

Reference Design Maximizing Transimpedance Bandwidth for LIDAR and Time-of-Flight Applications



Description

This design demonstrates a high-speed optical front-end with a ToF distance measurement circuit using a fiber-optic transmission medium and can be adapted to any type of ToF measurement such as through free space. This design features an industry leading 2.5-V output linear transimpedance front-end with 10 k Ω of gain and over 200-MHz bandwidth for high-accuracy measurements. The received signal is digitized using the TDC7201 converter operating in *short time* mode, which improves the measurement accuracy of the device from 12 ns to 250 ps, further reinforcing the high accuracy nature of the design. The measurement is controlled using the MSP430 microcontroller on a LaunchPad™ development kit for easy plug and play compatibility. Overall, the design focuses on high speed and accuracy while reducing complexity and lowering power compared to fully digitized designs that require high-speed ADCs and FPGAs.

Resources

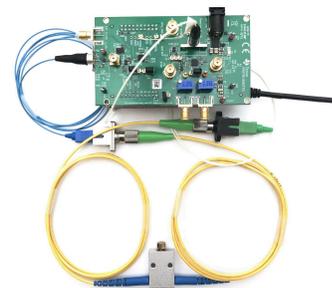
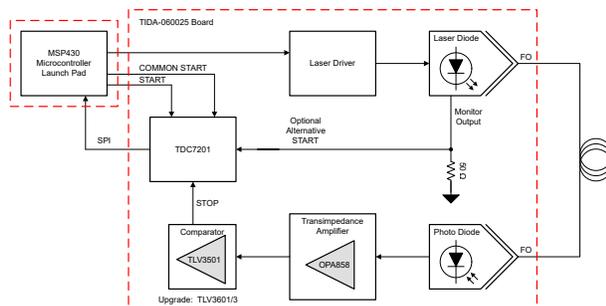
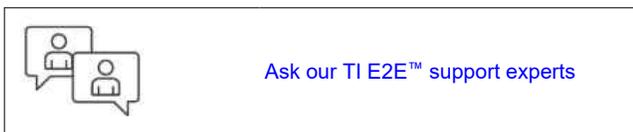
TIDA-060025	Design Folder
OPA858	Product Folder
TDC7201	Product Folder
TLV3501 or TLV3601/3	Product Folder
MSP-EXP430F5529LP	Tool Folder

Features

- Optical Front-End Design With Demonstrated Time-of-Flight Measurement
- High-Speed Amplifier Signal Path With Bandwidth Greater Than 200 MHz at Gain = 10 k Ω
- Centimeter Level Measurement Accuracy
- High-Speed Time-to-Digital Converter
- Ultrafast Laser-Diode Driver and Laser Diode to Generate Tx Signal
- PIN Photodiode Front-End With Onboard Voltage Supply
- High-Speed Transimpedance Amplifier (TIA) for I-to-V Conversion
- Low Computational Cost and Power Requirements

Applications

- Laser Distance Measurement
- LiDAR
- 3D Scanning
- Machine Vision
- Vacuum Robots
- Drone Vision
- Optical Amplifiers
- CAT-Scanner Front Ends
- Photodiode Monitoring
- Missile Guidance



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 Ω . 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

[Table 1-1](#) lists key specifications for this reference design.

Table 1-1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Supply voltage	5-V external supply	See Section 2.2.4
Analog bandwidth	>200 MHz at gain = 10 k Ω	See Section 2.4.1.1
Rise and fall time	< 1.5 ns	See Table 3-1
Averaged accuracy	< 1 cm	See Section 3.2.2.1.2
Standard deviation	< 7 cm	See Section 3.2.2.1.2
Maximum amplifier output signal swing	2.5 V _{PP}	See Section 3.2.2.1.4

2 System Overview

2.1 Block Diagram

Figure 2-1 shows a detailed block diagram of the evaluation design and subblocks. Figure 2-1 is composed of the MSP-EXP430F5529LP EVM and the reference design board.

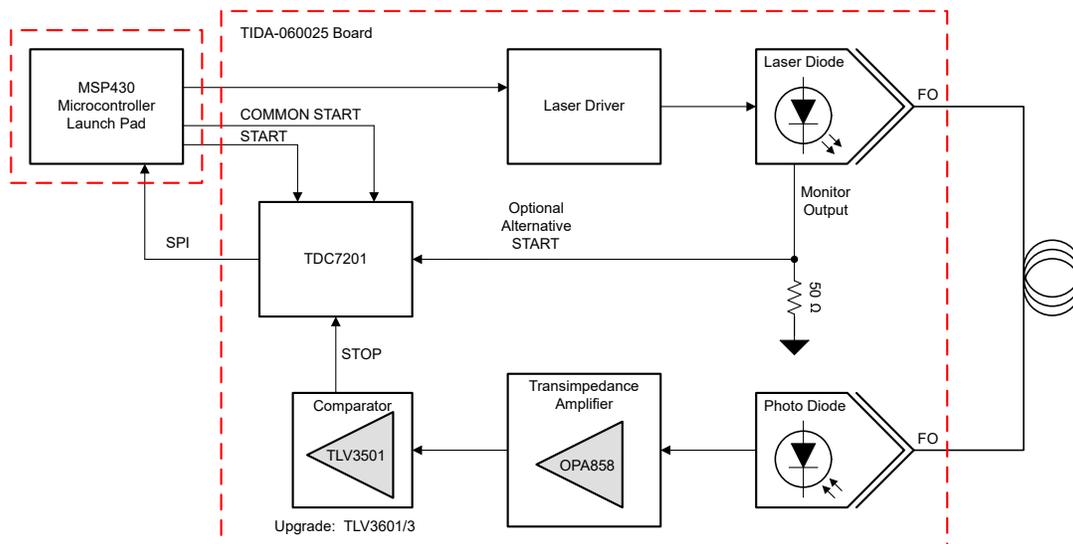


Figure 2-1. TIDA-060025 Block Diagram

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 k Ω 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/ $\sqrt{\text{Hz}}$. 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 k Ω of gain, which is higher than the initial target of 200 MHz. For more information on the design theory, see [Section 2.4](#).

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.

Figure 2-2 shows a simplified schematic of the laser setup. See Figure 4-2 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

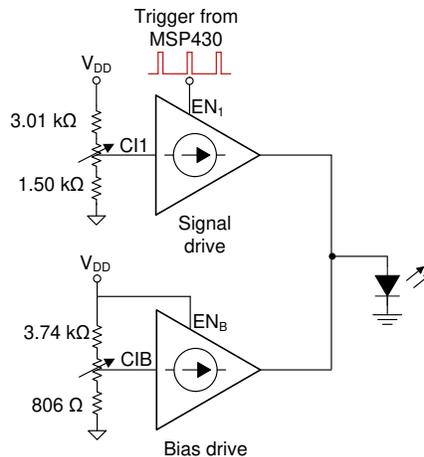


Figure 2-2. Laser Diode Block Diagram

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 [Figure 2-1](#).

