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Linear Regulator Power Solution Reference Design for Reducing MSP430G2xx3 Power Dissipation

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Design Resources

TIDA-00691	Design Folder
LP5900	Product Folder
MSP430G2xx3	Product Folder

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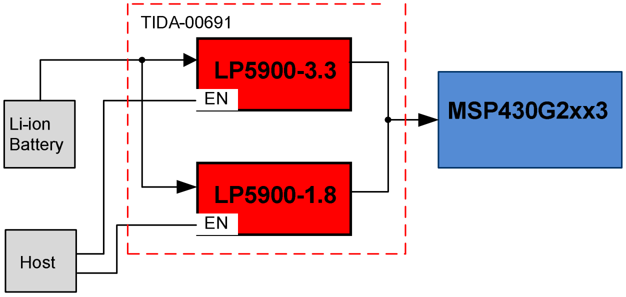
Block Diagram



Design Features

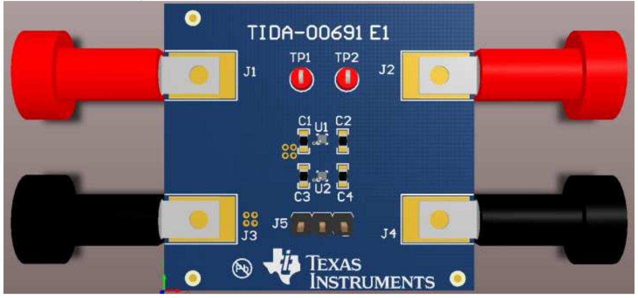
- Low power dissipation solution
- Small size solution
- Cost optimized solution
- Ripple free and low noise solution
- TIDA-00691 provides design guide and design files of the power solution

Featured Applications

Single li-ion battery applications

- MSP430 power supplies
- Personal electronics
- E-meter power supplies
- DSP and FPGA power supplies
- Home or office security monitoring

Board Image



1 System Description

MSP430G2xx3 are a line of ultra-low-power mix-signal microcontroller that can operate from a voltage supply range of 1.8V to 3.6V. This voltage range is ideal for single li-ion battery systems, usually a linear regulator is used to power MSP430G2xx3 after li-ion battery.

MSP430 features low power dissipation, while at a given frequency, the power dissipation rises if increasing MSP430 supply voltage, that means the power dissipation is reduced if reducing supply voltage.

The TIDA-00691 is a power reference design for powering MSP430G2xx3. In this design, a 3.3V voltage is rail is generated from a Li-ion battery using a low quiescent current LDO (LP5900-3.3) to power MSP430G2xx3. Another low quiescent current LDO (LP5900-1.8) is parallel with LP5900-3.3, which output is 1.8V. These two LDO are controlled separately by EN pin, at any time, there is one LDO on working. In the application where if only one EN signal is presented, then a NOT gate might be needed to realize there is one LDO on working at any time.

This power solution can power MSP430 operation and also can reducing total power dissipation if changing to a lower supply voltage.

The TIDA-00691 reference design provides test the data, design guide and Gerber files, all the files can be obtain from the design folder at www.ti.com/tool/TIDA-00691

2 Block Diagram

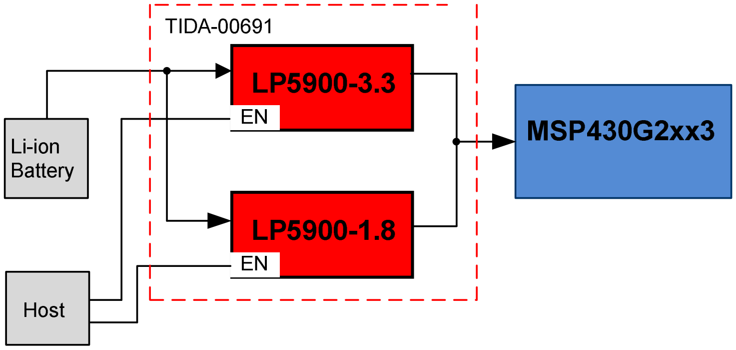


Figure 1 TIDA-00691 High Level Block Diagram

The Figure 1 shows the high level block diagram of the TIDA-00691 design. The red blocks represent the main components of this document. The components in blue (MSP430G2xx3) defined the voltage and current requirements of the design. The MSP430G2xx3 was not designed in the TIDA-00691 evaluation board, but its power requirements were taken into consideration to define the design parameters.

2.1 Highlighted Power Management Components

2.1.1 LP5900 Low Quiescent Current, Low Noise Linear Regulator

LP5900 is a 150mA, low quiescent current, ultra-low noise, low-dropout and small size linear regulator, Figure 2 shows LP5900 Functional Block Diagram.

