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Keywords: power supply, switching regulators, linear regulators, charge pumps, switched capacitor, voltage converters, regulator ICs, inductorless voltage regulator, portable power, dc dc, DC-DC converters, step-up, step-down, buck, boost, inverter, isolated p

TUTORIAL 737

# Choosing the Right Power-Supply IC for your Application

Oct 28, 2009

*Abstract: This article discusses the process of choosing a power supply for a given application. It reviews the features of the three most common types of DC-DC converting power-supply ICs. It also provides links to other application notes and tutorials that discuss more advanced topics.*

Choosing a power-supply IC can be a daunting task for the inexperienced. This application note will help the novice engineer take the first step toward becoming a confident power-supply designer. This article discusses how to choose these ICs at the most fundamental level. First, it explains why power-supply ICs are necessary. It then shows how to choose among the three most common power-supply ICs powered with DC voltages: linear regulators, switching regulators, and charge pumps. Links to supportive application notes and tutorials will address more advanced power-supply topics.

## Why Power-Supply ICs?

The chief purpose of most power-supply ICs is to *regulate*. These devices take an unregulated input voltage and provide a regulated output voltage. Restated most simply, these ICs provide an output voltage that remains steady despite varying input voltage or output current. This accounts for the names *linear regulator* and *switching regulator*. The exception to this simple definition is the charge pump. Depending on the specific device, a charge pump's output can be either regulated or unregulated.

Sometimes regulators create a regulated output voltage from a regulated input voltage. In that case, the regulator's function is to change the input voltage to another voltage level, without necessarily improving the voltage regulation.

You might be tempted to power a circuit without a regulator. In fact, in some cases you can be successful with this. You could, for example, power portable equipment directly from a battery. But this approach usually leads to problems. The circuitry within portable equipment typically operates correctly only within a certain narrow voltage range. This is especially true with microprocessors and memory, particularly if high speed is needed. For microprocessors, memory, and many other types of circuitry, the voltage range over which the battery operates could extend beyond acceptable levels. Therefore, adding a regulator ensures that your circuitry receives the appropriate voltage.

The battery's internal resistance can also present a problem if a regulator is not used. This difficulty arises because circuitry within portable equipment often demands a varying level of supply current. This varying current, when drawn from the battery, creates a varying battery voltage due to the battery's

internal resistance. Portions of the circuitry can "object" to these variations in battery voltage because the PSRR (*power-supply rejection ratio*) of the circuitry's various components might not be sufficient to reject these voltage variations. To combat this problem, a regulator maintains a steady output voltage despite these varying load currents. A regulator provides this steady voltage, because its active circuitry maintains an output resistance that is significantly lower than the battery's series resistance.

Any attempt to design without a regulator challenges the necessity of the steady voltage that regulators provide, despite varying input voltage or output current. But there is even more to consider. In most cases switching and linear regulators, as with regulated and unregulated charge pumps, serve an additional purpose: they create a voltage with a different magnitude from the voltage that powers them. This explains for the name *DC-DC converter*. Technically speaking, all three types of power-supply ICs discussed here (e.g. linear regulators, switching regulators, and charge pumps) are DC-DC converters. However, the term is normally reserved for switching regulators.

Somewhat limited when converting voltage levels, a linear regulator can only produce a voltage lower than the voltage supplying it. Much more versatile, a switching regulator can step up (boost), step down (buck), or invert (change the polarity of) its supply voltage. Charge pumps perform these same three operations, but with limited output-current capability.

Please see application note 269, "[Trading Performance for Cost in Portable Power Supplies.](#)"

There are exceptions to the idea that power-supply ICs create voltages of a different magnitude than the voltages fed to them. The exceptions are most often found in transformer-coupled converters. It is not unusual to find a transformer-coupled converter whose output voltage equals its input voltage. See **Figure 1**. In most cases, the sole purpose of a converter configured this way is to provide isolation, which prevents a DC connection between the input voltage supplied to the converter and the output voltage created by the converter. See **Figure 2**. Isolation is often used for safety reasons. The power for circuitry connected to a patient through electrodes, for example, is isolated from the power derived from a wall socket to protect against the risk of shock. But you do not need to be in a hospital to require isolation. Nearly all consumer electronic products isolate the AC line from the operating circuitry.

