

## TI 设计: TIDA-060025

# 最大限度提升激光雷达和飞行时间的跨阻带宽的参考设计 应用



### 说明

此设计展示的高速光学前端通过采用光纤传输介质的 ToF 距离测量电路实现, 该电路适用于任何类型的 ToF 测量, 例如在自由空间中进行测量。此设计采用行业领先的 2.5V 输出线性跨阻前端, 配备 10kΩ 增益和超过 200MHz 的带宽, 以实现高精度测量。在短时间模式下的 TDC7201 转换器将接收到的信号进行数字化转换, 将设备的测量精度从 12ns 提高到 250ps, 由此强化了设备的高精度特点。测量由 LaunchPad™ 开发包上的 MSP430 微处理器控制, 便于轻松实现即插即用兼容性。总体来说, 该设计不仅专注于高速与精度, 与需要高速 ADC 以及 FPGA 的全数字化设计相比, 还降低了复杂性和能耗。

### 资源

<a href="#">TIDA-060025</a>	设计文件夹
<a href="#">OPA858</a>	产品文件夹
<a href="#">TDC7201</a>	产品文件夹
<a href="#">TLV3501</a>	产品文件夹
<a href="#">MSP-EXP430F5529LP</a>	工具文件夹



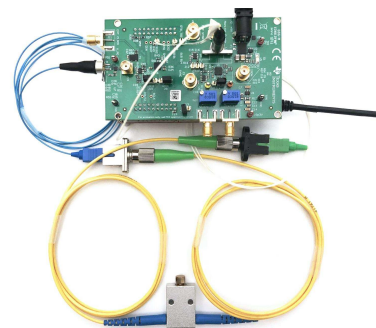
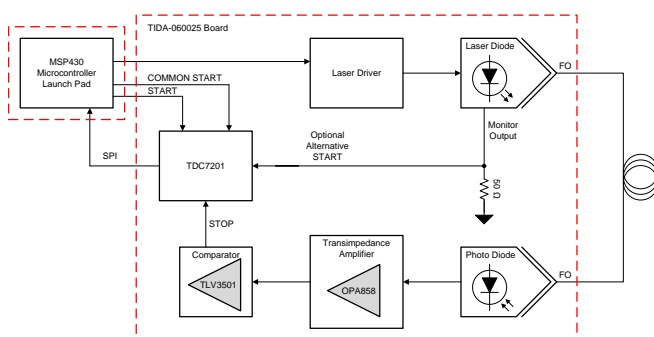
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### 特性

- 具备展示的飞行时间测量的光学前端设计
- 带宽大于 200MHz、增益为 10kΩ 的高速放大器信号路径
- 测量数值精确到厘米
- 高速时间数字转换器
- 产生 Tx 信号的超快激光二极管驱动器和激光二极管
- 具备板载电压电源的 PIN 光电二极管前端
- 用于电流到电压转换的高速跨阻放大器 (TIA)
- 低计算成本与能耗要求

### 应用

- 激光测距
- 激光雷达
- 3D 扫描
- 机器视觉
- 扫地机器人
- 无人机视觉
- 光学放大器
- CAT 扫描仪前端
- 光电二极管监控
- 导弹制导



该 TI 参考设计末尾的重要声明表述了授权使用、知识产权问题和其他重要的免责声明和信息。

## 1 System Description

This reference design showcases the capabilities of Texas Instruments high-speed amplifiers, comparators, and time-to-digital converters (TDCs) to demonstrate a high-accuracy, low-power, time-of-flight (ToF) measurement system. The receive path consists of a PIN photodiode receiver biased with a 5-V reference coupled into the OPA858 amplifier in a transimpedance configuration with a gain of 10 k $\Omega$ . The OPA858 amplifier is a decompensated, 5.5-GHz, operational amplifier with low bias current complementary metal oxide semiconductor (CMOS) inputs. The design uses the OPA858 5.5-GHz amplifier by default, but can be easily configured to use the [OPA855](#) 8-GHz, bipolar input amplifier or the [OPA859](#) 900-MHz, CMOS input, unity-gain stable amplifier. The OPA858 output is connected to the TLV3501 4.5-ns comparator to amplify and propagate the signal to the next stage.

The received signal is measured using the TDC7201 time-to-digital converter in its short-time measurement mode. The TDC7201 internally calculates the time difference between the start and stop pulses to determine a ToF measurement. In this design, the start signal is provided by the microcontroller or by the built-in monitor diode packaged in the laser diode and the stop signal is the received signal from the TLV3501. By default, the TDC7201 has a minimum measurement time of 12 ns that limits the minimum measurement distance to 3.6 meters. However, the short-time mode of the device allows the two measurement cores to work in conjunction to reduce the minimum measurement time to 250 ps, which reduces the minimum measurement distance to 7.5 centimeters in a vacuum. The digital output of the TDC7201 is connected to the MSP430 microcontroller that calculates the actual distance measurement and sends the information to the computer graphical user interface (GUI).

The transmit path of the design is also controlled by the MSP430, which commands the laser driver to fire and also starts the TDC7201 measurement based on inputs from the computer GUI. The laser driver is connected to a laser diode that features an onboard monitoring photodiode. When the diode transmits, the onboard photodiode outputs a current signal that is converted to a simple voltage using a resistor. Optionally, the measurement start of the TDC7201 can be triggered by the laser diodes onboard the photodiode instead of the MSP430 to provide a connection with less latency. For this design, the optical signal is transmitted through an optical fiber for ease of measurement and setup. The design can be modified to an over-the-air measurement using alternate diodes and lenses in place of the fiber optics.

### 1.1 Key System Specifications

表 1 lists key specifications for this reference design.

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Supply voltage	5-V external supply	See <a href="#">节 2.2.4</a>
Analog bandwidth	>200 MHz at gain = 10 k $\Omega$	See <a href="#">节 2.4.1.1</a>
Rise and fall time	< 1.5 ns	See <a href="#">表 2</a>
Averaged accuracy	< 1 cm	See <a href="#">节 3.2.2.1.2</a>
Standard deviation	< 7 cm	See <a href="#">节 3.2.2.1.2</a>
Maximum amplifier output signal swing	2.5 V <sub>PP</sub>	See <a href="#">节 3.2.2.1.4</a>

## 2 System Overview

### 2.1 Block Diagram

图 1 shows a detailed block diagram of the evaluation design and subblocks. 图 1 is composed of the MSP-EXP430F5529LP EVM and the reference design board.

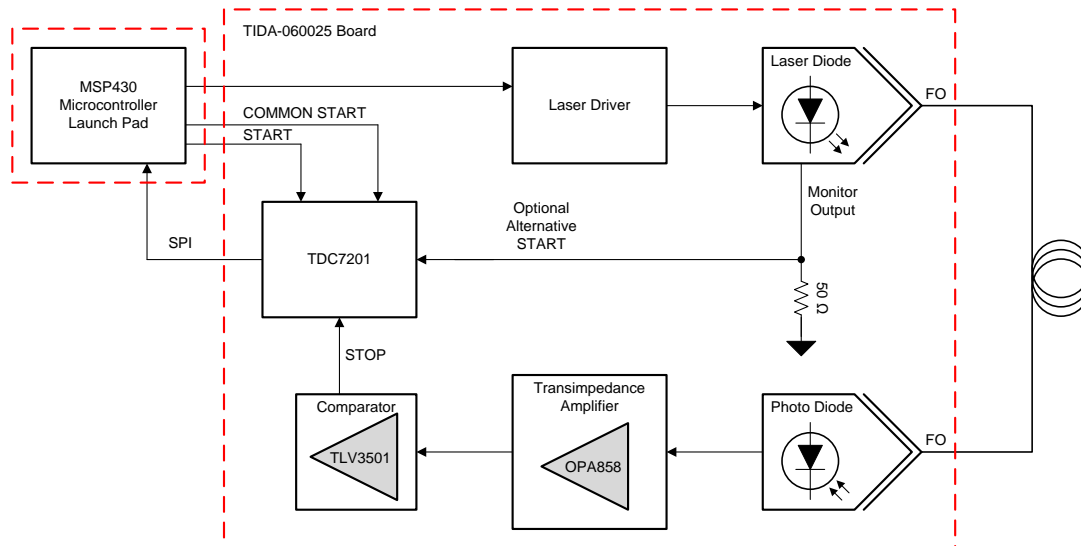


图 1. TIDA-060025 Block Diagram

### 2.2 Design Considerations

#### 2.2.1 Amplifier and Comparator

The primary goal of this design is to reach a front-end linear transimpedance bandwidth greater than 200 MHz while maintaining a gain of 10 kΩ that is commonly encountered in optical systems. To meet these requirements, the OPA858 operational amplifier was chosen, which features a gain bandwidth product of 5.5 GHz, low bias current CMOS inputs, and a low noise of 2.5 nV/√Hz. With the photodiode and feedback capacitance used in the design, the amplifier is able to achieve over 250 MHz of closed-loop bandwidth with 10 kΩ of gain, which is higher than the initial target of 200 MHz. For more information on the design theory, see 2.4 节.

