comparator in the receiver path is input overdrive dispersion. Input Overdrive refers to how much the input signal to the comparator exceeds its threshold or reference voltage value, and dispersion is defined as the amount of propagation delay variance over a certain range of input overdrives.

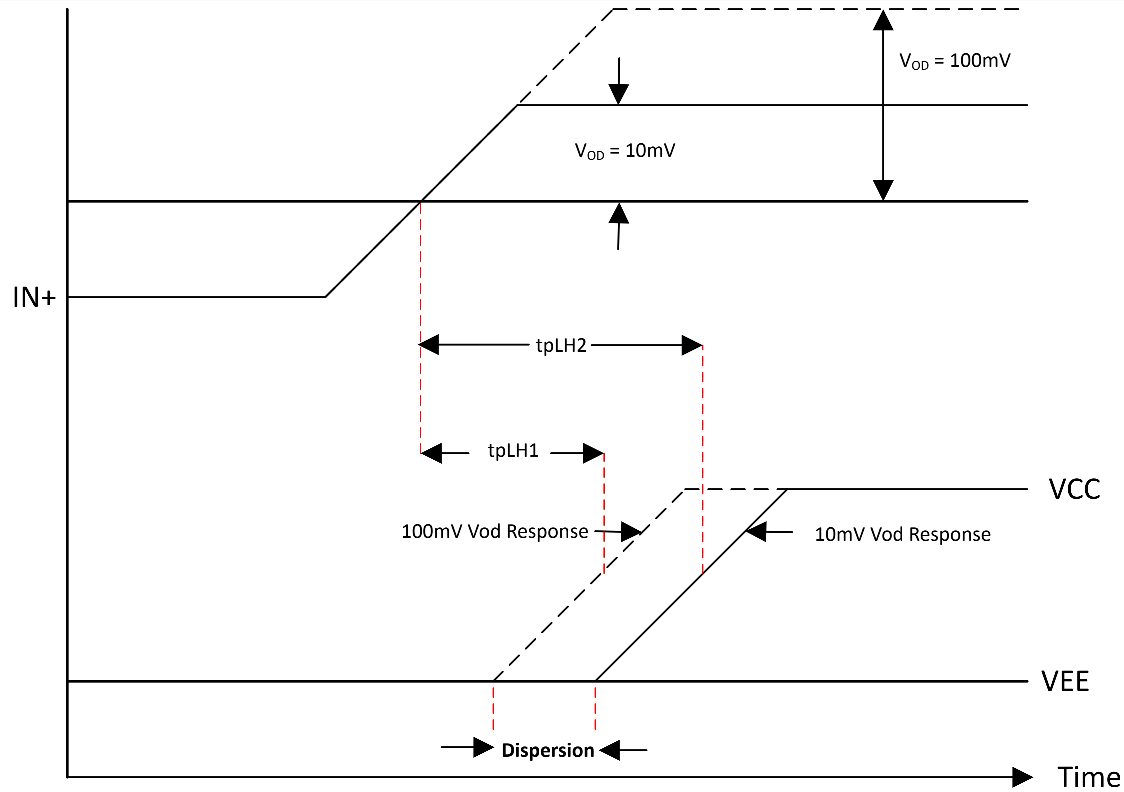

Figure 3-2. Input Overdrive Dispersion Plot

Below is a curve showcasing the propagation delay response of a comparator with varying input overdrives. As seen below, larger input overdrives result in a faster response time –however this faster response tends to saturate at input overdrive > = 100 mV.

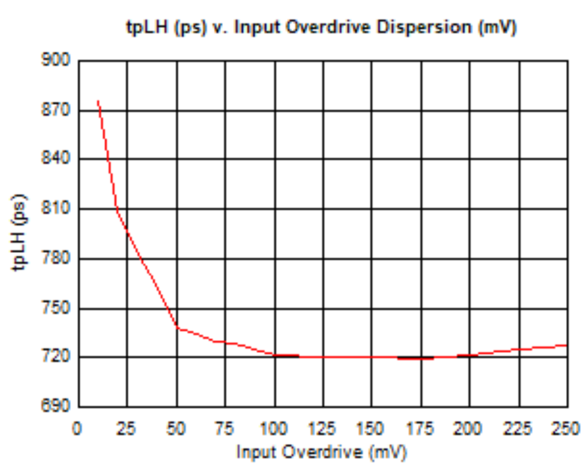

Figure 3-3. Propagation Delay vs. Input Overdrive Dispersion

There is not a simple solution to be able to deskew the different propagation delay times according to different input overdrives, so it is important to select a comparator with very small input overdrive dispersion so that the system can calculate an accurate distance to an object regardless of the amplitude of the reflected pulse.