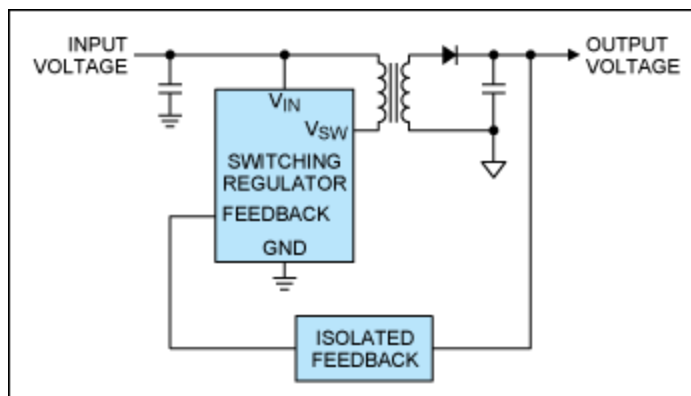


Figure 1. This transformer-coupled switching-regulator circuit isolates the input voltage from the output voltage. Power-supply designers often use an optocoupler to isolate the circuit's output from the regulator's feedback pin.

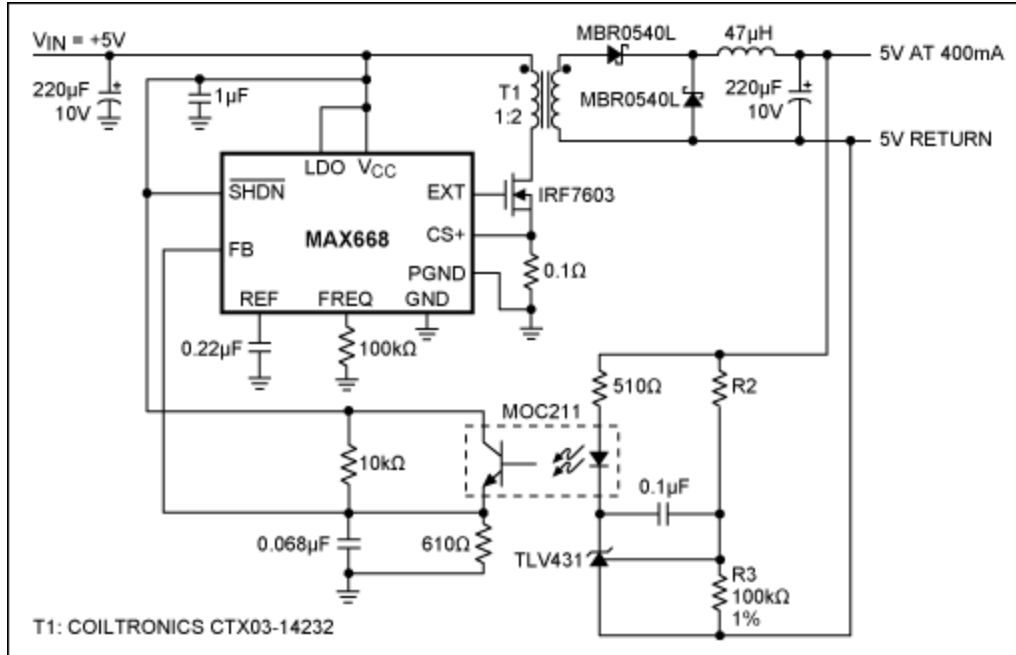


Figure 2. Circuit has an isolated 5V to 5V at 400mA power supply. The MAX668 step-up controller is featured.

See the [Isolated-Power Supply Reference Guide](#). Maxim's application notes for isolated power supplies are categorized for convenient reference.

The advantages and disadvantages of linear regulators, switching regulators, and charge pumps will now be explained.

## Linear Regulators

Linear regulators are often the smallest, usually the least expensive, and always the least noisy of the various types of power-supply ICs. See **Figure 3**. Use a linear regulator if it is appropriate for your application, especially because a linear-regulator circuit is more likely to work correctly the first time than circuits built around other types of power-supply ICs.