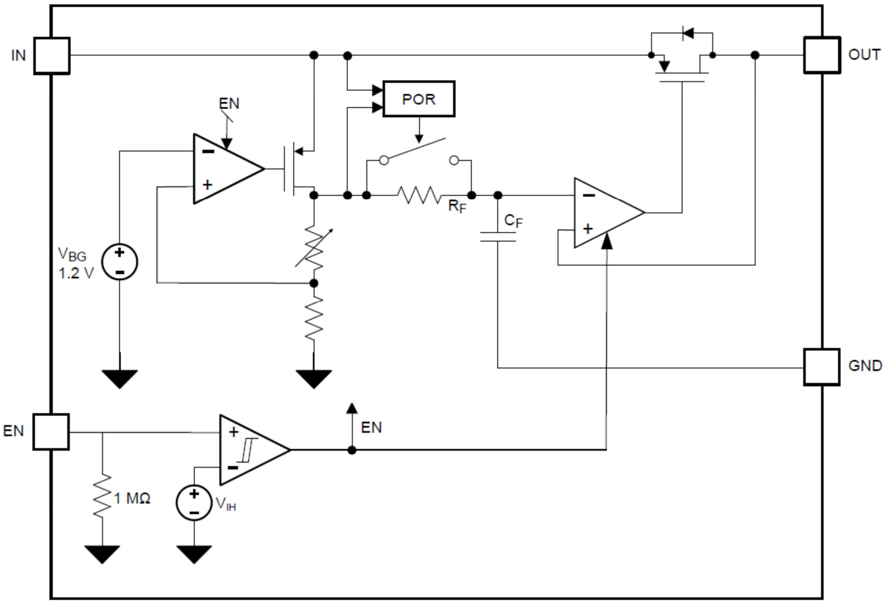


Figure 2 LP5900 Functional Block Diagram

LP5900 has below features:

- -40°C to 125°C Junction Temperature Range for Operation
- Stable with 0.47-µF Ceramic Input and Output Capacitors
- Thermal-Overload and Short-Circuit Protection
- Low Output Voltage Noise, 6.5µVRMS
- No Noise Bypass Capacitor Required
- Input Voltage Range, 2.5V to 5.5V
- Virtually Zero IQ (Disabled), < 1µA
- Output Voltage Tolerance, ±2%
- Very Low IQ (Enabled), 25µA
- Low Dropout, 80 mV Type
- Output Current, 150mA
- Logic Controlled Enable
- Start-up Time, 150 µs
- PSRR, 75 dB at 1kHz

Table 1 Key LP5900 Parameters

PARAMETERS	TYPICAL VALUES	
Package Size	1.108 mm × 1.083 mm	
PSRR	>75dB @ 1kHz	
Output Noise	I_{OUT}=1mA	10 µVRMS
	I_{OUT}=150mA	6.5 µVRMS
Load Transient I_{OUT}=150mA to 1mA in 10 µs	50 mV	
IQ Quiescent Current VEN=0.3 V (Disabled)	< 1 µA	

2.2 Other TI Components

2.2.1 MSP430G2xx3 Low Power Consumption Microcontroller

The MSP430G2xx3 family of ultra-low-power microcontrollers consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low-power modes, is optimized to achieve extended battery life. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 1 µs.

The MSP430 has one active mode and five software selectable low-power modes of operation. An interrupt event can wake up the device from any of the low-power modes, service the request, and restore back to the low-power mode on return from the interrupt program.

