

# TI Designs

## Small-Size, Low-Noise, and High-PSRR Power Reference Design for CMOS Image Sensors



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### Design Resources

[TIDA-00718](#)

Tool Folder Containing Design Files

[LP5907](#)

Product Folder

[LM3281](#)

Product Folder



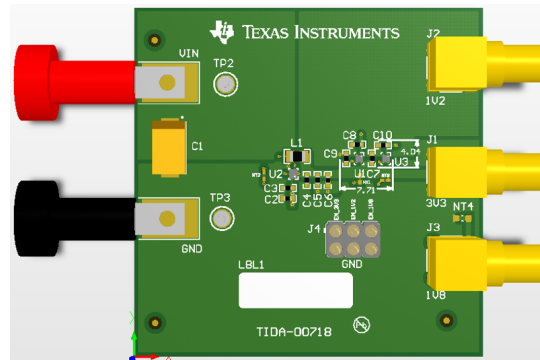
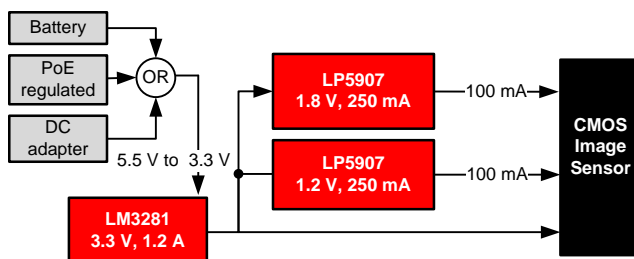
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### Design Features

- Great Transient Response
- 1.8-V Ripple Free and 1.2-V Voltage Rails
- Small Form Factor Solution
- Cost-Efficient Solution With Few Compensation Components
- TIDA-00718 Provides Design Guide and Design Files of Power Management Section

### Featured Applications

- Video Doorbell
- Factory Automation
- Machine Vision Applications



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## 1 System Description

Complementary metal-oxide semiconductor (CMOS) imaging sensors are dramatically impacting the field of digital imaging. One of the great advantages of CMOS sensors over charged coupled devices (CCDs) is the high level of product integration, such as the possibility to include the timing logic, digitalization, and capture control on a miniature single chip, which reduces system power, cost, and size without much compromise in performance.

A limitation of the CMOS imaging sensors is sensitivity to noise. Common noise sources are power supply ripple and fluctuation, electromagnetic interference (EMI), and substrate noise coupling. External noise sources such as power supply fluctuation and EMI can be mitigated or reduced to satisfactory levels by proper circuit design.

CMOS imaging sensors generally require at least two voltage sources for the analog and digital circuits in the chip. The analog circuits are typically powered from 2.8 V to 3.3 V and the digital circuits are powered from 1.2 V to 1.8 V. Considerable ripple or substantial undershoot or overshoot transients can cause distortion in the captured images.

The TIDA-00718 reference design provides a small size and high-input, voltage-ripple rejection power supply to provide a stable and clean voltage source for the CMOS image sensor. In this design, a main power rail of 5 V from a battery, Power over Ethernet (PoE), or DC adaptor is regulated down to three voltage rails: 3.3 V, 1.8 V, and 1.2 V. [Table 1](#) lists the values that correspond to each parameter.

This solution can be utilized in consumer electronics and commercial applications, such as IP network cameras, analog security cameras, video doorbells, and many more.

The TIDA-00718 reference design provides test data, schematics, and PCB layout files, all of which can be obtained from the design folder at [www.ti.com/tool/TIDA-00718](http://www.ti.com/tool/TIDA-00718).

**Table 1. TIDA-00718 Parameters**

PARAMETERS	VALUES
Input voltage range	3.3 V to 5.5 V
Output voltages	1.2 V, 1.8 V, and 3.3 V
3.3-V rail: $I_{OUT}$ maximum including LDOs connected at the output	1.2 A
1.8-V rail: $I_{OUT}$ maximum current	250 mA
1.2-V rail: $I_{OUT}$ maximum current	250 mA

## 2 Applications

The TIDA-00718 design is scalable for many applications and systems that can benefit from the high-power ripple rejection and small foot print.

For example, if a TIDA-00718 device has been complemented with a PoE power device (PD), then the TIDA-00718 can serve as a power solution for IP cameras. Such applications benefit from the high-power supply rejection capabilities of the LP5907 device because, in many PoE voltage delivery methods, the power source equipment (PSE) supplies the DC voltage using active data pairs. On the receiver side (IP camera), the DC voltage and data must be separated using a PoE controller and an AC filter or transformers. The resulting voltage is typically a 5-V rail and it may contain crosstalk noise or induce ripple. The TIDA-00718 power solution reduces the ripple and provides the necessary regulated voltage rails for the CMOS image sensor.

For more information about IP cameras, visit the following links:

- [www.ti.com/solution/camera\\_surveillance\\_ip\\_network](http://www.ti.com/solution/camera_surveillance_ip_network)
- <http://www.ti.com/tool/TIDA-00079>
- [www.ti.com/tool/SAT0027](http://www.ti.com/tool/SAT0027)

## 3 Block Diagram

Figure 1 shows the comprehensive block diagram of the TIDA-00718 design. The red blocks are the focus components of this document. The grey blocks show the scalability of the TIDA-00718 power management design. The CMOS image sensor has not been included in this design.

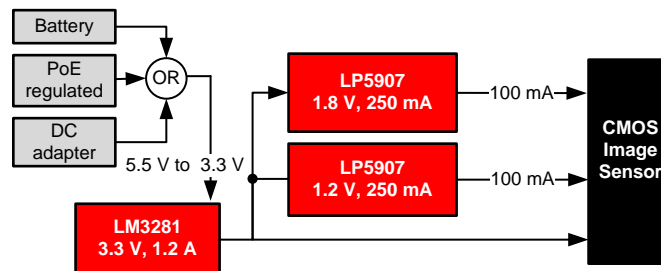


Figure 1. TIDA-00718 High-Level Block Diagram

## 4 Highlighted Design Components

### 4.1 LP5907

The LP5907 linear regulator provides low noise, high PSRR, low quiescent current, and low-line and load transient response. The device offers excellent noise performance without the requirement for a noise bypass capacitor and is stable with input and output ceramic capacitors with a value of 1  $\mu\text{F}$ . The LP5907 delivers this performance in industry standard packages such as DSBGA (0.675 mm  $\times$  0.675 mm), X2SON (1.00 mm  $\times$  1.00 mm), and SOT-23 (2.90 mm  $\times$  1.60 mm), which, are specified with an operating junction temperature ( $T_J$ ) of  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  for this device. Figure 2 shows the LP5907 functional block diagram.

This device is available with fixed output voltages from 1.2 V to 4.5 V in 25-mV steps. Contact a Texas Instruments (TI) sales representative for specific voltage requirements.

