XAPP389 (v1.1) October 29, 2007

Powering CoolRunner-II CPLDs

Summary

Frequently, the power voltage applied to a board is higher (or lower) than the nominal 1.8V V_{CCINT} level required by CoolRunner™-II CPLDs. In these situations, power-ICs are commonly used to perform the required DC-to-DC conversion of the power voltage. These devices, known as regulators, take an unregulated input voltage and provide a regulated output voltage independent of input voltage variations or output current fluctuations. Many different types of regulators exist. This application note will provide an explanation of each regulator type and present some typical circuits to highlight currently available commercial regulators.

Regulator Overview

There are two main categories of regulators—linear and switching. The linear regulator is perhaps the most basic building block of every power supply used in the industry. These are incredibly easy to use and are usually the least expensive solution. Additionally, linear regulators are the least noisy of the various types of regulators.

Switching regulators, on the other hand, are gaining popularity because they offer both higher power conversion efficiency and the flexibility of having multiple output voltages derived from a single input voltage source. In addition, while linear regulators can only provide an output voltage that is lower than the input voltage, switching regulators can create output voltages that are higher than the input voltages.

There is not a single answer for which type of regulator should be used, as the selection depends upon the specific application. Each regulator type has inherent advantages and disadvantages. This application note will attempt to simplify regulator selection.

Linear Regulators

Linear regulators operate by using a voltage-controlled current source to force voltage to appear at the regulator output terminal (Figure 1). Control circuitry exists to monitor this output voltage and to adjust the current source accordingly (in order to maintain a fixed output voltage). The design specification of the current source defines the maximum load current that the regulator can supply and still remain under proper regulation.

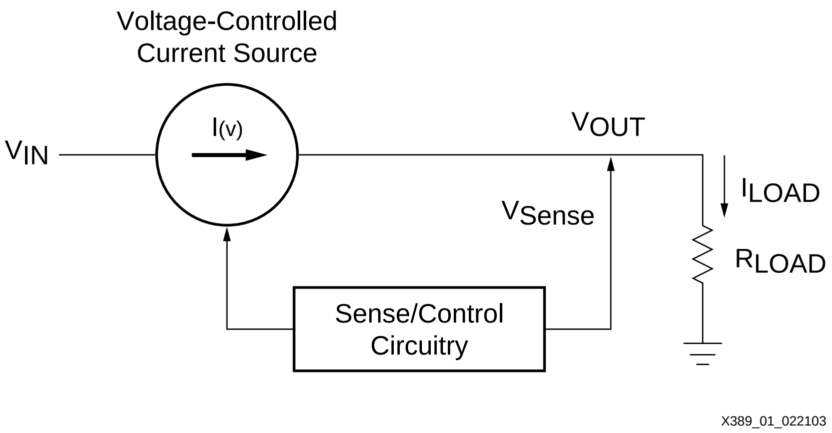


Figure 1: **Linear Regulator Functional Diagram**

Linear Regulator Types (Standard vs. Low-Dropout)

There are two main types of linear regulators: the Standard and the Low-Dropout (LDO) regulators. The single most important difference between these two is the dropout voltage, which is defined as the minimum voltage drop required across the regulator in order to maintain proper output regulation. The linear regulator with the lowest dropout voltage will dissipate the least internal power, and will exhibit the highest efficiency. Not surprisingly, LDO regulators require the least voltage across them, while the standard regulator requires the most.

Standard Linear Regulators

A standard linear regulator will typically have a dropout voltage of approximately 1.5V to 2.2V. In other words, the input voltage to the regulator must be at least 1.5V - 2.2V above the output voltage. On the other hand, LDO regulators typically have dropout voltages of around 500 mV, with newer ultra-low dropout regulators having dropout voltages around 100 mV.

Low-Dropout Regulators

A lower dropout voltage translates to maximized use of the available input voltage. This is critical in the battery-powered world, as LDO regulators will remain in regulation for a longer duration of the battery's discharge cycle. This increase in efficiency is the reason LDO regulators have come to dominate in the battery-powered world.

Choosing a Linear Regulator

It may seem as though an LDO regulator would be the ideal choice for most applications. However, this may not be the case.

The standard regulator is usually best suited for AC-powered applications, where low cost, and high load current dominate. In these applications, the voltage drop across the regulator is typically 3.0V or higher. As a result, dropout voltage is not a big concern.

Interestingly, in AC-powered environments, a standard regulator can actually be more efficient than an LDO regulator, due to the fact that standard regulators have lower ground pin currents (ground pin current is defined as the amount of current required by the regulator when driving a load). When the drop across the regulator is high, a lower ground pin current translates to maximal efficiency and lowest power consumption (calculated by multiplying voltage drop across the regulator by ground pin current).

However, while an LDO regulator may not be as efficient as a standard regulator in such situations, LDO regulators typically have additional features and have better output voltage precision. Based on these two properties, an LDO regulator may be more suitable for AC-powered applications.

The LDO regulator is no doubt a better choice for battery-powered applications. The low dropout characteristics of these devices allow for a system to use fewer battery cells. This not only reduces system cost by decreasing the amount of batteries required by a system, but also results in much lower power, because the input-output voltage differential can be lowered.

> **Note:** A switching buck regulator will almost always be more efficient than an LDO regulator. Thus, if battery life is the top priority (as opposed to cost), a switching regulator should be used.