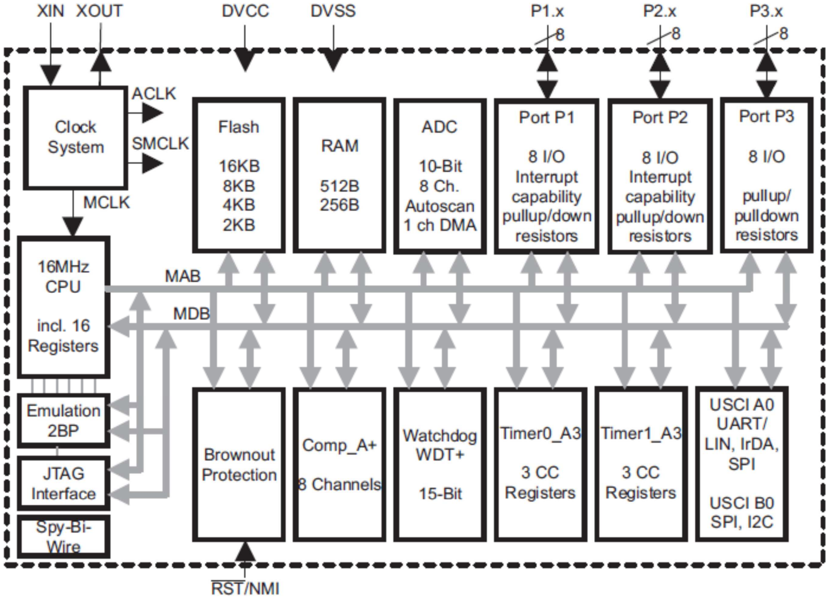


Figure 3 Functional Block Diagram, MSP430G2x53

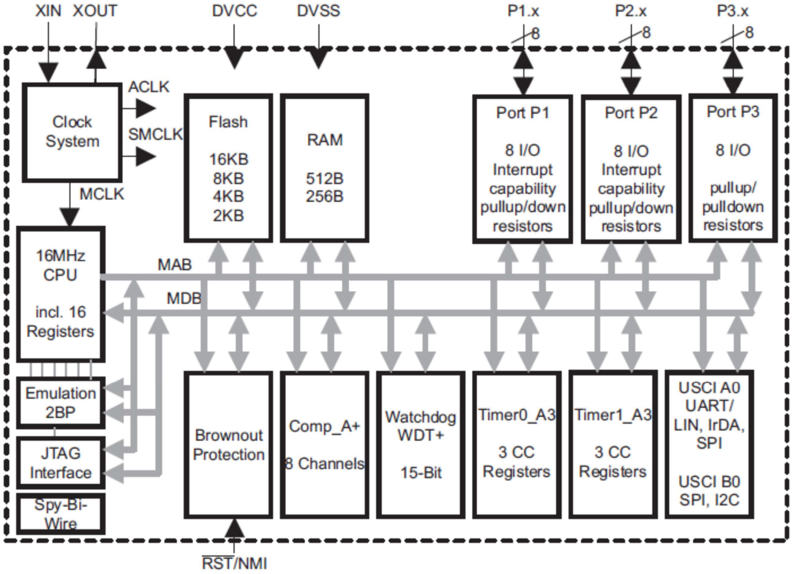


Figure 4 Functional Block Diagram, MSP430G2x13

Power specification overview as:

- V_{CC} Supply Voltage: 1.8V to 3.6V (During program execution)
- V_{CC} Supply Voltage: 2.2V to 3.6V (During flash programming or erase)
- Processor frequency (maximum MCLK frequency):
  - 6 MHz (V_{CC}=1.8V)
  - 12 MHz (V_{CC}=2.7V)
  - 16 MHz (V_{CC}=3.3V)
- Active mode current at 1MHz: 230 µA (V_{CC}=2.2V), 330 µA (V_{CC}=3V)
- Active mode current at 16MHz: 4.2 mA (V_{CC}=3.3V)
- Low-power mode 0 current: 56 µA (V_{CC}=2.2V)
- Low-Power mode 1 current: 22 µA (V_{CC}=2.2V)
- Low-power mode 2 current: 0.7 µA (V_{CC}=2.2V)
- Low-power mode 3 current: 0.5 µA (V_{CC}=2.2V)
- Low-power mode 4 current: 0.1 µA (V_{CC}=2.2V)

3 Design Consideration

3.1 MSP430G2xx3 Supply Voltage and Current

MSP430 is popular for its low power dissipation; it can limit the current drawn on batteries to extend the battery life. In Li-ion battery supply application, it usually uses a linear regulator after the li-ion battery to power the MCU, because the linear regulator features smaller external components, simple design, no switching ripple and lower noise by comparing with switching supply, and at very light load, the linear regulator even has better efficiency than switching supply.

The MSP430 frequency is related with supply voltage, this is shown in the figure 5, if running the system at 16MHz, MSP430 requires a minimum supply of 3.3V, and in initiative startup the supply voltage is set as 3.3V where a 3.3V output linear regulator is used.

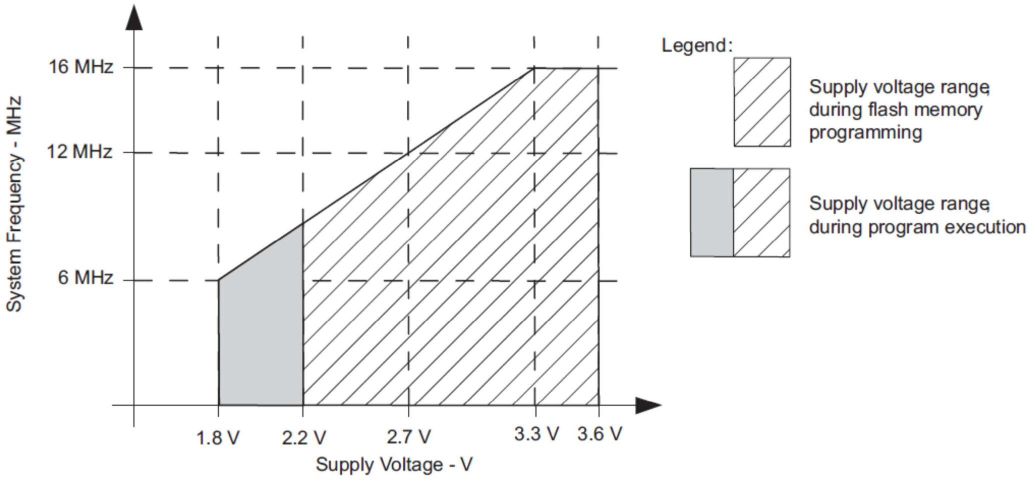


Figure 5 MSP430 Frequency vs Supply Voltage

If looking at current consumption at different supply voltage – system frequency combinations as below figure 6 and figure 7, it shows that at a given frequency, if increasing the supply voltage then current consumption rises as well, conversely, if holding supply voltage constant and increasing operating frequency, current consumption will also rise. It can be concluded that by lowering the supply voltage more power dissipation will be saved.