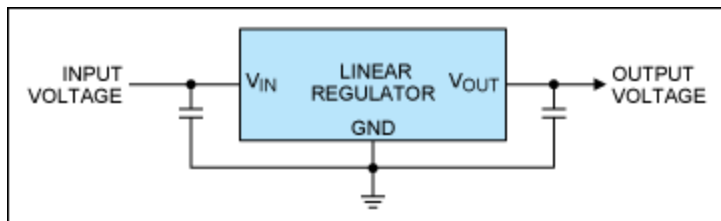


Figure 3. A linear regulator both steps down and regulates the voltage supplied to it with a minimal number of external components. Because these devices contain no switching elements, they generate little noise. Also, the circuit-board layout of linear regulators is less critical than for switching regulators and charge pumps.

Why would you use any power-supply IC other than a linear regulator? There are two reasons. First, a linear regulator can only provide an output voltage that is smaller than its input voltage. As mentioned above, if you wanted to create a voltage that is higher than the input voltage or of opposite polarity, you

have no choice but to use a switching regulator or a charge pump.

The second reason is efficiency. Converting a voltage to another voltage always wastes power. In the ideal situation, a regulator wastes no power; its efficiency rating would be 100%. If half the power supplied to a regulator found its way to the regulator's load, its efficiency would be 50%.

A linear regulator is usually, although not always, less efficient than a switching regulator. You can calculate a linear regulator's efficiency by dividing its output voltage by its input voltage. (This formula is sufficiently accurate if the current that powers the regulator, the regulator's supply, or quiescent current, is a small percentage of the current drawn from the regulator's output. In most cases, it is.) Thus, with LDOs (low dropout linear regulators), where the voltage of the source powering a linear regulator is near the regulator's output voltage, efficiency is high. In that case, an LDO might be a better choice than a switching regulator because the LDO has less noise. The [MAX1725/MAX1726](#) are ultra-low supply current LDOs with a maximum 4.5µA quiescent current.

A high-efficiency regulator provides a distinct advantage in portable equipment, as less wasted power results in longer battery life. You may need a high-efficiency regulator for another reason: wasted power is dissipated as heat. Thus, a high-efficiency power supply often suits wall-powered equipment as well as portable equipment. This power supply can reduce the temperature within an enclosure to a tolerable level in either case.

In automotive applications, usually a higher input voltage and wider temperature range are required. For example, the [MAX6765–MAX6774](#) operate from 4V to 72V over the -40°C to +125°C temperature range. These linear regulators feature control inputs which make them "automotive friendly."

See [low-dropout linear regulators](#).

## Switching Regulators

Switching regulators share none of the advantages of linear regulators. Switching regulators consume more board area (except, perhaps, when a linear regulator requires a heatsink to dissipate the power lost within it); cost more; and generate more noise than their linear counterparts. Yet, for years switching regulators have been enormously popular with power-supply designers. Why?

Switching regulators remain popular because these devices boast excellent efficiency when subjected to many combinations of input voltage and load current. (The levels can be as high as 96% for both step-up and step-down switchers, although a step-down is typically more efficient, and up to 90% for an inverter). Also, if you need to step up, step down, or invert a voltage, switching regulators are the only devices capable of these operations for load currents above approximately 125mA. You can, admittedly, use charge pumps to perform these operations, but the load currents that these devices allow are limited. It is simply too expensive to integrate switches large enough to handle load currents above the 125mA level into charge pumps, although a few charge pumps do supply several hundred milliamps.

Switching regulators are so named because they switch a power transistor, which, when used in conjunction with an inductor, efficiently converts one voltage to another. See **Figure 4**. When these power transistors switch, they do so very quickly, as fast transitions improve the regulator's efficiency. To understand why, first consider the power transistor's power dissipation when it is not transitioning. When the transistor is off, voltage appears across it, but no current flows through it. Thus, no power is lost. When the transistor is on, a small voltage appears across it while appreciable current may flow through it. Thus, typically, a small amount of power is lost. When the power transistor transitions from an OFF state to an ON state, or vice versa, voltage appears across the transistor while current flows through it. Therefore, appreciable power can be lost. Speeding up the switching process reduces these *transition*

losses.

To minimize the power loss associated with the rectifier diode in a switching power supply, a synchronous configuration can be used. In a synchronous configuration, the rectifier diode is replaced with a MOSFET switch. This approach increases the efficiency of the switching converters even further. The [MAX15023](#) is an example of a synchronous buck controller.