A final word regarding dropout voltage

When considering an LDO regulator for CoolRunner-II CPLDs, it is important to note that dropout voltage is often a misleading indicator. A more important parameter to consider is the regulator's V_{IN} minimum, the lowest allowed input voltage. Many regulators are capable of output voltages which are considerably less than their minimum input voltages. *In these cases, where* $V_{OUT} << V_{INminimum}$*, the specified low dropout voltage does not apply*! Instead, the true dropout voltage becomes the differential between V_{INmin} and V_{OUT} ($V_{INmin} - V_{OUT}$). If maximal use of the battery is a concern, one should choose a regulator with low V_{INmin} first, then check to see if the specified dropout voltage is applicable. See **Appendix A: LDO Regulator Application Examples**, page 5 for recommended LDO regulators.

Switching Regulators

Switching regulators do not share any of the advantages of linear regulators. They are more expensive, typically consume more board space, and generate more noise than linear regulators. Yet switching regulators are increasing in popularity for one reason: increased power conversion efficiency. High efficiency power supplies correspond to longer battery life in portable equipment, since they waste less power. Switching regulators also produce less heat than their linear counterparts, as wasted power is dissipated in the form of heat. Thus, switching power ICs can be found in wall-powered equipment where temperature is a critical design factor, as well as in portable equipment, where battery life is key.

Unlike linear regulators, which use a current source to force voltage at the output, most switchting converters use a form of voltage regulation known as pulse width modulation (Figure 2). These regulators require the presence of external inductors and capactiors to form an L-C network. The series of square waves generated by the PWM output of the regulator is filtered and provides a DC output voltage equal to the duty cycle of the pulse multiplied by the peak amplitude of the square wave. Thus, a control loop can be used to monitor and alter the pulse width in order to control the voltage output. Switching regulators are more power efficient than their linear counterparts because of PWM—the total power consumed is proportional to the duration of time during which the pulse is high, as opposed to being at a static, continuous DC level.

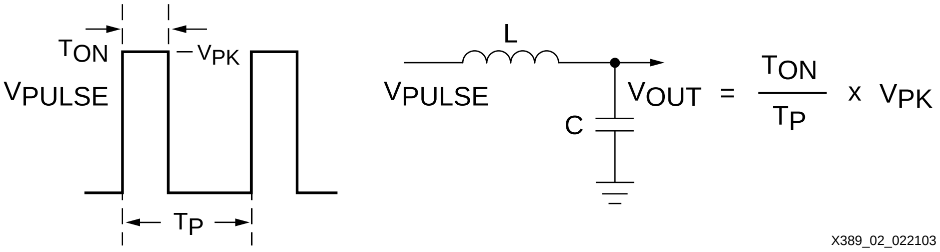


Figure 2: **Pulse Width Modulation**

Switching Regulator Types (Buck vs. Boost)

Two commonly used DC-DC switching converter circuits are the Buck and the Boost. Buck converters are used to down convert a higher DC voltage to a lower DC voltage. Likewise, Boost converters are used to convert a lower DC voltage to a higher level DC voltage. Buck converters play a key role in systems that have a main system voltage rail that must be down converted to lower voltages. Boost converters are useful in battery-powered applications where a single battery or a series of batteries is not quite enough to reach full rail.

Buck Regulators

In down-conversion applications for which V_{IN} is greater than V_{OUT}, the switching buck regulators are almost always more efficient than LDO regulators. This is increasingly true as V_{IN} becomes much greater than than V_{OUT}. However, keep in mind that DC-DC buck converters will exhibit some output ripple and switching noise.

Boost Regulators

Boost regulation can only be accomplished by switching regulators, as LDO regulators cannot provide the same functionality. The closest competition to a switching boost regulator is the regulated charge pump, which has lower efficiency and lower output power. As with all switching regulators, these ICs will require external inductors and capacitors, and the designer must be careful with PCB layout. Another important fact to remember when designing with a boost regulator is that the output current will always be less than the input current.

CoolRunner-II CPLD Power-Up Recommendations

Xilinx CPLDs have been designed to work with most comercially available regulators with different power-up conditions. Thus, there is no requirement for V_{CCINT}/V_{CCIO} rise time, nor is there a requirement for V_{CCINT}/V_{CCIO} power-up sequencing.

However, if possible, Xilinx recommends the following guidelines:

1) The V_{CC} ramp should be monotonic

A loaded power supply (e.g. board with CPLD) should exhibit a steadily increasing V_{CCINT} ramp. It is acceptable for the V_{CCINT} profile to level off to form a "shelf" before continuing on to the recommended operating V_{CCINT}voltage. This is the normal result of a current limit. However, dips in the negative direction should be avoided. The power supply should be monotonic, as shown in Figure 3.

An *unloaded* power supply should exhibit a steadily increasing voltage during turn-on. Power supplies that exhibit power-on voltage shelves when unloaded should be avoided, as the voltage profile can worsen when a load is present.