To drive the digital inputs of the TDC7201 stage following the OPA858, TI's TLV3501 high-speed comparator was chosen to provide a conditioned signal. The TLV3501 features a push-pull output design with low rise and fall times of 1.5 ns and a delay of 4.5 ns. A faster comparator can be used, but such devices typically have low-voltage differential signaling (LVDS) or other differential outputs that may require an additional converter and delay to drive the TDC7201 input. Furthermore, the full system is designed with a calibration that eliminates the delay errors from the distance measurement.

## 2.2.2 Digital Processing and Control

To keep the design simple, low cost, and low power, the TDC7201 time-to-digital converter was chosen to measure the time delay instead of using a high-speed ADC. The TDC7201 is configured in its short-time measurement mode, which uses both cores of the device to allow for measurement accuracy to 0.25 ns. This configuration creates a system measurement accuracy of approximately 7.5 cm in a vacuum or 5 cm in a single mode fiber with a refraction index of 1.444. With the high bandwidth of the analog front-end driving the TDC7201, the full measurement is able to achieve an accuracy less than 10 cm with all error sources added. For more information on the TDC7201 short-time measurement mode, see the [Short Time Measurement Using TDC7201 application report](#).

To control all components and process the digital information from the TDC7201, the design uses Texas Instrument's MSP430 LaunchPad™ featuring the MSP430FF5529 microcontroller. The MSP430FF5529 is one of TI's low-power series microcontrollers and the LaunchPad™ interface allows for an easy plug-and-play design that connects directly to a computer GUI using a universal serial bus (USB) cable. The microcontroller handles the commands to fire the laser diode and the timing setup and processing of information from the TDC7201.

## 2.2.3 Optical Components

### 2.2.3.1 Laser Driver and Laser Diode

The laser driver used in the design is an iC-HB, 155-MHz, triple-laser switch from iC-Haus™. See the [Triple 155MHz Laser Switch data sheet](#) for the recommended laser driver for this design. The recommended laser diode is a 1550-nm distributed feedback laser (DFB) [LDM5S515-015](#) from OEQuest™. In a pulsed high-speed application, toggling a laser on and off causes suboptimal performance. Rather than turning the laser off, configure the laser to just less than its turnon threshold when the laser is inactive to ensure a smoother and quicker turnon. This configuration minimizes the effects of parasitic capacitances that require charging and discharging during transient operation.

[图 2](#) shows a simplified schematic of the laser setup. See [图 24](#) for the complete printed circuit board (PCB) schematic. Consider each channel of the laser-diode driver to be a voltage-controlled current source (VCCS) with an enable and disable switch. The three parallel channels are as follows:

- The bias channel sets the laser at its threshold condition
- Channel 1 drives the signal current that toggles the laser on or off
- Channel 2 is unused in this application

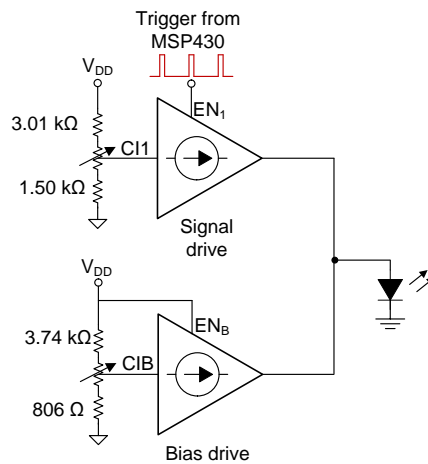


图 2. Laser Diode Block Diagram

Using the onboard resistor divider and potentiometer subcircuit connected between the 5-V supply and ground sets the bias voltage to control the VCCS. Set the bias supply to 1.15 V and the signal supply on channel 1 to 1.65 V. The jumper statically controls the bias channel state and the trigger generated by the MSP430 controls the signal channel. The adjustable linear regulator (U3) is configured to drive an output voltage of 3.3 V on the 3p3V line. This voltage drives the primary side of the SN74LVC1T45 logic-level translator to shift the 0-V to 3.3-V logic level from the trigger signal of the MSP430 to a 0-V to 5-V digital signal required to drive the iC-HB device. For more information, see 图 1.

### 2.2.3.2 Photodiode

A high-speed, low-voltage indium gallium arsenide (InGaAs) photodiode (such as the CEL™ NR-7500) biased with five volts was used to evaluate the system.

### 2.2.4 Power Supply

The entire design is powered from a 5-V wall pluggable power supply and the 5-V connection through a computer USB. By default the design uses the USB power for the MSP430 LaunchPad™ and the TDC7201. However, the board can optionally power all devices from the 5-V wall supply.

## 2.3 Highlighted Products

### 2.3.1 OPA858 Operational Amplifier

The OPA858 is a wideband, low-noise, operational amplifier with CMOS inputs for wideband transimpedance and voltage amplifier applications. When the device is configured as a transimpedance amplifier (TIA), the 5.5-GHz gain bandwidth product (GBP) enables applications requiring high closed-loop bandwidths at transimpedance gains in the tens to hundreds of kilohms range.

图 3 and 图 4 demonstrate the bandwidth and noise performance of the OPA858 as a function of the photodiode capacitance when the amplifier is configured as a TIA. The total noise is calculated over a bandwidth range extending from DC to the calculated  $f_{-3dB}$  frequency on the left-hand scale. The OPA858 package features a feedback pin (FB) that simplifies the feedback network connection between the input and the output.

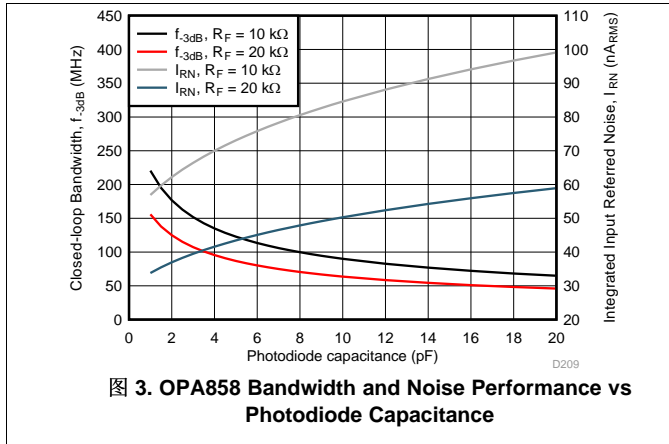


图 3. OPA858 Bandwidth and Noise Performance vs Photodiode Capacitance

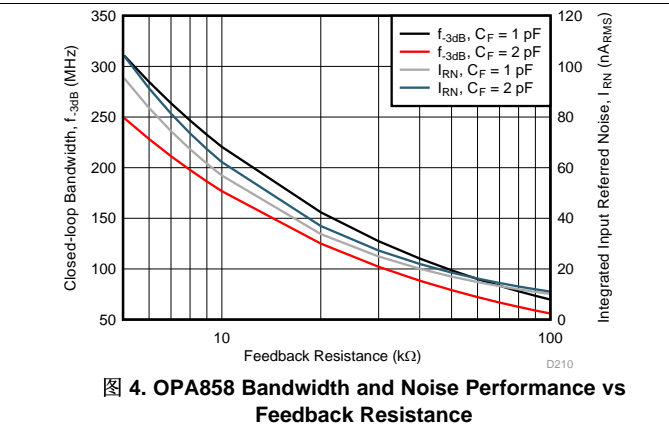


图 4. OPA858 Bandwidth and Noise Performance vs Feedback Resistance

### 2.3.2 TLV3501 High-Speed Comparator

The TLV350x family of push-pull output comparators features a fast 4.5-ns propagation delay and operation from 2.7 to 5.5 V. Beyond-the-rails input common-mode range makes the TLV350x an ideal choice for low-voltage applications. The rail-to-rail output directly drives either CMOS or transistor-transistor logic (TTL) logic.