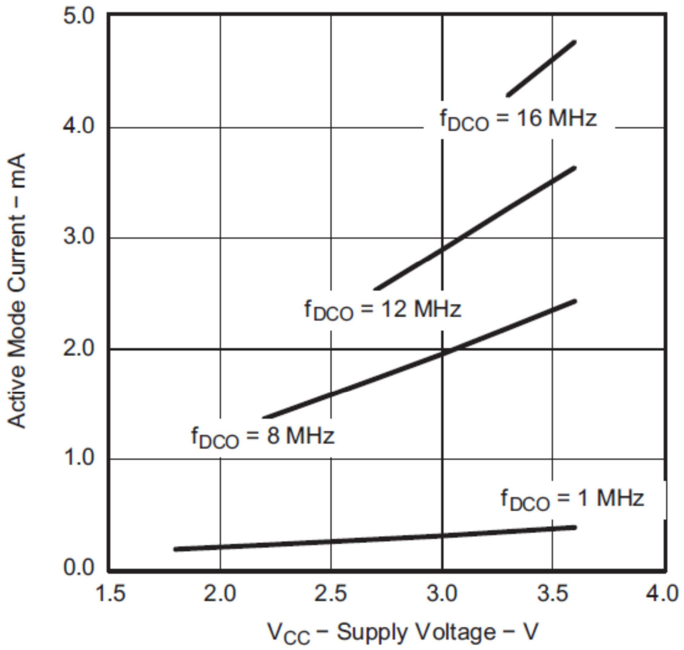


Figure 6 MSP430 Active Mode Current vs V_{CC}, TA=25°C

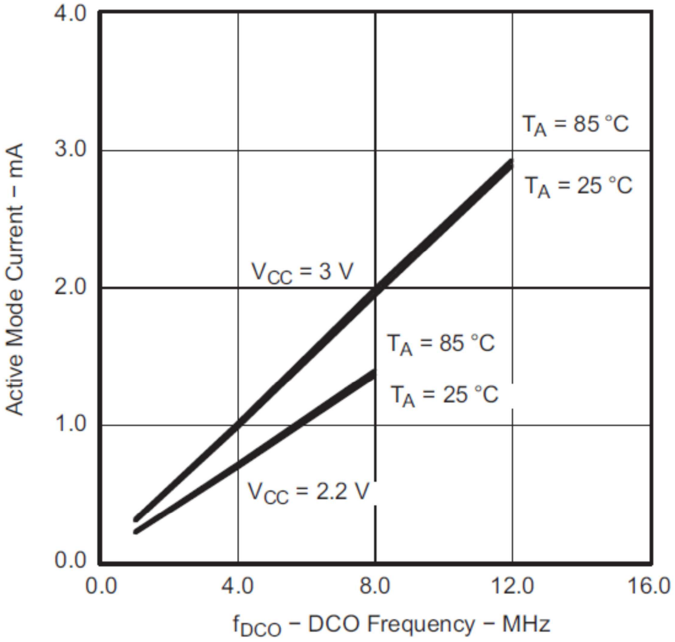


Figure 7 MSP430 Active Mode Current vs DCO Frequency

For example, if powering the MSP430 running at 1MHz with 3.3V, it is expected that the active mode current will be 400 µA. If lower the voltage from 3.3V to 1.8V, the current consumption drops down to 200 µA. That is 50% reduction in current consumption.

3.2 Low Quiescent Current Linear Regulator

LP5900 is low quiescent current linear regulator. A 3.3V output of LP5900 is used to power MSP430 at all system frequencies. While if system frequency is lower, for example, just 1MHz, then a lower output linear regulator, 1.8V output of LP5900 can be used to take over the supply role.

In this power structure, LP5900-3.3 and LP5900-1.8 work in parallel to power MSP430, but not work at same time, there is only one LDO at most on working at any time. The shutdown LDO consume less than 1 µA, and LP5900 doesn't have auto discharge resistor when in shutdown, overall, the shutdown one doesn't add any additional power consumption.

4 Design Implementation Guidelines

LP5900 application circuit is as Figure 8.

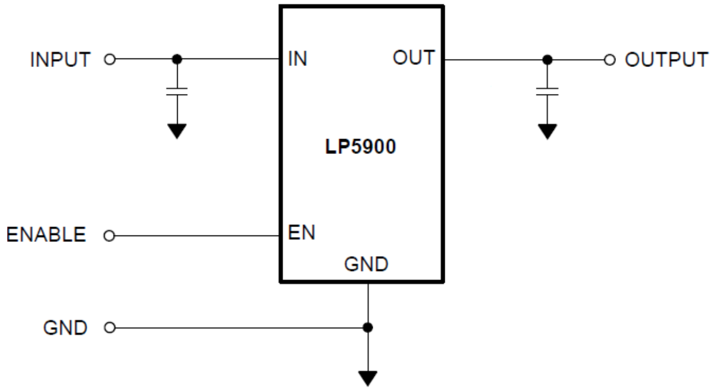


Figure 8 LP5900 Application Circuit

Table 2 shows the design parameters of the power management design

Table 2 Power Design Parameter

PARAMETERS		TYPICAL VALUES
V_{IN}		3.6 V (typical)
V_{OUT}	LP5900-3.3	3.3 V
	LP5900-1.8	1.8 V
I_{OUT} Max		150 mA

4.1 Input Output Voltage

The LP5900 operates from an input voltage range of 2.2V to 5.5V and comes in fixed output voltages in the range of 1.2V to 4.5V and is available in two packages DSBGA and WSON. In this application, the LP5900-1.8YZR and LP5900-3.3YZR were selected which are DSBGA package with 1.8V and 3.3V output voltage.