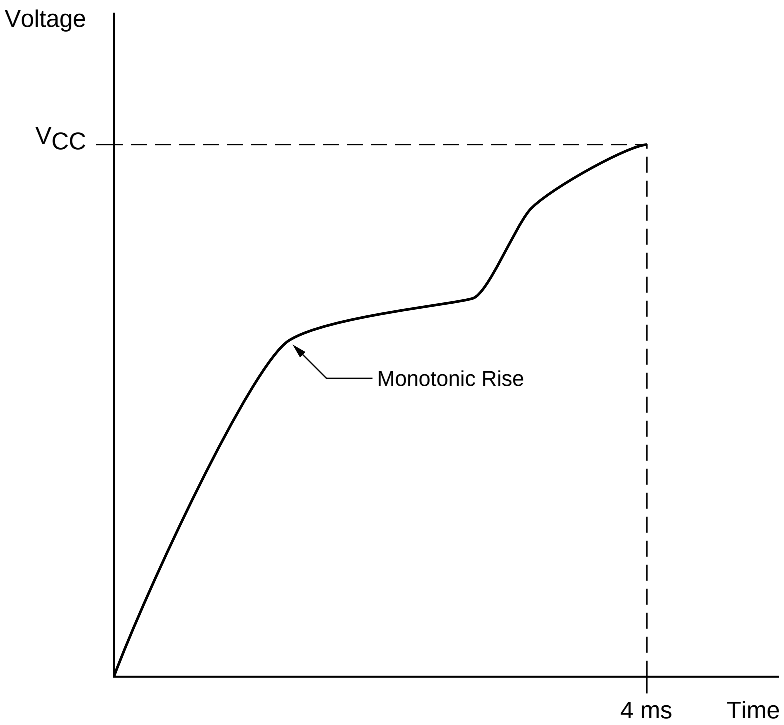


Figure 3: **Realistic, loaded power supply ramp**

2. V_{CCINT} rise time

A loaded power supply should deliver 0V to 1.8V to V_{CCINT} as quickly as possible. As a general guideline, a power supply which can provide a 1.8V ramp rate of less than 4 ms is recommended.

In order to achieve this 4 ms (or faster) ramp rate, utilize the "enable" features provided by power supplies/regulators. It is often the case that a slow ramp is caused by a regulator being always enabled. Thus, the output voltage ramp time can only ramp as fast as the input voltage ramp time. The power supply should only be enabled when the input voltage has reached its final level.

3. V_{CCINT}/V_{CCIO} power-up sequence

For designs in which V_{CCIO} and V_{CCINT} are not connected to the same power supply (e.g. V_{CCINT}/V_{CCIO} reside at different voltages), it is recommended to have V_{CCINT} ramp before V_{CCIO}. Powering up the core before the I/O is a good practice for most Xilinx devices.

4. Avoid clamping V_{CCINT} and V_{CCIO}

When the CPLD core and I/O voltages exist on different power rails, the V_{CCIO} and V_{CCINT} lines should be isolated from each other. Noise on V_{CCIO} should not affect V_{CCINT}, and vice versa. Also, clamping diodes placed (in either direction) between V_{CCINT} and V_{CCIO} should be avoided. Clamping diodes can delay the rise time of either voltage rail, and can also create artificial voltage shelves/dips.

5. Choose a power supply with sufficient current

The largest CoolRunner-II device (XC2C512 CPLD) typically requires 40 mA peak current during the power-up sequence. Since this is the largest part in the CoolRunner-II family, it is safe to assume that a power supply that can deliver at least 100 mA to any CoolRunner-II device during the start up sequence will minimize voltage shelves during the power ramp and will prevent the power supply ramp from dipping in the negative direction.

6. Use decoupling capacitors

Transient current demands in digital devices are the cause of ground bounce and power supply noise. In order to minimize this, CoolRunner-II CPLDs must be properly decoupled. As a general rule, all V_{CCINT}/ground pairs and V_{CCIO}/ground pairs should be decoupled using capacitors. For each V_{CC}/ground pair, one capacitor should be dedicated to filter high frequency noise, while a second capacitor should be dedicated to filter low frequency noise.

Application Examples

The CoolRunner-II CPLD supply voltage must be 1.8V while the I/O voltage could be 3.3V, 2.5V, 1.8V or 1.5V. The following section presents design examples using different types of regulators from various manufacturers. These regulators have been tested by Xilinx and are recommended for use with CoolRunner-II devices.

Appendix A: LDO Regulator Application Examples

Micrel Semiconductor MIC221X Dual Output LDO Regulator

The MIC221X family of dual LDO Regulators feature two independent LDO regulators integrated on a single chip. This dual output capability makes the MIC221X family an ideal choice for powering CoolRunner-II CPLDs in mixed voltage environments. The first output (V_{OUT1}) is capable of 150 mA, while the second output (V_{OUT2}) is capable of 300 mA.

Designed for battery-powered equipment, the MIC221X regulators feature extremely low dropout voltage (80 mV @ 100 mA) as well as extremely low ground pin current (48 µA). The MIC221X devices also allow for a very wide input voltage range (2.25V to 5.5V). These devices are extremely popular in wireless modems, cellular phones, and PDAs.

Figure 4 shows a typical application of the MIC221X device, where the CoolRunner-II CPLDs V_{CCINT} and V_{CCIO} are powered by V_{OUT2} and V_{OUT1}, respectively

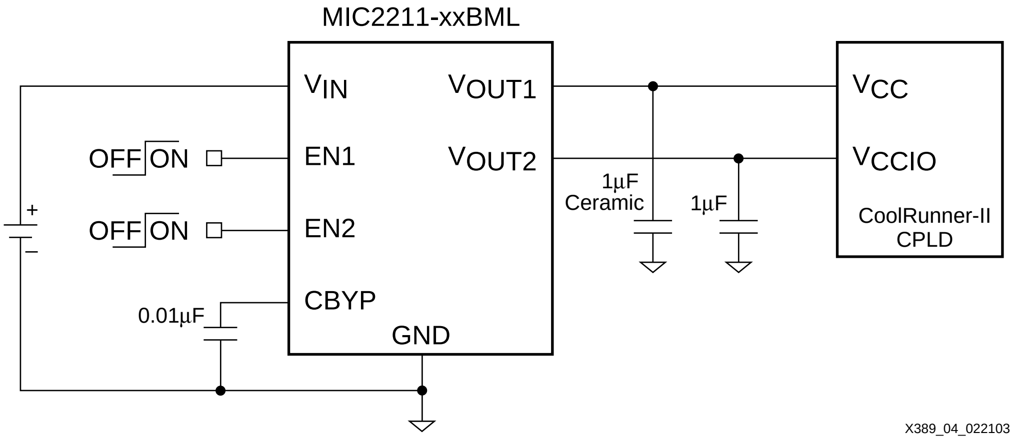


Figure 4: **Typical MIC2211 Application Circuit**

MIC221X regulators are offered in small footprint MLF-10 packages, and offer a variety of configurations. The MIC221X is available in fixed output voltages or with adjustable output voltages.