Microsize packages provide options for portable and space-restricted applications. The single (TLV3501) is available in 6-pin SOT-23 and 8-pin SO packages. The dual (TLV3502) comes in the 8-pin SOT-23 and 8-pin SO packages.

图 5 shows a block diagram of the TLV3501.

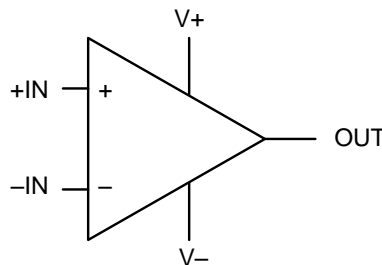


图 5. TLV3501 Block Diagram

### 2.3.3 TDC7201 Time-to-Digital Converter

The TDC7201 is designed for use with ultrasonic, laser and radar range-finding equipment using the time-of-flight (ToF) technique. The TDC7201 has two built-in time-to-digital converters (TDCs) that can be used to measure distance down to 4 cm and up to several kilometers using a simple architecture, thus eliminating the need to use expensive field-programmable gate arrays (FPGAs) or processors.

Each TDC performs the function of a stopwatch and measures the elapsed time (time-of-flight or ToF) between a START pulse and up to five STOP pulses. The ability to measure simultaneously and individually on two pairs of START and STOP pins using two built-in TDCs offers high flexibility in time-measurement design.

The device has an internal self-calibrated time base that compensates for drift over time and temperature. Self-calibration enables time-to-digital conversion accuracy in the order of picoseconds. This accuracy makes the TDC7201 ideal for range-finder applications. 图 6 shows a LiDAR block diagram for the TDC7201.

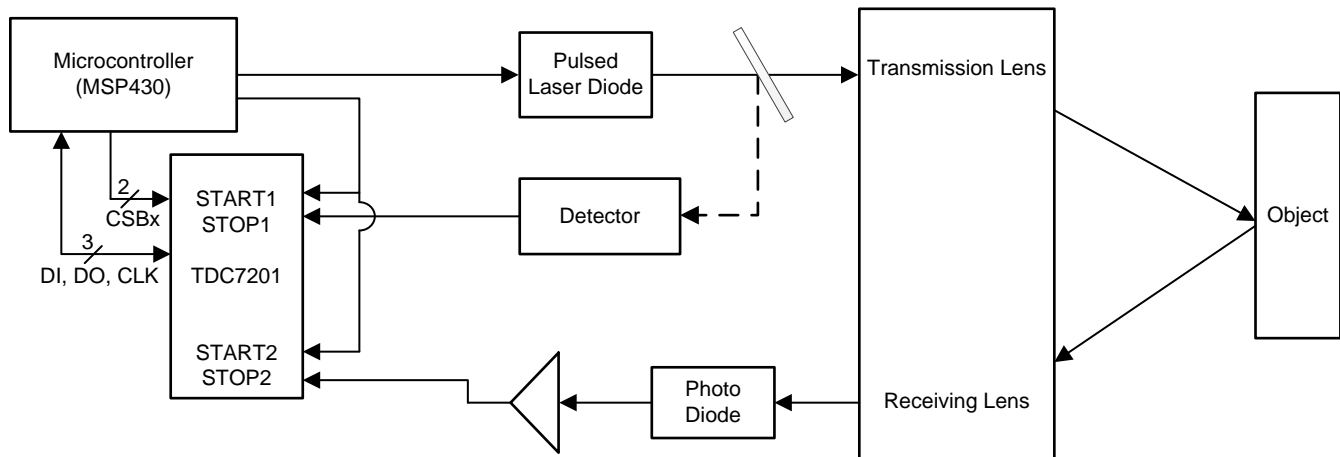


图 6. Simplified TDC7201 LiDAR Application Block Diagram

## 2.4 System Design Theory

### 2.4.1 Transimpedance Amplifier

#### 2.4.1.1 Bandwidth

The goal for the OPA858 transimpedance amplifier design is to achieve greater than 200 MHz of bandwidth with a gain of 10 k $\Omega$ . The maximum achievable transimpedance bandwidth of a circuit is a function of the amplifier gain bandwidth, gain, input capacitance, and feedback capacitance. The NR-7500 photodiode chosen for this design has an input capacitance of approximately 1.1 pF with a reverse bias voltage of 5 V. The photodiode capacitance coupled with the input 800-fF input capacitance of the OPA858 and the expected parasitic capacitance from the PCB yields a total input capacitance of approximately 2 pF. Using the transimpedance design theory stated in the [Transimpedance Considerations for High-Speed Amplifiers application report](#), a Butterworth response with a quality factor (Q) of 0.707 yields a required feedback capacitance of approximately 100 fF and a bandwidth of 205 MHz. In order to achieve a higher bandwidth, relax the Q value to 0.95 to change the feedback capacitance to 75 fF and the bandwidth to 260 MHz. The higher Q value does cause peaking in the frequency response and overshoot in the pulse response, but with the edge-triggered nature of the TDC7201 measurement, the tradeoff of some overshoot allows a faster edge rate from the amplifier.

#### 2.4.1.2 Stability Considerations

As with any high-speed amplifier design, always pay attention to the stability of the circuit. The OPA858 is a decompensated amplifier that is only stable at noise gains of 7 V/V or higher and can oscillate at lower gains. Decompensated amplifiers are a natural fit for transimpedance circuits because the combination of input capacitance and feedback capacitance form the high-frequency gain value at the point where the noise gain of the circuit intersects with the open-loop gain from the amplifier (this point is also the reference point for the phase margin measurement). With the input capacitance and selected feedback capacitor for the circuit, the noise gain measured at the open-loop gain ( $A_{ol}$ ) crossing point is approximately 20 V/V, which is far higher than required for stability.



### 2.4.1.3 Noise Performance

For the selected OPA858 amplifier circuit design, the total calculated noise without any post filtering results in an input RMS current noise of 132 nArms. This value determines the smallest signal that can be measured without averaging from the OPA858, and at the output yields an output voltage noise of 1.3 mVrms. The circuit noise can be improved by adding a post filter set at or higher than the frequency of the transimpedance bandwidth. Using a simple single-pole, low-pass filter set at 260 MHz reduces the input noise of the circuit to 90 nArms, which only lowers the bandwidth slightly to 253 MHz. Even better noise performance can be obtained with higher-order filters; however, for this design the input signal current is significantly higher than 132 nArms and does not require any additional filtering.

### 2.4.2 Time-of-Flight Measurement

To make the actual time-of-flight measurement, the TDC7201 time-to-digital converter was chosen with its fast measurement mode yielding an accuracy of 0.25 ps or 5 cm in a single-mode fiber. This mode enables high-speed measurement with a high level of accuracy that is easy to use and does not require significant processing overhead. Drive the TDC7201 input with a TLV3501 comparator that has a rise time of 1.5 ns and a delay of 4.5 ns. The laser driver pulse is set by two clock cycles of the MSP430 GPIO pin running at 12 MHz for a pulse width of 167 ns. This pulse can be shortened by using one of the PWM pins of the MSP430; however, the actual pulse duration is not critical in the measurement because the TDC7201 is set to trigger only on a rising or falling edge. Therefore, the edge rates and accuracy determine the actual measurement value.