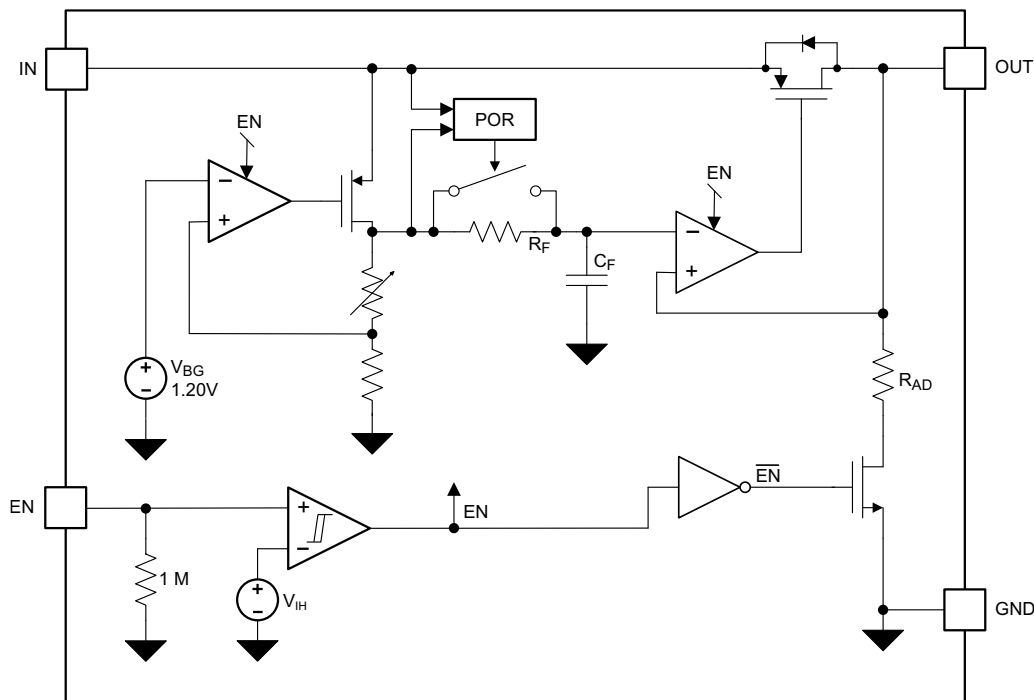


Figure 2. LP5907 Functional Block Diagram

## 4.2 LM3281

The LM3281 converter steps down an input supply voltage to a fixed output voltage of 3.3 V with an output current up to 1200 mA. Five different modes of operation are used to optimize efficiency and minimize battery drain. In pulse width modulation (PWM) mode, the device operates at a fixed frequency of 6 MHz, which minimizes RF interference when driving medium-to-heavy loads. At a light load, the device automatically enters into economy (ECO) mode with reduced quiescent current. In a low-battery voltage condition, a bypass mode reduces the voltage dropout to 60 mV (typically) at 600 mA. If the user desires a very-low output voltage ripple at light loads, the device can also be forced into PWM mode. Shutdown mode turns the device off and reduces battery consumption to 0.1  $\mu$ A (typically). [Figure 3](#) shows the LM3281 functional block diagram.

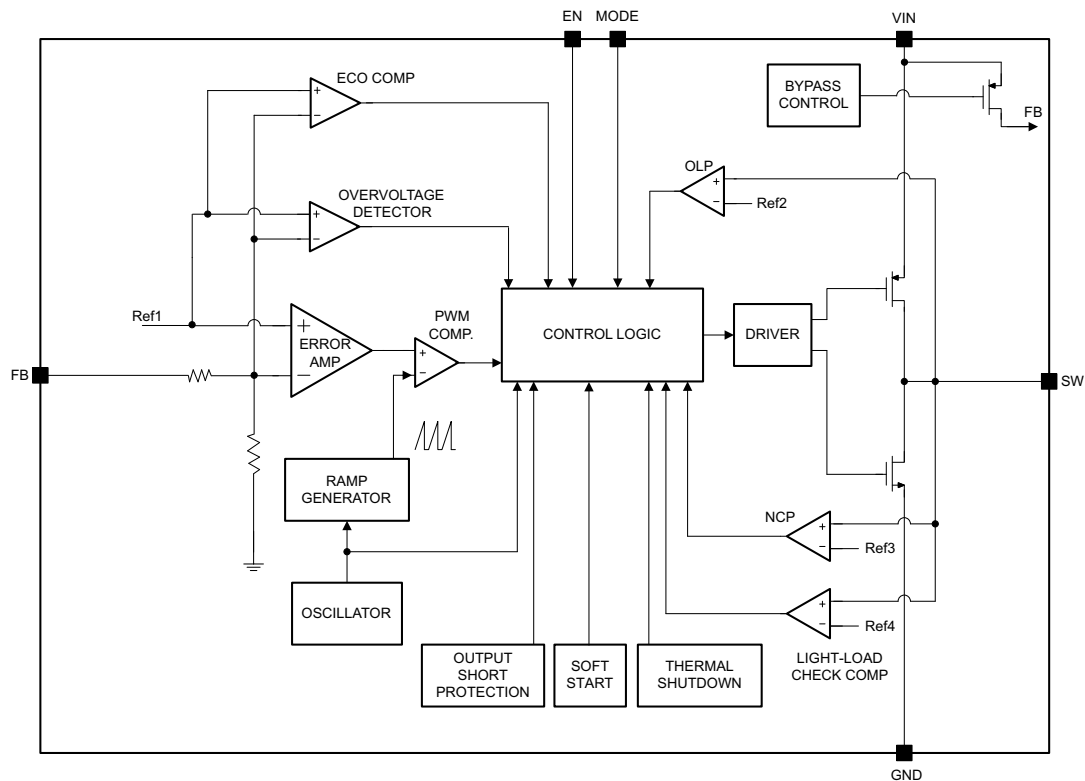


Figure 3. LM3281 Functional Block Diagram

## 5 Design Implementation and Guidelines

### 5.1 CMOS Sensor

The CMOS image sensors are basically an array of light-sensitive components that produce an electrical signal proportional to the incident light illuminating the subject. A CMOS image sensor is composed of switching transistors, a photo-detector, and an active charge amplifier. All of these devices are sensitive to fluctuation in the power supply. A noisy power supply affects the ability of a pixel to capture light and the array readout process, which affects the quality of the image.

The typical voltage rails for power CMOS sensors are usually between 1.2 V and 3.3 V. The LP5907 device is available in a wide range of fixed output voltages from 1.2 V to 4.5 V in 25-mV steps.

#### 5.1.1 LP5907

The LP5907 linear regulator only requires a minimum of 1- $\mu$ F capacitors near the input and output pins. Capacitor tolerances such as temperature variation and voltage loading effects must be considered when selecting capacitors to ensure that the capacitors can provide the minimum required amount of capacitance under all operating conditions for the application.

In general, ceramic capacitors are best for noise bypassing and transient response because they have ultralow equivalent series resistance (ESR). Note that if using ceramic capacitors, only the types with X5R or X7R dielectric ratings can be used.

In cases where the load has a fast slew rate and demands high current very quickly, TI recommends to add more capacitance at the output to improve the transient response.

The LP5907 device has been used in the X2SON package, which is a very small package (1 x 1 mm) and has a thermal pad for better thermal performance.

##### **Enable control:**

The LP5907 device can be switched ON or OFF by a logic input at the EN pin. A voltage on this pin greater than the high input threshold  $V_{IH}$  turns the device ON, while a voltage less than  $V_{IL}$  turns the device OFF. This pin has an internal 1-M $\Omega$  pulldown resistor to hold the regulator off by default. This feature can also be used to enable the LP5907 output voltage in sequence after the 3.3 V is high, which is a requirement of some CMOS image sensors.

#### 5.1.2 LM3281

##### 5.1.2.1 Operation Mode

###### **PWM mode:**

To ensure a low output voltage ripple, set the LM3281 device to operate in PWM mode with a fixed frequency of 6 MHz. To select the PWM mode, the MODE pin (pin B1) must be connected to ground.

###### **Bypass mode:**

If the LM3281 device is operating from a battery source and the input voltage approaches the output voltage, a bypass mode becomes activated. In this bypass mode, the battery connects to the output through an internal bypass field-effect transistor (FET) and the bypass is turned on enough to maintain regulation. When the device enters into dropout, the output voltage is the input voltage minus the voltage drop across the  $R_{SON}$  of the bypass FET in parallel with the PFET and the inductor.