Input overdrive dispersion is also tied to the rated distance the ToF system can calculate. Selecting a comparator with small input overdrive dispersion will result in a system that can more accurately compute distances for a wide range of target objects. For example, an object at the same distance as another object may have better reflective properties. This would result in a reflected pulse that has a larger amplitude than the other object.

Selecting a comparator with small input overdrive dispersion means the system can measure the distance between these two objects with little to no variance.

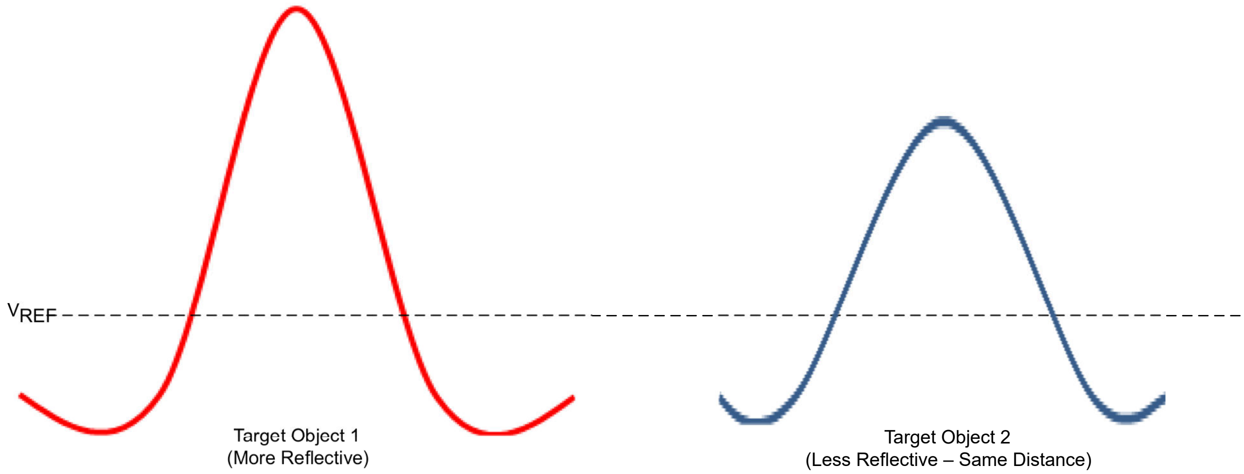

Figure 3-4. Reflectivity and Its Effect on Input Overdrive

A great comparator option for ToF systems is Texas Instruments' newest high speed comparator with LVDS outputs. The device has just 800 ps of propagation delay and a high toggle frequency of 1.5 GHz (3.0 Gbps). It's narrow pulse width detection capabilities of 600 ps, and input overdrive dispersion of just 450ps make it a great option as a receiver in optical ToF systems The device has favorable specs compared to similar comparators in the same package and pinout options, and can be easily used as a drop in replacement for ToF systems already using comparators in their receiver path.

In comparison to similar parts, the TLV3604 boast both overdrive dispersion specs and minimum pulse width specs that are at least 2 times better than similar pin-to-pin comparators, while operating with less power consumption. This means that the part would be able to both measure distances to objects further and measure it more accurately as well.

	TLV3604
Supply Range	2.4 V – 5.5 V
Propagation Delay	800 ps
Overdrive Dispersion	450 ps
Toggle Frequency	1.5 GHz (3.0 Gbps)
Min. Pulse Width	600 ps
Iq	12 mA
Offset	+/- 5.0 mV

4 Conclusion

If more than just a distance measurement needs to be computed from the reflected pulse, an ADC can be an appropriate receiver solution. However, if only a distance measurement is needed, an ADC solution can be quite wasteful in terms of both power and cost. It would be highly advisable in this case to go with a comparator solution as part of the receiver in the ToF system as it is not only easier to integrate, but also allows further distances to be measured accurately at significantly less cost.

It is important to keep in mind a comparator's minimum pulse width capabilities and input overdrive dispersion performance, as they are the most significant specs when selecting a comparator for a ToF system. A comparator's minimum pulse width detection capability correlates directly to the maximum distance the ToF system can measure, while its input overdrive dispersion correlates directly to the accuracy of measurement over a range of distances. The TLV3604 is an excellent option as part of the receiver solution in a ToF system due to its impressive minimum pulse width capabilities and input overdrive dispersion performance. For more information on this part, including the datasheet, simulation tools, and EVM board, please visit https://www.ti.com/product/TLV3604.

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