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

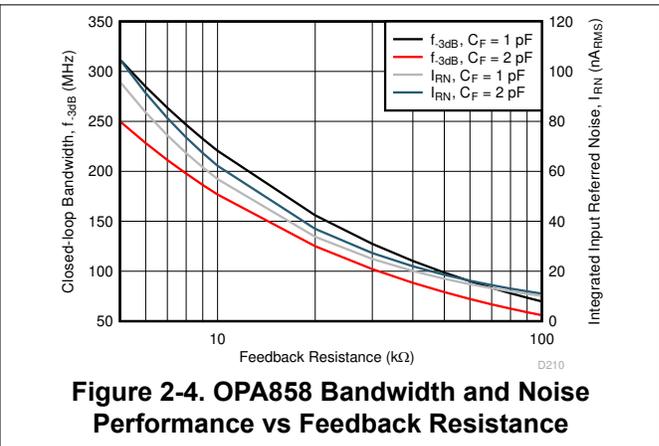
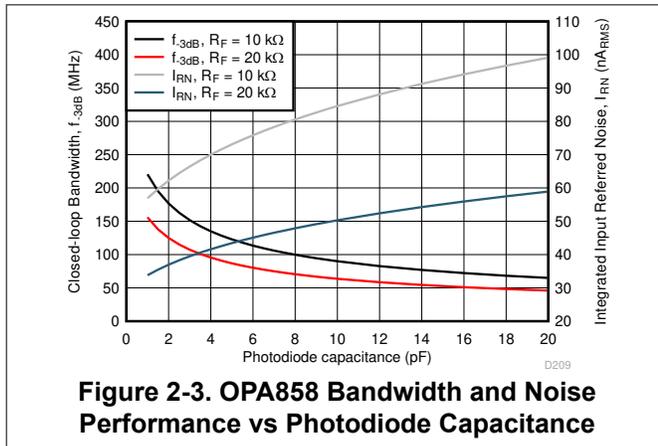
The entire design is powered from a 5-V wall pluggable power supply and the 5-V connection through a computer USB. By default the design uses the USB power for the MSP430 LaunchPad™ and the TDC7201. However, the board can optionally power all devices from the 5-V wall supply.

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.

Figure 2-3 and Figure 2-4 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.



2.3.2 TLV3501 and TLV3601/3 High-Speed Comparators

The TLV360x and TLV350x families of push-pull output comparators features a fast 2.5 ns and 4.5 ns propagation delay respectively and operation from 2.4 to 5.5 V. Rail-to-rail input common-mode ranges make these comparators a well-suited for low-voltage applications. The single-ended, push-pull outputs directly drive either CMOS or transistor-transistor logic (TTL) logic. Likewise, the TLV3603 has an adjustable hysteresis feature that can be configured to reject noise in the system.

Microsize packages provide options for portable and space-restricted applications.

Figure 2-5 shows a block diagram of the TLV3501 and TLV3601.

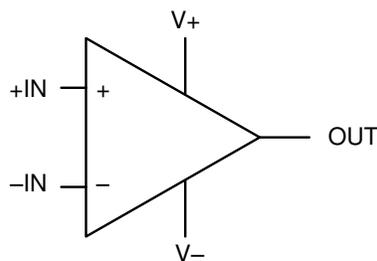


Figure 2-5. TLV3501/3601 Block Diagram

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. Figure 2-6 shows a LiDAR block diagram for the TDC7201.

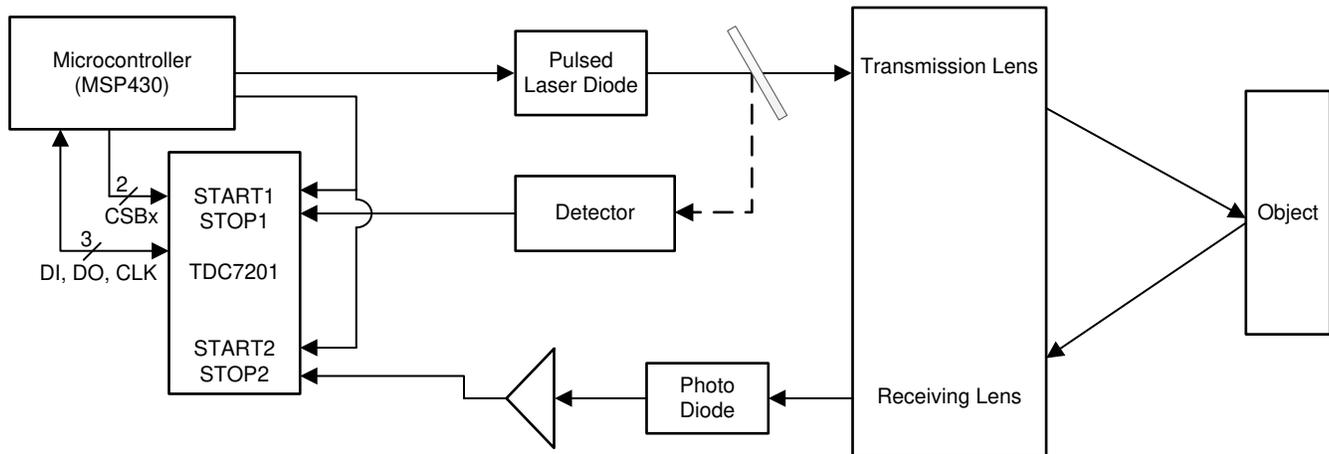


Figure 2-6. Simplified TDC7201 LiDAR Application Block Diagram

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 Ω . 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 TLV3601 (upgrade to TLV3501) comparator that has a rise time of 0.75 ns and a delay of 2.5 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 TLV3601 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

Figure 2-7 shows the TINA-TI™ simulation schematic for the OPA858 amplifier design. The current source represents the photodiode and the 1.1-pF capacitor is the equivalent capacitance from the NR-7500 photodiode. The noninverting input of the amplifier is biased positive because the input of the photodiode only pulses one direction.

