

TI Designs

Reference Design for Extending OPA857 Transimpedance Bandwidth



TI Designs

The OPA857 is a wideband, ultra-low noise transimpedance amplifier (TIA) that supports photodiode monitoring applications. The OPA857 has two selectable gain configurations of 5 k Ω and 20 k Ω while maintaining a constant closed-loop bandwidth greater than 100 MHz. In this reference design, an external resistor is added in parallel with the internal gain resistor of the OPA857 to extend the transimpedance bandwidth of the amplifier.

Design Resources

[TIDA-00978](#) Design Folder
[OPA857](#) Product Folder
[TINA-TI™](#) Tools Folder



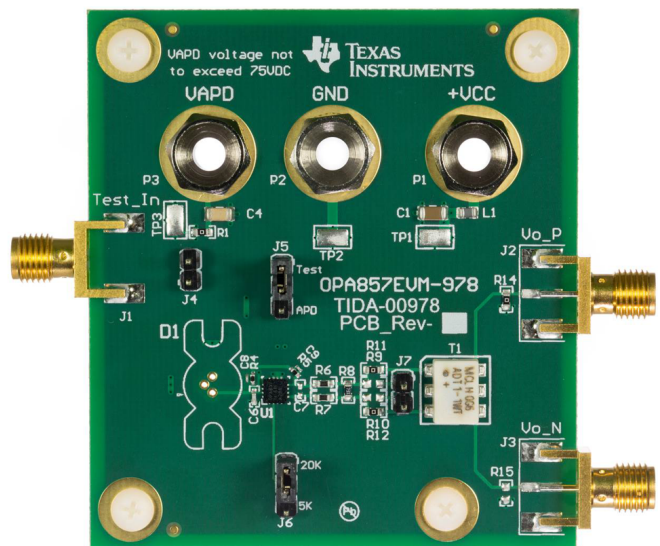
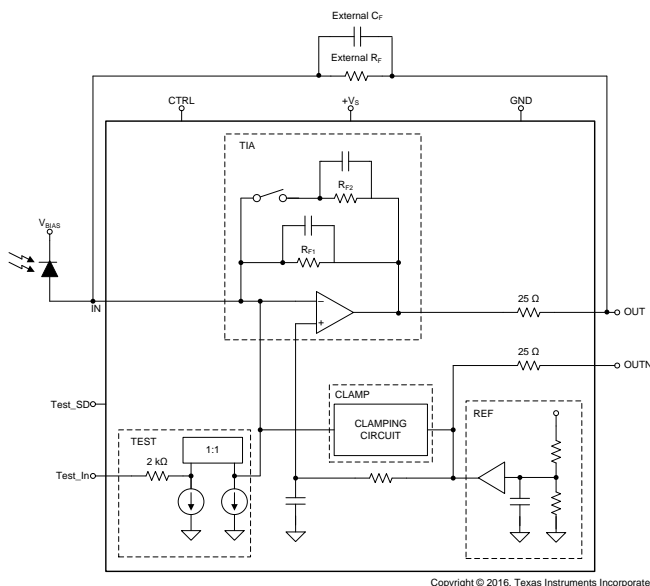
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Design Features

- Bandwidth of OPA857 Extended From 100 MHz to More Than 250MHz
- Gain of OPA857 Adjustable Between 1 k Ω and 20 k Ω
- Evaluation Module (EVM) Facilitates Testing OPA857 in Internal-Test Mode or With External Photodiode

Featured Applications

- Optical Amplifiers
- LIDAR
- OTDR
- Photodiode Monitoring
- Machine Vision
- Missile Guidance



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1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS
Supply Voltage	3.3 V external supply
Output swing	500 mV _{pp}
Differential-output Load	500 Ω and 1 kΩ
Target bandwidth	> 250 MHz
Effective transimpedance-gain range	2 kΩ to 20 kΩ

2 System Description

The OPA857 described in [Section 2.1](#) is a fixed-gain, high-bandwidth amplifier designed for transimpedance applications. By adding an external resistor in parallel with the internal fixed-gain resistor, circuit designers can use the high-gain bandwidth product (GBP) of the internal core amplifier to achieve transimpedance bandwidths that are greater than 250 MHz at the expense of a lower closed-loop transimpedance gain.

2.1 OPA857

The OPA857 provides a combination of low-noise, high-bandwidth, and high-transimpedance gain. With a targeted low input capacitance of 1.5 pF, the OPA857 achieves greater than a 100-MHz bandwidth with the 5-kΩ or 20-kΩ transimpedance gain and adds the lowest possible RMS noise.

NOTE: The 1.5-pF capacitance includes the parasitic capacitance of the board; stray capacitance must be minimized in the layout.

The 1.5-pF value is selected because the device should be driven by a photodiode with biasing that is high enough to include the capacitance of the photodiode between approximately 0.5 pF and 0.7 pF, leaving between 0.8 pF to 1 pF for the parasitic capacitance of the board.

The OPA857 is a dedicated TIA with a pseudo-differential output, shown in [Figure 2](#). The diagram has four distinct blocks: a transimpedance amplifier (TIA), a reference voltage (REF), a test structure (TEST), and a clamping circuit (CLAMP).

The TIA block includes two selectable gain configurations (R_{F1} and R_{F2}). For a 500-Ω external output load, the effective transimpedance gain across the output pins OUT and OUTN is 4.5 kΩ (CTRL = 0 V) and 18.2 kΩ (CTRL = 3.3 V) because of the voltage drop across the 25-Ω internal-series resistor on each output. The TIA block is designed to provide excellent bandwidth (> 100 MHz) in both gain configurations with the lowest possible RMS noise over the entire bandwidth. This level of performance is achieved by minimizing the noise-gain peaking at higher frequencies. The noise-gain peaking that results from feedback and source capacitance is the primary noise contributor in high-speed TIAs.

The reference-voltage block shown in [Figure 2](#) has two purposes.