### 5.1.2.2 Inductor

When selecting an inductor for use with the LM3281 device, select an inductor with the following characteristics over the operating temperature range:

- DC resistance (DCR)  $\leq 70 \text{ m}\Omega$
- Inductance at 0-mA current =  $0.47 \text{ }\mu\text{H} \pm 20\%$
- Inductance at 1.4-A current  $\geq 0.29 \text{ }\mu\text{H}$
- Inductance at 2-A current  $\geq 0.26 \text{ }\mu\text{H}$ .

### 5.1.2.3 Capacitors

The total effective output capacitance, including load capacitance ( $C_{\text{LOAD1}}$  and  $C_{\text{LOAD2}}$ ) and solution capacitance ( $C_{\text{OUT}}$ ), must be  $3.4 \text{ }\mu\text{F}$  to  $9 \text{ }\mu\text{F}$ .

The LM3281 has been designed for use with ceramic capacitors for its input and output filters. Ceramic capacitors types such as X5R and X7R are recommended for both filters. Note that the suggested LM3281 solution capacitors are derated by 50% to 65% at a 3.3-V DC bias.

## 6 Test Data

Before applying power to the TIDA-00718 board, verify all of the external connections. The external power supply must be turned off before connecting. Confirm a proper polarity to the  $V_{IN}$  and output terminals before turning the external power supply on.

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**NOTE:** The TIDA-00718 EVM is not available for purchase; however, reference design files can be downloaded at <http://www.ti.com/tool/tida-00718>.

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### 6.1 Test Equipment

The following [Table 2](#) shows the test equipment used to collect test data.

**Table 2. Test Equipment**

TEST EQUIPMENT	PART NUMBER
Oscilloscope	Agilent DPO4014B
DC voltage supply	Agilent E3631A
Multimeter	Agilent E34401A
Network Analyzer	Agilent E5061B ENA

### 6.2 Test Results

The following [Table 3](#) shows a summary of the tests performed on the TIDA-00718.

**Table 3. Test Summary**

PARAMETERS	1.8-V RAIL	1.2-V RAIL	SECTION
Line transient (100-mV line step, 10- $\mu$ s edge time)	Undershoot: 20 mV Overshoot: 20 mV	Undershoot: 20 mV Overshoot: 20 mV	<a href="#">Section 6.2.3</a>
Load transient (100-mA load step, 10- $\mu$ s edge time)	Undershoot: 20 mV Overshoot: 3 mV	Undershoot: 20 mV Overshoot: 4 mV	<a href="#">Section 6.2.2</a>
Load transient (100-mA load step, 30- $\mu$ s edge time)	Undershoot: 2 mV Overshoot: 0.5 mV	Undershoot: 2 mV Overshoot: 0.5 mV	
Noise spectral density (NSD)	10 Hz to 100 kHz $I_{OUT} = 1$ mA 12 $\mu$ V <sub>RMS</sub>	10 Hz to 100 kHz $I_{OUT} = 1$ mA 10 $\mu$ V <sub>RMS</sub>	<a href="#">Section 6.2.4</a>
Power supply ripple rejection	PSRR: 82 dB at 1 kHz	PSRR: 75 dB at 1 kHz	<a href="#">Section 6.2.5</a>



### 6.2.1 Sequencing

Sequencing can be achieved by independently controlling the signal at the EN pin of the LP5907 LDO, LP5910 LDO, and the LM3281 switching regulator.

Figure 4 shows a sequencing example. The 1.2- and 1.8-V output voltage of the LP5907 device and LP5910 device comes up after the LM3281 device.

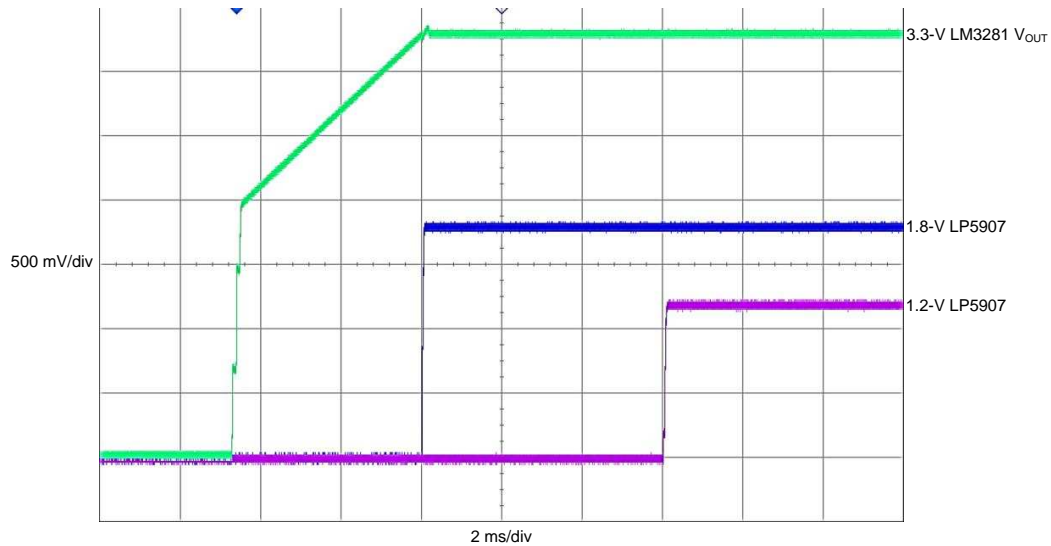


Figure 4. LP5907 Output Voltage Sequencing

### 6.2.2 Load Transients

The load transient test is defined as the change in output voltage from a nominal value resulting from a change in load current.

This subsection shows the load transient responses using the minimal required output capacitance for the LP5907 device and LP5910 device. The LM3281 device has two additional load capacitors. The transient response can be improved by adding more capacitance between the output pin and ground.