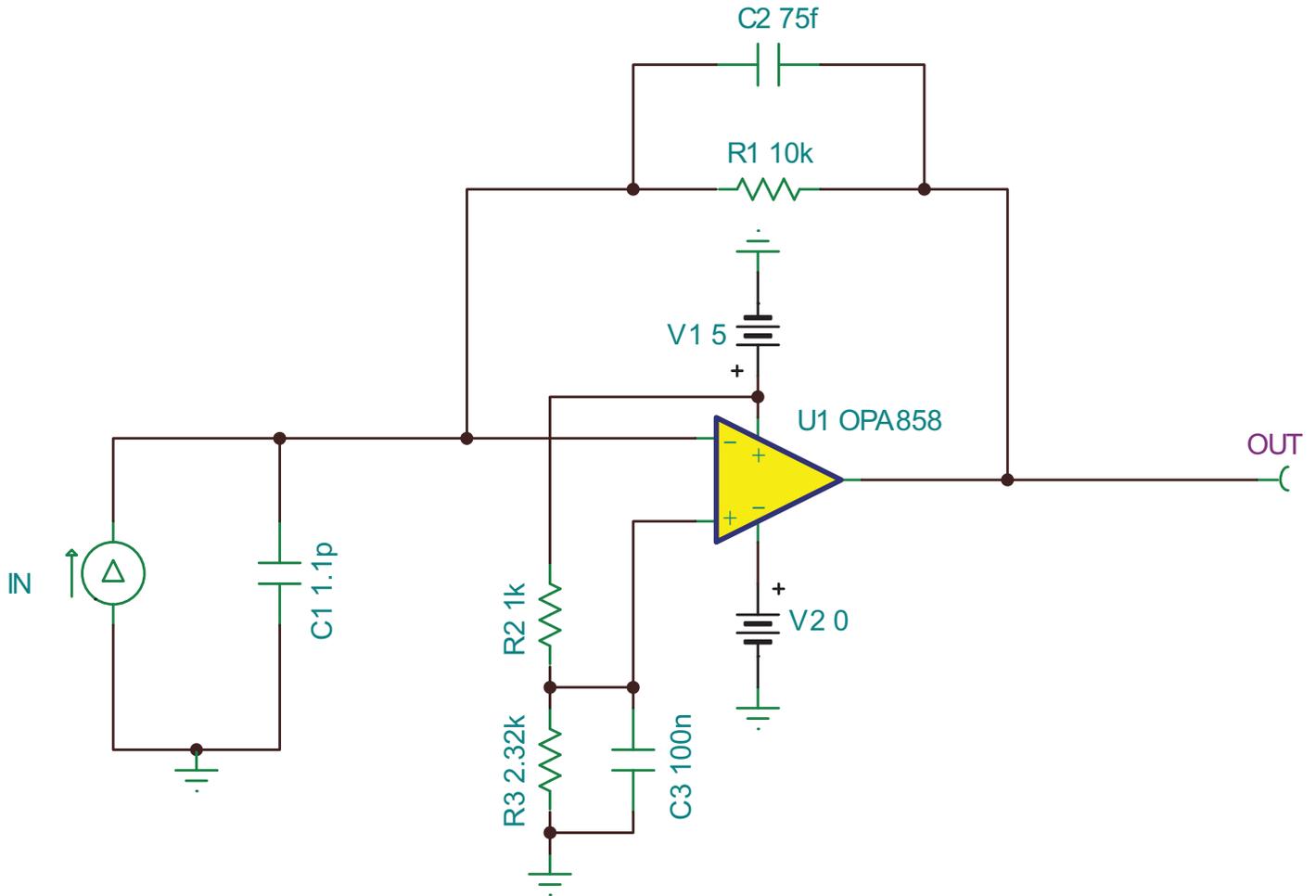


Figure 2-7. OPA858 Bandwidth and Noise Simulation Schematic

Figure 2-8 shows the bandwidth simulation results of the OPA858 transimpedance circuit. The simulated bandwidth is higher than the predicted value in Section 2.4.1.1. This difference in value is because the model more accurately models the open-loop response of the amplifier and the calculated value is only based on a first-order approximation of the circuit.

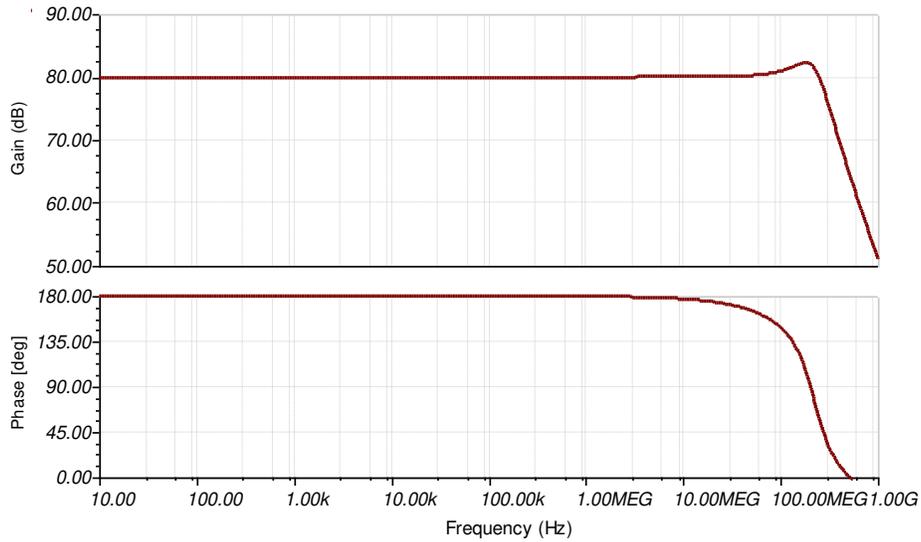


Figure 2-8. OPA858 Bandwidth Simulation Results

2.4.3.2 Noise Simulation

Noise is simulated using the same circuit as in Figure 2-7. Figure 2-9 shows the output noise of the amplifier system measured at the OPA858 output node. The total simulated output noise for the 10-kΩ transimpedance-gain setting is 1.245 mVrms with no filtering. This value is lower than value of 1.3 mVrms predicted in Section 2.4.1.3 because the calculation uses a first-order approximation for the noise gain of the circuit that is inaccurate compared to the model. However, the calculation still yields a reasonably accurate prediction that is useful for initial design considerations.