Table 1 lists some MIC221X family members that are applicable to CoolRunner-II CPLDs.

Table 1: **Micrel MIC221X Applicable Part Numbers**

Family	Part Number	Vout1/Vout2
MIC2214 (1)	MIC2214-SGBML	3.3V/1.8V
	MIC2214-AABML	Adj/Adj
MIC2213 (2)	MIC2213-AABML	Adj/Adj
MIC2211 (3)	MIC2211-GSBML	1.8V/3.3V
	MIC2211-JGBML	2.5V/1.8V
MIC2210 (3)	MIC2210-GSBML	1.8V/3.3V

Notes:

1. MIC2214 includes: 2 separate enables, open-drain driver, POR function
2. MIC2213 includes: 1 enable, open-drain driver, POR function
3. MIC2211 includes: 2 separate enables
4. MIC2210 includes: 1 enable, open-drain driver

Micrel Semiconductor MIC5211 Dual Output LDO Regulator

The MIC5211 is a dual output LDO regulator with each output capable of 80 mA load current. This LDO regulator is similar to the Micrel MIC221X family described above, but does not have as many features in terms of dropout voltage, output current capability, and ground pin current. Although the MIC5211 is not as feature-rich as the MIC221X, it is a more cost effective solution.

The MIC5211 has an input voltage specification of 2.5V - 16V and a ground pin current specification of 225 µA at 20 mA output current. Dual output configurations of 1.8V/3.3V and 1.8V/2.5V exist, making the MIC5211 an ideal regulator for powering CoolRunner-II CPLD’s in mixed voltage environments. A dual output 1.8V/1.8V configuration is also available. Table 2 summarizes the applicabale MIC5211 LDO family members.

Table 2: **MIC5211 Family Members**

Part Number	Vout1/Vout2
MIC5211-1.8BM6	1.8V/1.8V
MIC5211-1.8/2.5BM6	1.8V/2.5V
MIC5211-1.8/3.3BM6	1.8V/3.3V

This device comes in the SOT-23-6 package and is optimized to work with low-value, low-cost ceramic capacitors. Each output typically requires only 0.1 µF of capacitance for stability. A typical circuit is showin in Figure 5.

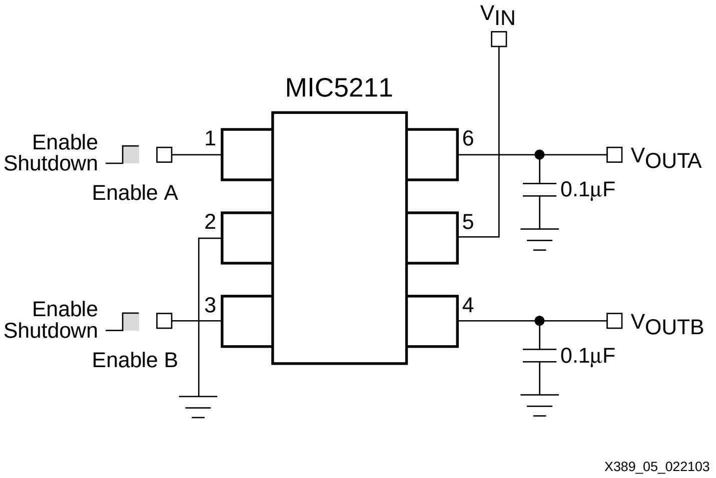


Figure 5: **Typical MIC5211 Application**

Texas Instruments TPS712xx Low-Dropout Linear Regulator

The TPS712xx family of low dropout (LDO) voltage regulators is tailored to noise sensitive and RF applications. These products feature dual 250 mA LDOs with ultra low noise, high power-supply rejection ratio (PSRR), and fast transient and start up response. Each regulator output is stable with low cost 2.2 uF ceramic output capacitors, and feature very low dropout voltages (125 mV typical at 250 mA). The TPS712 family is offered in a thin 3 mm x 3 mm SON package and is fully specified from –40° C to +125° C. Samples are available from http://ti.com/power. Figure 6 shows the typical TPS712xx circuit. Table 3 shows the voltage outputs of the TPS712xx family.

Table 3: **TPS712xx Family**

Product	Voltage	
	V_{OUT1}	V_{OUT2}
TPS71202	Adjustable	Adjustable
TPS71219	1.8V	Adjustable
TPS71229	2.8V	Adjustable
TPS71247	1.8V	2.85V
TPS71256	2.8V	2.8V
TPS71257	2.85V	2.85V