- Provide a good DC reference voltage to the input
- Provide a DC reference voltage at the output (thus allowing a dc-coupled interface to a fully-differential signal chain)

The common-mode rejection ratio (CMRR) provided by the fully-differential signal chain reduces any feedthrough from the OPA857 power supply, increasing the power-supply rejection ratio (PSRR) of the amplifier.

The test structure block has a V-to-I converter that allows a user to drive the OPA857 with current inputs by using standard voltage-output function generators and network analyzers.

The clamping circuit and the ESD diodes on the IN pin provide internal protection and ensure that the amplifier can recover quickly after saturation.

3 Block Diagram

A block diagram of the system is shown in [Figure 1](#).

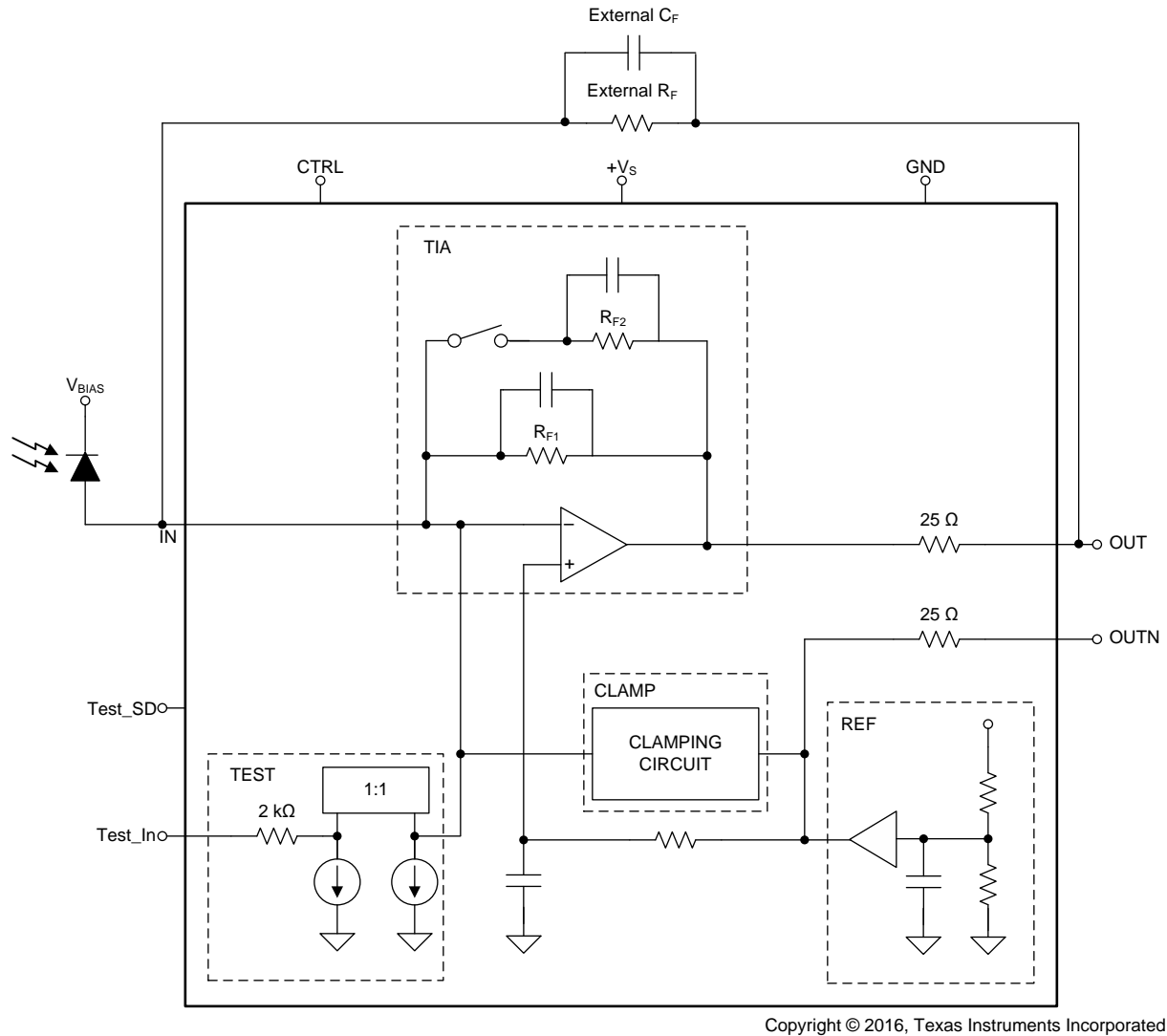


Figure 1. System Block Diagram

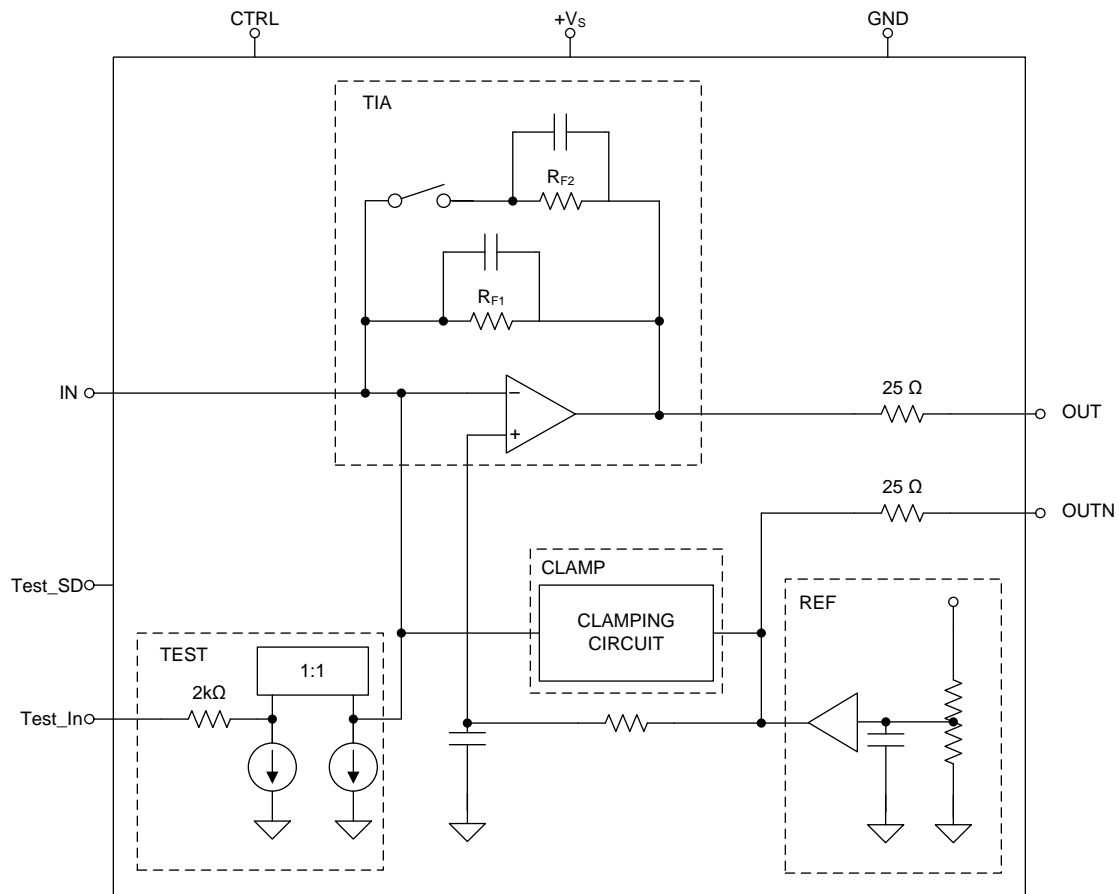
3.1 Highlighted Products

This reference design features the OPA857.

For more information on the OPA857 device, see the product folder at [OPA857](#).

3.1.1 OPA857 Features

Figure 2 shows the OPA857 block diagram (also detailed in Section 2.1).



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Figure 2. OPA857 Block Diagram

- Bandwidth = 105 MHz (Transimpedance gain = 20 k Ω , 1.5-pF input capacitance)
- Bandwidth = 130 MHz (Transimpedance gain = 5 k Ω , 1.5-pF input capacitance)
- Pseudo-differential output to simplify driving a fully-differential amplifier or ADC
- Internally-generated common-mode reference voltage
- Integrated noise = 15 nA_{RMS} (Noise Bandwidth = 140 MHz)

4 System Design Theory