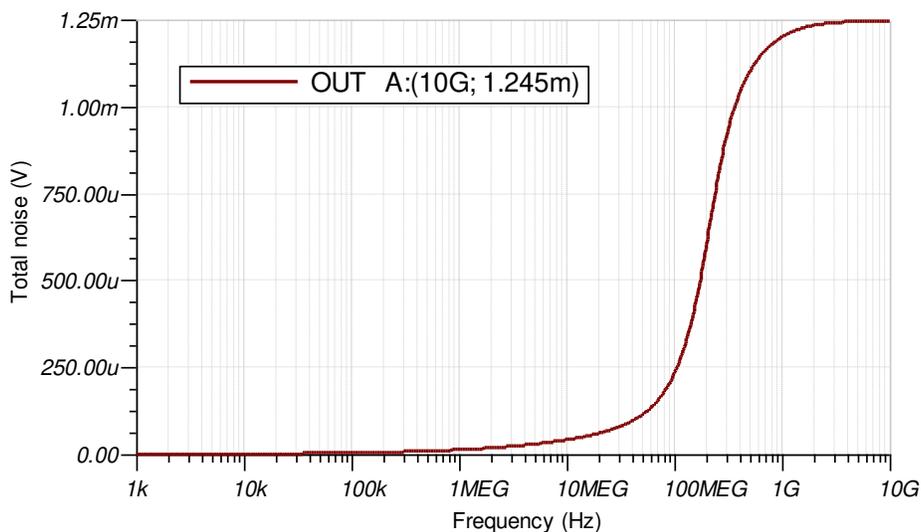


Figure 2-9. Simulated Output Noise of the OPA858 Amplifier Chain

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° to achieve a Q factor of 0.95. Use the circuit in Figure 2-10 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](#).

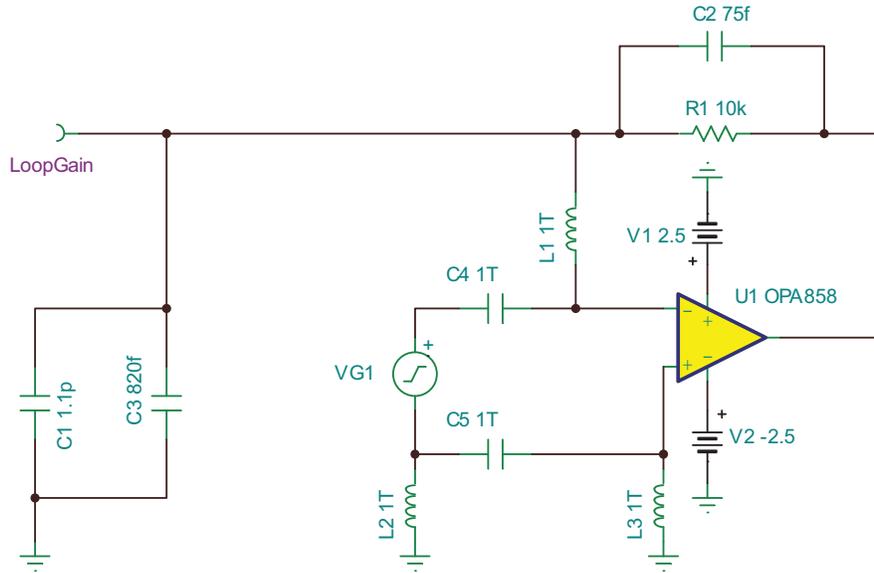


Figure 2-10. OPA858 Loop-Gain Analysis TINA Schematic

The simulated loop-gain magnitude and phase plotted in Figure 2-11 predict a phase-margin of approximately 45° , which is lower than the expected calculated value because the calculation is only a first-order approximation.

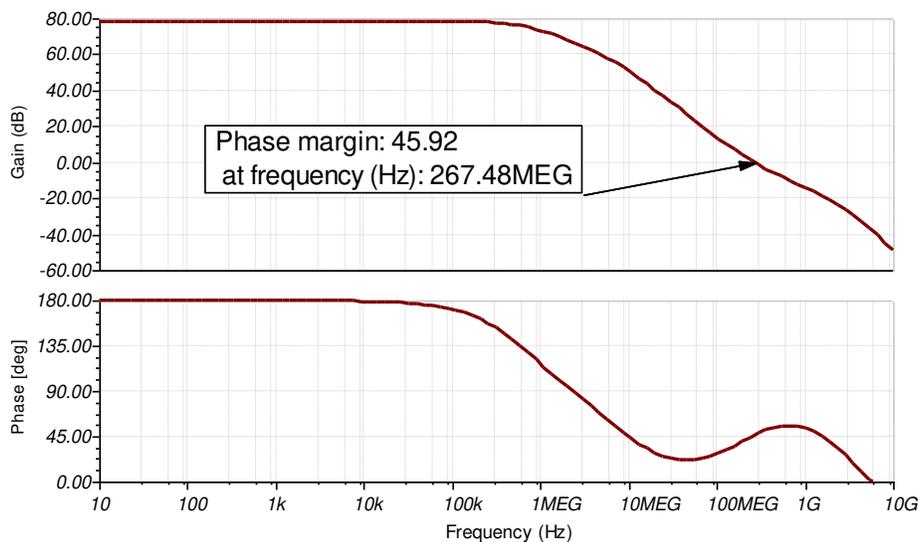


Figure 2-11. Simulated Loop Gain of the OPA858 Circuit

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.

Note

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

3. Use the R60 potentiometer to set the voltage on CI1 (pin 12) to 1.65 V \pm 25 mV.

Note

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 [Section 3.2.1.1.1](#).
2. Turn the knob on the variable optical attenuator (VOA) clockwise for maximum attenuation.

Note

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.

3. Connect a multimeter to the IMON connector.

Note

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.

Note

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

[Figure 3-1](#) shows the bench setup to evaluate the performance of the system in the lab.

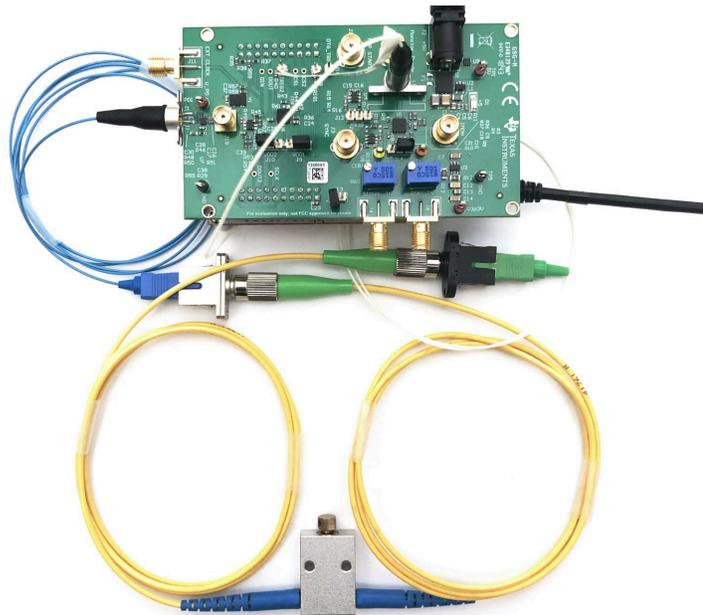
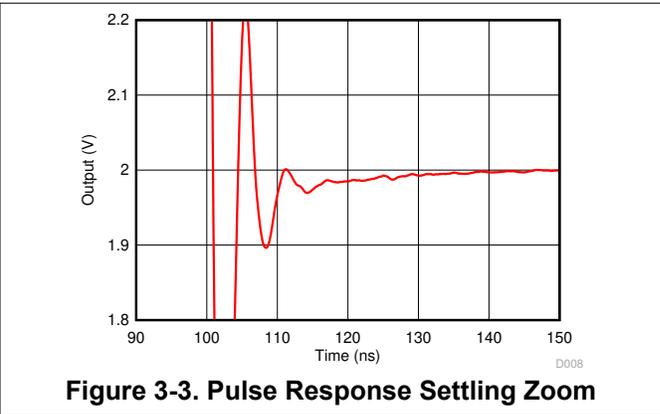
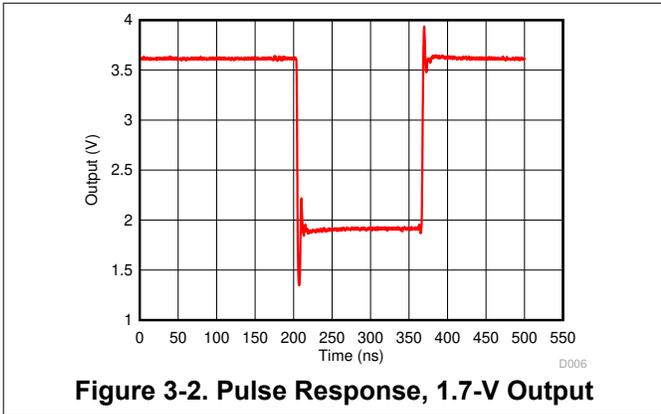