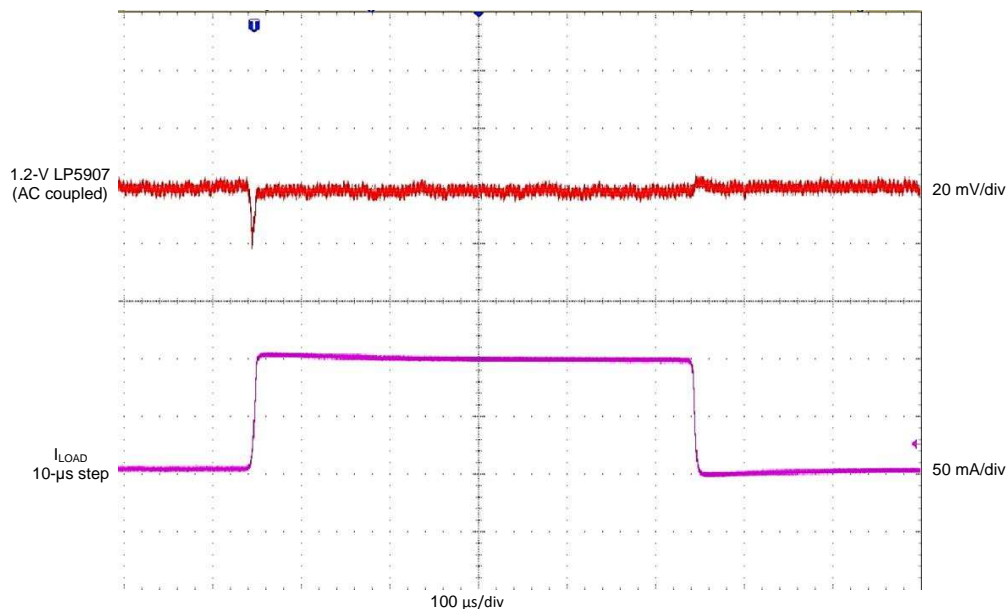


Figure 5. LP5907 1.2 V

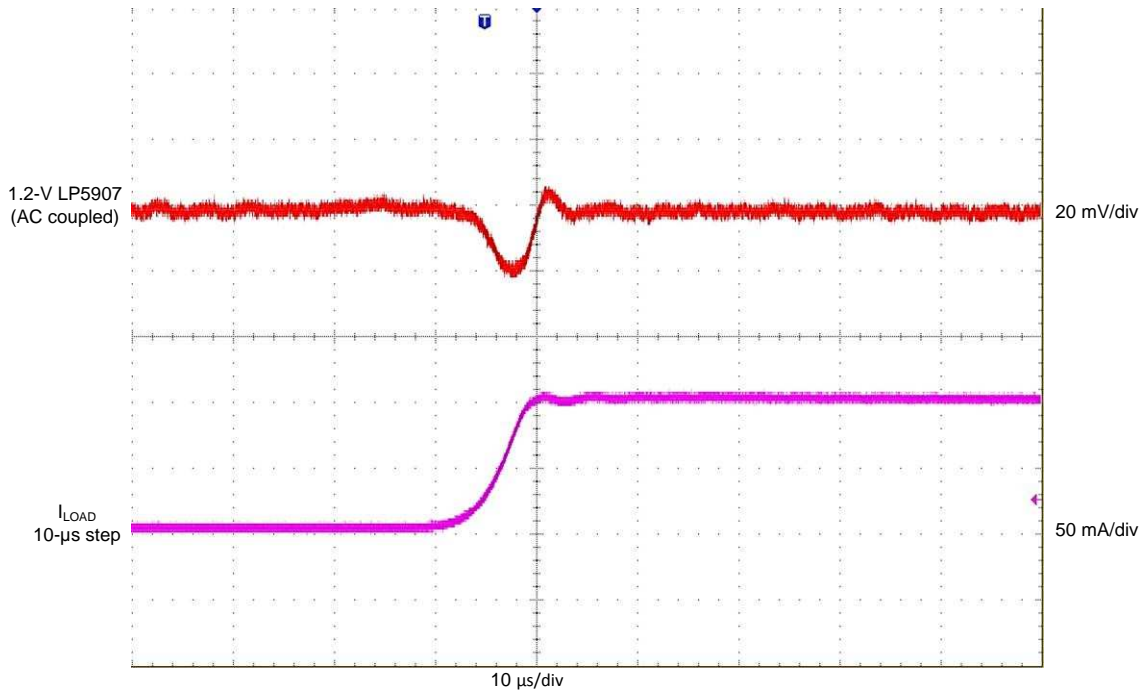


Figure 6. LP5907 1.2-V Undershoot Close-up

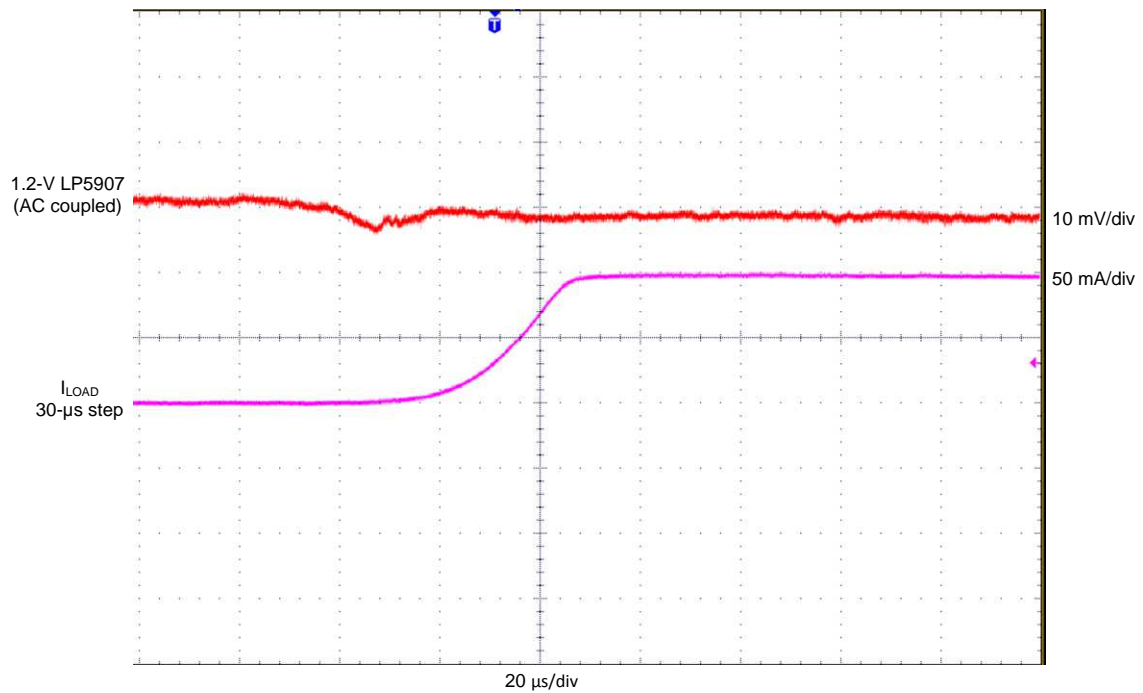


Figure 7. 1.8-V LP5907 Load Transient 30- $\mu$ s Load Step

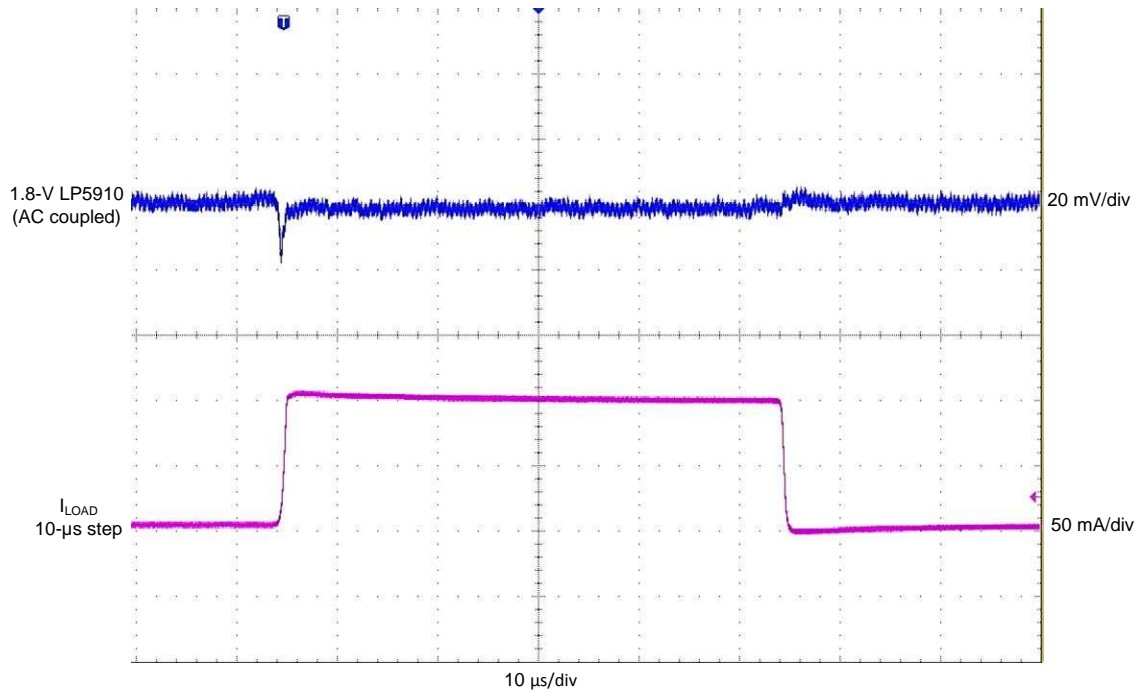


Figure 8. LP5910 1.8-V Transient Response

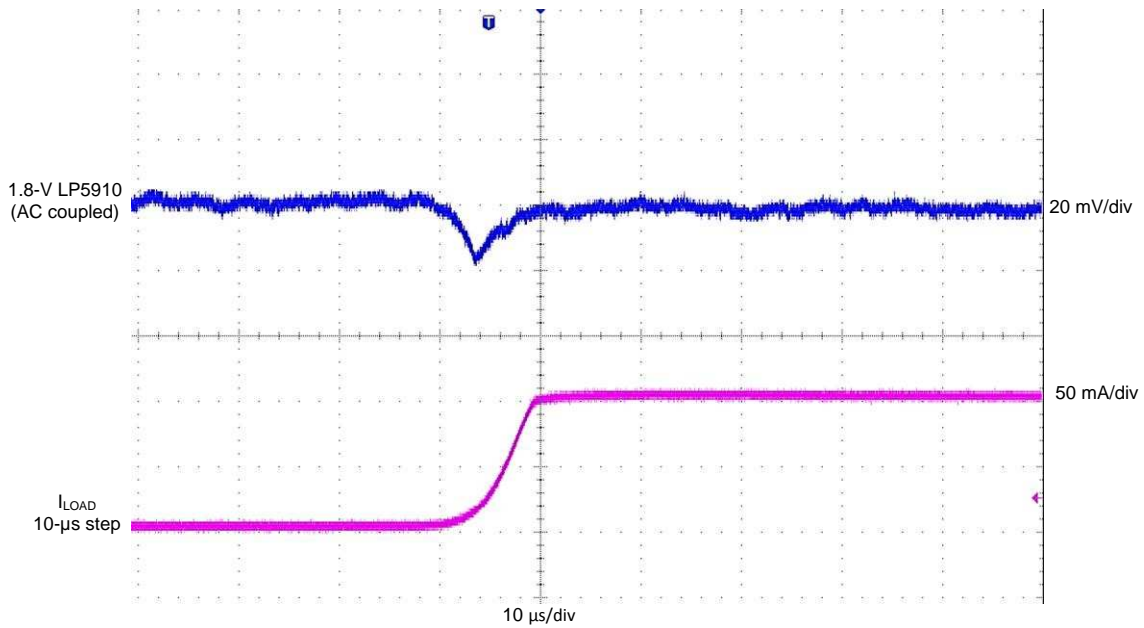


