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LP5910 and TPS61221 as a Power Reference Design for Ultra-Low Voltage MSP430X09X Companion Devices

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Design Resources

TIDA-00599	www.ti.com/tool/TIDA-00599
LP5910	www.ti.com/product/LP5910
TPS61221	www.ti.com/product/TPS61221
MSP430L092	www.ti.com/product/MSP430l092
MSP430C092	www.ti.com/product/MSP430C092

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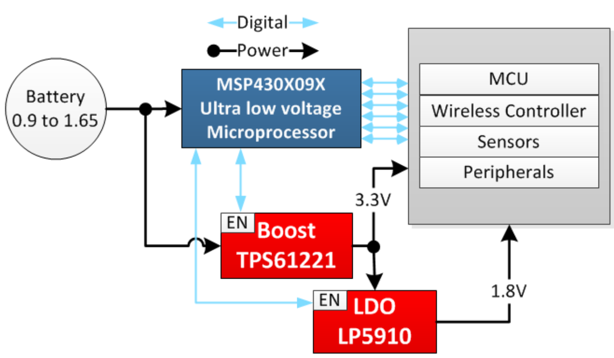
Block Diagram



Design Features

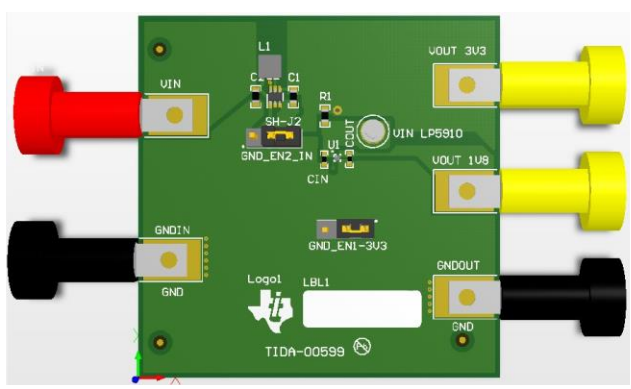
- Power management for devices interacting with the ultra-low voltage µController family (MSP430X09X) from a 0.9 V to 1.65 V single battery cell
- Generates 1.8V and 3.3V voltage rails from an ultra-low voltage source.
- Combine output current
  - 50mA at 0.9V input voltage
  - 100mA at 1.65V input voltage
- Ripple free and low noise 1.8 V voltage rail
- Small solution size, with minimum compensation components
- Cost efficient solution
- TIDA-00599 provides design guide and design files of the power management solution

Featured Applications

Low-cost single battery cell applications

- Consumer electronics
  - Wearables
  - Personal electronics
  - low power gadgets
  - toys or games
- Single battery remote controls
- Motion or light sensors
- Home or office security monitoring

Board Image



1 System Description

The MSP430X09X are a line of ultra-low voltage (ULV) mixed-signal microcontrollers (µC) that can operate from a voltage supply range of 0.9V to 1.65V. This low voltage operation is ideal for single-cell systems (ranging from AAA to coin Cell) requiring a full analog signal chain.
On the other hand many of the sensors interacting with the ultra-low voltage microcontroller require higher input voltage typically in the range of 1.8V and 3.3V.

The TIDA-00599 is a power reference design for MSP430X09X companion devices which requires input voltage of 1.8V and 3.3V. In this design a 3.3V voltage rail is generated from 0.9V to 1.65V battery using the TPS61221 boost converter and a 1.8V voltage rail is generated using a high PSRR LDO (LP5910) connected in series with the boost converter output voltage rail. The combine output current is 100 mA at 1.65V input voltage and 50 mA at 0.90 V input voltage.
This power solution is deal to power sensors and peripherals from the same low voltage battery as the MSP430X09X microcontroller.

The TIDA-00599 reference design provides test data, design guide and Gerber files; all the files can be obtain from the design folder at www.ti.com/tool/TIDA-00599

2 Block Diagram

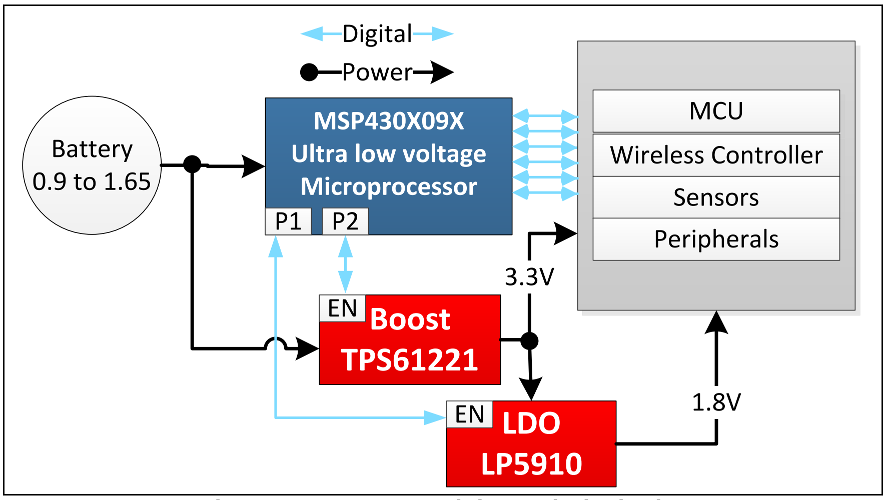


Figure 1 TIDA-00599 High Level Block Diagram

The **Figure 1** shows the comprehensive block diagram of the TIDA-00599 design. The red blocks represent the main components of this document. The blue blocks represent other TI devices that are described in this document. The MSP430x09x was not designed in the evaluation board, but its power requirements were taken into consideration to define the design parameters.

2.1 Highlighted Power Management Components

2.1.1 LP5910 Ultra Low Noise, Low Dropout Regulator

The LP5910 device provides low noise, high PSRR, low quiescent current and low line/load transient response. Using new innovative design techniques the LP5910 offers class-leading noise performance without a noise bypass capacitor and the option for remote output capacitor placement. The device contains a reverse current protection circuit that prevents a backward current flow through the LDO. The LP5910 is stable with an effective output capacitance of only 1 µF. This feature enables the use of cost-effective capacitors that have higher bias voltages and temperature drifting. The LP5910 regulate to specified accuracy with no output load. No bypass ccapacitor is required.

- I_Q (VEN = 0.3V) = 0.2 µ A
- I_Q (VEN = 1.0V, I_{OUT} = 100mA) = 200µA
- Maximum load current 300mA

Alternative parts
LP5907

2.1.2 TPS61221: Low Input Voltage Step-UP Converter in 6 pin TSOT-23 package

The TPS6122x family devices provide a power-supply solution for products powered by either a single-cell, two-cell, or three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-polymer battery. Possible output currents depend on the input-to-output voltage ratio. The boost converter is based on a hysteretic controller topology using synchronous rectification to obtain maximum efficiency at minimal quiescent currents. The output voltage of the adjustable version can be programmed by an external resistor divider, or is set internally to a fixed output voltage. The converter can be switched off by a featured enable pin. While being switched off, battery drain is minimized. The device is offered in a 6-pin SC-70 package (DCK) measuring 2 mm × 2 mm to enable small circuit layout size.