See application note 2031, "[DC-DC Converter Tutorial](#)."

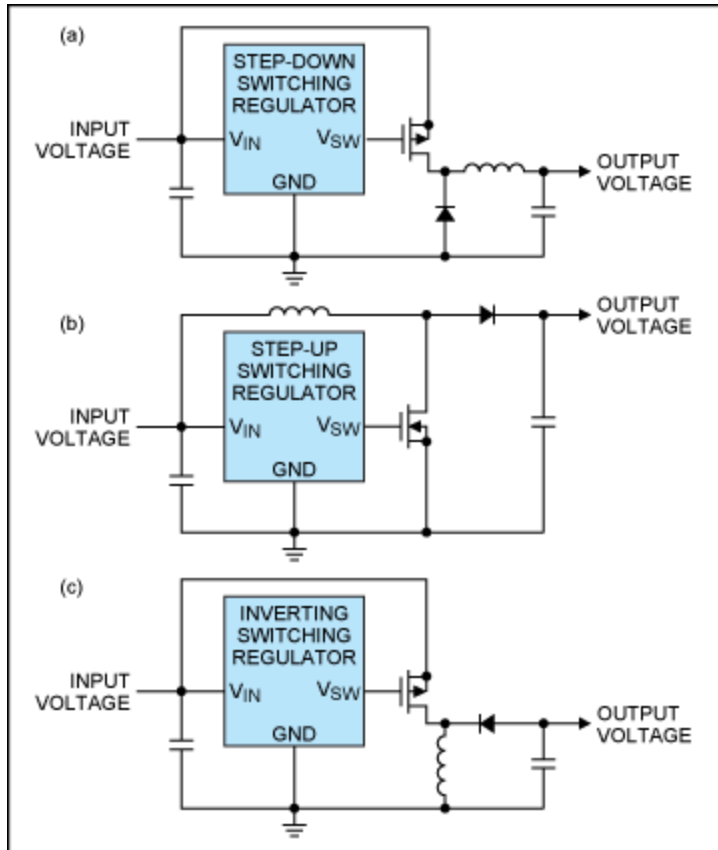


Figure 4. Switching regulators can (a) step down (buck), (b) step up (boost), or (c) step down/up and invert (buck boost) the voltage that powers them. The external transistor switches pictured for each of these three switching regulator types are often included within the switching regulator, usually when the device is specified for moderate-load currents. Occasionally, step-down and step-up switching-regulator ICs comprise the rectifier shown here.

These fast transitions, along with the heavy currents that often flow in these circuits, make circuit-board layout critical. Switching-regulator circuits require a well-thought-out layout and the components external to the switching-regulator IC must be specified correctly. Considering the various types of power supplies, switching regulators require the most careful design.

Fortunately, there is a way around these layout concerns. For applications with lower output-current requirements, switching regulators with integrated MOSFETs are offered. The [MAX17083](#) is a step-down regulator with integrated switches and it supports continuous load current up to 5A. The internal switch facilitates the circuit-board layout significantly. However, this limits the output power to the power dissipation limits and design specifications of the IC.

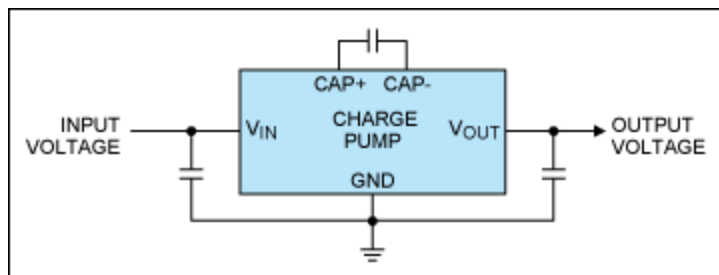
Maxim also supplies EV (evaluation) kits for most switching regulators. These kits demonstrate a working layout of the power supply, which in many cases can be adapted to a particular circuit board. Also, multiple sources for the various external components are usually listed in the regulator's data sheet. Deciding which external components to use is simply a matter of choosing from among several devices already specified, each of which is capable of working well with the particular switching-regulator IC.

See [application notes for power-supply circuits](#), and the Maxim's [Power-Supply Cookbook](#).