Figure 9. LP5910 1.8-V Undershoot Close-up

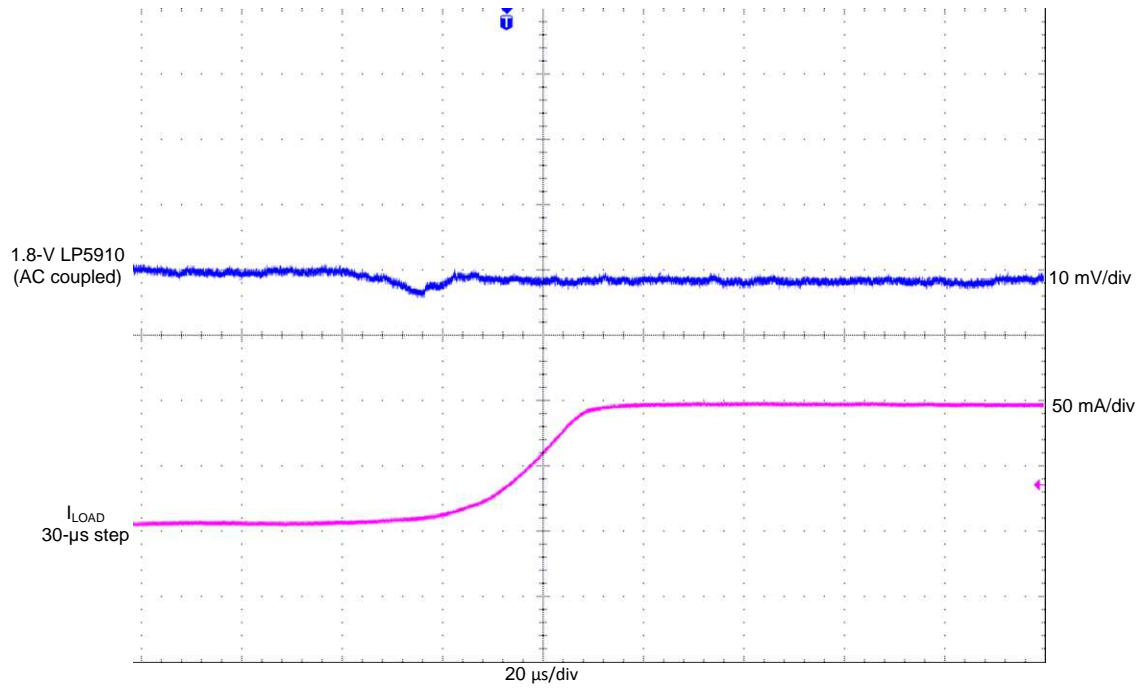


Figure 10. 1.2-V LP5910 Load transient 30- $\mu$ s Load Step

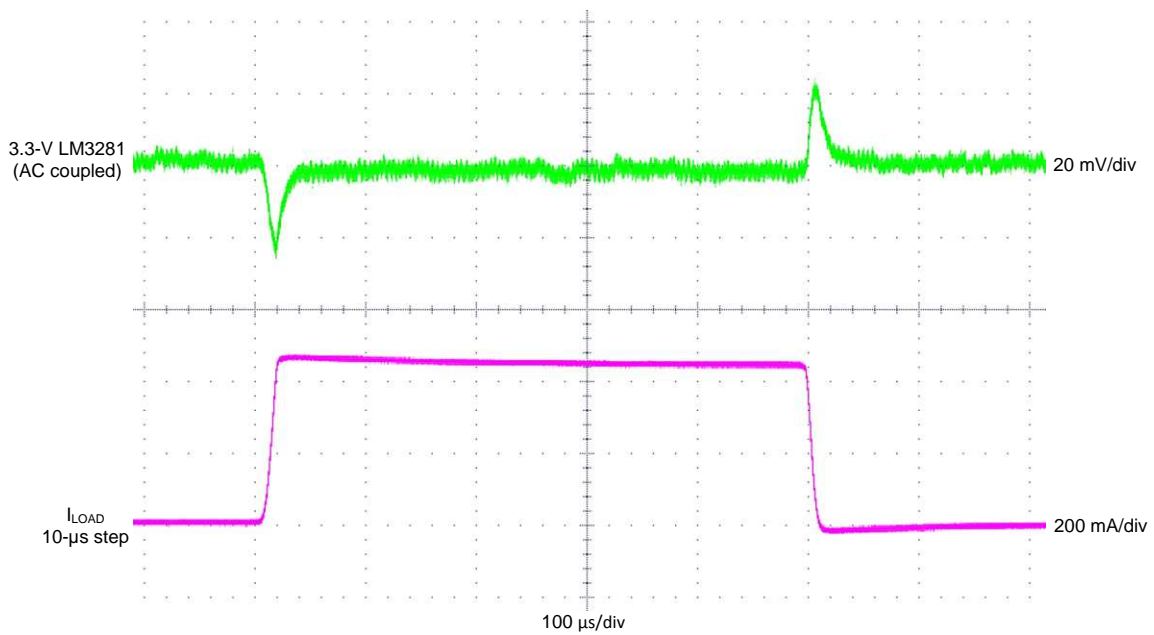


Figure 11. LM3281 Transient Response

### 6.2.3 LDO Line Transient Test

The line transient response test is the response of the power supply to changes in the line voltage.