Figure 3-1. Laboratory Bench Setup of the Design

3.2.2.1.1 Pulse Response Measurements

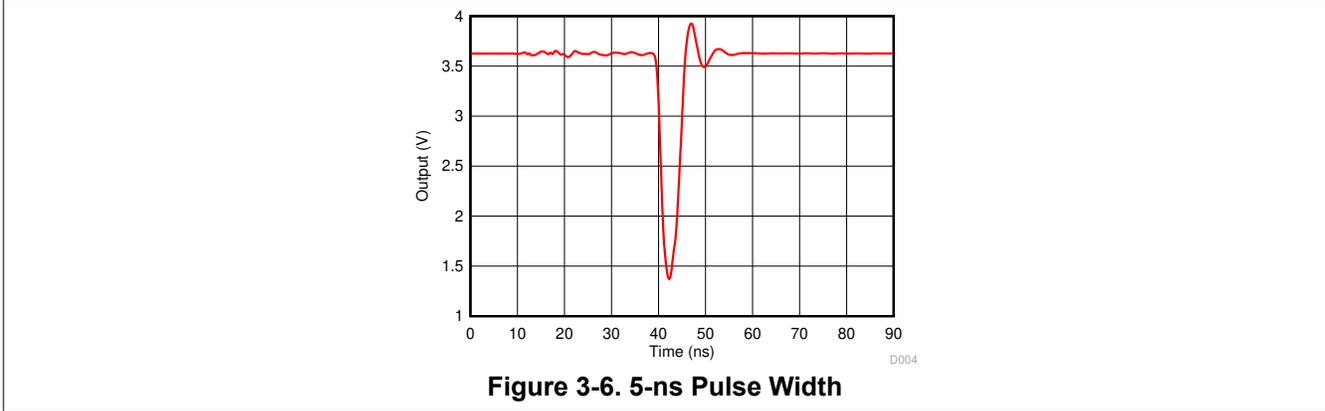
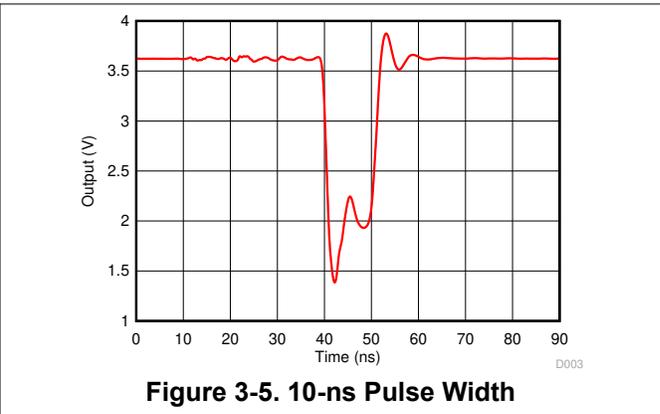
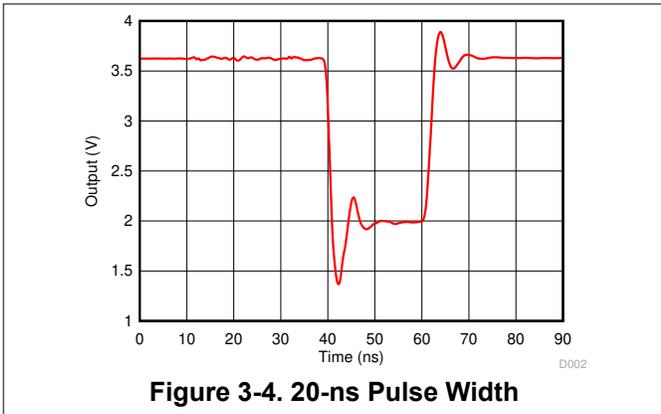
3.2.2.1.1.1 Pulse Response Settling

Figure 3-2 shows the standard pulse response as triggered by the MSP430. The optical power to the photodiode is controlled with an attenuator to obtain a 1.7-V output voltage amplitude. Figure 3-3 shows the detail of the pulse response settling to a final value of 2 V. Settling performance can be improved for this design by altering the amplifier response, but is not a necessity for the TDC7201-based design.



3.2.2.1.1.2 Pulse Response vs Output Pulse Width

Figure 3-4, Figure 3-5, and Figure 3-6 show the pulse response as a function of the pulse width measured at the OPA858 output. The optical attenuator is adjusted to drive an output voltage final value of 2 V. A high-speed pulse generator is used to drive the laser driver for these tests by removing resistor R17 and connecting the pulse generator to jumper J12 directly.



3.2.2.1.1.3 Rise and Fall Time

Table 3-1 lists the pulse response rise and fall times for the various pulse width measurements described in Section 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.

Table 3-1. 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

Figure 3-7 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 Figure 3-4. 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 Section 3.2.2.1.2. The plot in Figure 3-7 also shows the maximum achievable signal swing of 2.6 V when measured from the bias set in the design.