An op-amp with wide bandwidth is the core of the TIA block of the OPA857, shown in [Figure 2](#). The CTRL logic controls an internal single-pole double throw (SPDT) switch to configure the amplifier in a transimpedance gain of 5 k Ω or 20 k Ω . The switch also selects the internal feedback capacitance needed to properly compensate the amplifier.

A benefit of the OPA857 is the small decrease in the transimpedance bandwidth when the internal gain is switched from 5 k Ω (BW = 130 MHz) to 20 k Ω (BW = 105 MHz). Theoretically, a 4x increase in gain should reduce the bandwidth by 2x, however, the bandwidth reduction of the OPA857 is less than the predicted reduction of 2x. The OPA857 achieves this minimal-bandwidth reduction by recompensating the open-loop response of the amplifier depending upon the CTRL input. Setting CTRL to a high logic level (+V_S) selects the 20-k Ω gain configuration and compensates the internal amplifier core for the maximum GBP (\approx 4 GHz). In this reference design, use the 4-GHz GBP of the core amplifier and add additional feedback resistance in parallel (this reduces the transimpedance gain but extends the closed-loop bandwidth). For completeness, the TIA response is also tested by setting CTRL to a low logic level (ground).

For more information on the various factors that contribute to the frequency response of an amplifier when configured as a TIA, refer to [1]. The article in [1] also contains a reference to an Excel[®] calculator for TIA designs when using discrete op-amps.

5 Test Setup

The performance of the OPA857 was evaluated in the test mode and the standard photodiode-input mode of the OPA857. These modes are detailed in [Section 5.1](#) and [Section 5.2](#).