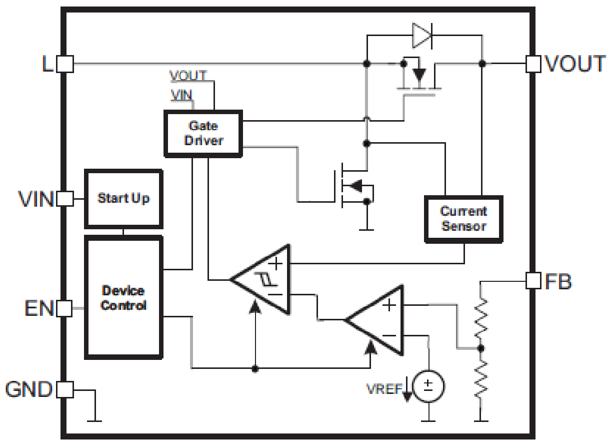


Figure 2 TPS61221 Functional Block Diagram

Alternative parts
TLV61220: Similar functionality, same price range
TPS61025: Higher output current at given conditions
TPS61291: Similar functionality, higher output current than TPS61221 at TIDA-00599 operating conditions

2.2 Other TI Components

2.2.1 MSP430X09X Low Voltage microcontrollers Family

The Ultra-Low Voltage Series include the MSP430C09x and MSP430L092 parts. These 2 series of low voltage 16 bit microcontrollers have configurations with two 16-bit timers, an 8-bit analog-to-digital (A/D) converter, an 8-bit digital-to-analog (D/A) converter, and up to 11 I/O pins. For more information, see MSP430 Low Voltage Wiki.

"**L**" as in the MSP430L09x series, which indicates a RAM-only part; it must remain continuously powered to retain its programming.
Family Members Include
Native 0.9V -1.5V operating range

- No charge pump
- Logics at 0.9-1.5V range
- Utilize entire battery life
- RAM development/ROM production

Ultra low voltage family

- MSP430C091
  1KB ROM Memory
  128 Bytes RAM + 96 Bytes CRAM (Lockable)
- MSP430C092
  2KB ROM Memory
  128 Bytes RAM + 96 Bytes CRAM (Lockable)
- MSP430L092
  2KB Loader ROM with service functions
  2KB RAM (1792 + 128 + 96 Bytes Lockable)

"**L**" as in the MSP430L09x series, which indicates a RAM-only part; it must remain continuously powered to retain its programming.

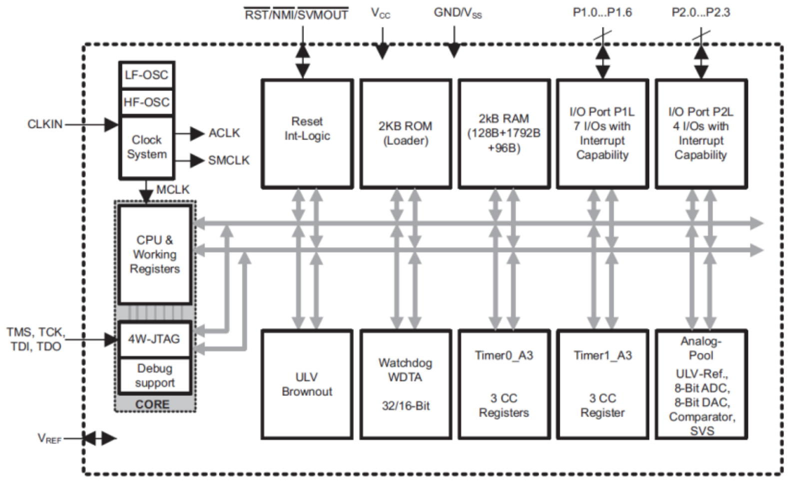


Figure 3 Functional Block Diagram, MSP430L092PW

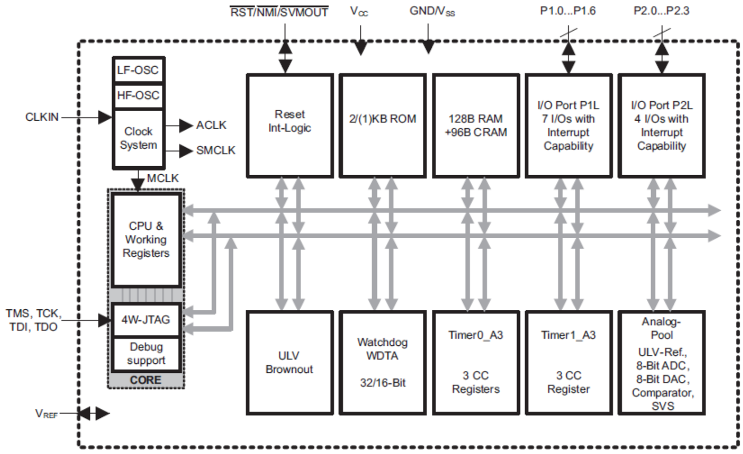


Figure 4 Functional Block Diagram, MSP430C092PW, and MSP430C091PW

Power specification overview, as low as:

- 1 µA RAM retention
- 1.7 µA real-time clock mode
- 180 µA / MIPS active
- 0.9 V to 1.5 V (1 MHz)
- 1.5 V to 1.65 V (4 MHz)
- Power Consumption
  - Active Mode (AM): 45 µA/MHz (1.3 V)
  - Standby Mode (LPM3, WDT_A Mode): 6 µA
  - Off Mode (LPM4): 3 µA

Device parameters:

- Speed options: 4 MHz
- ROM options: 1-2 kB
- SRAM options: 2 kB
- ADC options: 8-bit SAR
- GPIO options: 11 pins
- Other integrated peripherals: up to 2 16-bit timers, watchdog timer, brown-out reset, SVS, comparator, temperature sensor

3 Design Implementation Guidelines

Table 1 shows the design parameters of the power management design

Table 1 Power Design Parameter

PARAMETERS		NOMINAL VALUES @ T=25 °C
V_{OUT} (Regulated output)	Boost Converter (TPS61221)	3.3V
	LDO (LP5910)	1.8V
I_{OUT} Max[1]	Boost Converter (TPS61221)	50mA – I_{LDO}
	LDO (LP5910)	40mA[2]
V_{IN} (limited by ULV MSP430 power supply)		0.9 V to 1.65 V

3.1 MSP430x09x Ultra Low Voltage Microcontroller

The MSP430x09x has various low power consumption modes: active mode, CPU OFF, Stand By, and OFF. The active mode consumes the most current because all oscillators and clocks are running. During the OFF mode the CPU is turn off but the oscillators and clocks are still running in the using only 3 µA.

The **Figure 5** shows MSP430L092 current consumption per modes of operation.

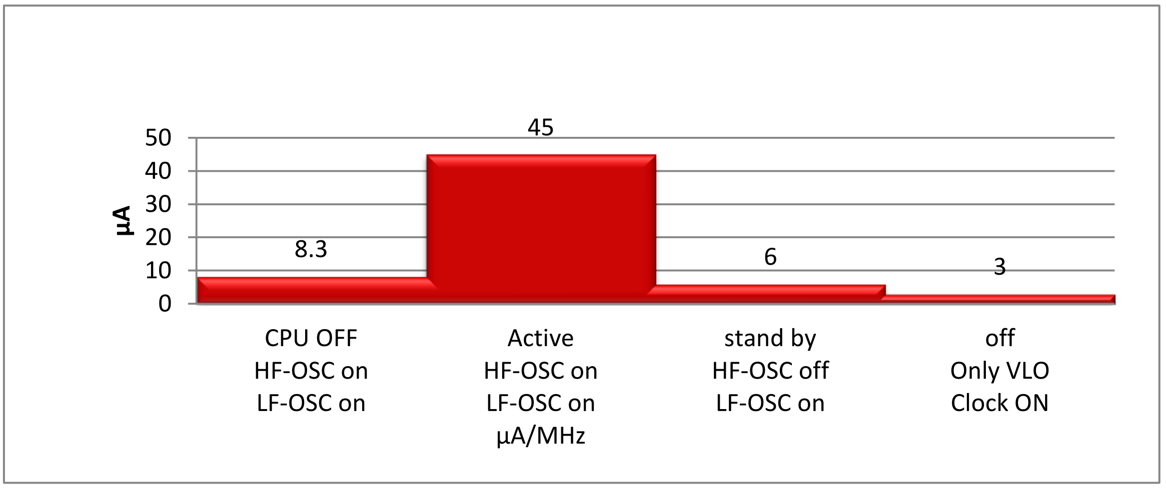


Figure 5 MSP430L092 Power Modes

MSP430x09x family consumes an average of 45µA per MHz; the frequency of operation is limited by the input voltage. The MSP430x09x can operate up to 1 MHz from 0.9 V to 1.5 V input voltage and from 1.5 V to 1.65 V it can operate at higher frequencies up to 4 MHz.