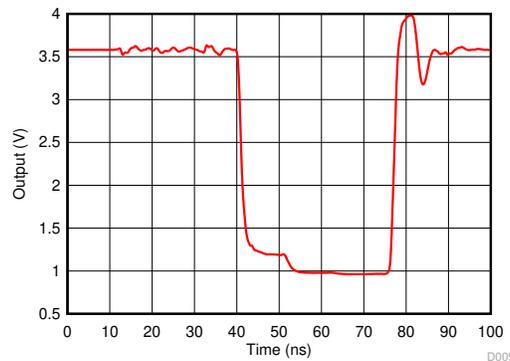


Figure 3-7. OPA858 Overdriven Response

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 [Section 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 k Ω .

[Figure 3-8](#) and [Figure 3-9](#) 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. [Figure 3-9](#) 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.

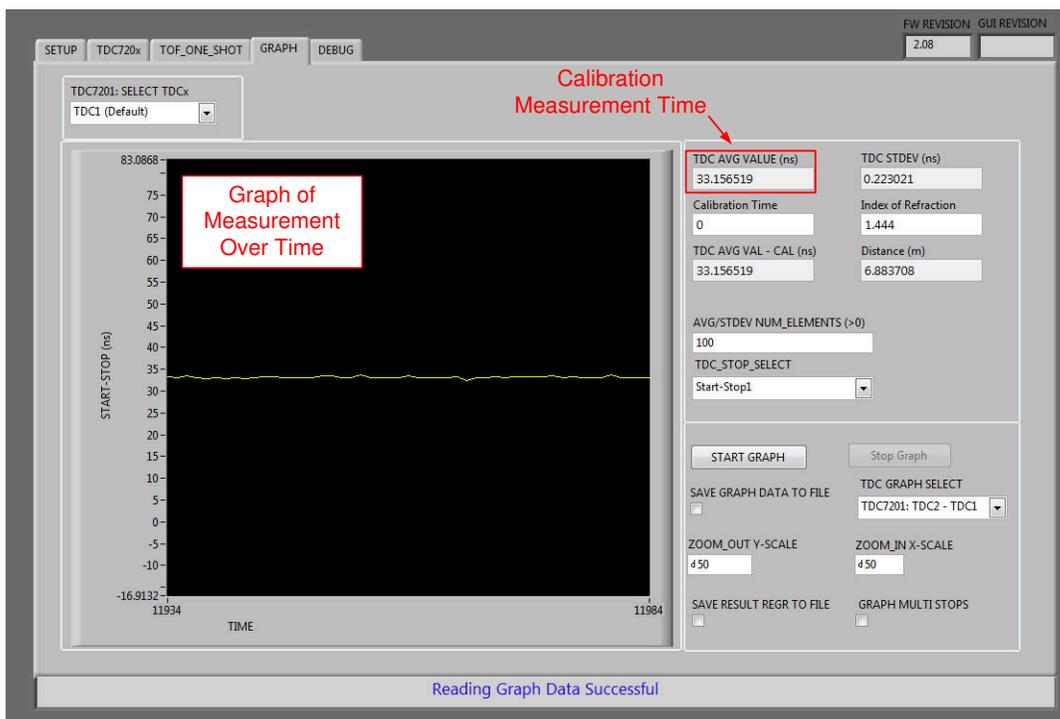


Figure 3-8. 1.1-m Cable Measurement Calibration

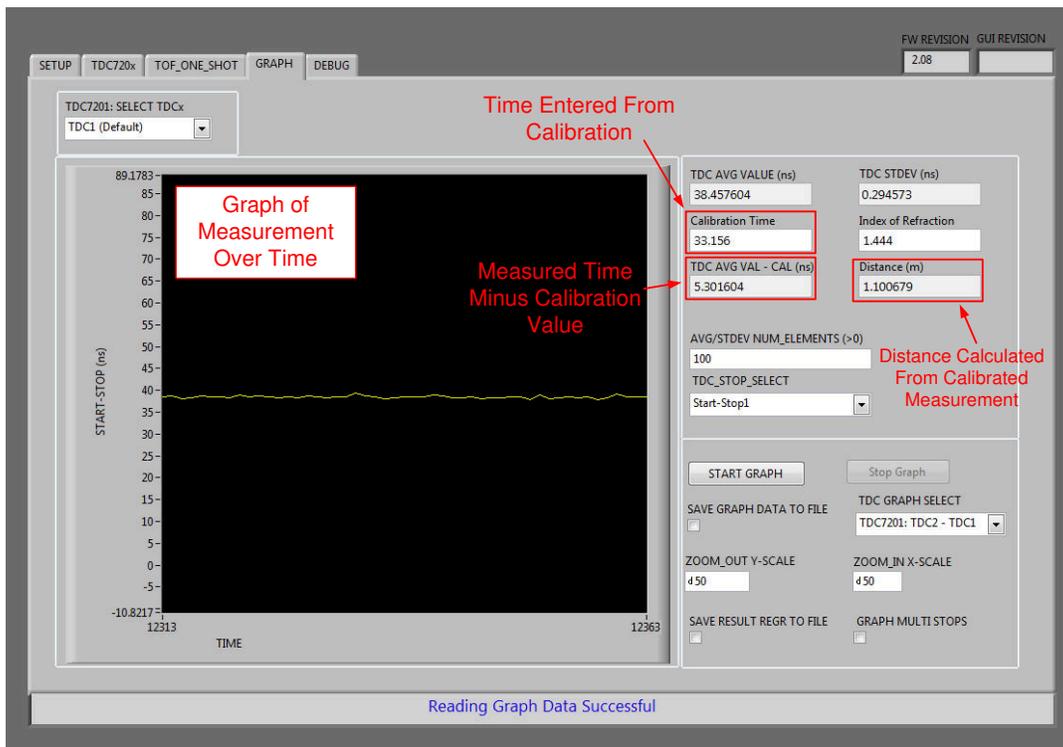


Figure 3-9. 1.1-m Cable Measurement

Figure 3-10 and Figure 3-11 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 Figure 3-7, 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.