5.1 Test Mode

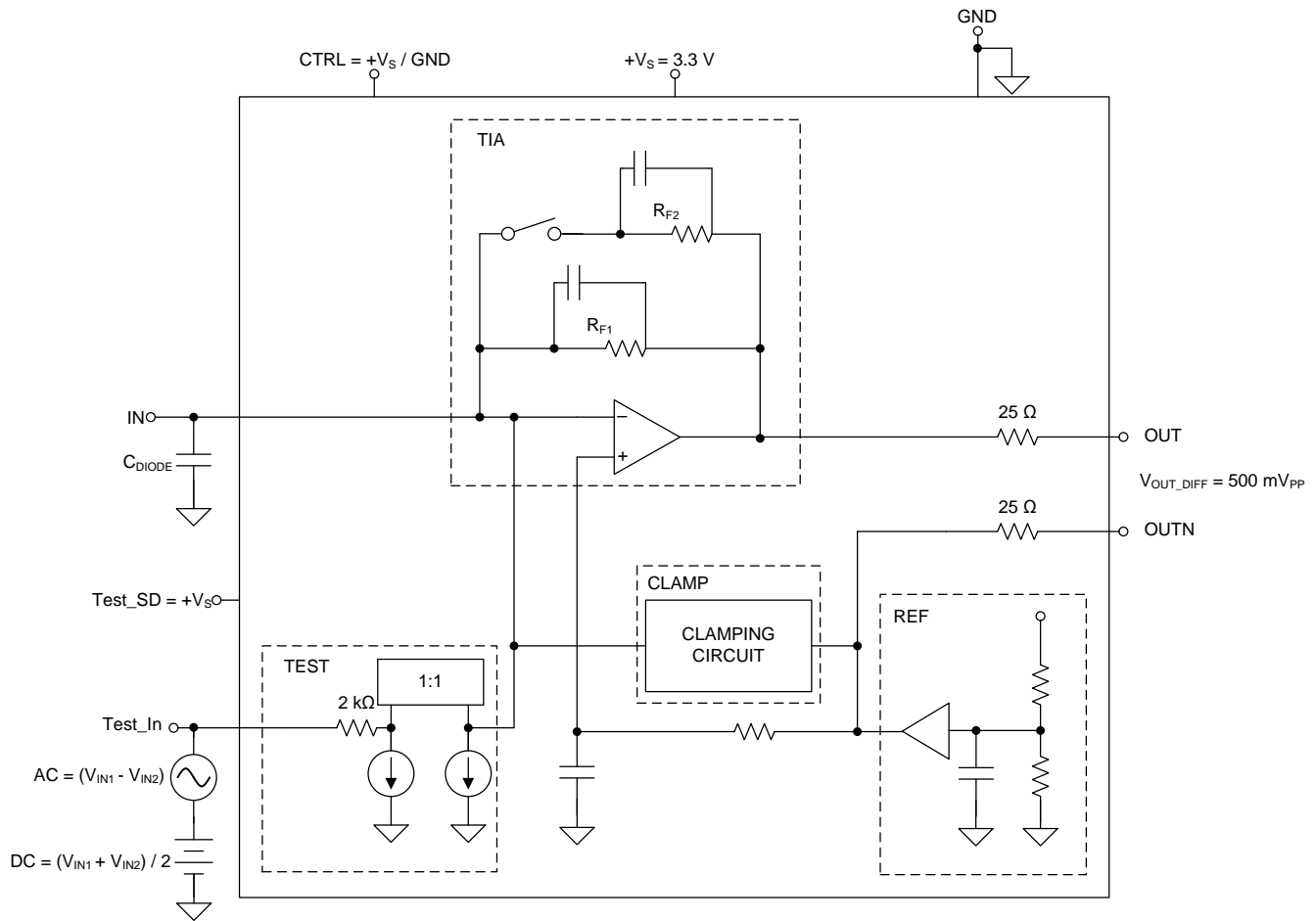
In test mode, an internal voltage-to-current converter drives a current stimulus through the TIA block of the OPA857. This test mode facilitates evaluating the performance of the OPA857 with voltage-output function generators and network analyzers. To configure the OPA857 in test mode, set the Test_SD pin to +V_S. A DC-bias voltage must be applied to the Test_In pin to setup the test mode correctly. The required DC bias varies with the supply voltage and the fabrication lot. The typical dc bias is usually between 2.3 V to 2.4 V. To determine the V-to-I transfer function of the test circuit, use the following procedure.

1. Set the power supply to 3.3 V (assuming the amplifier will be tested with a 500 mV_{pp} output swing)
The common-mode output from the REF block is $+V_S \times (5/9) = 1.83$ V.
2. Determine the DC bias where there is no current output from the V-to-I test circuit
(a) Adjust the DC bias on Test_In until $V_{IN1} = OUT = OUTN = 1.83$ V
3. Adjust the DC bias of VIN2 until $OUT = 1.83$ V - 0.5 V = 1.33 V for a 500-mV_{pp} output swing.
OUTN remains constant at 1.83 V. In practice, there will be a voltage drop across the internal 25- Ω resistors of the OPA857 depending on the external output load. Assume a large external load \gg 25 Ω so the voltage drops across the internal resistors are negligible.
4. Set the DC bias to Test_In to $(V_{IN1} + V_{IN2}) \div 2$ to produce a 500-mV_{pp} output swing below the common-mode voltage

The output stage of the OPA857 is optimized to swing below the internal common-mode reference voltage (1.83V) because photodiodes generate a unidirectional output current. The AC signal applied for a 500-mV_{PP} output swing is equal to $V_{IN1} - V_{IN2}$. The circuit shown in Figure 3 was used to test the frequency response of the OPA857.

This procedure was also used to measure the frequency response of the OPA957.

NOTE: When evaluating the performance of the amplifier in test mode, add a physical capacitor at the IN pin of the OPA957 to mimic the input capacitance of the target photodiode.



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Figure 3. Frequency Response Test Circuit

5.2 Photodiode Mode

When using a photodiode to drive the OPA857, the test mode must be disabled. To disable the test mode, set Test_SD = GND and Test_In = +V_S. The circuits used to test noise is shown in Figure 4, and the circuit used test pulse response is shown in Figure 5. For clarity, the external R_F and C_F are not drawn in the test circuits.