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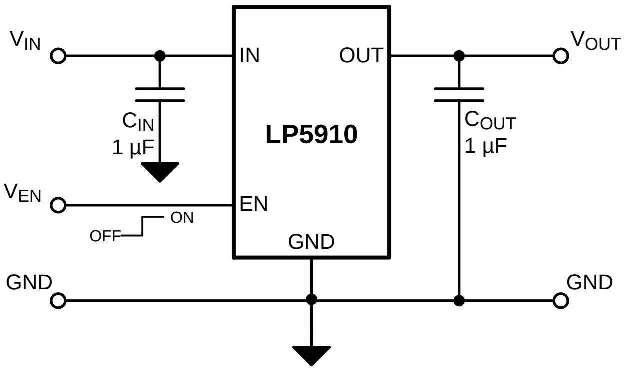
[1] For higher current options please see alternative boost converters in section 2.1.2

[2] The LP5910 $I_{OUT\_Maximum}$ is 300mA, but in this application is recommended to use a load under 40 mA to keep the boost converter from saturating

3.2 LP5910 High PSRR LDO

The LP5910 was selected for this design due to the small form factor package, high PSRR and cost optimize.



3.2.1 Output Current

The LP5910 is capable of delivering 300mA output current, however in this design it is recommended to limit the output current to a max of 40 mA because the LP5910 is sharing the output current of the TPS61221 with loads connected in the 3.3 V rail. If higher current is required the TPS61025 can be used which is capable of providing ~250 mA when boosting to 1.8 V from a 0.9 V input voltage, however the TPS61025 comes in a bigger package, has higher quiescent current and is less cost effective than the TPS61221

3.2.2 Input Output Voltage

The LP5910 operates from an input voltage range of 1.3V to 3.3V and comes in fixed output voltages in the range of 0.8 V to 2.3 V in increments of 25 mV steps and is available in two packages DSBGA and WSON. In this application the LP5910-1.8YKAR was selected which is a DSBGA package with 1.8 V output voltage. However if the user application requires different voltage

3.2.3 Capacitors

The LP5910 requires that at least 1uF 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 they will 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 of their ultra-low ESR. It must be noted that if ceramics are used, only the types with X5R or X7R dielectric ratings should be used.

Input Capacitor

To ensure proper loop operation, the ESR of the capacitor used for C_{IN} must not exceed 0.5ohm. Any good quality ceramic capacitor will meet this requirement.

Output Capacitor

Any type of capacitor may be used for C_{OUT}, with no limitations on minimum or maximum ESR, as long as the minimum amount of capacitance is present. The amount of capacitance can be increased without limit. Increasing the size of C_{OUT} typically will give improved load transient response.
On top of the small package size the LP5910 saves more board space by not requiring a bypass capacitor.

3.3 TPS61221 Boost Converter with 5.5µA Quiescent Current

The TPS61221 was selected for its low quiescent current and small foot print package with only a three compensation components.

3.3.1 Output Current

The TPS61221 is capable to deliver a maximum of 200 mA when is operating from a high power supply, however in this design the TPS61221 is operating from a power supply in the range of 0.9V to 1.65V which limit the output current to ~50mA.

3.3.2 Input Output voltage

The TPS61221 output voltage is fixed to 3.3V. At low extremes of input voltage, less output current is available, and efficiency is lower. To save power the boost is only going to be enable to power the peripherals or sensors for a short period of time and then it will enter the shutdown mode by pulling the EN pin low ($0.2 \times V_{IN}$). During the shutdown mode the converter stops switching and all internal control circuitry is turned off, but the input is connected to the output through the MOSFET back-gate diode typical leakage current is 1 µA. It is recommended to disable the LP5910 at the same time that the TPS61221 is disabled to minimize the leakage current.

For alternative output voltage option use the adjustable output voltage version TPS61220

3.3.3 Inductor Selection

To make sure that the device can operate, a suitable inductor must be connected between pin VIN and pin L. Inductor values of 4.7 µH show good performance over the whole input and output voltage range. Choosing other inductance values affects the switching frequency *f* proportional to 1/L as shown in Equation 1.

Equation 1

$$L = \frac{1}{f \times 200\ mA} \times \frac{V_{IN} \times (V_{OUT} - V_{IN})}{V_{OUT}}$$

A higher inductor value might improve efficiency by reducing the switching frequency thus reducing the switching loses, but it might affect the transient response.

3.3.4 Capacitor selection

Input Capacitor

A 10 µ capacitor is recommended to improve transient behavior

Output Capacitor

The output capacitor is 10µF. The output capacitor needs to be half of the inductance or higher for stability reasons.

3.4 Alternative Voltage Boost Method

This section shows a discrete method to generate a higher voltage rail from the single cell powering the MSP430 using a discrete boost and a high PSRR LDO.

Note

The design presented in this section is a model that have not been tested of validated further than the presented simulation

The **Figure 6** represents the alternative voltage boost method. The MSP430 is used as a switch controller for the boost converter circuitry. The output of the boost is followed by a high PSRR, low noise LDO to generate a steady and ripple free 1.8 V voltage rail.

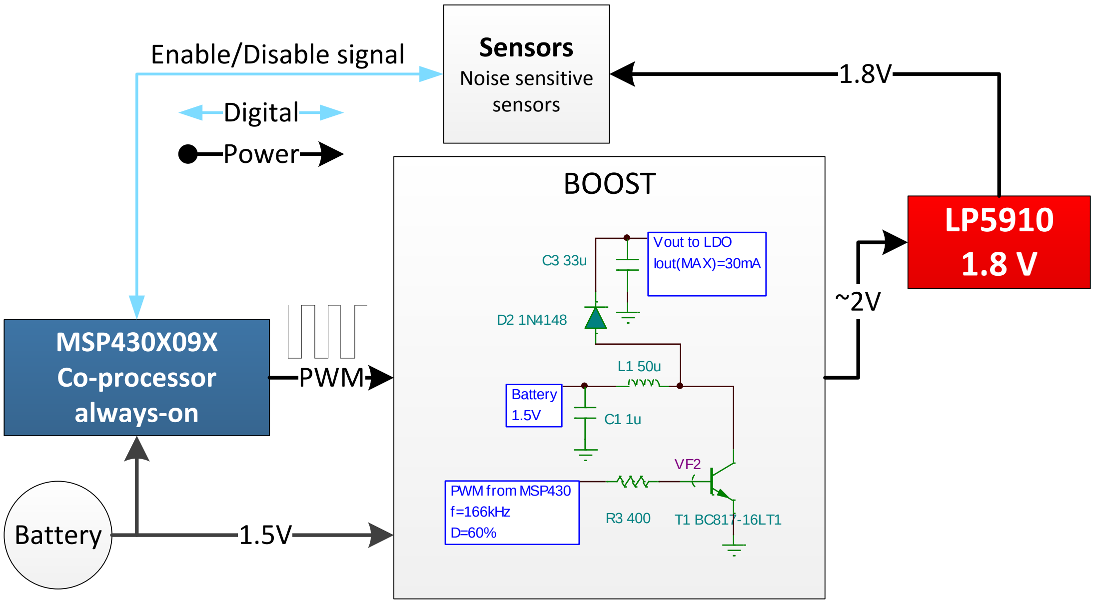


Figure 6 Booster Circuit

The boosted voltage permits interaction with Serial Peripheral Interfaces (SPI) and low voltage sensors interacting with the ULV microcontroller. For additional examples and more detail explanation about the discreet boost circuit please see SLAU324 MSP430L092 User's Guide

Figure 7 shows a Tina spice simulation of the output of the boost converter circuitry and the LP5910 regulator. The input voltage is 1.5V and the maximum recommended load current for this model is 15 mA.