4.2 Capacitors

The LP5900 requires that at least 0.47 µF 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.

4.2.1 Input Capacitor

To ensure proper loop operation, the input capacitor must be located a distance of not more than 1 cm from the input pin and returned to a clean analog ground. Any good quality ceramic, tantalum, or film capacitor may be used for the input.

4.2.2 Output Capacitor

The LP5900 is designed specifically to work with very small ceramic output capacitors. A ceramic capacitor in the 0.47 µF to 10 µF range, and with ESR between 5 mΩ to 500 mΩ, is suitable in the LP5900 application circuit. For this device the output capacitor should be connected between the OUT pin and a good ground connection and should be mounted within 1 cm of the device.

It may also be possible to use tantalum or film capacitors at the device output, OUT, but these are not as attractive for reasons of size and cost.

The output capacitor must meet the requirement for the minimum value of capacitance and have an ESR value that is within the range of 5 mΩ to 500 mΩ for stability.

5 Test Setup

Before applying power to the TIDA-00691 board, all external connections should be verified. The external power supply must be turned off before being connected. Confirm proper polarity to the VIN and VOUT 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 3 Test Equipment

TEST EQUIPMENT	PART NUMBER
Oscilloscope	TEK DPO5104B
DC voltage supply	Agilent E3634A
Multimeter	Agilent E34401A

6 Test Data

6.1 LP5900-3.3 and LP5900-1.8 Start Up

The startup waveforms were captured by toggling EN signal.

Test parameters

- V_{IN}=3.6V
- V_{OUT}=1.8V (LP5900-1.8), 3.3V (LP5900-3.3)

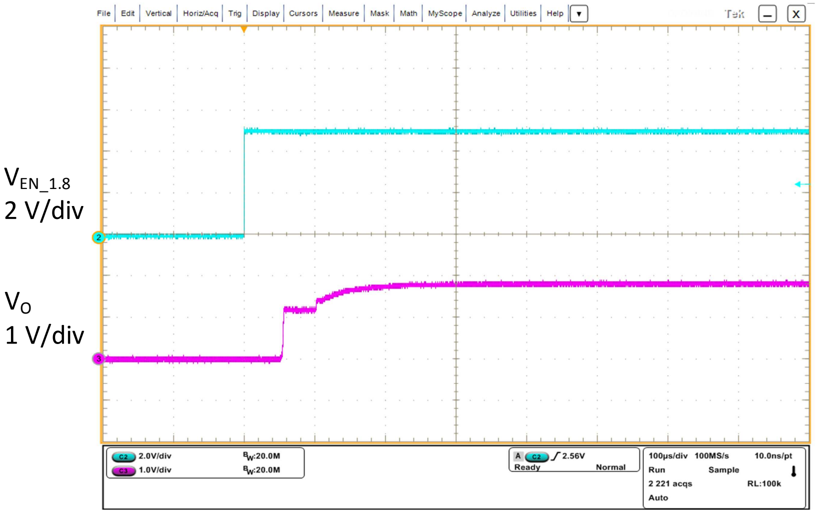


Figure 9 LP5900-1.8 Startup by Enable

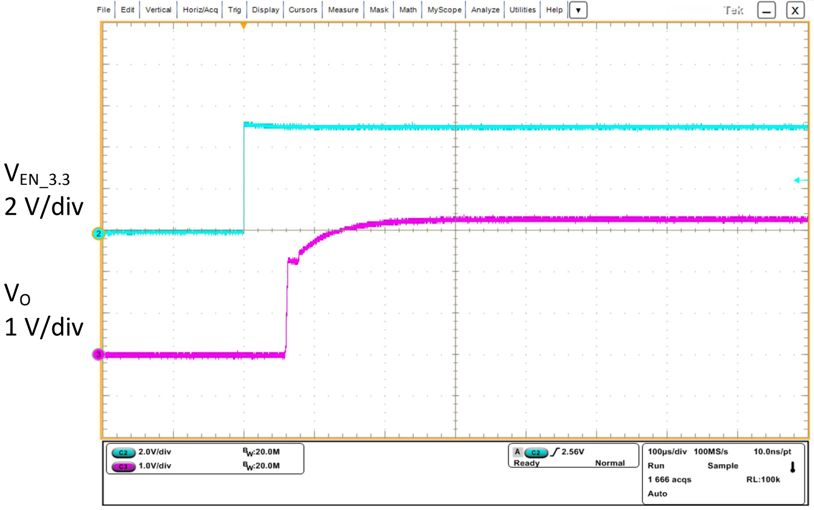


Figure 10 LP5900-3.3 Startup by Enable

6.2 MSP430 Supply Changing

This section shows TIDA-00691 power solution output by controlling LP5900-3.3 and LP5900-1.8 enable separately to realize MSP430 supply changing, and low power dissipation can be achieved. The test setup is as in Figure 11, in this setup, MSP430G2553 launch pad is as the load.