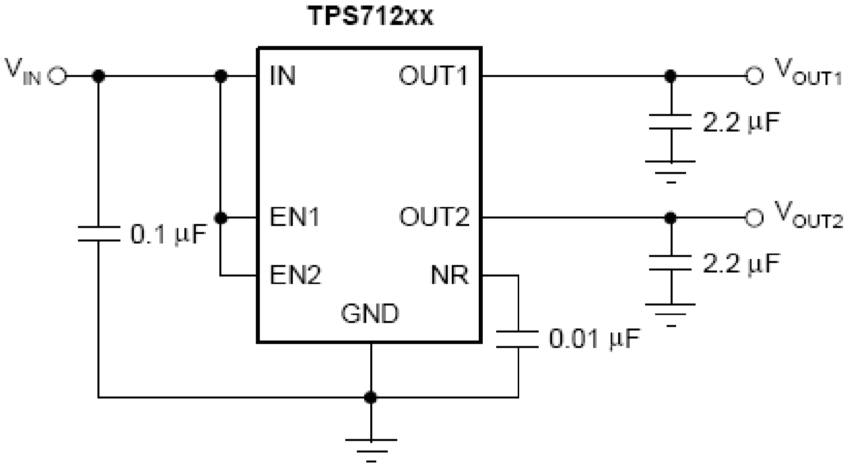


Figure 6: **Typical TPS712xx Application Circuit**

Texas Instruments TPS789xx Low-Dropout Linear Regulator

The TPS789XX family of low dropout LDO voltage regulators offers the benefits of low dropout voltage, ultra low-power operation, low-output noise and miniaturized packaging. The usual PNP pass transistor has been replaced by a PMOS pass element. Because the PMOS pass element behaves as a low-value resistor the dropout voltage is very low, typically 115 mV at 100 mA of load current (PS78930), and is directly proportional to the load current. The quiescent current is ultra low (17 uA typically) and is stable over the entire range of output load current. Intended for use in portable systems the ultra lowdropout voltage feature and ultra low power operation result in a significant increase in system battery operation like. Samples are available from **http://ti.com/power**. Table 4 shows the voltage output of the TPS789xx family. Table 7 shows the typical output circuit.

Table 4: **TPS789xx Family**

Product	Voltage
	V_{OUT1}
TPS78915	1.5V
TPS78918	1.8V
TPS78925	2.5V
TPS78928	2.8V
TPS78930	3.0V

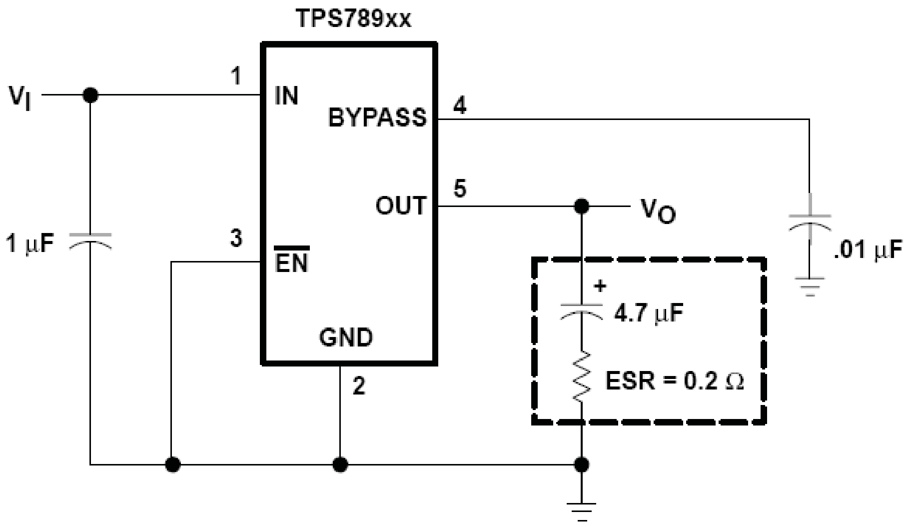


Figure 7: **Typical TPS712xx Application Circuit**

National Semiconductor LP3964 Ultra Low Dropout Regulator

The LP3964 series of ultra low dropout regulators are capable of sourcing up to 800mA, and can operate from a +2.5V to 7.0V input voltage. Ground pin current is specified to be 4 mA at 80 mA load current. Dropout voltage is approximately 240 mV at 80 mA load current and 240 mV at 800 mA load current. Note that this dropout voltage specification is inapplicable if V_{OUT} is set to 1.8V (In this case, the true dropout voltage becomes 2.5V - 1.8V = 0.7V).

The LP3964 regulators are available in SOT223-5, TO220-5, and TO-263-5 packages. They are also available with preset or adjustable voltage options as shown in Figure 8 (preset) and Figure 9 (adjustable).

This regulator is suited for applications which demand a high load current. It is not as well suited for applications which require low power and high power efficiency.