The blocks in Figure 12 represent the test setup and the color-coded circles indicate the test points.

Figure 13, Figure 14, and Figure 15 show how the 1.8- (blue) and 1.2-V (red) voltage rails respond to fast line transients.

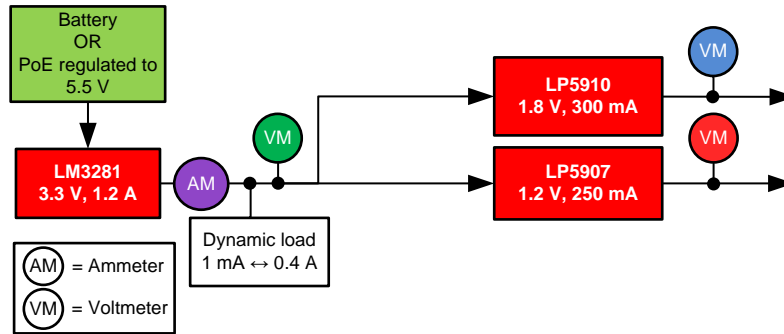


Figure 12. LDO Line Transient Test Setup

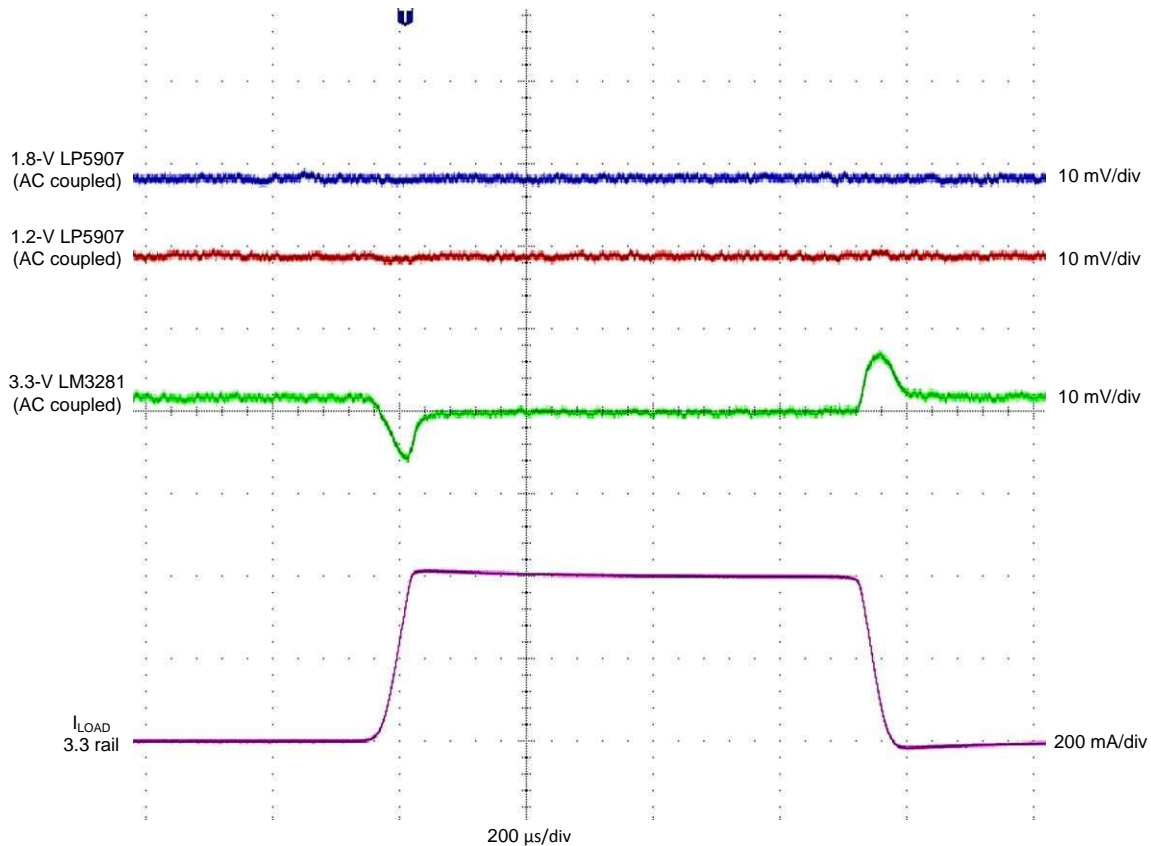
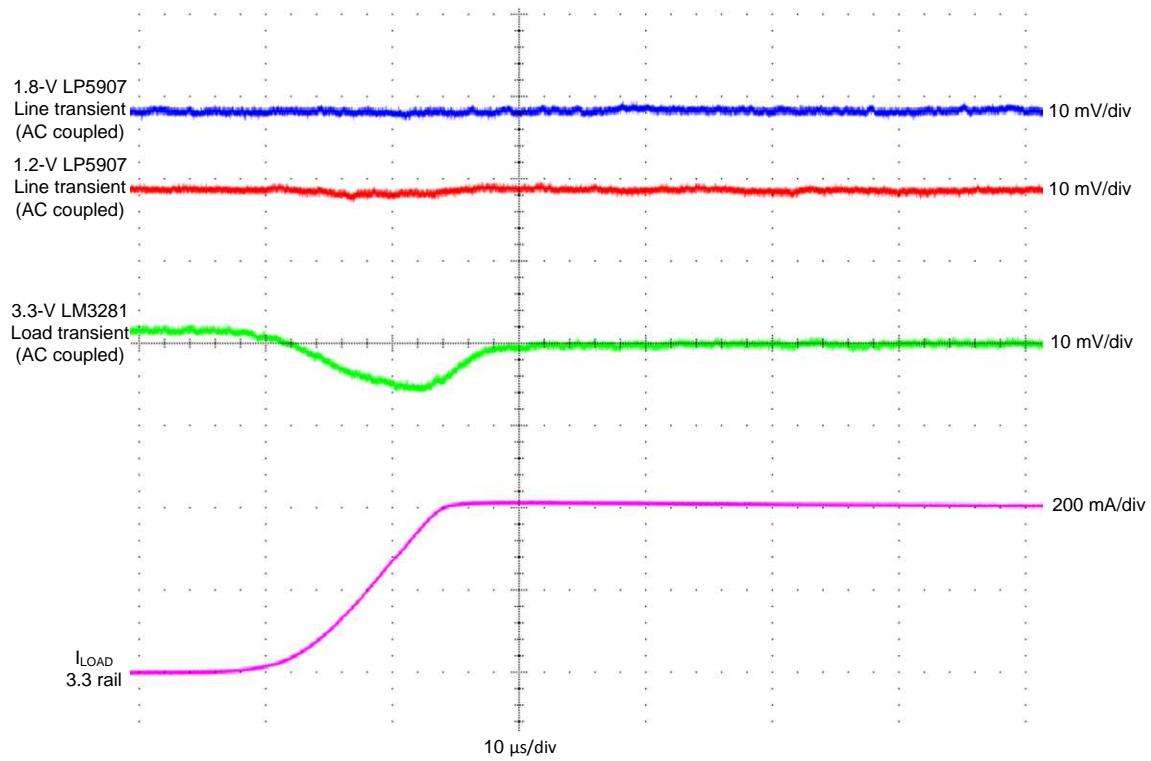
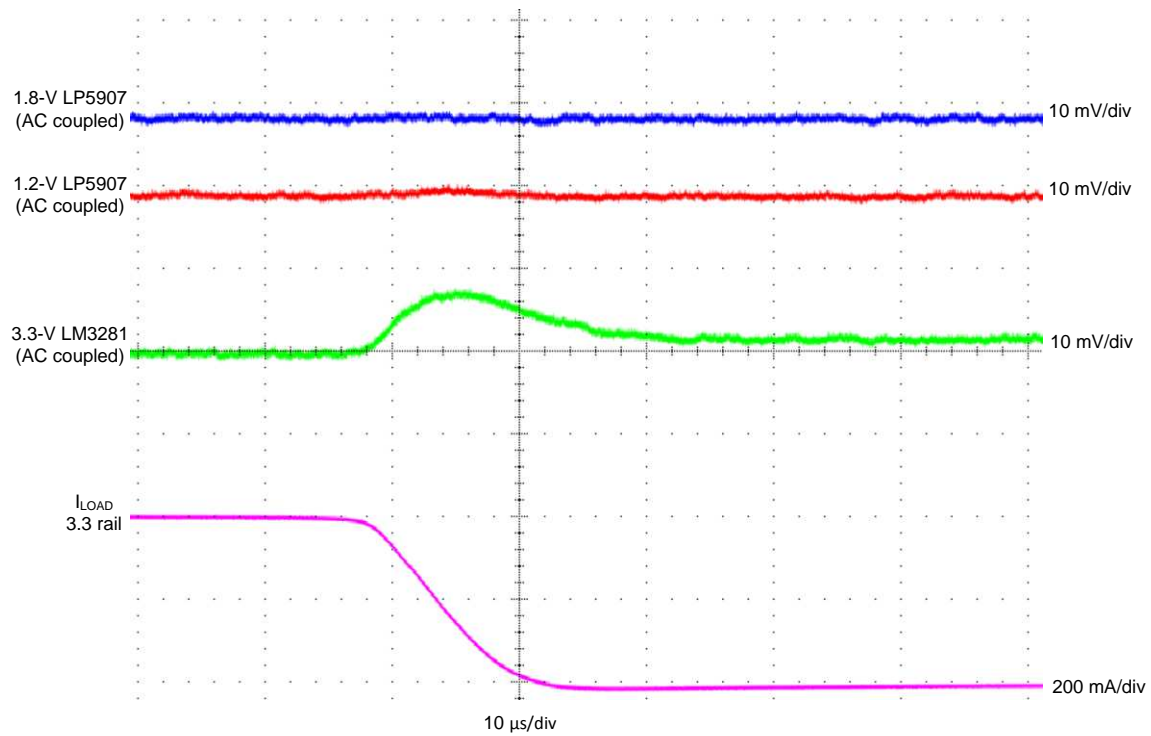