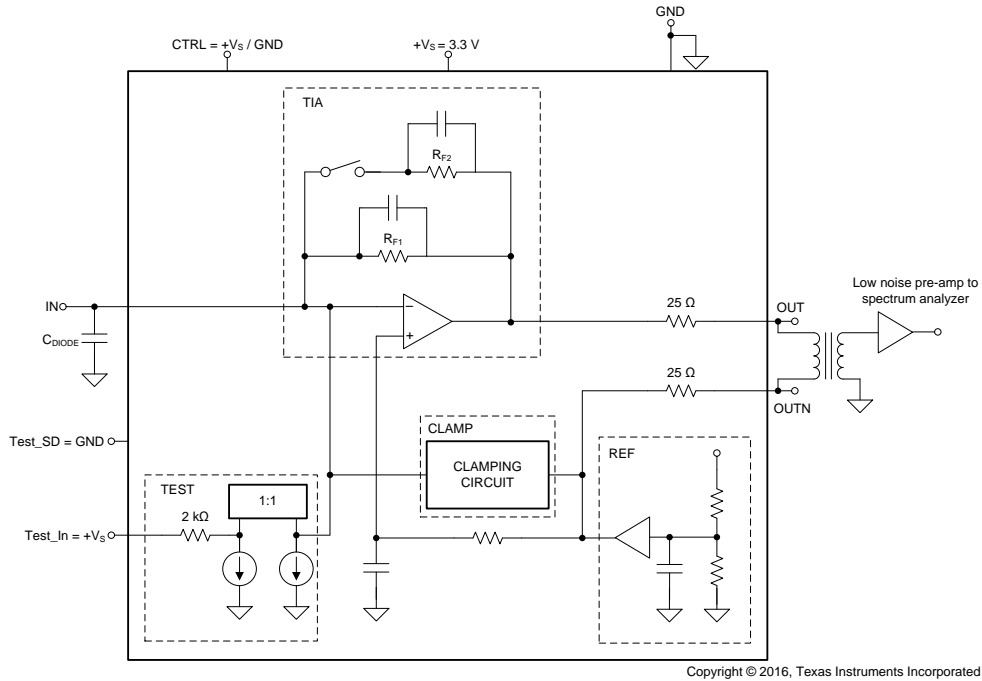


Figure 4. Noise Measurement Test Circuit

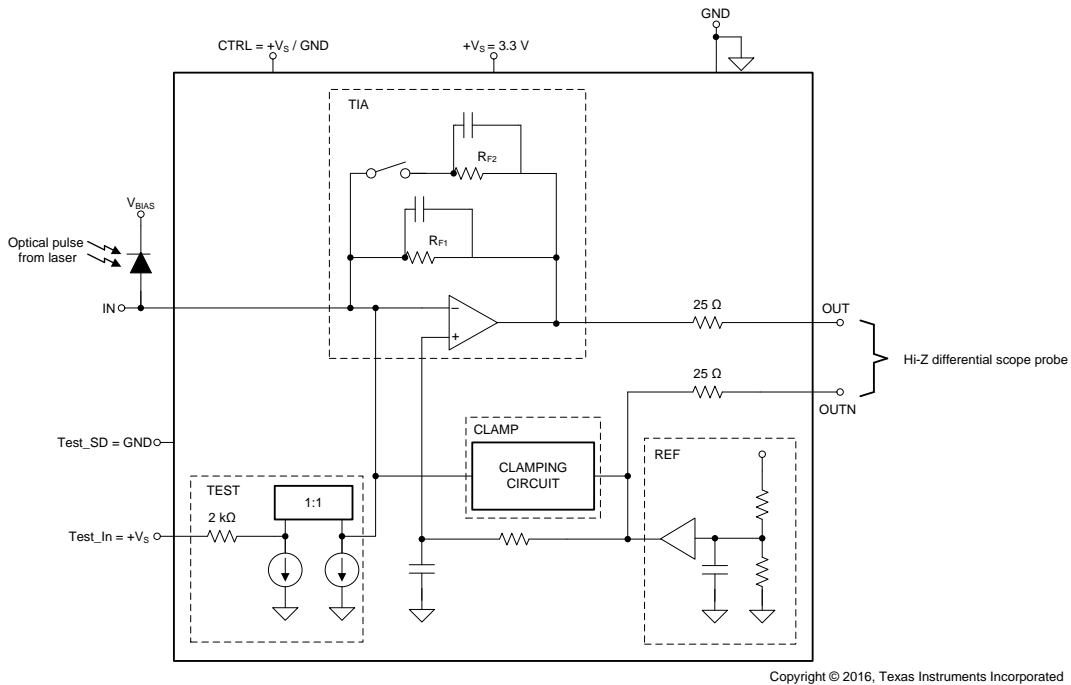


Figure 5. Pulse Response Test Circuit

6 Test Data

6.1 Frequency Response

Figure 6 to Figure 8 show the frequency responses of the OPA857 at different gain configurations with an output differential load of 500 Ω. The circuit in Figure 3 was used to conduct these tests with $C_{DIODE} = 1.5$ pF. The frequency response was measured for a 500-mV_{PP} output signal.

