

Testing tips for applying external power to supply outputs without an input voltage

By Chris Glaser

Applications Engineer, Member Group Technical Staff

Introduction

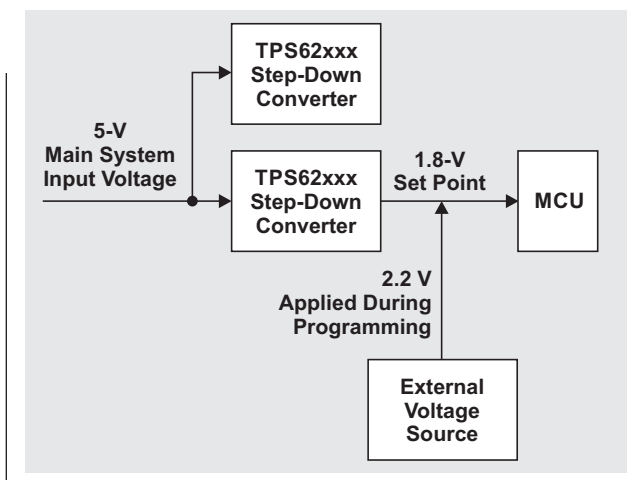
In many industrial systems, such as test and measurement and building automation, it is common that a processor must be programmed after the circuit board is assembled. Programming the processor, such as a field programmable gate array (FPGA), digital signal processor (DSP) or microcontroller (MCU), requires powering up certain voltages in the circuit. One way to power up the system is to apply the normal input voltage that the system sees in the application. However, this may not be possible or desirable for a variety of reasons, such as needing a different programming voltage than the application uses or safety concerns that occur when other subsystems receive power from the same input supply. In such cases, the required voltages are applied directly onto the outputs of the in-system power supplies. Powering a step-down (buck) converter with a voltage on the output and without a voltage on the input is an atypical application scenario that raises a flag for special considerations. This article explains the main concerns and their mitigation strategies.

Typical testing scenarios

In test and measurement applications, a MSP430G2955 might be operated at 1.8 V because this voltage already exists in the system. However, to program its flash memory, a voltage of at least 2.2 V is required. In applications where a supply voltage below 2.2 V is used, it is necessary to temporarily raise the supply voltage to the 2.2-V minimum to program the memory. In the production test environment where the memory is typically programmed, it is usually simplest to externally apply 2.2 V to the supply rail of the MSP430™ MCU. Figure 1 shows a block diagram of this scenario.

In some applications for building automation, newer FRAM-memory technology found in the MSP430FR5969 family eliminates the required higher programming voltages. However, even when the MSP430's supply voltage is set above the minimum required programming voltage in the final application, safety considerations may dictate applying an external voltage to the supply rail instead of applying the main system input voltage and generating the supply voltage rail from the on-board DC/DC converter.

Figure 1. An external voltage may be applied to the output of a converter to program an MCU



If the main supply voltage is the AC line voltage, for example, it may be physically unsafe for an operator to apply this voltage to the system during production when all safety mechanisms are not yet installed. Also, if the system contains motors or heating elements, powering up the full system may activate these sub-systems in unsafe ways. Applying an external voltage is still a common method for programming the MCU.

In both of these cases and many more, the power supply providing the processor's supply voltage sees a voltage on its output. Since processors typically have low supply voltages well below the common 5-V input voltage, the power supply is typically a step-down converter topology.

Specific considerations

When applying a voltage to the output of a step-down converter without an input voltage, the applied output voltage may appear on the input as well. Unless the specific integrated circuit (IC) is designed to prohibit reverse current flow, where current flow is from the output back to the input, the applied voltage on the

output appears on the input due to the body diode in the high-side MOSFET. Figure 2 shows this current path. See the TPS62750 data sheet for a device which specifically does not have this path because of the types of applications this device supports.

This bears repeating: When a voltage is applied to the output without an input voltage present, the applied output voltage appears on the input through the high-side MOSFET's body diode. Once this fundamental point is understood, the following are the seven most common considerations for a given application.

1. All circuits connected to the input rail are powered

Since the output voltage appears on the input, all other devices connected to this same node see this voltage as well. Ensure this is acceptable for each of these devices and the application as a whole because other sub-systems may receive sufficient voltage to turn on. Adding a diode in series with the input supply connection prevents this behavior. Figure 3 shows its placement in the circuit. A diode in series with the output also blocks the applied voltage, but this causes load regulation due the diode's voltage drop unless a circuit like Figure 4 is used.

2. Reverse current flows backwards through the IC

Since the input supply rail is powered from the output, there is reverse current flow through the IC to the other circuits on the input rail. The average reverse current should be kept less than the forward current rating of the IC. For example, the TPS62097 general-purpose industrial IC has a 2-A rated current. As well, the input voltage should not be shorted as this draws excessive current.