Figure 13. Line Transient Response



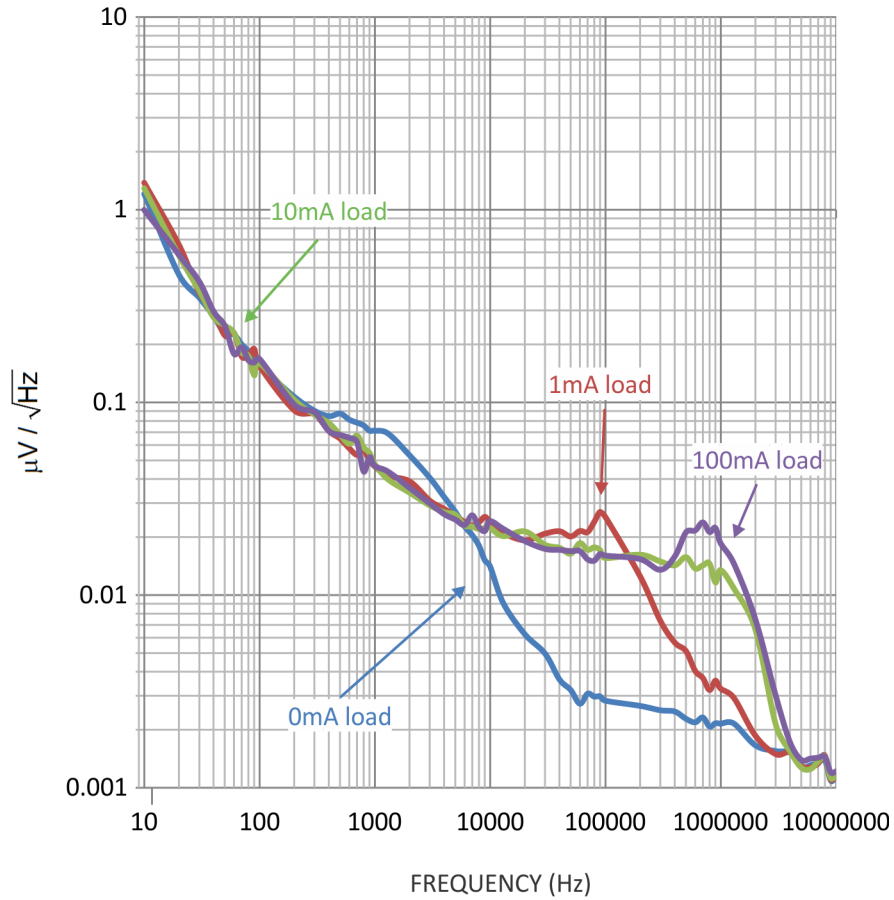
**Figure 14. Close-up of LM3281 Undershoot and LDO Line Transient Response**



**Figure 15. Close-up of LM3281 Overshoot and LDO Line Transient**

### 6.2.4 LP5907 Spectral Noise Density

This test shows the spectral noise density over the unit of frequency. [Figure 16](#) compares frequency and noise power in dBs.



**Figure 16. LP5907 Spectral Noise Density 10 Hz to 10 MHz**

### 6.2.5 LP5907 Power Supply Ripple Rejection

Calculate the ratio of output voltage ripple rejection by comparing the regulated output voltage of the device under test (DUT) with the input voltage ripple over a frequency range of 10 Hz to 10 MHz.

The chart in Figure 17 compares the power supply rejection ratio over frequency under the following parameters.

**Test parameters:**

$$C_{IN} = C_{OUT} = 1 \mu F$$

$$V_{IN\_AC} = \text{Sweep from 10 Hz to 10 MHz}$$

Room temperature = 23°C

EN pin tied to  $V_{IN}$

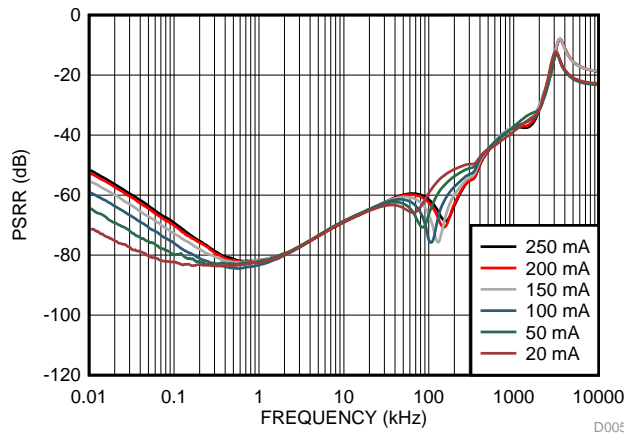


Figure 17. LP5907 PSRR

### 6.2.6 LM3281 Efficiency

Figure 18 and Figure 19 show the LM3281 in two different modes of operation: PWM and forced PWM. PWM mode provides a higher efficiency by automatically changing to ECO mode during low loads and the forced PWM has a lower efficiency but has a lower output voltage ripple.