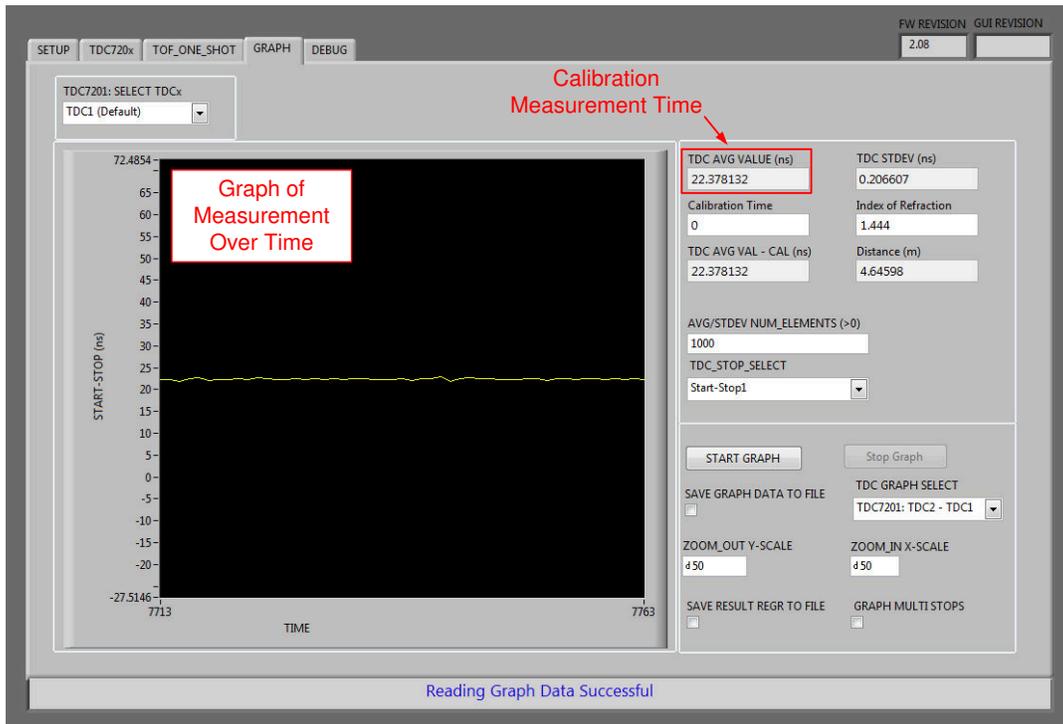


Figure 3-10. 2-m Cable Measurement Without Any Attenuation Calibration

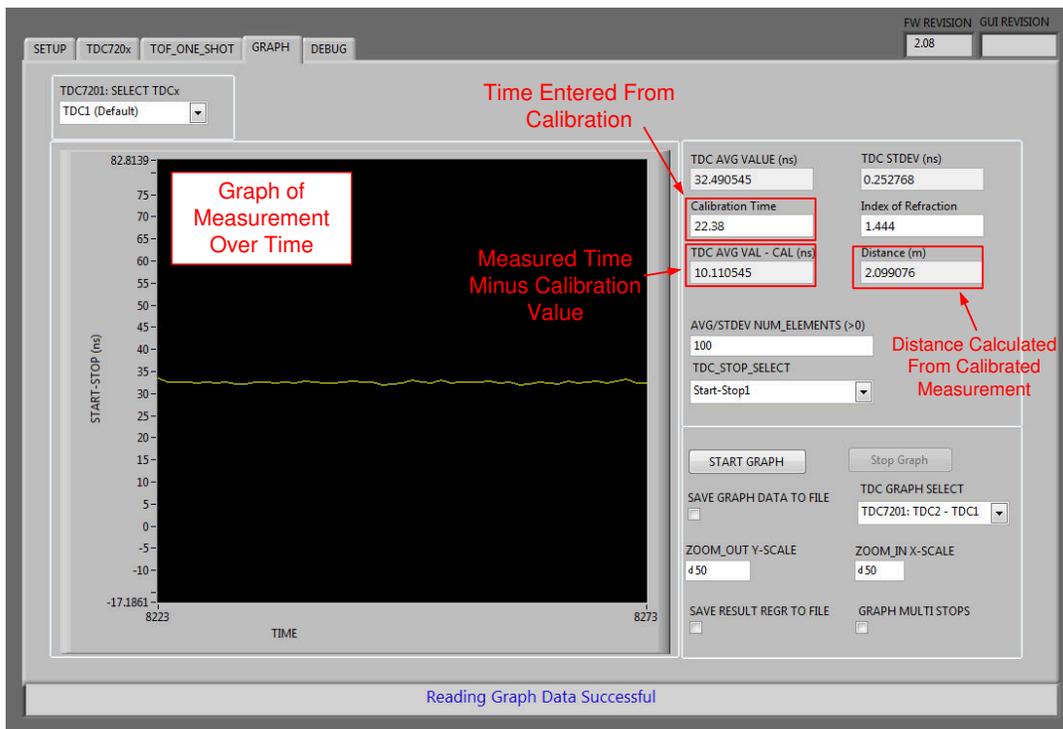


Figure 3-11. 2-m Cable Measurement Without Attenuation

3.2.2.1.3 Time-of-Flight Measurement Error Sources

With the optical ToF measurements made in this design, consider the other potential error sources that can be present in the optical connections, cables, and attenuators. The connections made between fiber-optic cables are sensitive and can introduce errors from misalignment, dust, or any other material that can obscure the connection interface. Additionally, bends or twists in the fiber cables can potentially alter the propagation of

light if they are too severe. For the measurements in this design, the fiber connections were kept as clean and accurate as possible, but potential errors can also result from the optical cables and not just the measurement.

4 Design Files

4.1 Schematics

Figure 4-1 and Figure 4-2 illustrate the schematics for the reference design EVM board that interfaces with the MSP430 LaunchPad™ EVM.