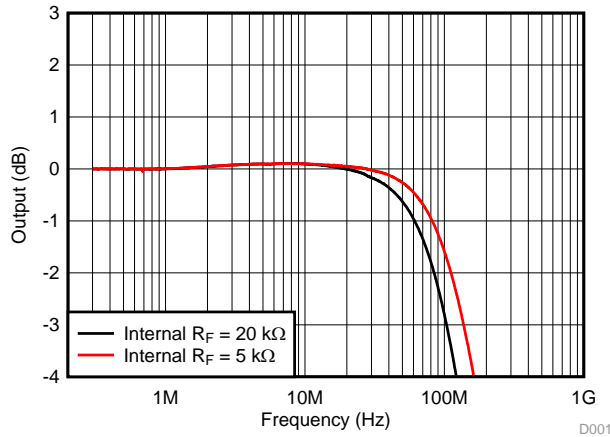


Figure 6. Frequency Response With no External Feedback

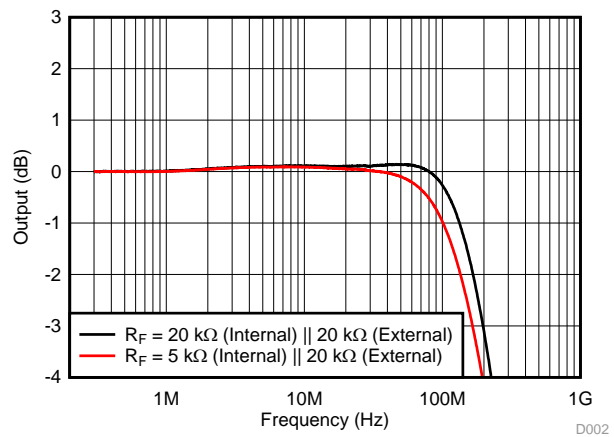


Figure 7. Frequency Response With External Feedback— $R_F = 20$ kΩ

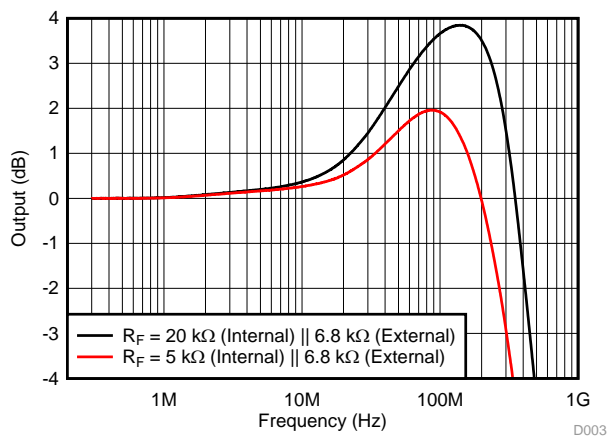


Figure 8. Frequency Response With External Feedback— $R_F = 6.8$ kΩ

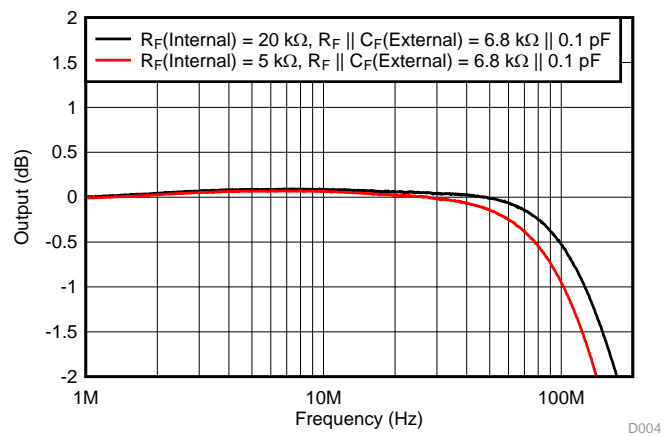


Figure 9. Frequency Response With External Feedback— $R_F = 6.8$ kΩ and $C_F = 0.1$ pF

Table 2 shows the -3 dB bandwidths at different gain configurations with an output differential load of 500 Ω.

Table 2. -3 dB Bandwidth, $R_L = 500$ Ω

FEEDBACK CONFIGURATION	EFFECTIVE TRANSIMPEDANCE GAIN (kΩ), CTRL = LOW	-3 dB BANDWIDTH (MHz), CTRL = LOW	EFFECTIVE TRANSIMPEDANCE GAIN (kΩ), CTRL = HIGH	-3 dB BANDWIDTH (MHz), CTRL = HIGH
$R_F = \text{Open}$	5	138	20	104
$R_F = 20$ kΩ	4	165	10	196
$R_F = 6.8$ kΩ	2.9	304	5	447
$R_F = 6.8$ kΩ $C_F = 0.1$ pF	2.9	176	5	217

Figure 10 to Figure 12 show the frequency responses of the OPA857 at different gain configurations with an output differential load of 1 kΩ. The resulting –3 dB bandwidths are shown in Figure 12.

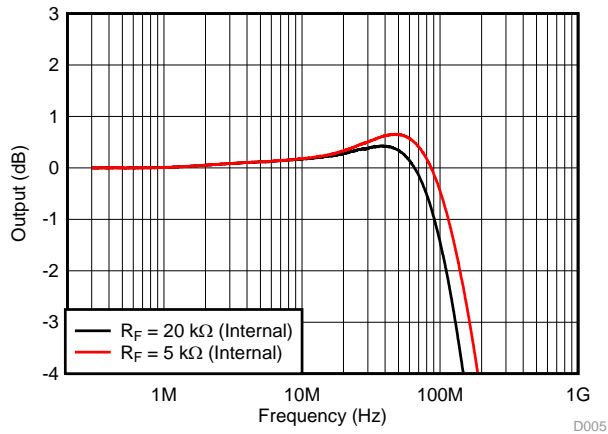


Figure 10. Frequency Response With no External Feedback

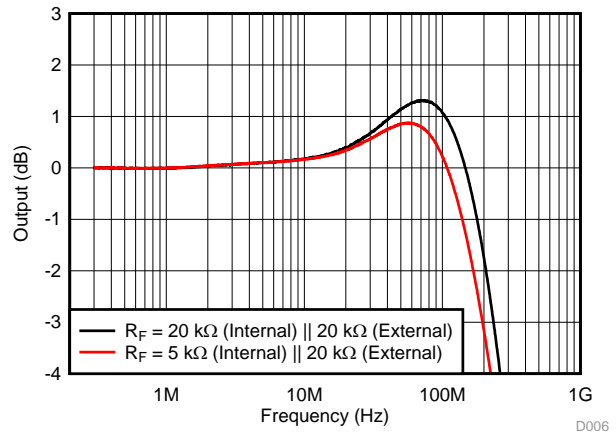


Figure 11. Frequency Response With External Feedback— $R_F = 20\text{ k}\Omega$

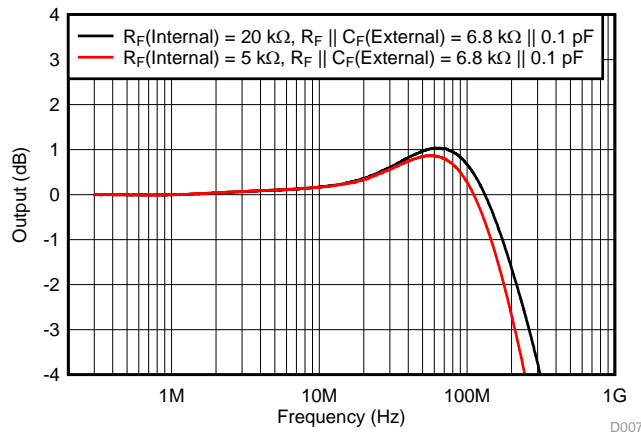


Figure 12. Frequency Response With External Feedback— $R_F = 6.8\text{ k}\Omega$ and $C_F = 0.1\text{ pF}$

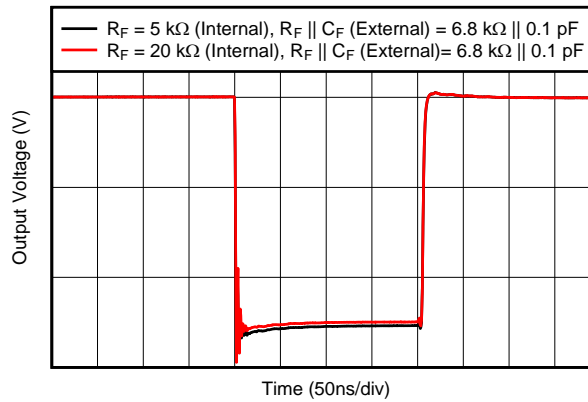
The results in Table 3 show that a closed-loop transimpedance bandwidth in excess of 250 MHz is possible by configuring the OPA857 in an internal high-gain mode and by adding an external resistor in parallel.