The gate current of the FET is less than 4mA which is within the MSP430 maximum output pin current specs of 5mA.

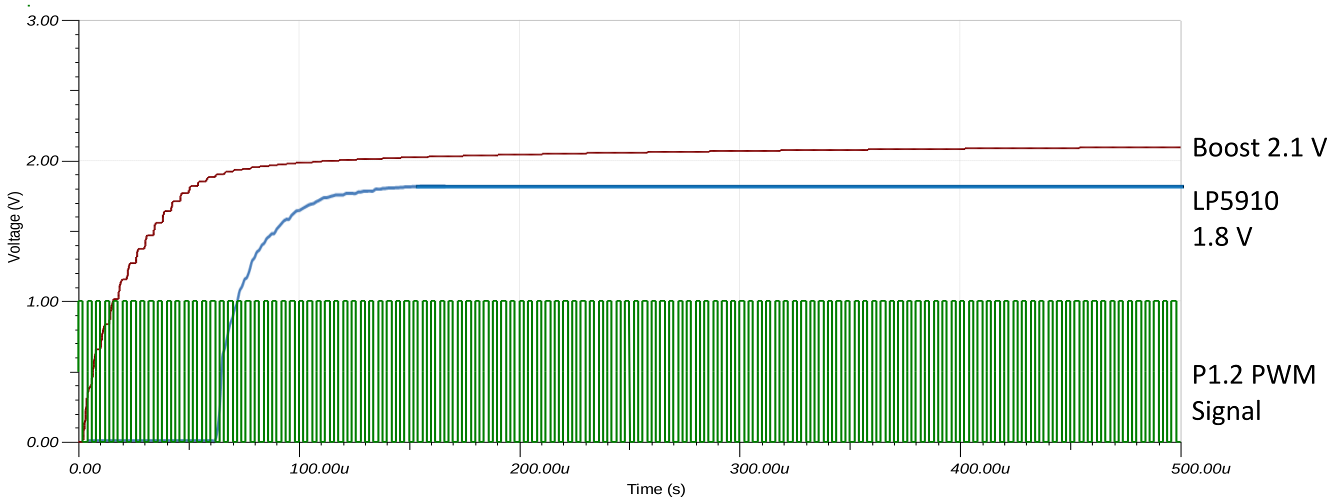


Figure 7 Boost Circuitry Output Voltage

4 Design Power parameters

4.1 Total Typical leakage current

The table below shows the total typical leakage current in shutdown/disable mode, which only 1.217 µA are contributed by the voltage regulators.

Table 2 Total Shutdown Current in Shutdown Mode

DEVICE	TOTAL SHUTDOWN CURRENT (µA)
LP5910	0.02
TPS61221	1.215
MSP430x09x	3
Total	**4.235**

4.2 Power-Up Time Diagram

The microcontroller send an enable signal high to pin B2 of the LP5910 and Pin 6 of the TPS61221 for as long as needed to power the peripherals or sensors, and then disable the regulators output voltage by pulling the EN pin low. Table 3 Shows the EN pin requirements of each device and the MSP430x09x port output voltage capability.

Table 3 Enable Pin voltage requirements

DEVICE	PIN NAME	VOLTAGE LEVEL
LP5910	EN pin B2 Input Voltage	High level voltage → 0.85V Typical EN pin Input current: 3.3µA
		Low Level voltage = 0.75
TPS61221	EN Pin 6 Input Voltage	High level voltage = 0.8 × VIN Max EN pin Input current: 0.1µA
		Low Level voltage = 0.2 × VIN
MSP430x09x	Ports P1, P2 Output voltage	High level voltage = Vcc-0.0125 Output current: 0.1µA
		Low Level voltage =0.2 × VIN

Figure 8 shows the typical power up time diagram of the power system

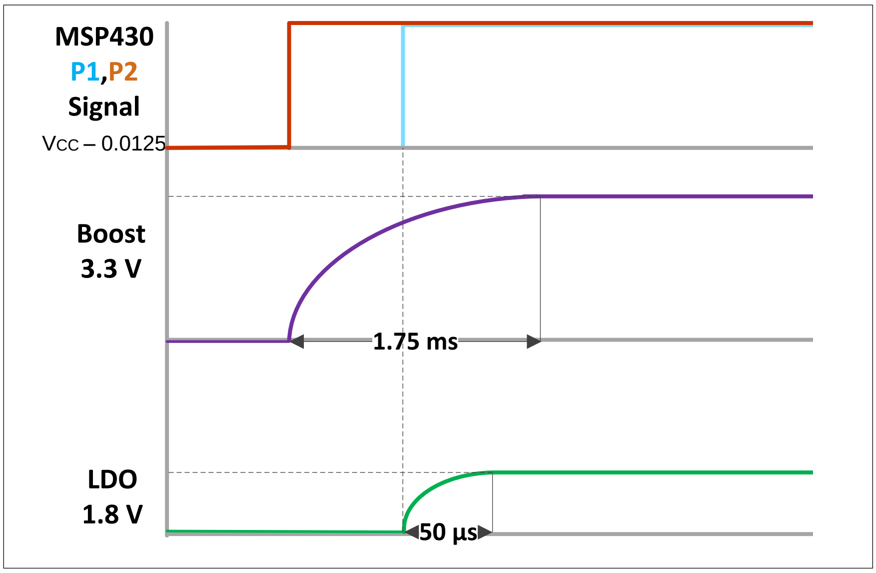


Figure 8 Power-Up Time Diagram

5 Test Setup

Note

The TIDA-00599 board is not available for purchase, but the design files can be downloaded from **http://www.ti.com/tool/tida-00599.**
Also the EVMs for LP5910 (LP5910YKA18EVM) and TPS61221 adjustable version (TPS61220EVM) can be ordered at **www.ti.com**

Before applying power to the TIDA-00599 board, all external connections should be verified. The external power supply must be turned off before being connected. Confirm proper polarity to the V_{IN} and V_{OUT} terminals before turning the external power supply on.

5.1 Test Equipment

The following table shows the test equipment used to collect test data.

Table 4 Test Equipment

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

6 Test Data

6.1 LP5910 Test Data

6.1.1 Power Supply Rejection Ratio

The output voltage ripple rejection ratio was calculated by comparing the regulated output voltage ripple to the input voltage ripple of 50 mV over a frequency range of 10 Hz to 1 MHz