In this measurement, the edge rate of the TLV3501 and the pulse width from the MSP430 limit the smallest and fastest pulse achievable from the design. Higher performance can be obtained by using a high-speed ADC to directly measure the output of the OPA858 and control the laser pulse with a narrower control signal. [TIDA-00725](#) and [TIDA-01187](#) designs describe this type of solution, but more power, a higher cost, and a more complex processing solution is required.



## 2.4.3 Simulations

### 2.4.3.1 Bandwidth Simulation

图 7 显示了 TINA-TI™ 仿真原理图，用于 OPA858 放大器设计。电流源代表光电二极管，而 1.1-pF 电容器是等效电容，来自 NR-7500 光电二极管。放大器的非反相输入端偏置为正值，因为光电二极管的输入仅在一个方向上脉冲。

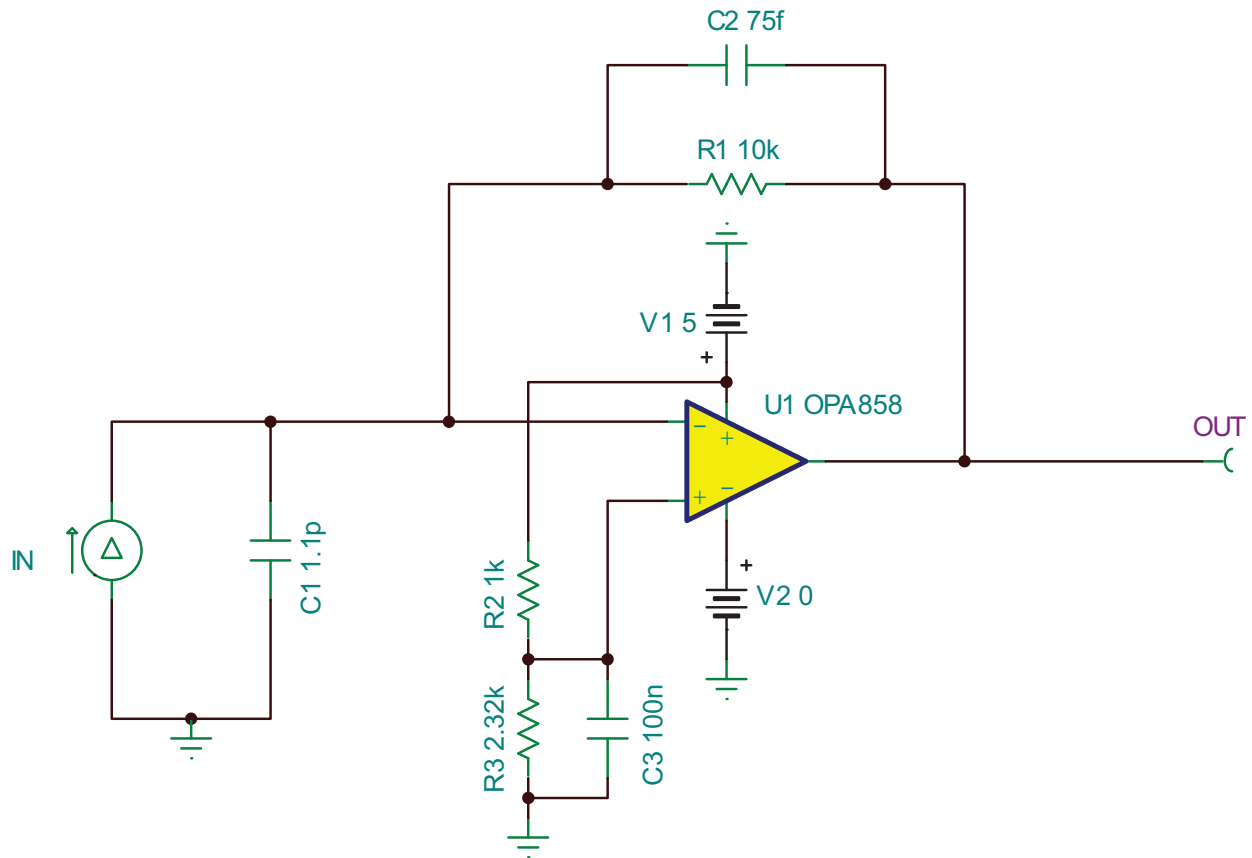


图 7. OPA858 Bandwidth and Noise Simulation Schematic

图 8 显示了 OPA858 跨阻电路的带宽仿真结果。模拟带宽高于第 2.4.1.1 节中的预测值。这是因为模型更准确地模拟了放大器的开环响应，而计算值仅基于电路的一阶近似。

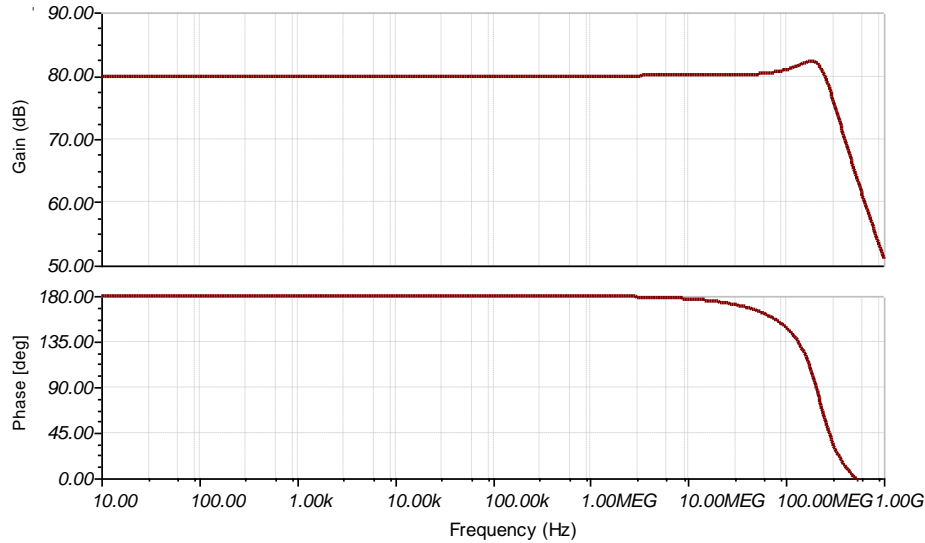


图 8. OPA858 带宽仿真结果

### 2.4.3.2 Noise Simulation

噪声仿真使用与图 7 相同的电路。图 9 显示了放大器系统在 OPA858 输出节点处测量的输出噪声。对于 10-kΩ 跨阻增益设置，总模拟输出噪声为 1.245 mVrms，无滤波。该值低于第 2.4.1.3 节中预测的 1.3 mVrms 值，因为计算使用了电路噪声增益的一阶近似，这比模型不准确。然而，计算仍然提供了一个合理的准确预测，这对于初步设计考虑是有用的。

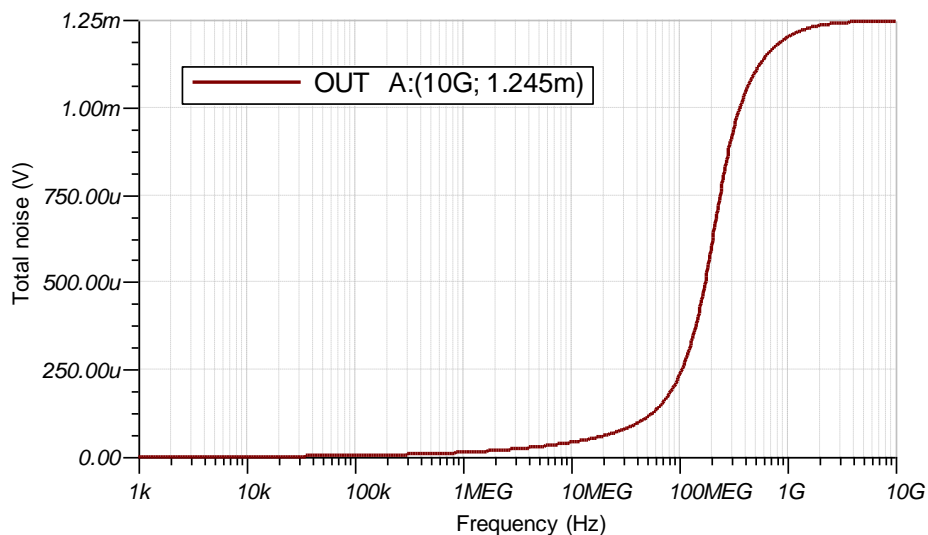


图 9. 模拟 OPA858 放大器链的输出噪声

### 2.4.3.3 OPA858 Loop-Gain and Phase Margin Simulation

To get a pulse-response with fast rise and fall time, some overshoot and ringing on the rising and falling edges of the pulse is expected. The phase-margin of the OPA858 circuit is targeted at  $55^\circ$  to achieve a Q factor of 0.95. Use the circuit in 图 10 to simulate the loop-gain of the OPA858. For more information on transimpedance amplifier stability theory and design, see the *What You Need To Know About Transimpedance Amplifiers* blog, [part 1](#) and [part 2](#).