Table 3. –3 dB Bandwidth, $R_L = 1\text{ k}\Omega$

FEEDBACK CONFIGURATION	EFFECTIVE TRANSIMPEDANCE GAIN (kΩ), CTRL = LOW	–3 dB BANDWIDTH (MHz), CTRL = LOW	EFFECTIVE TRANSIMPEDANCE GAIN (kΩ), CTRL = HIGH	–3 dB BANDWIDTH (MHz), CTRL = HIGH
$R_F = \text{Open}$	5	164	20	130
$R_F = 20\text{ k}\Omega$	4	195	10	235
$R_F = 6.8\text{ k}\Omega \parallel C_F = 0.1\text{ pF}$	2.9	211	5	264

6.2 Pulse Response

The output pulse response of the OPA857 is shown in Figure 13 with $R_F = 6.8\text{ k}\Omega$ and $C_F = 0.1\text{ pF}$. An NR8300 avalanche photodiode driven by a laser was used to generate a current input to the OPA857. The circuit was configured for a load resistance of $1\text{ k}\Omega$.

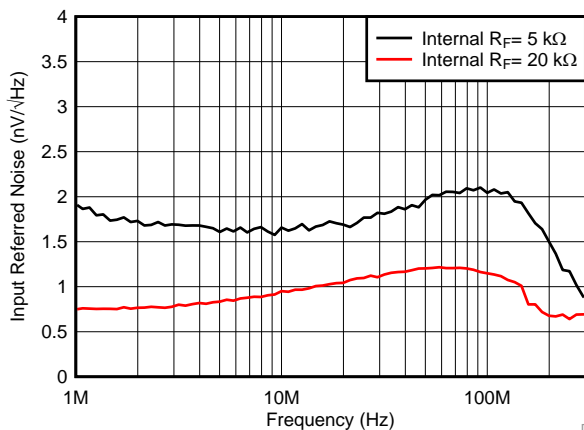


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Figure 13. 500mV_{pp} pulse response

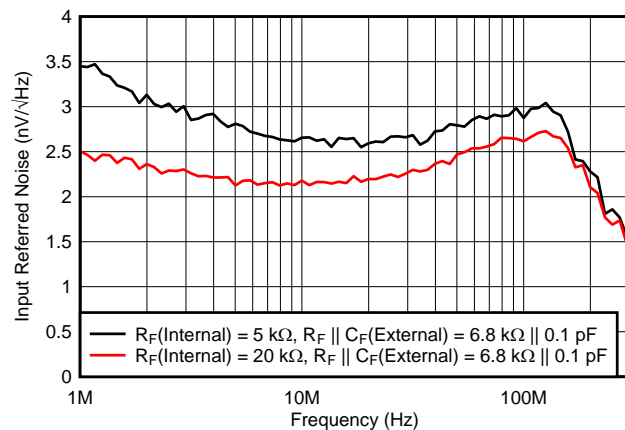
6.3 Noise

The input-referred noise spectral density for the various gain configurations of the OPA857 are shown in Figure 14 and Figure 15.



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Figure 14. Input-Referred Spot Noise With no External Feedback



D010

Figure 15. Input-Referred Spot Noise With External Feedback— $R_F = 6.8\text{ k}\Omega$ and $C_F = 0.1\text{ pF}$

Table 4 shows the summary of the total integrated input-referred noise of the system.

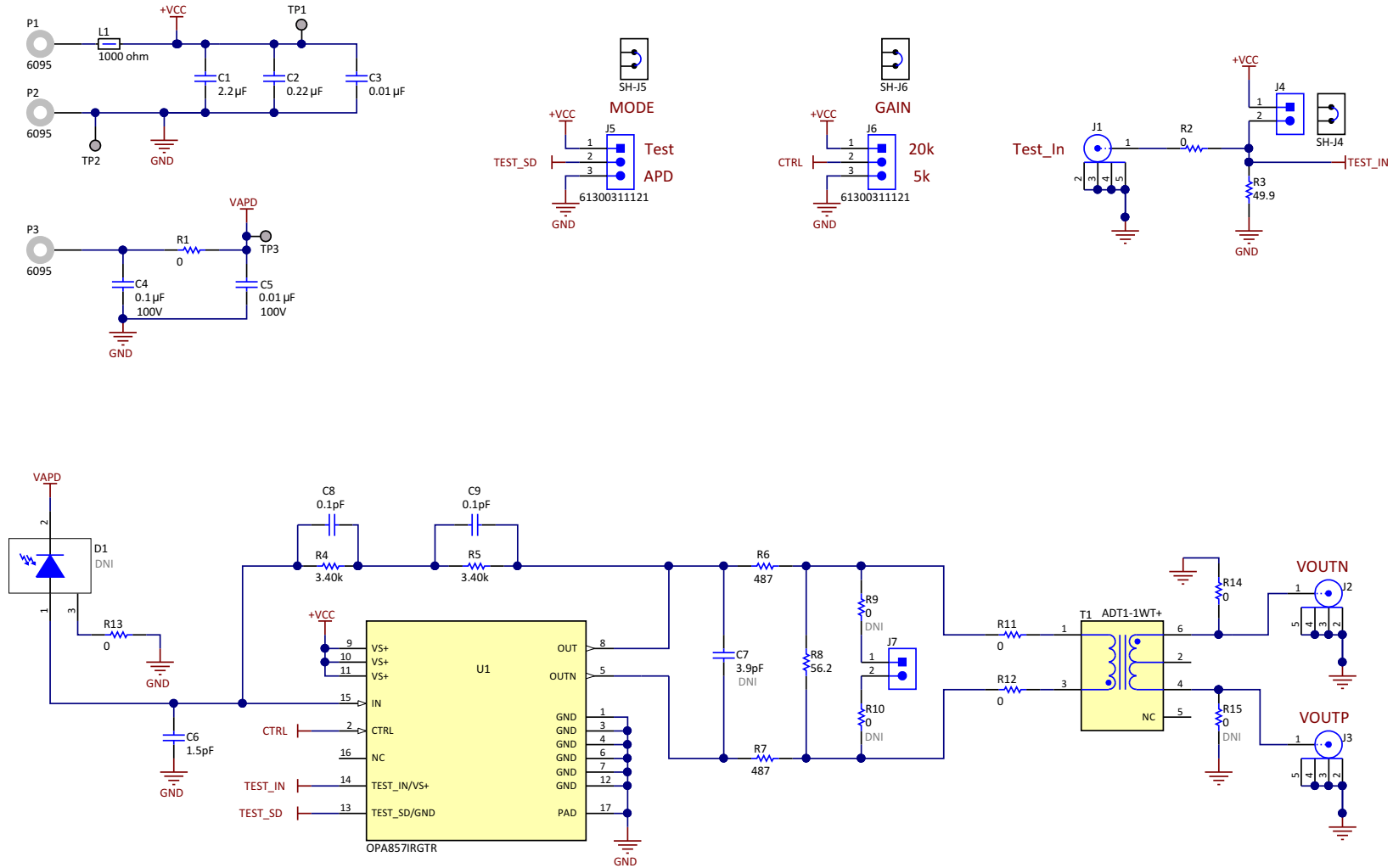
Table 4. Integrated Input Referred Noise