Multiplied by the voltage drop from output to input across the IC, the reverse current creates a power dissipation and corresponding temperature rise. Because of the relatively high forward voltage drop of the high-side MOSFET's body diode, this power may be quite high. Ensure that the IC's junction temperature rating is not exceeded. The diode in series with the input also mitigates reverse current concerns.

3. If enabled, the IC consumes current

If the enable (EN) pin of the IC is driven high, either from a controlling signal or because it is connected to V_{IN} (which is also high from #1 above), the IC is on and drawing current. When the applied output voltage is above the output-voltage set point and the mode for pulse-frequency modulation (PFM) is enabled, the IC draws its quiescent current (I_Q) which is typically in the tens of microamperes. When the applied output voltage is below the set point and the corresponding voltage at the input is above the IC's under-voltage lockout (UVLO) level, the IC typically enters 100% mode in order to try and increase the output voltage to the target level. In 100% mode, the current consumption is much higher—typically in the

Figure 2. Current path from output to input for a step-down converter

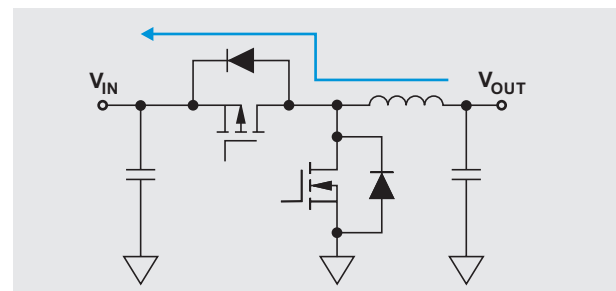
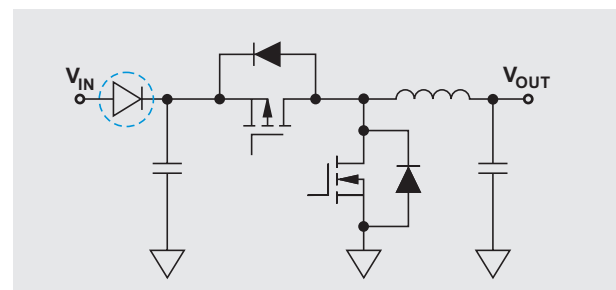


Figure 3. The input diode blocks the input supply rail from voltage applied to the output



milliampere range.^[1] This must be considered if the applied voltage's current is measured and used for pass/fail testing in production. A simple solution to this is to disable the IC.

4. If disabled, the IC may consume current

For ICs with an integrated output-discharge function, current is drawn from the output when they are disabled. Depending on the output discharge implementation, the IC may draw significant current. If the output discharge current is an issue, the IC should remain enabled because it is usually not possible to open the output discharge path. In some cases, an equivalent IC without output discharge is available.

5. Ensure that voltage ratings are not exceeded

When applying a voltage to the output of an IC, be sure that the voltage rating of each pin is not exceeded. This is especially important when the applied voltage is greater than the set point; the V_{OUT} , V_{OS} and FB pins need to be checked. Finally, check that the output voltage remains within the IC's limits even if it is hot-plugged.^[2] Slowly applying the output voltage, instead of hot-plugging it, may be required.

Figure 4 shows an example protection circuit used with a step-up (boost) converter. A diode in series with the output protects the VOUT pin from over-voltage. On the TPS61240, the FB pin is rated for a higher voltage than the VOUT pin in order to withstand a V_{OUT} hot-plug event when the protection diode is used. Such a diode also eliminates any reverse current or voltage flowing into the IC.

Finally, applying a voltage to the output appears to exceed the SW pin's voltage limit shown in the absolute maximum ratings table of many ICs and shown in Figure 5. The applied output voltage appears on the SW pin through the inductor.

Since the input voltage is not applied, it might be assumed that the voltage rating of SW to VIN is exceeded. But from #1, VIN is connected to VOUT through the high-side MOSFET's body diode and the inductor. In many cases, the absolute maximum rating's DC voltage limit is not exceeded. Furthermore, exceeding this pin's specific voltage limit does not necessarily damage the IC. Rather, the limit is a warning that, depending on how this voltage is applied, the IC could be damaged as discussed in #2 above and in Reference 3.

6. Prohibit the boost mode of step-down converters

For ICs with a mode for forced pulse-width modulation (PWM) or MODE pin, such as the TPS62097, it is critical to specifically check that the conditions for boost mode are not fulfilled. These conditions are: forced PWM-mode operation is enabled, the IC is enabled, the applied output voltage is higher than the set point, and there is insufficient load or leakage on the input to sink the applied energy.