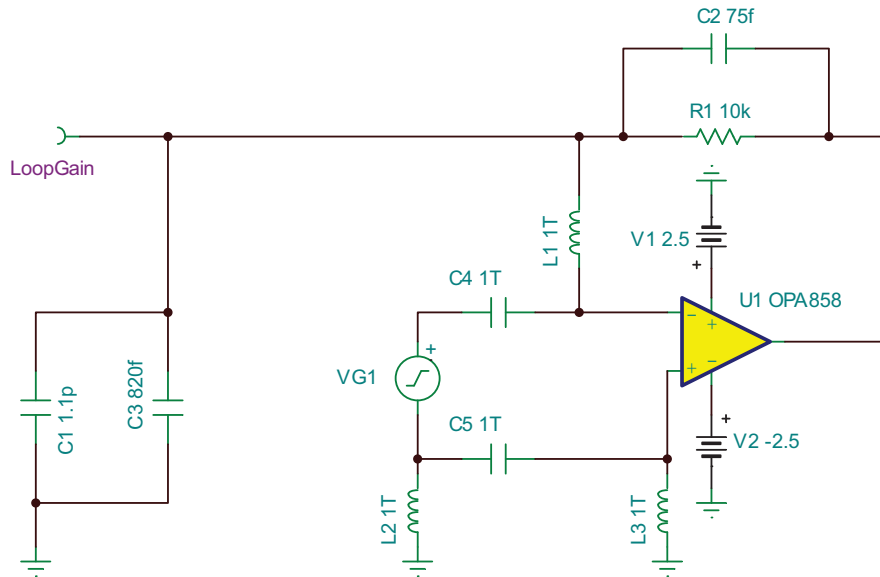


图 10. OPA858 Loop-Gain Analysis TINA Schematic

The simulated loop-gain magnitude and phase plotted in 图 11 predict a phase-margin of approximately  $45^\circ$ , which is lower than the expected calculated value because the calculation is only a first-order approximation.

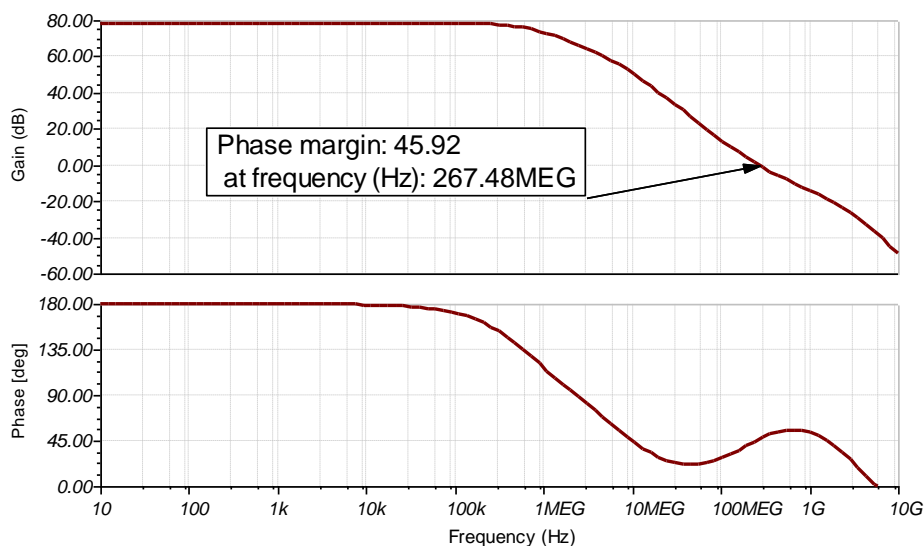


图 11. Simulated Loop Gain of the OPA858 Circuit

## 3 Hardware, Software, Testing Requirements, and Test Results

### 3.1 Required Hardware and Software

#### 3.1.1 Hardware

Two hardware boards and the associated test equipment are required to make all of the measurements outlined in this reference design. The required hardware are:

1. The TIDA-060025 EVM board
2. The MSP430F5529 USB LaunchPad™ Evaluation Kit
3. A computer compatible with the GUI software
4. A 5-V power supply
5. A high-speed oscilloscope
6. Fiber-optic cable and adjustable attenuator
7. A digital multimeter

#### 3.1.2 Software

This reference design used custom GUI software and firmware to control the MSP430 and TDC7201 in order to make time-of-flight measurements. The software is a modified version of the default software for the [TDC7201-ZAX-EVM](#) that adds the ability to subtract a calibration value from the time-of-flight measurement and also adds a distance calculation. The modifications to the MSP430 firmware send the COMMON\_START and LIDAR\_START signals on their appropriate signals.

## 3.2 Testing and Results

### 3.2.1 Test Setup

#### 3.2.1.1 Getting Started: System Setup

To prevent damage to the sensitive optical components and to ensure the software is operating in the correct mode, first connect the MSP430 board to the USB connector and then apply the 5-V supply to the reference design board.

##### 3.2.1.1.1 Laser-Driver Setup

1. Ensure jumpers JP12 and JP14 are grounded and J9, J10, and J13 are in their default positions.
2. Use the R31 potentiometer to set the voltage on CIB (pin 17) to 1.15 V  $\pm$ 25 mV.

---

注: This adjustment drives approximately 10 mA of current into the LDM5S515-015 laser diode. This current puts the laser diode at its lasing threshold.

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3. Use the R60 potentiometer to set the voltage on C11 (pin 12) to 1.65 V  $\pm$ 25 mV.

---

注: This adjustment drives approximately 40 mA of signal current into the laser diode.

---

4. Adjust the threshold and signal-bias voltages if using another laser diode.
5. Connect JP14 to VDD to set the laser at its threshold.

### 3.2.1.1.2 Receiver and Optical Setup

1. Keep the optical power output from the laser diode constant during evaluation in compliance with the settings in 节 3.2.1.1.1.
2. Turn the knob on the variable optical attenuator (VOA) clockwise for maximum attenuation.

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注: This adjustment ensures there is minimal optical power incident on the photodiode.

This [variable fiber optical inline attenuator](#) provides further details on the recommended optical attenuator.

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3. Connect a multimeter to the IMON connector.

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注: The IMON pin sources a current proportional to 20% of the photodiode current for external current monitoring. A 50-Ω resistor from IMON to GND is provided on the board by default to create a voltage.

---

4. Set jumper JP12 to VDD.

---

注: The laser diode remains on.

---

5. Perform a DC measurement of the photodiode output current.
6. Turn the knob on the VOA counterclockwise to reduce its attenuation.
7. Observe the voltage reading on the multimeter.
8. Calculate the photodiode output current.
9. Remove JP12 to return control of the laser-diode driver to the trigger signal from the MSP430.

## 3.2.2 Test Results

### 3.2.2.1 Verification and Measured Performance

图 12 shows the bench setup to evaluate the performance of the system in the lab.