FEEDBACK CONFIGURATION	INTEGRATION NOISE BANDWIDTH (MHz)	INPUT REFERRED INTEGRATED NOISE (nA_{RMS}), CTRL = LOW	INPUT REFERRED INTEGRATED NOISE (nA_{RMS}), CTRL = HIGH
$R_F = \text{Open}$	145	23.6	13.5
$R_F = 6.8\text{ k}\Omega \parallel C_F = 0.1\text{ pF}$	300	44.3	40.1

7 Design Files

7.1 Schematics

Figure 16 shows the circuit schematic of the TIDA-00978. To download the schematics, see the design files at [TIDA-00978](#).



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Figure 16. TIDA-00978 Circuit Schematic

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-00978](#).

7.3 PCB Layout Recommendations

7.3.1 Layout Prints

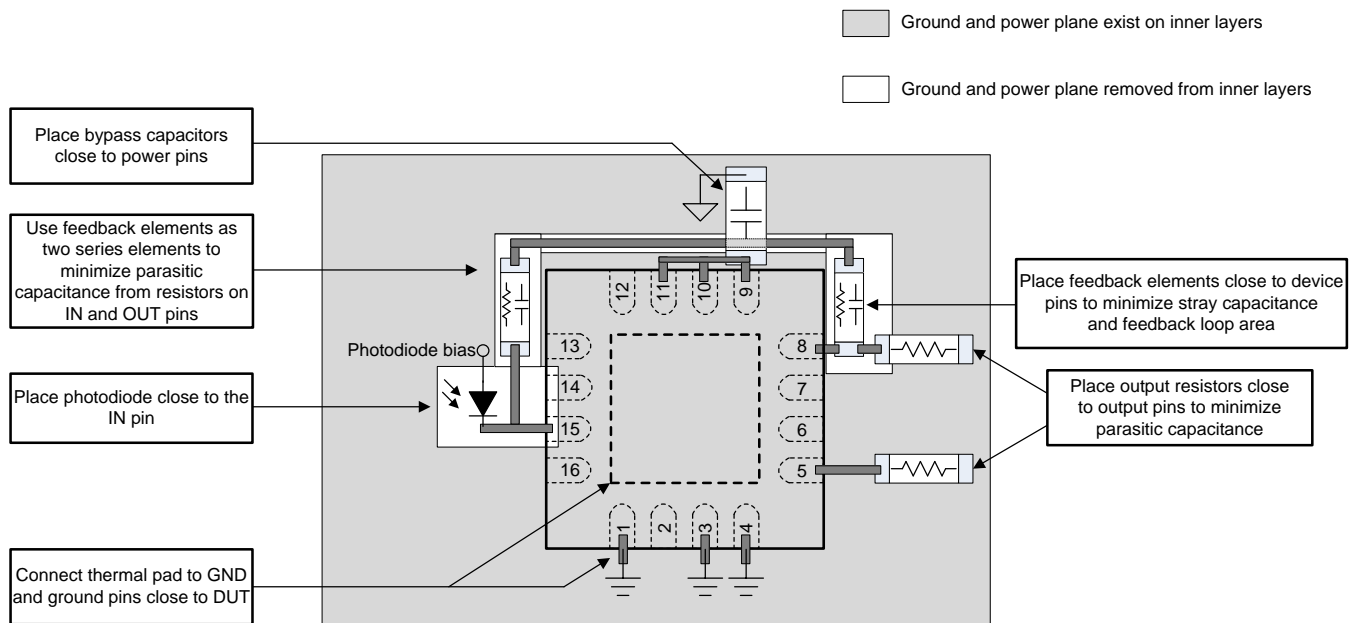
To download the layer plots, see the design files at [TIDA-00978](#).

7.4 Altium Project

To download the Altium project files, see the design files at [TIDA-00978](#).

7.5 Layout Guidelines

Figure 17 shows the layout guidelines for this TI Design.



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Figure 17. Example Layout

7.6 Gerber Files

To download the Gerber files, see the design files at [TIDA-00978](#).

7.7 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-00978](#).

8 References

1. Texas Instruments, *What you need to know about transimpedance amplifiers – part 1*, Article ([TI E2E™ Community](#))

9 About the Author

SAMIR CHERIAN is an applications engineer with TI in the High-Speed Amplifier division in Tucson, Arizona. He validates the performance and specifications of high-speed amplifiers and provides customer support through TI online forums, application notes, and reference designs.

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