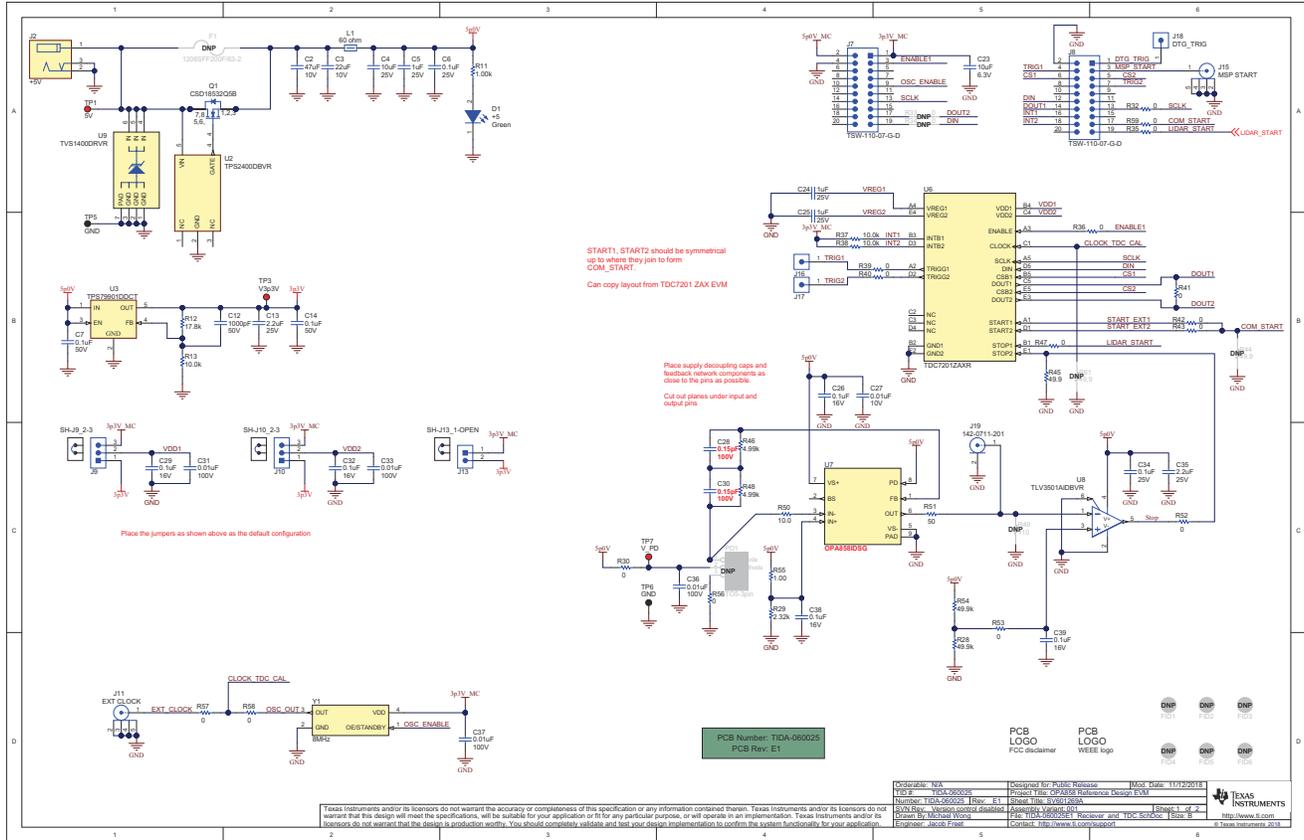


Figure 4-1. Reference Design Schematic Page 1 (Rx Path)

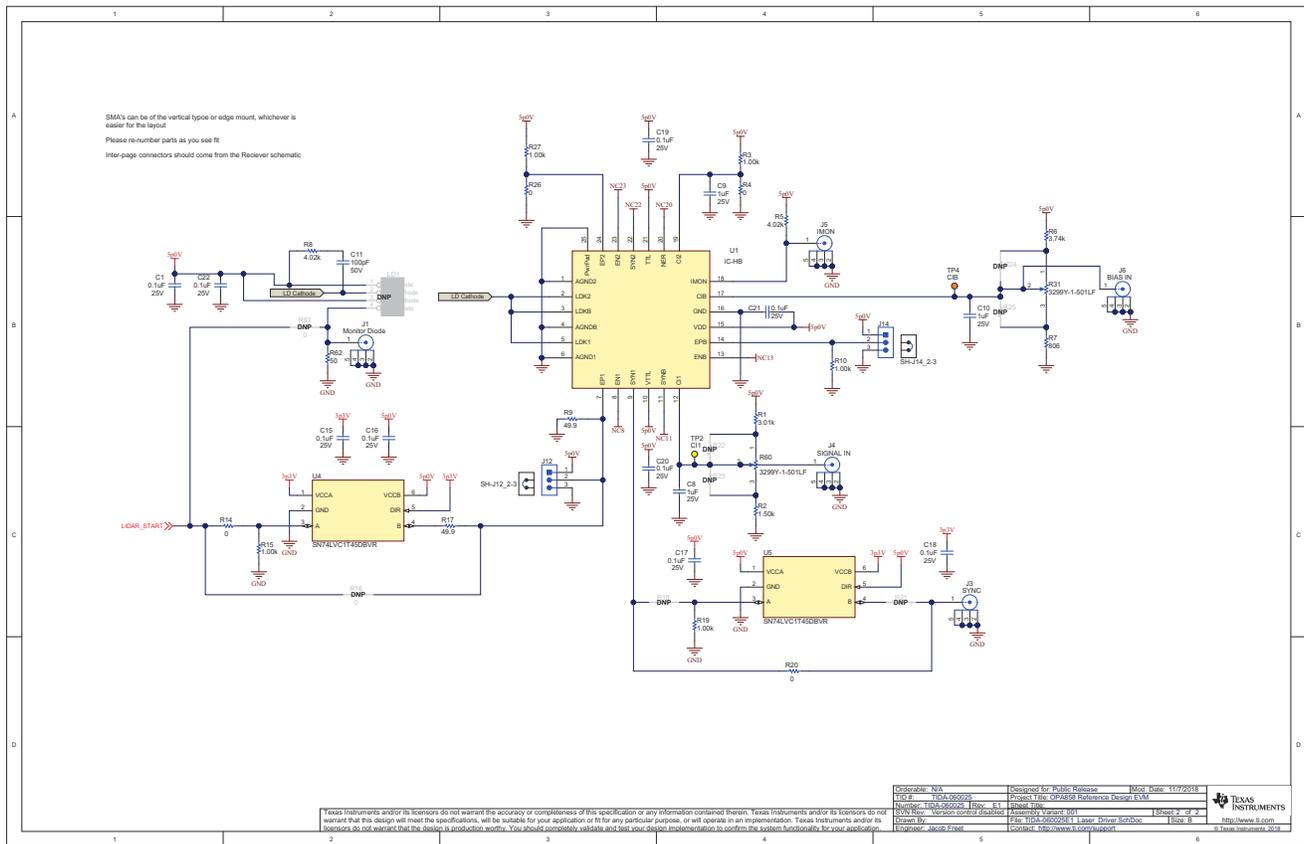


Figure 4-2. Reference Design EVM Schematic Page 2 (Tx Path)

To download the schematics, see the design files at [TIDA-060025](https://www.ti.com/lit/zip/TIDA-060025).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-060025](https://www.ti.com/lit/zip/TIDA-060025).

4.3 PCB Layout Recommendations

For a high-speed transimpedance design, pay close attention to the parasitic capacitances and inductances in the layout that can effect the input and feedback elements of the transimpedance amplifier and photodiode. This design follows the layout guidelines in the *Layout* section of the [OPA858 data sheet](https://www.ti.com/lit/dsp/opa858) to ensure best performance.

4.3.1 Layout Prints

To download the layer plots, see the design files at [TIDA-060025](https://www.ti.com/lit/zip/TIDA-060025).

4.4 Altium Project

To download the Altium Designer® project files, see the design files at [TIDA-060025](https://www.ti.com/lit/zip/TIDA-060025).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-060025](https://www.ti.com/lit/zip/TIDA-060025).

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](#)

5.1 Trademarks

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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.

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (November 2018) to Revision A (April 2022)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document.....	1
• Added alternative devices to the Design Guide.....	1

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