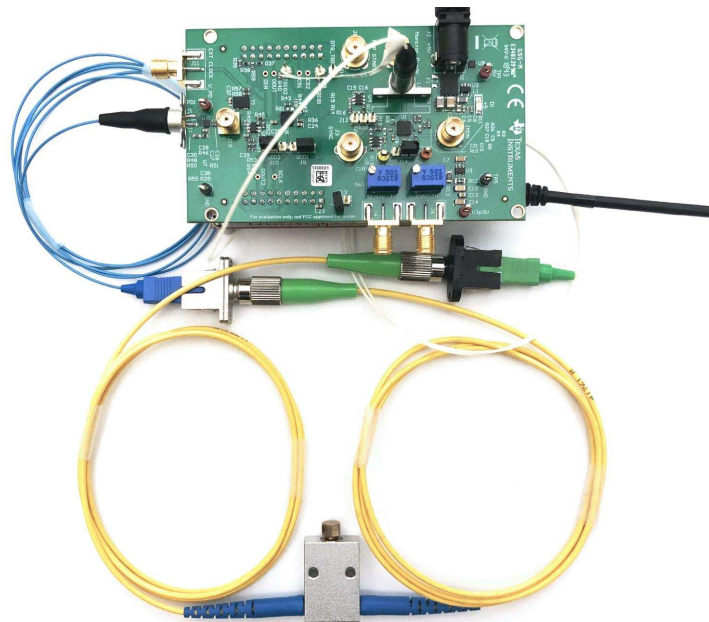
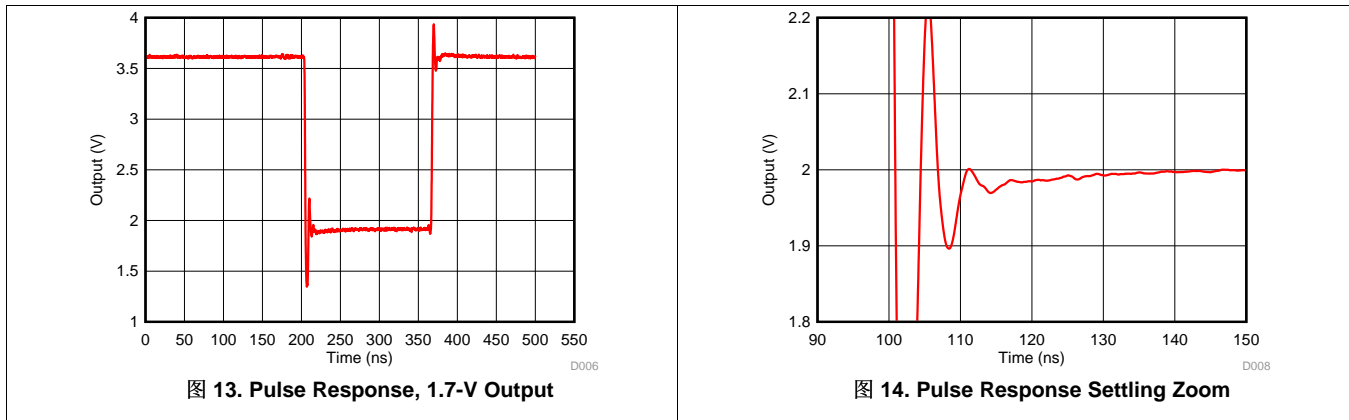


图 12. Laboratory Bench Setup of the Design

### 3.2.2.1.1 Pulse Response Measurements

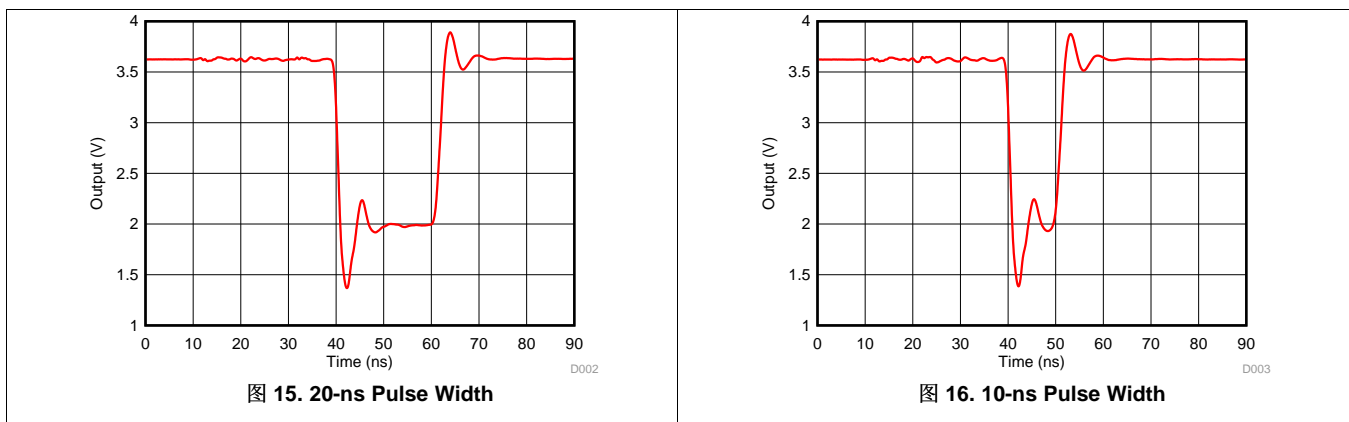
#### 3.2.2.1.1.1 Pulse Response Settling

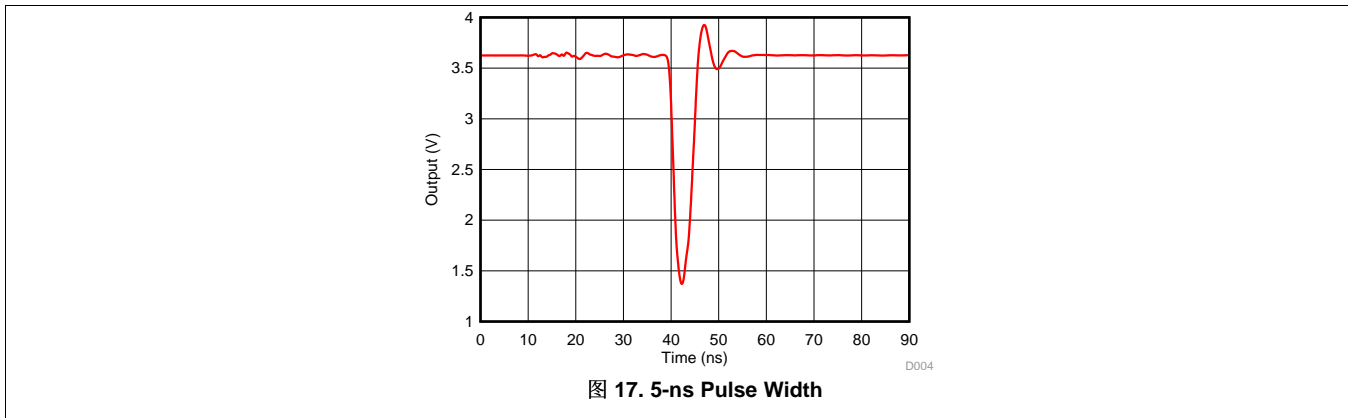
图 13 显示了由 MSP430 触发的标准脉冲响应。光电功率通过衰减器控制以获得 1.7-V 输出电压幅度。图 14 显示了脉冲响应 settling 到最终值为 2 V 的细节。settling 性能可以通过更改放大器响应来改进，但对于 TDC7201 基于的设计并非必需。



#### 3.2.2.1.1.2 Pulse Response vs Output Pulse Width

图 15, 图 16, 和 图 17 显示了脉冲响应作为在 OPA858 输出端测量的脉冲宽度的函数。光学衰减器被调整以驱动输出电压最终值为 2 V。高速脉冲发生器用于驱动激光驱动器，通过移除电阻器 R17 并将脉冲发生器连接到跳线 J12 直接。





### 3.2.2.1.1.3 Rise and Fall Time

表 2 lists the pulse response rise and fall times for the various pulse width measurements described in 节 3.2.2.1.1.2 compared to a baseline simulation. The fall time performance is slightly better than the simulated value but the rise time showed lower performance. The degradation in the rise time performance is likely because of the turn-off performance of the laser driver limiting the response instead of the amplifier.