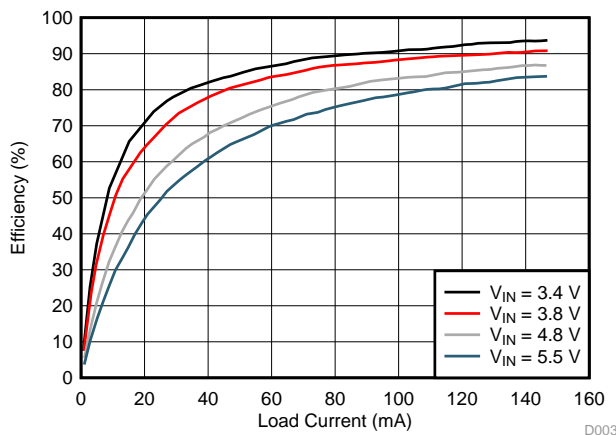


Figure 18. Forced PWM Efficiency vs Output Current

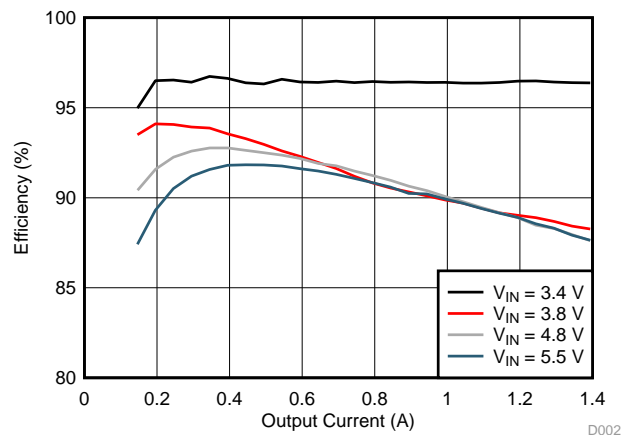


Figure 19. PWM Efficiency vs Output Current



## 7 Design Files

### 7.1 Schematics

To download the schematics, see the design files at [TIDA-00718](#).

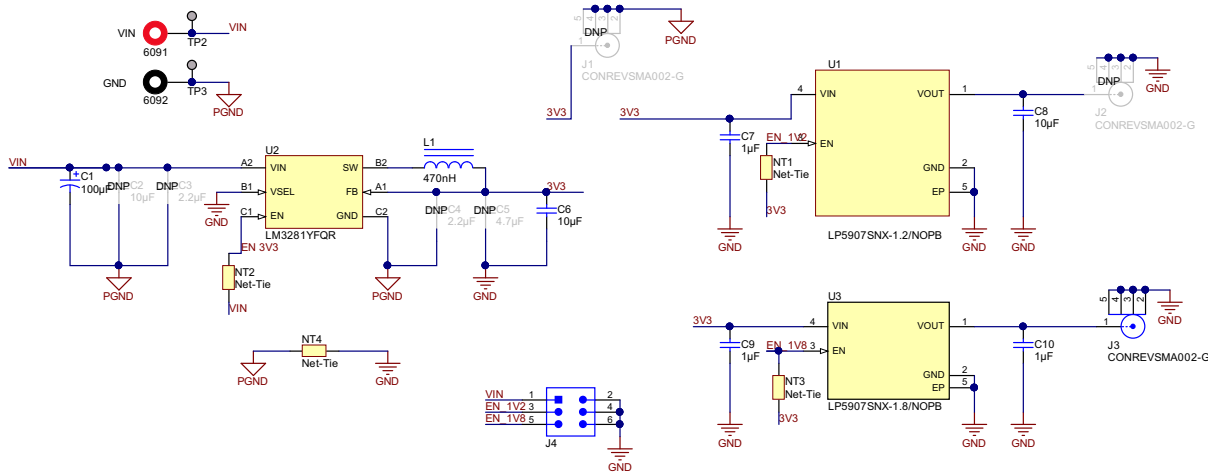


Figure 20. TIDA-00718 Schematic

### 7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-00718](#).

### 7.3 Layer Plots

To download the layer plots, see the design files at [TIDA-00718](#).

### 7.4 Altium Project

To download the Altium project files, see the design files at [TIDA-00718](#).

### 7.5 PCB Layout Recommendations

The following list offers recommendations for the PCB layout (see [Figure 21](#)).

- Minimize inductance in the path between the LM3281  $C_{OUT}$  capacitor and the load bypass capacitors C5 and C6 for the best performance. The total power path inductance from the LM3281 output to the load (including vias and traces) should target < 1 nH and must not exceed 2 nH.
- For all the components, minimize the inductance between the  $V_{IN}$  and GND for the best performance.
- As a general rule, avoid connections using long trace lengths and narrow trace widths. These kinds of connections add parasitic inductances and resistance that result in an inferior performance, especially during transient conditions.
- Avoid any sharp corners. Electric fields tend to build up on corners, which increases EMI coupling.
- The input and output capacitor must be placed as close as possible to the components input and output pin of the LP5907 device.
- Ensure a low impedance path for grounds and return paths.

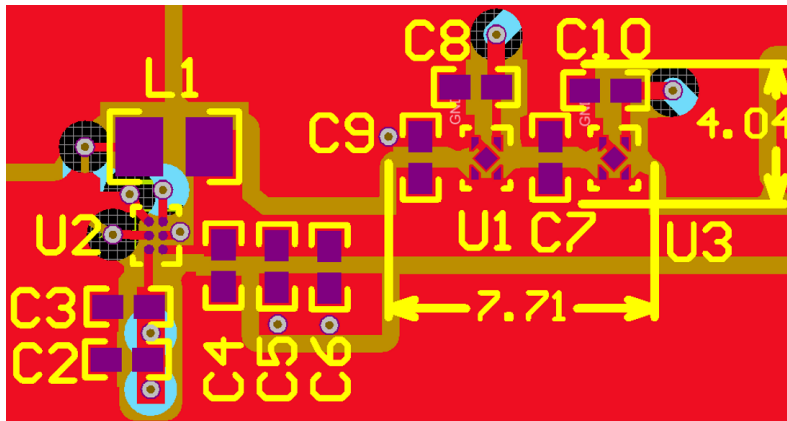


Figure 21. TIDA-00718 Layout Guidelines

## 7.6 Gerber Files

To download the Gerber files, see the design files at [TIDA-00718](#).

## 7.7 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-00718](#).

## 8 References

1. Tian, Hui; Stanford.edu, *Noise Analysis in CMOS Image Sensors*, August 2000 ([http://www-isl.stanford.edu/~abbas/group/papers\\_and\\_pub/hui\\_thesis.pdf](http://www-isl.stanford.edu/~abbas/group/papers_and_pub/hui_thesis.pdf))
2. Texas Instruments, *High-Efficiency IP Camera Power Module Design*, SAT0027 User's Guide ([TIDU188](#))
3. Texas Instruments, *Low-Noise CMOS Camera Supply*, Application Report ([SLVA672](#))
4. Texas Instruments, *Low Noise Power Management Reference Design for Automotive CMOS Imager Sensor and Data Serializer*, TIDA-00535 User's Guide ([TIDUA54](#))

## 9 About the Author

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