Test Parameters

- V_{IN} = 2.3 V
- V_{OUT} = 1.8 V
- Frequency sweep = 10 Hz to 1 MHz

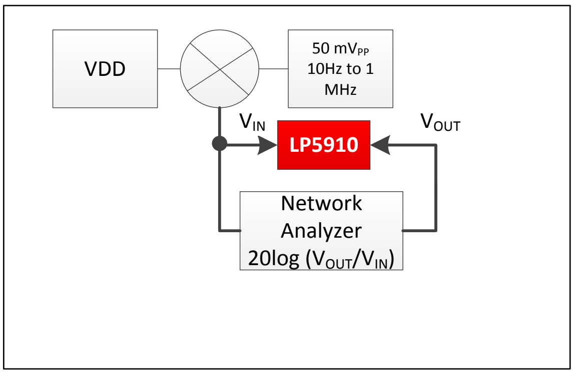


Figure 9 PSRR Test Setup

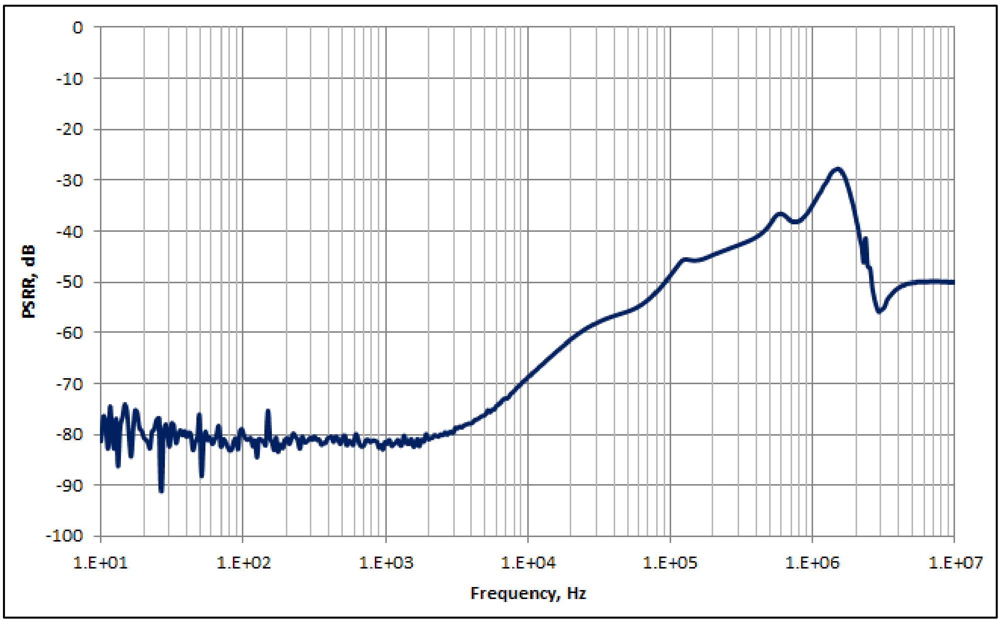


Figure 10: Comparison between Frequency and PSRR

6.1.2 LP5910 Noise Density

V_{OUT}= 1.8 V

Bandwidth = 10 Hz to 100 kHz

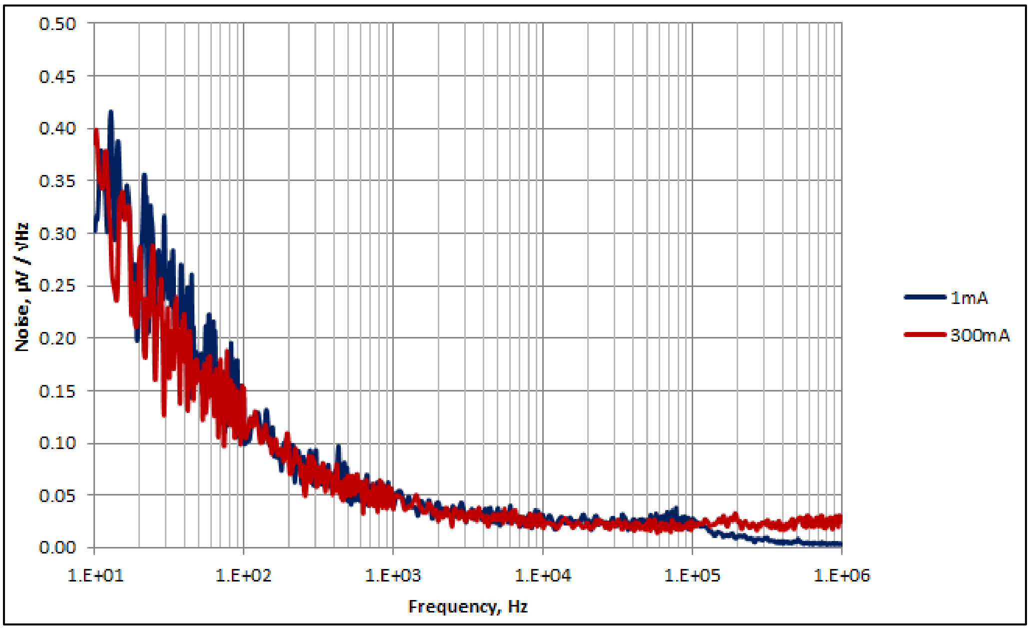


Figure 11 Noise Density

6.1.3 Load Transient and Regulation

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

Test parameters:

- Load current slew rate: 10 mA/µs
- Load Step: 100 mA to demonstrate the worst case, in this design the transient will be even smaller, because the load step should be a maximum of 40 mA
- V_{OUT}= 1.8
- C_{OUT} =1 µF

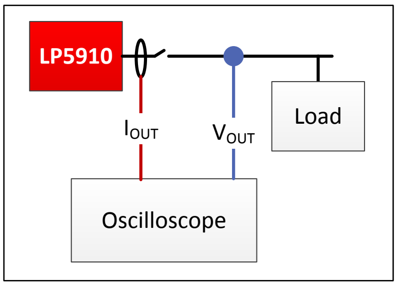


Figure 12 Load Transient Test setup

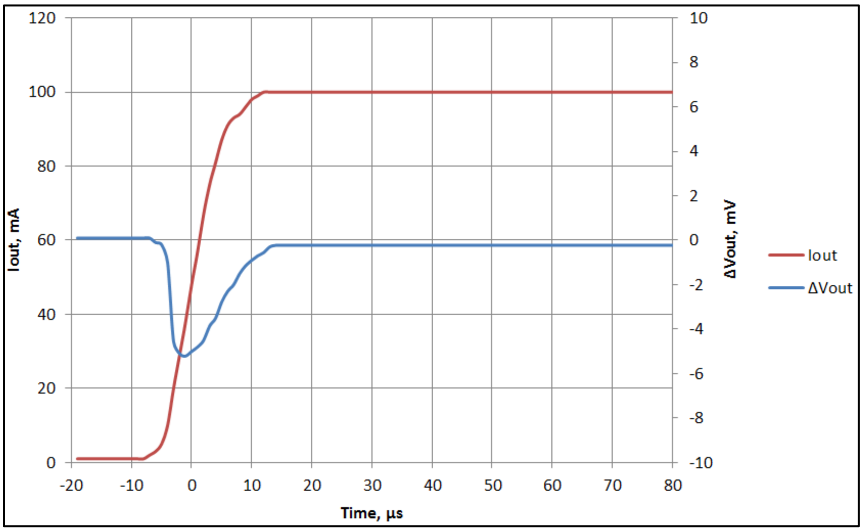


Figure 13 Load Transient Rising Edge Load Step

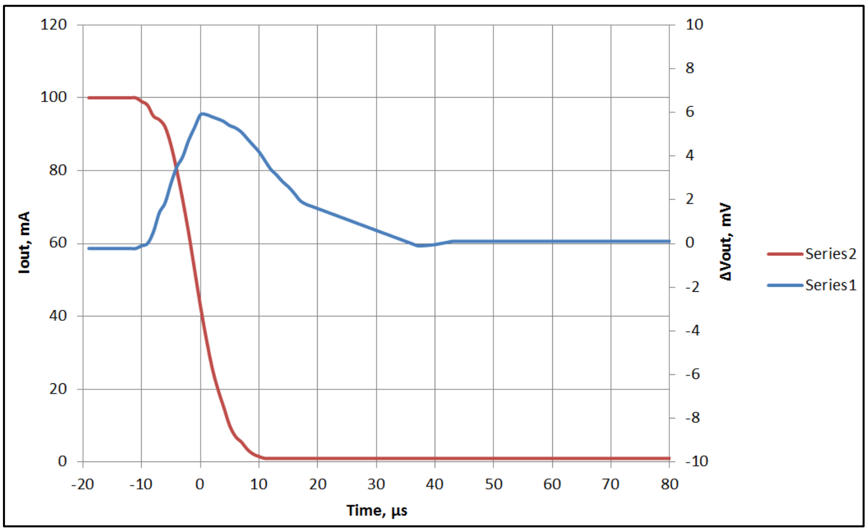


Figure 14 Load Transient Falling Edge Load Step

6.1.4 LP5910 Power up Timing

Test parameters:

- V_{OUT} = 1.8
- C_{OUT} =1 µF

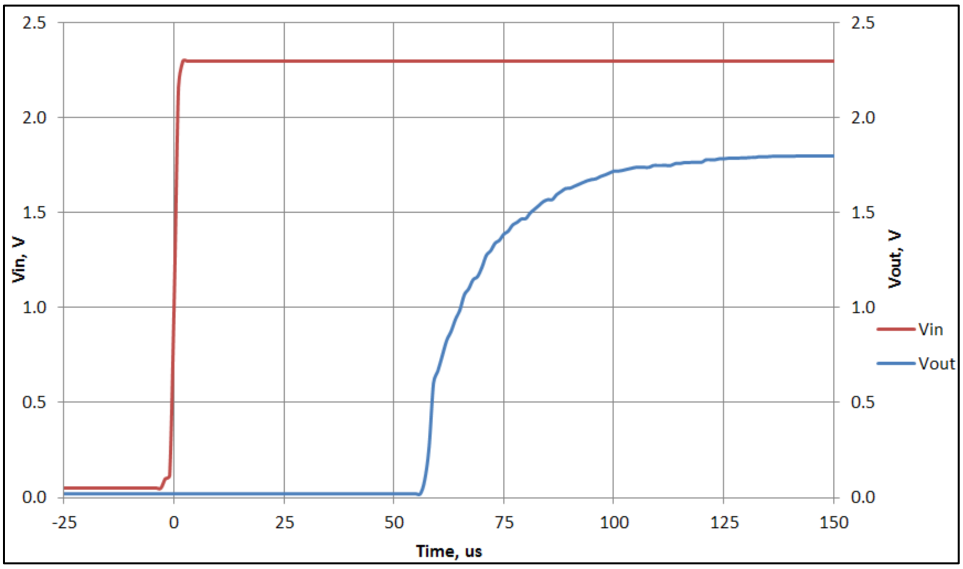


Figure 15 Power up Timing

6.1.5 LP5910 Dropout Voltage

Dropout voltage is the voltage difference between the input and the output at which the output voltage drops to 100 mV below its nominal value.

The maximum dropout voltage is expected to be 150 mV at room temperature, the nominal voltage of the boost converter in the alternative discreet boost method in section 3.4 should be 1.8 V+V_{DO}

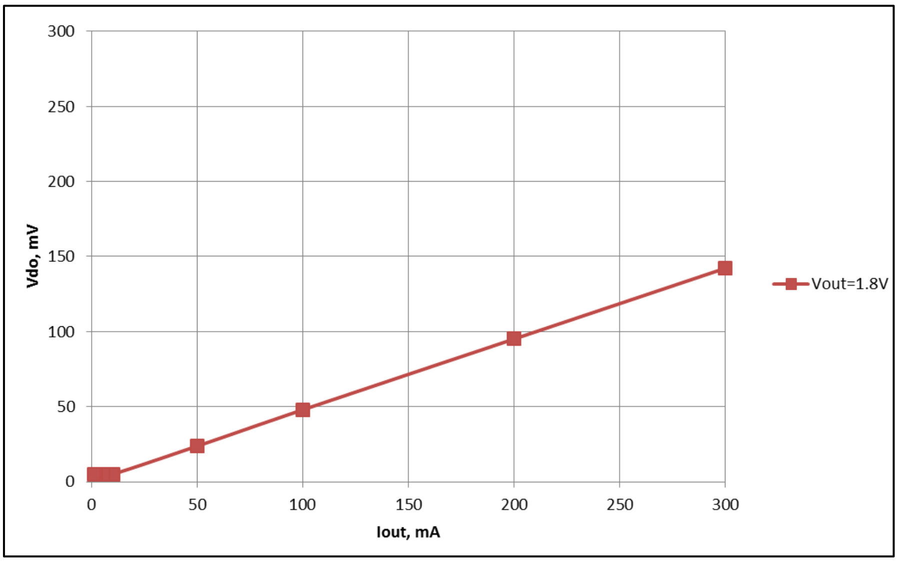
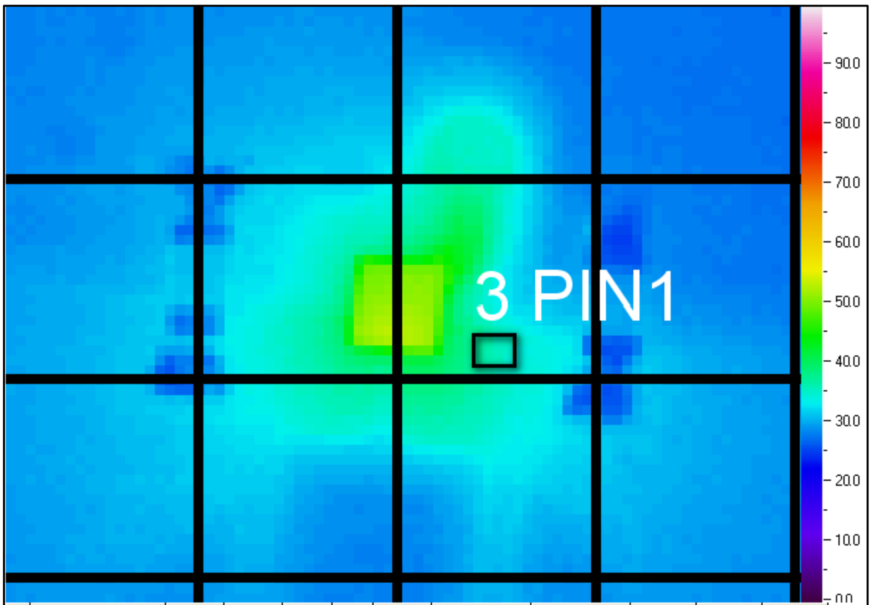


Figure 16 Dropout Voltage vs I_{OUT}

6.1.6 Thermal image

Test parameters:

- Package = DSBGA
- P_D= 450 mW (Power dissipation)
- $T_{AMBIENT}$ = 22 ^{o}C



#	Name	Hi Lim	Low Lim	Fail %	Emiss	Area	%>Hi (#pix)	%<Low (#pix)	Max	Min	Mean
1	IC perimeter	100.0	0.0		1.00	7,744			53.04	24.92	29.82
2	REGION	100.0	0.0		1.00	68,175			53.04	24.20	26.96
3	PIN1	100.0	0.0		1.00	12			37.22	34.92	36.07

Figure 17 DSBGA LP5910 Thermal Capture

Results:

$T_{CASE\ (TOP)}$ = 53 ^{o}C

The junction temperature (T_J) was approximated to be 59.7 ^{o}C with **Equation 2**

$$T_J = \psi_{JT} \bullet P_D + T_{CASE\ \mathbf{(TOP)}} \quad \textbf{Equation 2}$$

ψ_{JT}= LP5910 Junction-to-top characterization parameter is 15 °C/W

The junction to ambient thermal resistance ($R_{\Theta JA}$) of the LP5910 on the evaluation board was approximated using **Equation 3** and it came out to be 83.7 °C/W

$$R_{\Theta JA} = (T_J - T_{AMBIENT})/P_D \quad \textbf{Equation 3}$$

Note

Thermal results are directly related with PCB and board layout, the thermal characteristics will vary for a different PCB.
For more information about thermal metrics, Please refer to the IC Package Thermal Metrics application report SPRA953B