表 2. OPA858 Rise and Fall Time Measurements

MEASUREMENT	FALL TIME		RISE TIME	
	90-10%	80-20%	10-90%	20-80%
Simulation	1.20 ns	0.85 ns	1.18 ns	0.84 ns
100-ns pulse width	1.11 ns	0.77 ns	1.68 ns	1.19 ns
20-ns pulse width	1.12 ns	0.77 ns	1.72 ns	1.21 ns
10-ns pulse width	1.16 ns	0.80 ns	1.84 ns	1.27 ns
5-ns pulse width	2.00 ns	1.29 ns	2.68 ns	1.67 ns

### 3.2.2.1.1.4 Overdriven Response

图 18 shows the pulse response of the OPA858 without an optical attenuator in the signal path. In this condition, the amplifier output is saturated and extends the 20-ns input pulse to a measured pulse width of 36 ns and increases the fall time to 1.5 ns compared to the non-saturated graph in 图 15. The pulse extension does not affect this design because the measurement is triggered on the falling edge, but the fall time can potentially add an error as discussed further in 节 3.2.2.1.2. The plot in 图 18 also shows the maximum achievable signal swing of 2.6 V when measured from the bias set in the design.

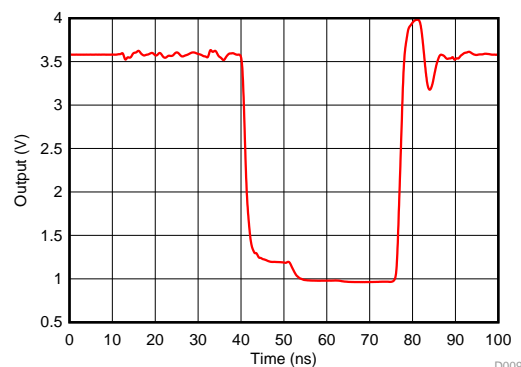


图 18. OPA858 Overdriven Response



### 3.2.2.1.2 Time-of-Flight Test

By using the constant speed of light through a fiber-optic medium, the reference design can be used to measure the length of any connected optical cable. This principal is the same as a measurement made through the air, but just uses a different constant for the speed of light. A standard index of refraction of 1.444 for the single mode fiber is used in the tests for this design, which divides the standard speed of light in a vacuum by a factor of 1.444. When the laser power is set according to 节 3.2.1 the design is then configured by default to perform a time-of-flight measurement using the TDC7201. The GUI software allows for the start of a measurement and can also control the TDC7201 settings. For the tests in this section, the transimpedance gain is 10 kΩ.

图 19 和 图 20 illustrate the calibration and distance measurements for a cable with a total length of 1.1 m including any added connectors. The GUI display shows a line of measurements over time and the calculated average values are displayed in the results at the top right of the display. The functionality is built into the default TDC7201EVM software. For more information see the [TDC7201-ZAX-EVM user's guide](#). The calibration time measurement removes the delay added by the fixed fiber cables attached to the photodiode and laser diode that are always present in the system. A 100-point average is used to calculate the calibration value with a standard deviation of 0.22 ns, which is expected from the TDC7201. 图 20 illustrates the measurement after calibration of a 1.09855-m cable, which yields an average error of only 2 mm and a standard deviation of 0.29 ns (6.1 cm). This measurement shows that the primary limitation of the system accuracy is dominated by the TDC7201 0.25-ns accuracy, as is expected. Use an optical attenuator to adjust the signal amplitude for these measurements.

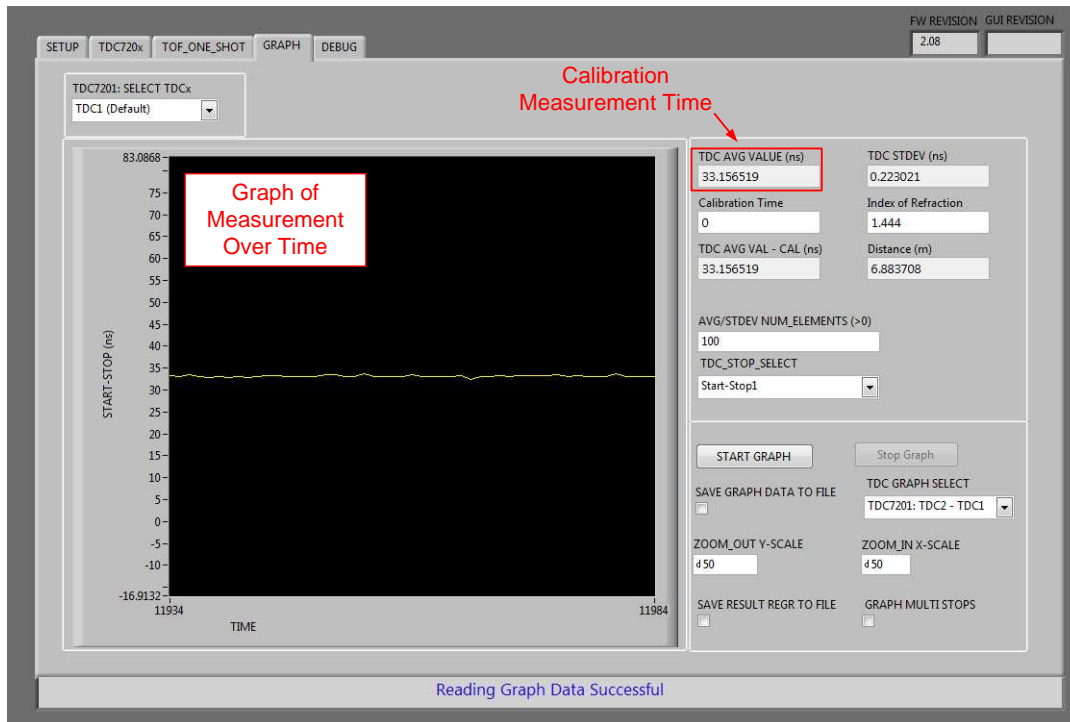


图 19. 1.1-m Cable Measurement Calibration

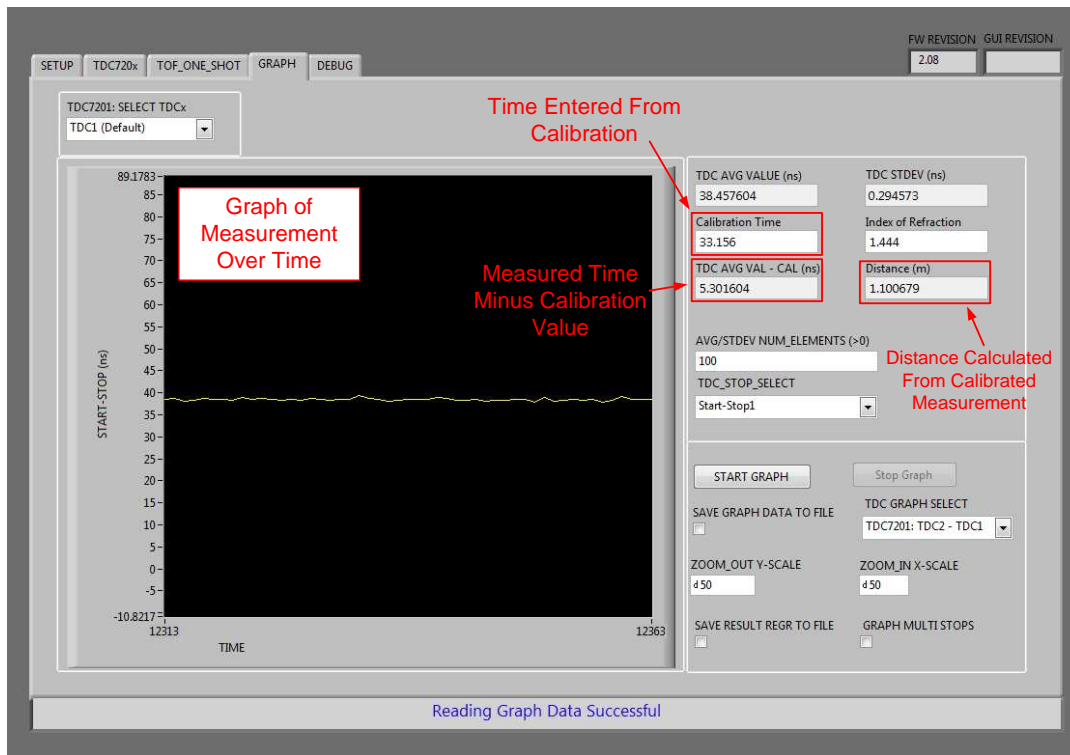


图 20. 1.1-m Cable Measurement

图 21 和 图 22 illustrate the calibration and measurement of a 2.07-m long cable with connectors made without any optical attenuation present in the system. The absence of attenuation causes the amplifier circuit to be overdriven during the measurements as illustrated in 图 18, which yields a larger average error of 2.9 cm compared to the measurements made with the non-overdriven signal, thus implying that the overdriven signal adds some delay to the system that is not accounted for in the calibration. The cable measured in this test has an *open* adjustable optical attenuator in its path that can also contribute some error. The standard deviation is 0.25 ns, as expected from the TDC7201.