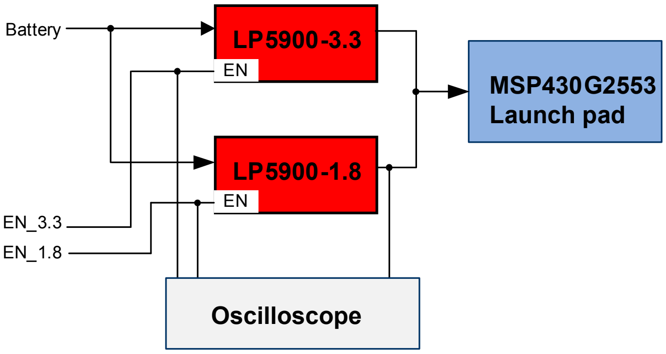


Figure 11 Test Setup

The MSP430 supply changing from 3.3 V to 1.8 V is shown in Figure 12. In this setup, the MSP430 clock frequency is configured to 1MHz. From the Zoom in Figure 13, MSP430 clock frequency operates normally during the changing.

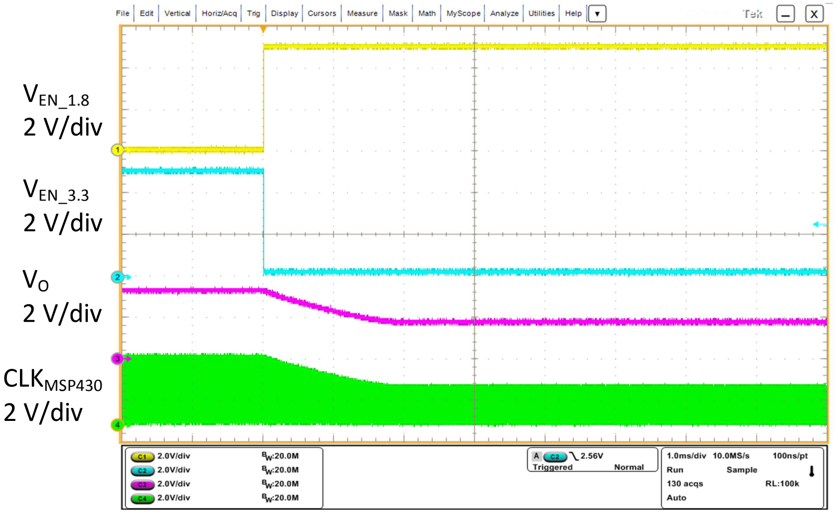


Figure 12 MSP430 Supply Changing from 3.3V to 1.8V

Figure 13 Zoom in on Figure 12

As shown in Figure 5, the minimum supply voltage required for 16MHz is 3.3V, if MSP430 is configured to 16MHz, the supply voltage should be changed firstly, then configure MSP430 frequency, so the supply changing from 1.8V to 3.3V is shown in figure 14. The frequency is also not affect during supply changing, as shown in Figure 15.