6.2 TPS61221 Test data

6.2.1 Efficiency vs Input Voltage and Output Current

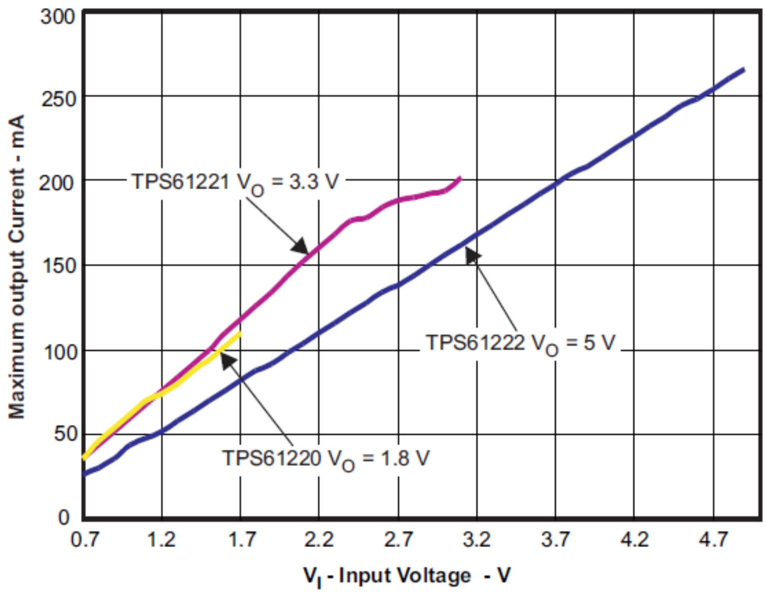


Figure 18 Efficiency vs Input Voltage and Output Current

6.2.2 Efficiency versus Output Current and Input Voltage

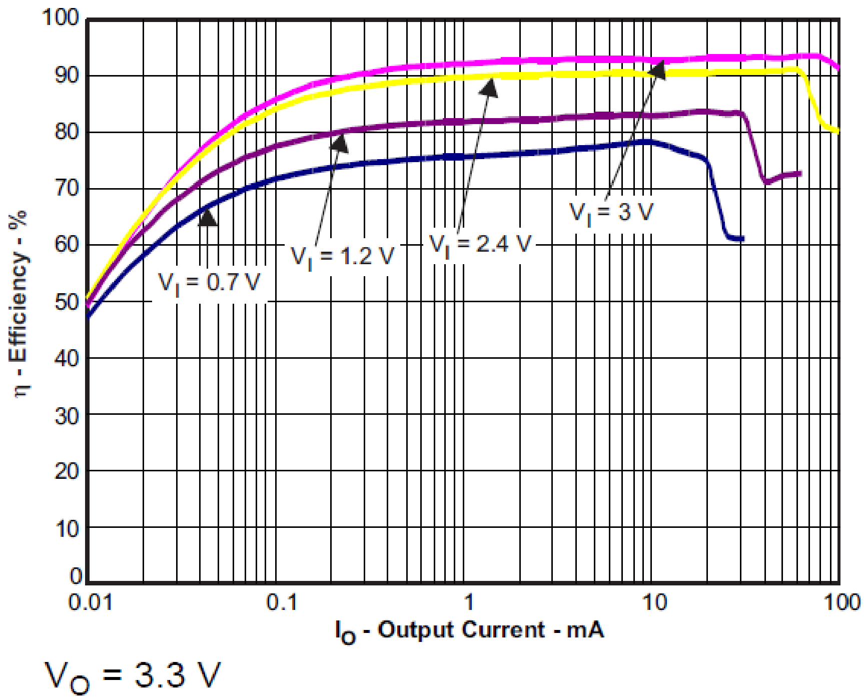


Figure 19 Efficiency versus Output Current and Input Voltage

6.2.3 Efficiency versus Input Voltage and Output Current

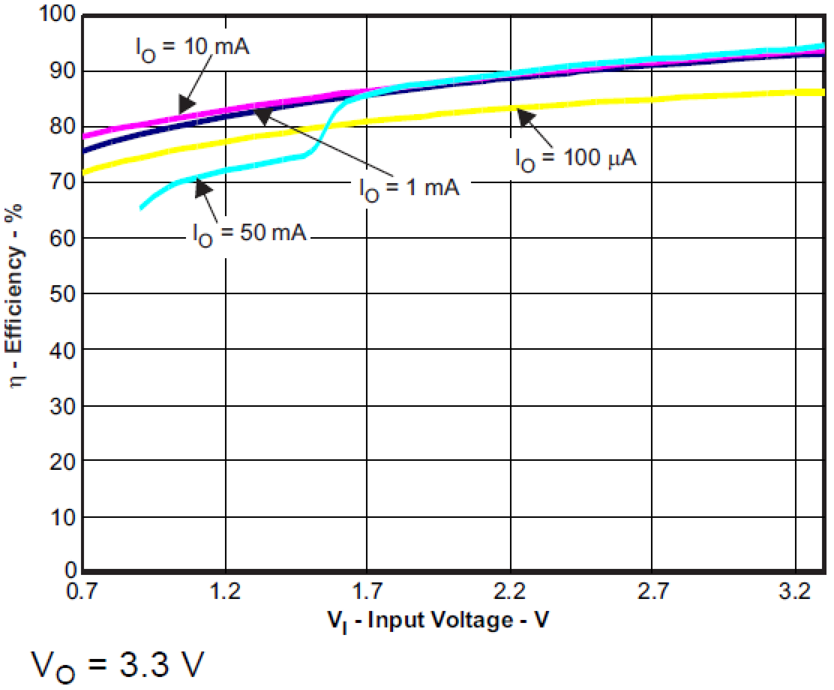


Figure 20: Efficiency versus Input Voltage and Output Current

6.2.4 Startup after Enable

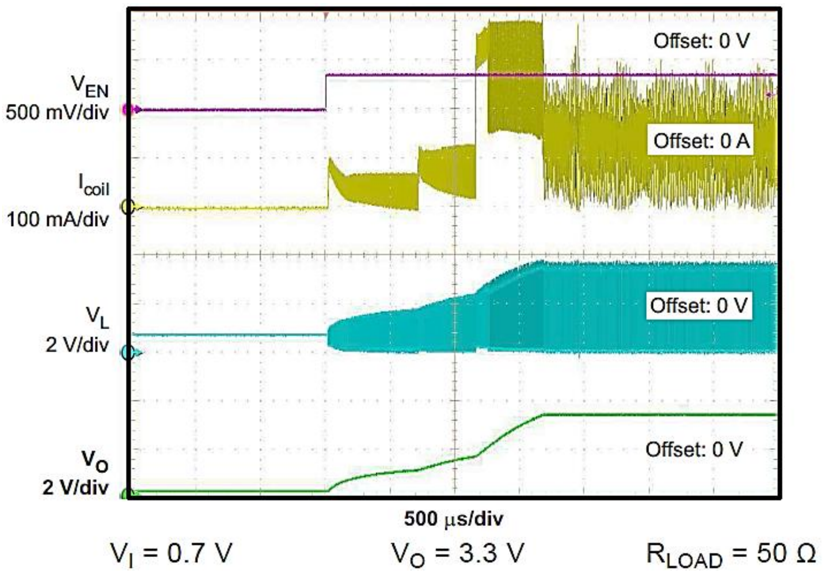


Figure 21: Startup after Enable

7 Design Files

7.1 Schematics

To download the Schematic, see the design files at http://www.ti.com/tool/tida-00599

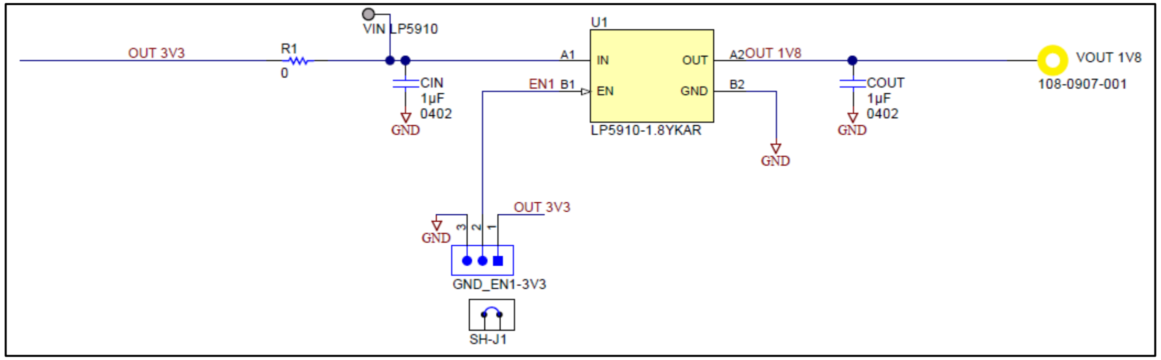


Figure 22 TIDA-00599 Schematic (LP5910)