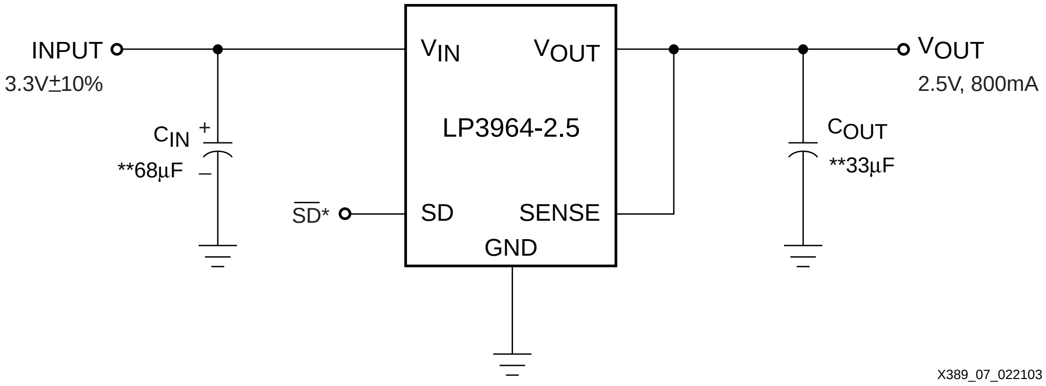
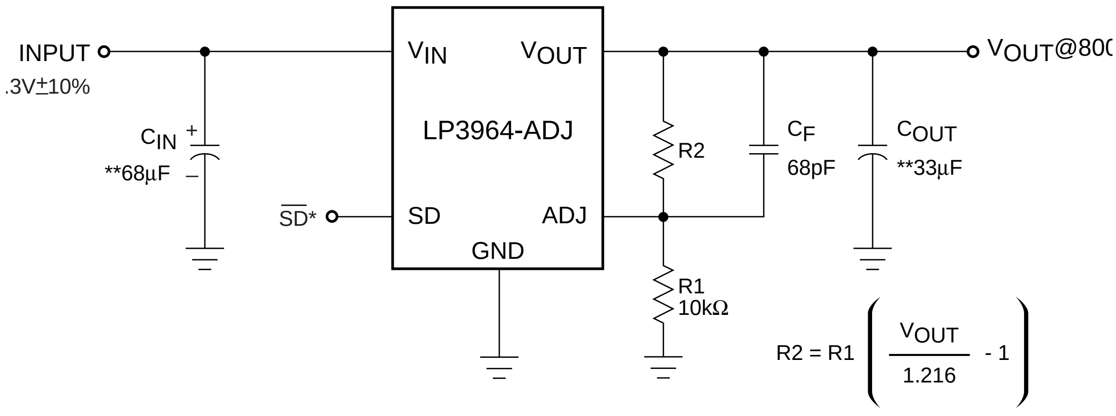


Figure 8: **Typical LP3964 (1.8V Preset) Application Circuit**



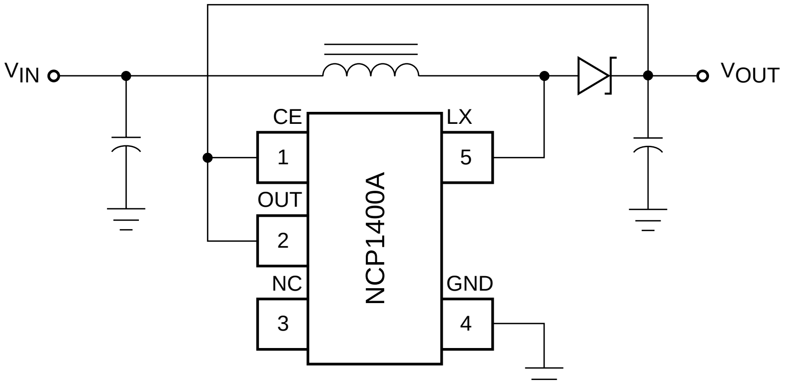
X389_08_0221

Figure 9: **Typical LP3964 (Adjustable) Application Circuit**

Switching Boost Regulator Application Examples

ON Semiconductor NCP1400A Switching Boost Regulator

The NCP1400A devices are ultra low power DC-DC boost converters that are specifically designed for portable equipment using one or two battery cells. These devices are designed to start-up at 0.8V and can remain in regulation down to less than 0.2V. The NCP1400A series requires only four external components and are capable of up to 100 mA of output current. They are available in a TSOP-5 package, and are available with a 1.8V fixed output. Figure 10 shows a typical application using the NCP1400A regulator.



X389_09_022103

Figure 10: **Typical NCP1400A Step-Up Converter Application**

Switching Buck Regulator Application Examples

Fairchild Semiconductor ML6554 Switching Bus Termination Regulator

The ML6554 switching regulator is designed to convert voltage supplies ranging from 2.3V to 4V into a desired output voltage or termination voltage for various applications. The ML6554, when used in conjunction with series termination resistors, is capable of sourcing or sinking up to 3A of current while regulating termination voltage to within 3% or less. For this reason, the ML6554 series provides an excellent voltage source for active termination schemes of high speed transmission lines as seen in high speed memory buses. The voltage outputs of this regulator can be used to generate the termination voltage V_{TT}, as well as the reference voltage

V_{REF} for bus interface standards such as SSTL and HSTL. A typical application circuit is shown in Figure 11.