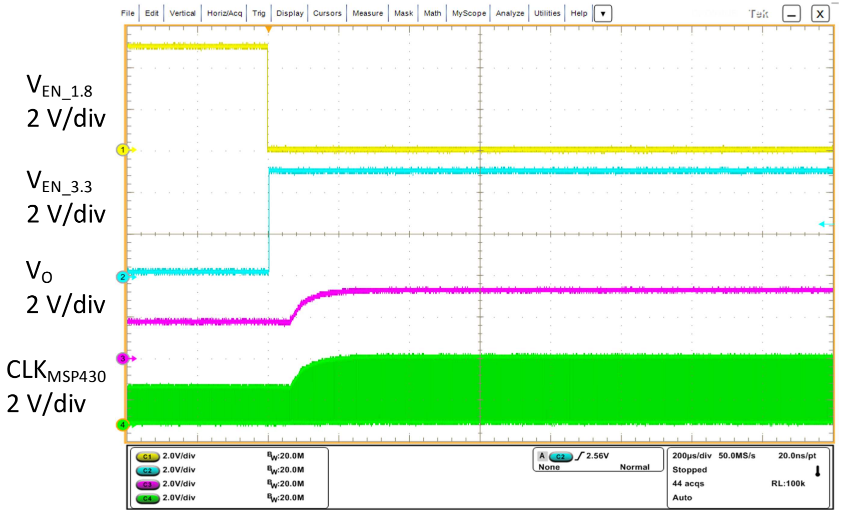


Figure 14 MSP430 Supply Changing from 1.8V to 3.3V

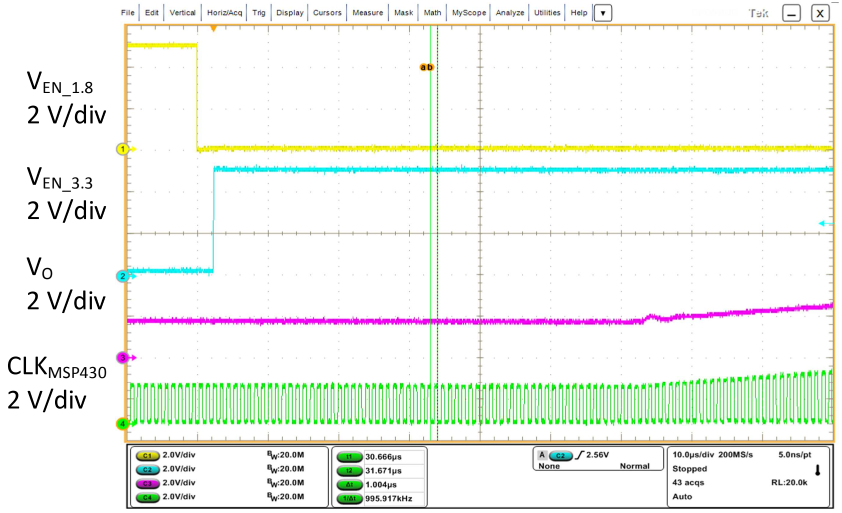


Figure 15 Zoom in on Figure 14

6.3 Power Dissipation Reduced Calculation

The power dissipation can be calculated as below, at 1MHz clock frequency, the MSP430 supply current under different supply voltage is list as below.

$$I_{supply1} = 400\mu A, \text{ at } V_{CC} = 3.3V \tag{1}$$

$$I_{supply2} = 200\mu A, \text{ at } V_{CC} = 1.8V \tag{2}$$

If the MSP430 supply voltage is 3.3V, the total power dissipation of linear regulator and MSP430 is as below.

$$P_{Loss} = (V_{battery} - 3.3) \times I_{supply1} + 3.3 \times I_{supply1} = V_{battery} \times I_{supply1} \tag{3}$$

If the MSP430 supply voltage is changed to 1.8V, then the total power dissipation is as equation (4)

$$P_{Loss} = (V_{battery} - 1.8) \times I_{supply2} + 1.8 \times I_{supply2} = V_{battery} \times I_{supply2} \tag{4}$$

That is 50% reduction in power dissipation.

While the LP5900-1.8 and LP5900-3.3 are parallel, there is a leakage current flowing into the shutdown one as Figure 16. The leakage current measured is 200uA.

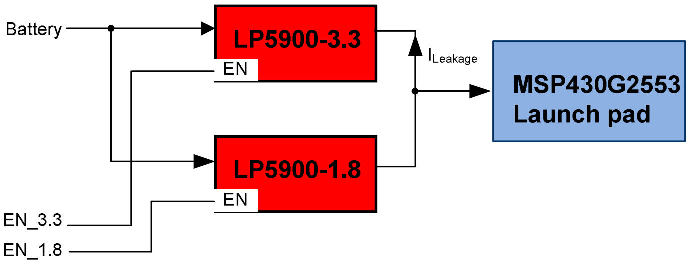


Figure 16 Leakage Current Path

The total power dissipation in equation (4) should be as equation (5),

$$P_{Loss} = V_{battery} \times I_{supply2} + 1.8 \times I_{leakage} \tag{5}$$

Under battery typical 3.6V voltage, TIDA-00691 also provides 25% reduction in power dissipation by comparing traditional one 3.3V linear regulator solution.

7 Design Files

7.1 Schematics

To download the Schematics for each board, see the design files at http://www.ti.com/tool/TIDA-00691