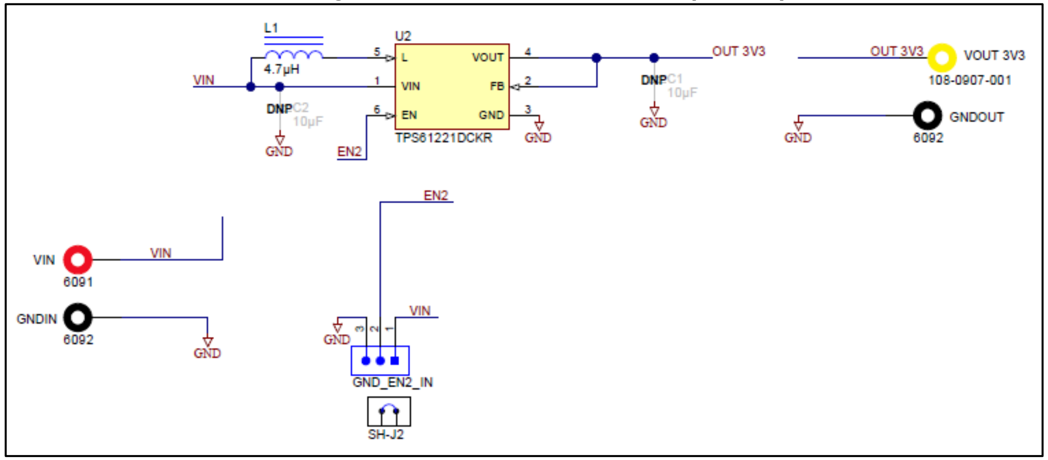


Figure 23: TIDA-00599 Schematic (TPS61221)

7.2 PCB Layout Recommendations

- As a rule of thumb avoid connections using long trace lengths and narrow trace widths. These will add parasitic inductances and resistance that resulting in inferior performance especially during transient conditions
- Avoid any sharp corners. Electric fields tend to build up on corners, increasing EMI coupling.
- The input and output capacitor, as well as the inductor should be placed as close as possible to the IC.
- Ensure a low resistance path for ground and return paths

7.2.1 PCB Layout Guidelines

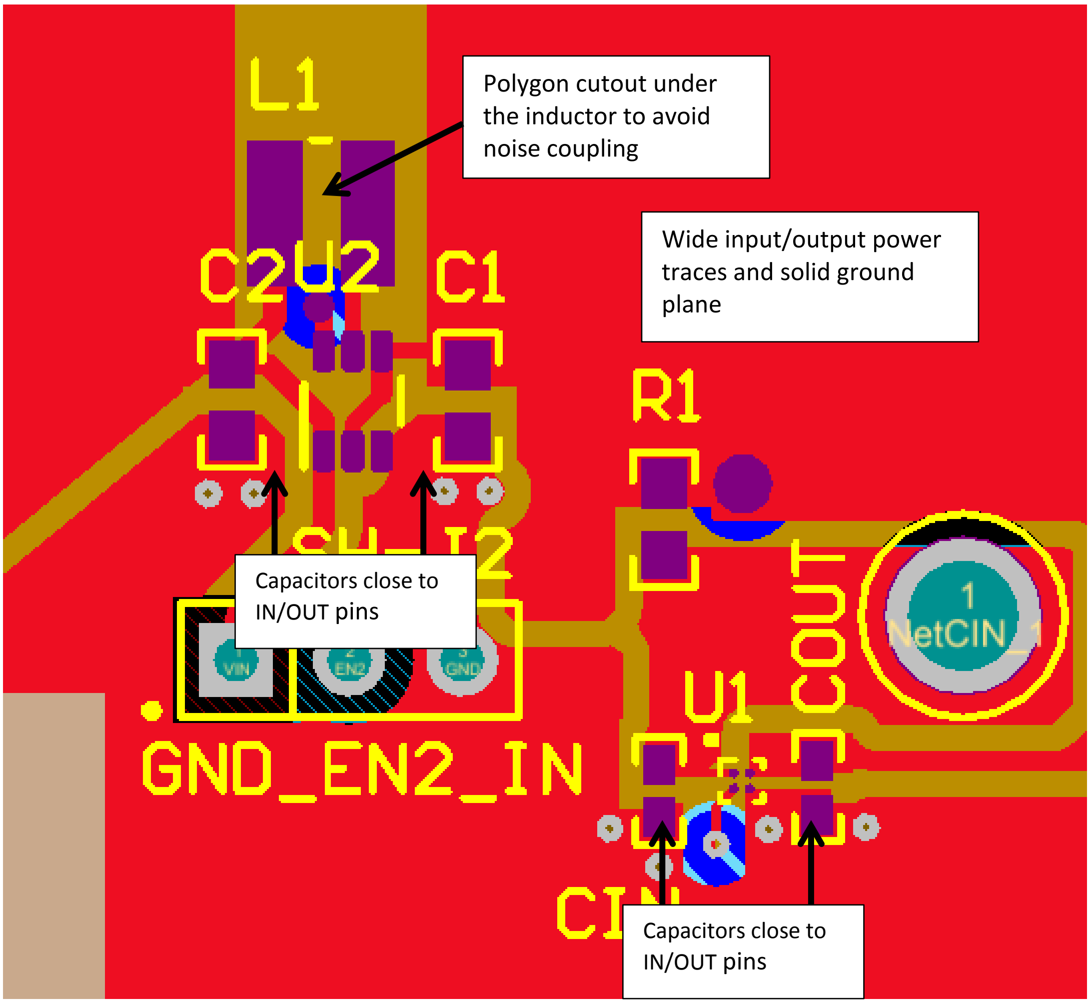


Figure 24: TIDA-00599 Layout Guidelines

7.2.2 Altium Project

The Altium project files can be downloaded at the link below.
http://www.ti.com/tool/TIDA-00599

- Gerber and NC-drills
- Bill of Materials (BOM)
- Assembly Drawings

8 References

1. Texas Instruments User's Guide, MSP430x09x Family, SLAU321, 2010
2. Texas Instruments User's Guide, MSP430L092, *SLAU324*, 2011
3. Texas Instruments Application Report, MSP430L092 Development Guide, *SLAA472A*, 2011
4. Texas Instruments Application Report, MSP430 Wiki page
5. Texas Instruments multimedia, MSP430L092 Introduction, *LINK*
6. Texas Instruments Application Report, Basic Calculation of a Boost Converter's Power Stage, SLVA372C, 2014
7. Texas Instruments TI Designs: Low-Input Voltage High-Current Boost Converter With TPS61088, PMP9772, 2014

9 Terminology

TI Glossary: SLYZ022 This glossary lists and explains terms, acronyms, and definitions.

10 About the Author

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Antony is a Systems and Applications Engineer at Texas Instruments Incorporated. Antony is responsible for developing reference design solutions for the mobile devices power RF (MDP-RF) power group. Antony brings to this role experience in system-level analog, mixed-signal, and power management design. Mr. Carvajales earned his bachelor of science (BS) in electrical engineering from the Florida International University in Miami FL. Antony is a member of the Institute of Electrical and Electronics Engineers (IEEE) and the Society of Hispanic Professional Engineers (SHPE).

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