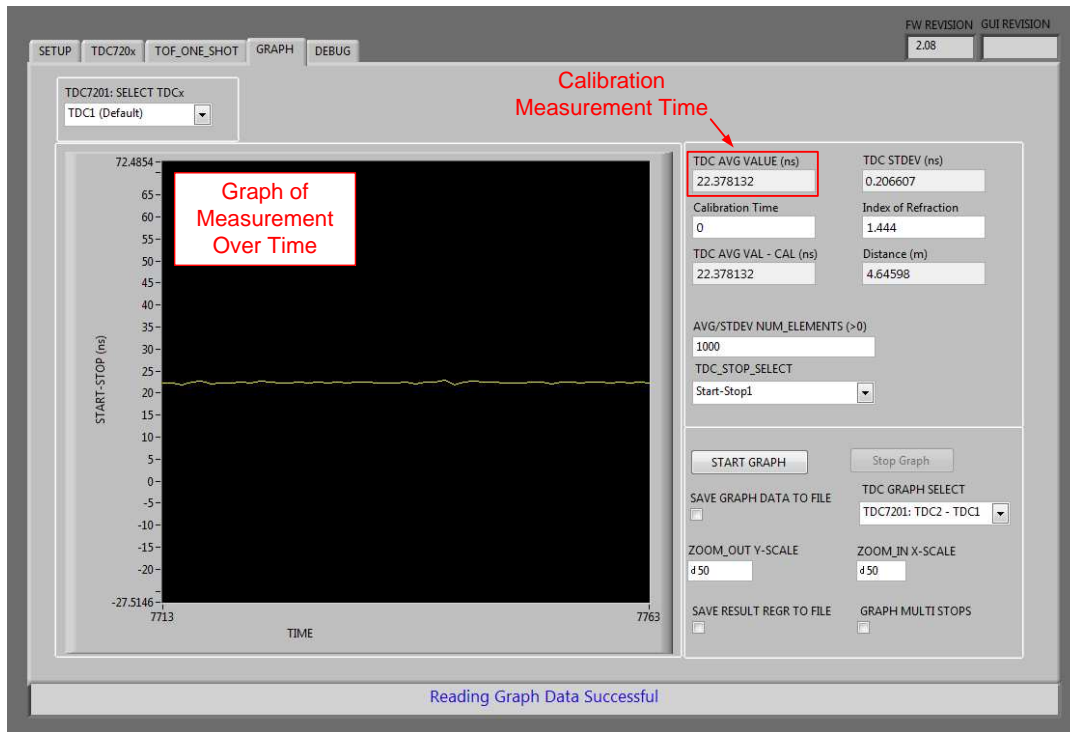


图 21. 2-m Cable Measurement Without Any Attenuation Calibration

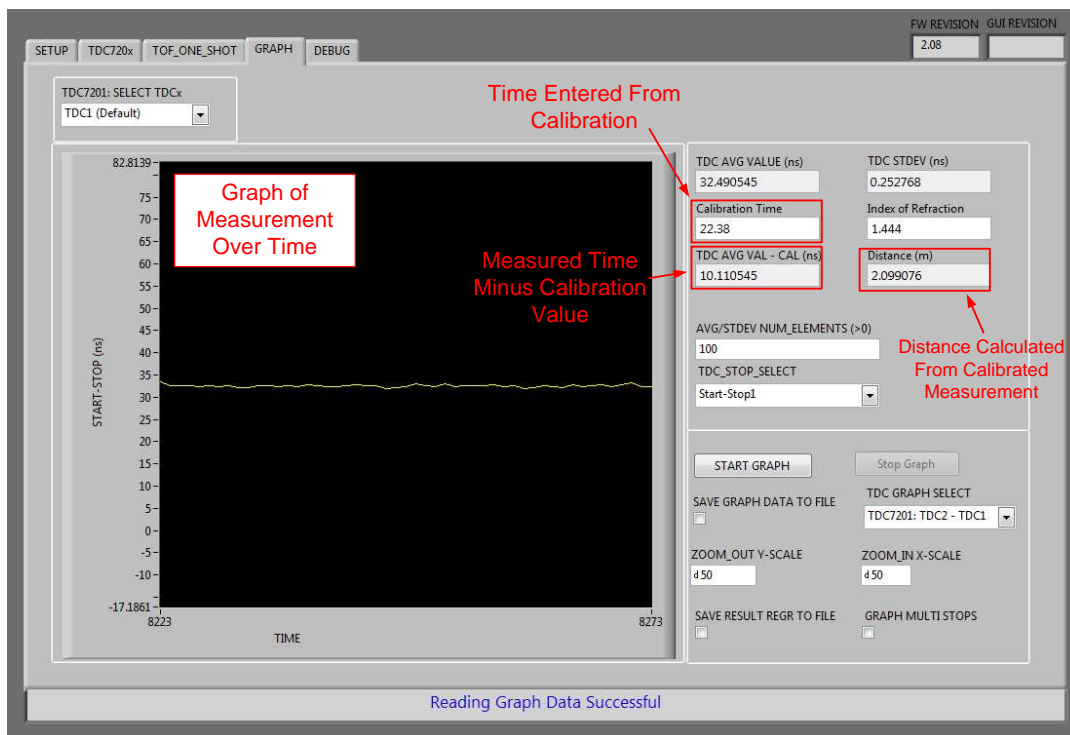


图 22. 2-m Cable Measurement Without Attenuation





## 5 Related Documentation

1. iC-HB, [Triple 155MHz Laser Switch data sheet](#)
2. OEQuest, [CWDM Coaxial DFB-LD Module for CATV Return-path LDM5S515 Series data sheet](#)
3. Fibermart, [Variable Fiber Optical Inline Attenuator](#)
4. Texas Instruments, [Transimpedance Considerations for High-Speed Amplifiers application report](#)
5. Texas Instruments, [OPA855 8-GHz Gain Bandwidth Product, Gain of 7-V/V Stable, Bipolar Input Amplifier data sheet](#)
6. Texas Instruments, [OPA859 1.8 GHz Unity-Gain Bandwidth, 3.3-nV/√Hz, FET Input Amplifier data sheet](#)
7. Texas Instruments, [Short Time Measurement Using TDC7201 application report](#)
8. Texas Instruments, [SN74LVC1T45 Single-Bit Dual-Supply Bus Transceiver With Configurable Voltage Translation and 3-State Outputs data sheet](#)
9. [NR-7500](#)
10. Texas Instruments, [Optical Front-End System Reference Design design guide](#)
11. Texas Instruments, [LIDAR-Pulsed Time-of-Flight Reference Design Using High-Speed Data Converters design guide](#)
12. Texas Instruments, [What You Need To Know About Transimpedance Amplifiers](#) blog, [part 1](#) and [part 2](#)
13. Texas Instruments, [TDC7201-ZAX-EVM user guide](#)

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## 6 About the Author

**Jacob Freet** is the applications manager for Texas Instrument's High Speed Amplifiers product line in Tucson, AZ. He works with a team of applications engineers to support TI's high speed op-amps in addition to fully differential, variable gain, and other high speed amplifiers.

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