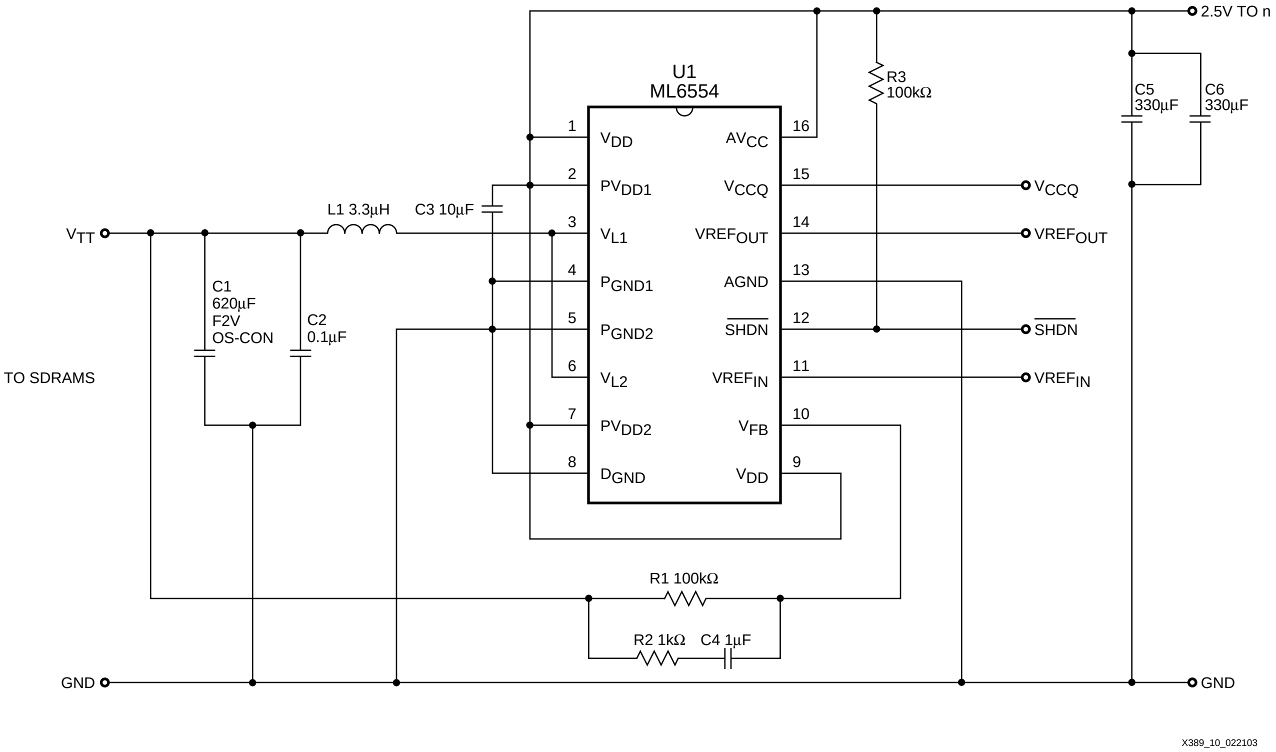


Figure 11: **Typical ML6554 Bus Termination Regulator Circuit**

Intersil ISL6527 Switching Buck Regulator

The ISL6527 DC-DC stepdown converter is designed to operate from a 3.3V to 5V output and is capable of producing an adjustable output voltage. Although not designed for low power, the ISL6526 is capable of producing low voltage and high current (5A at full load). The ISL6527 converter incorporates soft-start functionality during the start-up sequence. This soft-start feature provides a rapid and controlled output voltage rise

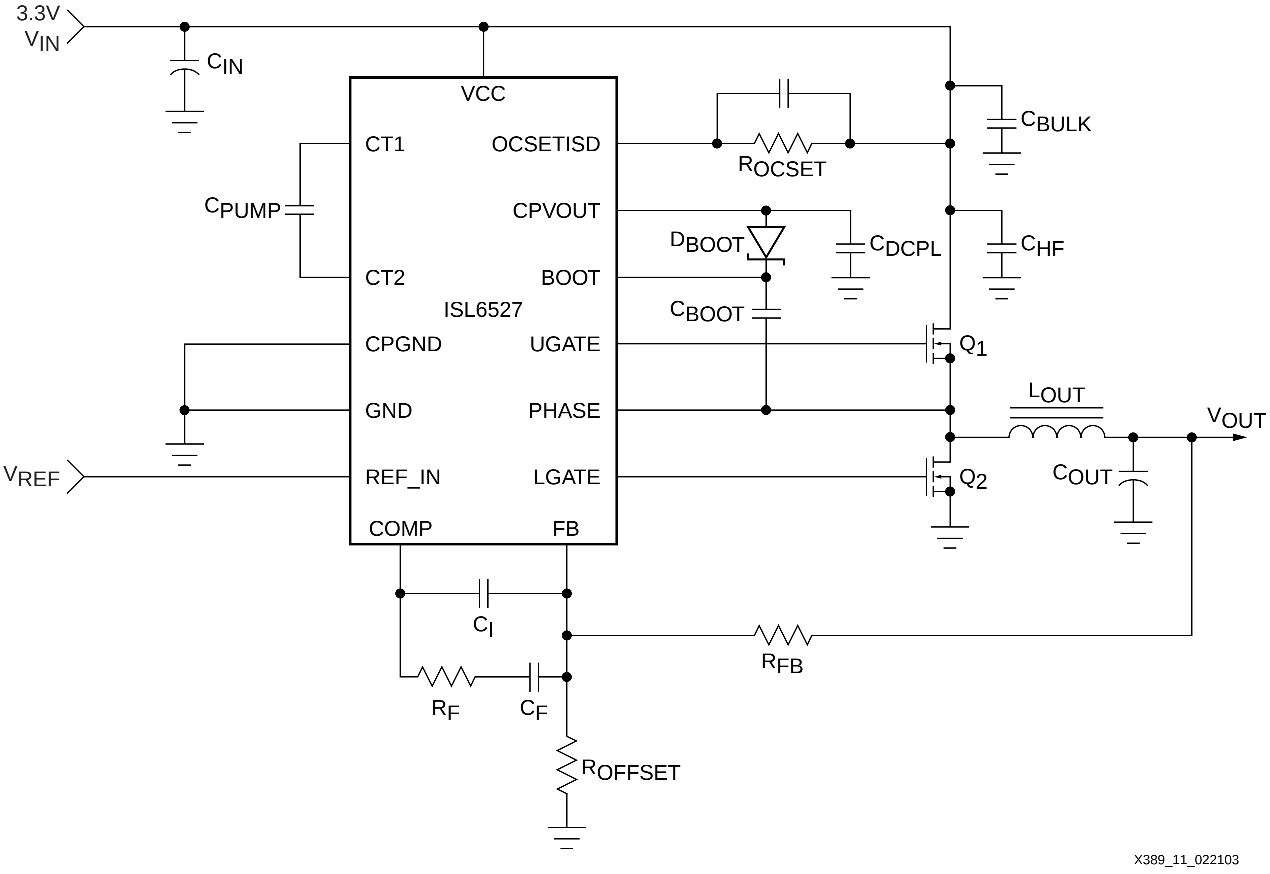


Figure 12: **Typical ISL6526 Application**

Standard Linear Regulator Application Examples

Micrel Semiconductor MIC5247 Linear Regulator

The MIC5247 is an efficient and precise CMOS regulator designed for low noise environments. The input voltage range can vary from +2.7V to +6V, while ground pin current is typically 85 µA. These devices are available in the SOT-23-5 package, and are offered in multiple fixed output configurations.