In boost mode, the IC sinks the applied output voltage to bring it back down to the set point. Since the forced PWM mode is enabled, it keeps switching to accomplish this. If the PFM mode is enabled instead, the IC simply stops switching when the output voltage is above the set point. But in forced PWM mode, the IC operates with reverse current and moves energy from the applied output voltage back to its input voltage rail. If there is insufficient load or leakage at the input, this voltage increases until the input voltage rating of the IC is exceeded and it is overstressed. Two simple solutions to avoid boost mode are: disabling the IC or disabling the forced PWM mode.

7. Consider the power-good (PG) pin operation

Depending on the level of the applied output voltage relative to the IC's set point and the state of the EN pin, the PG output may not be in the required or expected state. This may result in an incorrect system status reported or may interfere with other rails if sequencing is used. Since the PG pin is typically just an open-drain output, it is usually possible to provide the required system signals and voltages in the proper locations through other test points.

Figure 4. Diode on the output protects the IC from hot-plugged voltages

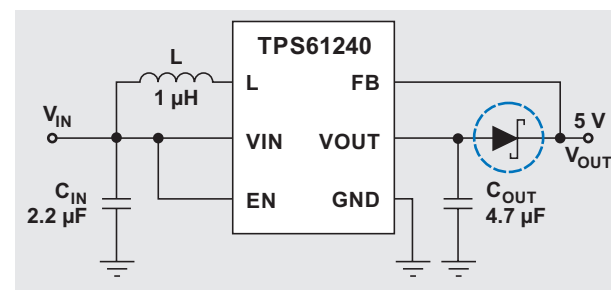


Figure 5. Many step-down converters have a voltage limit for the SW pin

Voltage at pins	MODE, SS/TR, SW	-0.3	VIN+0.3V	V
-----------------	-----------------	------	----------	---

Conclusion

Applying an output voltage to a step-down converter without an input voltage requires some system-specific analysis to ensure the safety of the system and its components, as well as the proper functioning of the system. Because this is an atypical setup, voltages and operation may be quite different from the system's normal operation. If this configuration is considered and analyzed during the system design phase, it is easy to add the appropriate diodes, disable connections, or other test points required to achieve a correctly functioning and safe system while in this mode.

References

1. Chris Glaser, "I_Q: What it is, what it isn't, and how to use it," Analog Applications Journal (SLYT412), 2Q 2011
2. Chris Glaser, "What is that giant tantalum cap on the input of the EVM?" TI E2E™ Fully Charged blog, May 20, 2015
3. Clancy Soehren, "Understanding the Absolute Maximum Ratings of the SW Node," Application Report (SLVA494A), January 2012

Related Web sites

Product information:

MSP430G2955, MSP430FR5969, TPS62750, TPS62097, TPS61240

TI Worldwide Technical Support

Internet

TI Semiconductor Product Information Center Home Page

support.ti.com

TI E2E™ Community Home Page

e2e.ti.com

Product Information Centers

Americas Phone +1(512) 434-1560

Brazil Phone 0800-891-2616

Mexico Phone 0800-670-7544

Fax +1(972) 927-6377
Internet/Email support.ti.com/sc/pic/americas.htm

Europe, Middle East, and Africa

Phone

European Free Call 00800-ASK-TEXAS
(00800 275 83927)
International +49 (0) 8161 80 2121
Russian Support +7 (4) 95 98 10 701

Note: The European Free Call (Toll Free) number is not active in all countries. If you have technical difficulty calling the free call number, please use the international number above.

Fax +(49) (0) 8161 80 2045
Internet www.ti.com/asktexas
Direct Email asktexas@ti.com

Japan

Fax International +81-3-3344-5317
Domestic 0120-81-0036
Internet/Email International support.ti.com/sc/pic/japan.htm
Domestic www.tij.co.jp/pic

Asia

Phone Toll-Free Number

Note: Toll-free numbers may not support mobile and IP phones.

Australia 1-800-999-084
China 800-820-8682
Hong Kong 800-96-5941
India 000-800-100-8888
Indonesia 001-803-8861-1006
Korea 080-551-2804
Malaysia 1-800-80-3973
New Zealand 0800-446-934
Philippines 1-800-765-7404
Singapore 800-886-1028
Taiwan 0800-006800
Thailand 001-800-886-0010

International +86-21-23073444
Fax +86-21-23073686
Email tiasia@ti.com or ti-china@ti.com
Internet support.ti.com/sc/pic/asia.htm

Important Notice: The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

AA021014

E2E and MSP430 are trademarks of Texas Instruments. All other trademarks are the property of their respective owners.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com