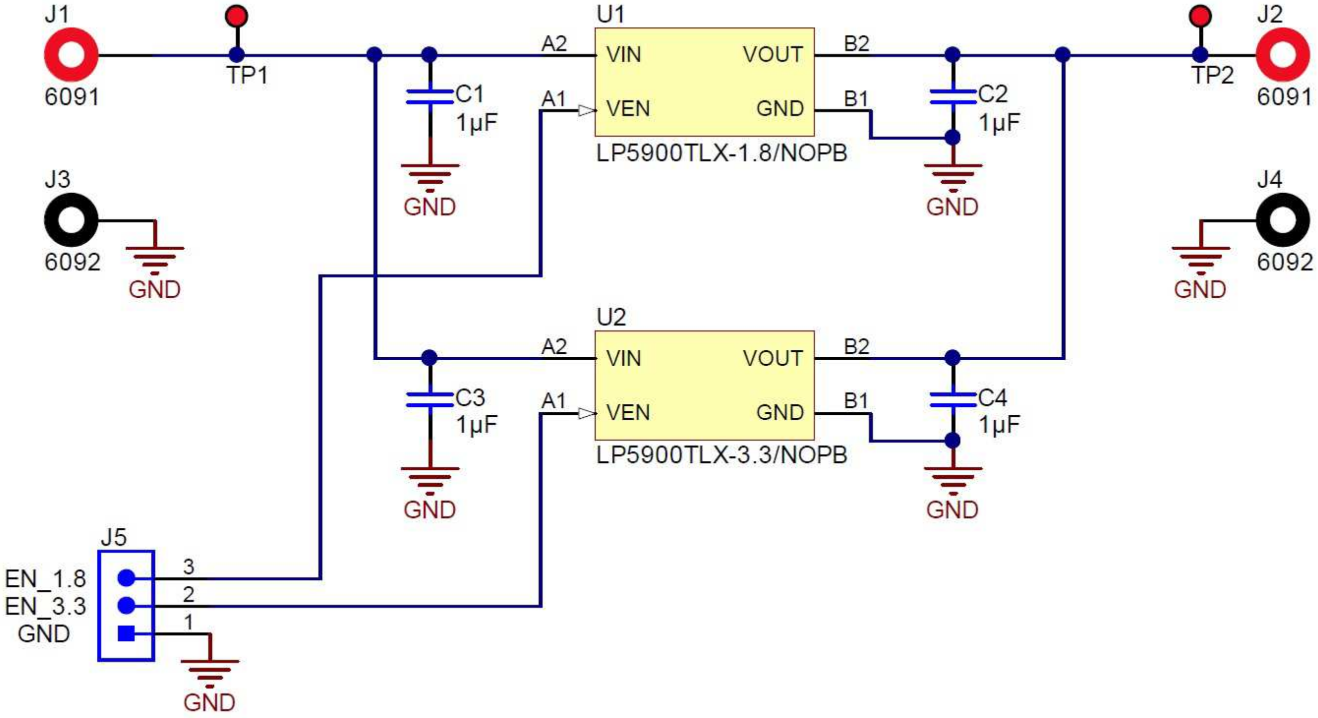
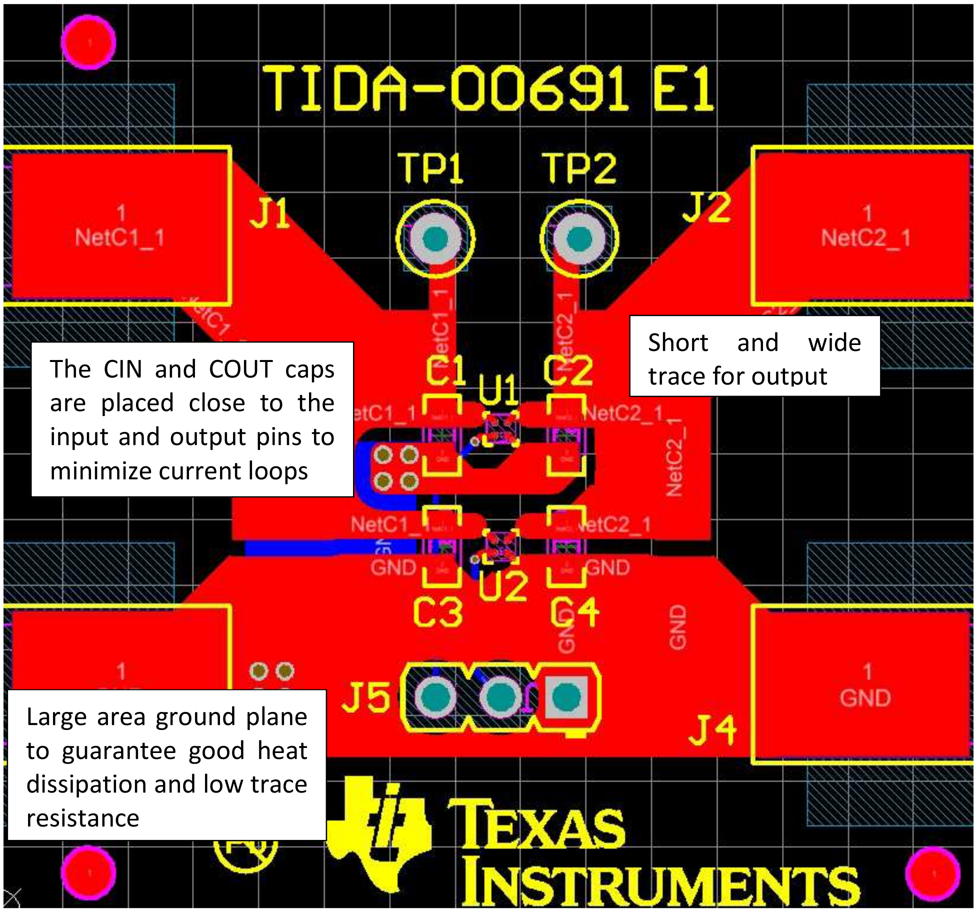


Figure 17: TIDA-00691 Schematic

7.2 PCB Layout Recommendations

7.2.1 Layout Guidelines



The CIN and COUT caps are placed close to the input and output pins to minimize current loops

Short and wide trace for output

Large area ground plane to guarantee good heat dissipation and low trace resistance

Figure 18: Layout Guidelines

7.2.2 Altium Project

To download the Altium project files for each board, see the design files at.
http://www.ti.com/tool/TIDA-00691

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

8 References

1. MCU + Analog Series: Driving Low-Power Even Lower – Part 1
   http://e2e.ti.com/blogs_/b/msp430blog/archive/2014/03/05/mcu-analog-series-driving-low-power-even-lower-part-1
2. MCU + Analog Series: Driving Low-Power Even Lower – Part 2
   http://e2e.ti.com/blogs_/b/msp430blog/archive/2014/03/12/mcu-analog-series-driving-low-power-even-lower-part-2

9 Terminology

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

10 About the Author

Hank Cao
Is a System Engineer at Texas Instruments in the RF power group at Texas Instruments.

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