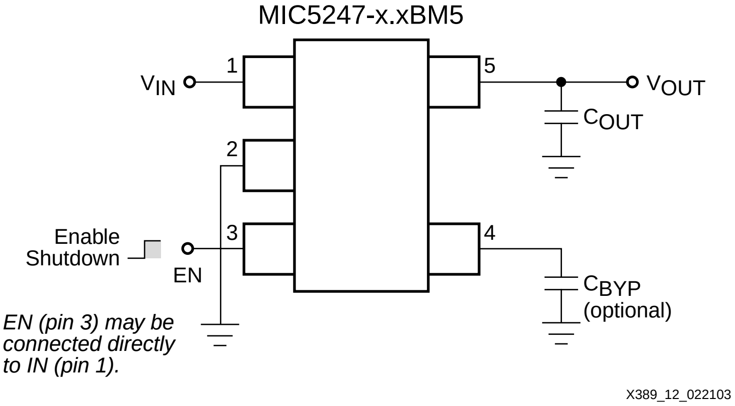
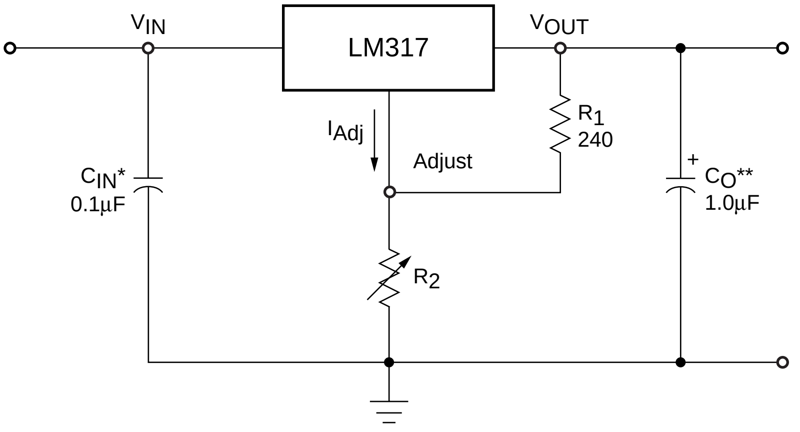


Figure 13: **MIC5247 Typical Application**

LM317 Standard Linear Regulator

The LM317 series of standard linear regulators is a generic 3-terminal positive voltage regulator designed to supply 1.0 -1.5 A of load current with an adjustable output voltage ranging from 1.2V to 3.7V. The LM317 regulator is easy to use and requires only two external resistors to determine the output voltage. Dropout voltage is approximately 2.5V at 1.5A. Manufacturers of the LM317 regulator include Linear Technology, National Semiconductor, Fairchild Semiconductor, and ON Semiconductor. A standard application of the LM317 device is shown in Figure 14.



X389_13_022103

Figure 14: **Typical LM317 Application Circuit**

Summary

This application note covers most of the practical considerations when choosing a power supply for CoolRunner-II CPLDs. While a wide variety of options exist for powering CoolRunner-II devices, advanced planning is clearly the most cost-effective and power-efficient approach for best results. Remember that an LDO regulator will not always be better than a switching regulator, nor will a switching regulator always be better than an LDO regulator. It is up to you to choose the regulator that is most applicable to your design. A good regulator choice will be one that is cost-efficient, power-savvy, and small in form factor.

CoolRunner-II Resources

xapp375.pdf (Timing Model)

xapp376.pdf (Logic Engine)

xapp377.pdf (Low Power Design)

xapp378.pdf (Advanced Features)

xapp379.pdf (High Speed Design)

xapp380.pdf (Cross Point Switch)

xapp381.pdf (Demo Board)

xapp382.pdf (I/O Characteristics)

xapp383.pdf (Single Error Correction Double Error Detection)

xapp387.pdf (PicoBlaze Microcontroller)

xapp388.pdf (On the Fly Reconfiguration)

xapp389.pdf (Powering CoolRunner-II CPLDs)

xapp393.pdf (8051 Microcontroller Interface)

xapp394.pdf (Interfacing with Mobile SDRAM)

CoolRunner-II Data Sheets

http://direct.xilinx.com/bvdocs/publications/ds090.pdf (CoolRunner-II Family Datasheet)
http://direct.xilinx.com/bvdocs/publications/ds091.pdf (XC2C32 Datasheet)
http://direct.xilinx.com/bvdocs/publications/ds092.pdf (XC2C64 Datasheet)
http://direct.xilinx.com/bvdocs/publications/ds093.pdf (XC2C128 Datasheet)
http://direct.xilinx.com/bvdocs/publications/ds094.pdf (XC2C256 Datasheet)
http://direct.xilinx.com/bvdocs/publications/ds095.pdf (XC2C384 Datasheet)
http://direct.xilinx.com/bvdocs/publications/ds096.pdf (XC2C512 Datasheet)

CoolRunner-II White Papers

wp165.pdf (Chip Scale Packaging)
wp170.pdf (Security)

Revision History

The following table shows the revision history for this document.

Date	Version	Revision
05/19/03	1.0	Initial Xilinx release.
10/29/07	1.1	Changes to TPS789xx and TPS712xx documentation.