Maxim also provides an on-line simulation tool ([EE-Sim](#)) to design and simulate the power-supply circuits.

## Charge Pumps

Charge pumps constitute the least understood category of power-supply ICs discussed here. These devices perform the same functions as switching regulators, but without an inductor. Instead, charge pumps use capacitors to step down, invert, or boost the voltages that power them. See **Figure 5**.



*Figure 5. Like switching regulators, charge pumps step down, step up, and invert voltages, but use capacitors instead of an inductor to perform these operations. In most cases, charge pumps handle lower output currents than switching regulators. Although the topologies vary somewhat, the circuit shown here is representative of both regulated and unregulated charge pumps, regardless of whether they step up, step down, or invert voltages.*

Charge pumps come with both unregulated and regulated outputs. Consider a circuit that is connected to an unregulated charge pump's output. As this circuit draws more and more current, its output voltage drops proportionately. The charge pump's output impedance is thus essentially a fixed resistance. When used in the inverting mode, unregulated charge pumps provide an output voltage equal to the voltage powering the device, but with opposite polarity (e.g., the [MAX828](#)). As load current increases, the magnitude of this voltage drops, as discussed above. When used in the doubling mode, these charge pumps precisely double the applied voltage (e.g., the [MAX1682](#)) and the output voltage also drops as load current increases.

Regulated charge pumps can step up, step down, or invert the applied voltage. Unlike unregulated charge pumps, these devices provide output-voltage levels that are not strictly dependent on the voltage level fed to them. Thus, these devices could, for example, create a 5V output from a 3.3V input. Also, because they are regulated, as the output current increases, the output voltage remains essentially constant. As mentioned above, the amount of current that can be drawn from these devices, as well as from unregulated charge pumps, is limited. The upper limit is about 125mA (e.g., the [MAX1595](#)), although there are a few parts that handle several hundred milliamps (e.g., the [MAX889](#)). It is not economical to build charge pumps that supply large load currents. Instead, inductor-based switching regulators are well suited for this situation.

A charge pump switches the capacitors connected to it, and thus creates noise. This noise is usually of smaller magnitude than a switching regulator's noise. There are three primary reasons for this. First, load currents are lighter. Second, because these circuits do not include an inductor, no magnetic noise is created. Finally, when a charge pump interrupts the current flowing through a capacitor connected to it, a voltage spike is not created. A switching regulator interrupting the current flowing through an inductor usually creates a voltage spike.

Charge-pump data sheets provide you with the information needed to select the only external components needed when using a charge pump: namely, capacitors. Although EV kits are not as necessary and are, thus, less available for charge pumps, any available EV kit can furnish a quick way to determine whether or not the part is right for a particular application.

See [application notes for charge pumps](#).

Related Parts		
<a href="#">MAX15023</a>	Wide 4.5V to 28V Input, Dual-Output Synchronous Buck Controller	<a href="#">Free Samples</a>
<a href="#">MAX1595</a>	Regulated 3.3V/5.0V Step-Up/Step-Down Charge Pump	<a href="#">Free Samples</a>
<a href="#">MAX1682</a>	Switched-Capacitor Voltage Doublers	<a href="#">Free Samples</a>
<a href="#">MAX17083</a>	Low-Voltage, Internal Switch, Step-Down Regulator	<a href="#">Free Samples</a>
<a href="#">MAX1725</a>	12V, Ultra-Low-I <sub>Q</sub> , Low-Dropout Linear Regulators	
<a href="#">MAX1726</a>	12V, Ultra-Low-I <sub>Q</sub> , Low-Dropout Linear Regulators	
<a href="#">MAX6765</a>	Automotive Micropower Linear Regulators with Supervisor	<a href="#">Free Samples</a>
<a href="#">MAX6766</a>	Automotive Micropower Linear Regulators with Supervisor	<a href="#">Free Samples</a>
<a href="#">MAX6767</a>	Automotive Micropower Linear Regulators with Supervisor	<a href="#">Free Samples</a>
<a href="#">MAX6768</a>	Automotive Micropower Linear Regulators with Supervisor	<a href="#">Free Samples</a>
<a href="#">MAX6769</a>	Automotive Micropower Linear Regulators with Supervisor	<a href="#">Free Samples</a>
<a href="#">MAX6770</a>	Automotive Micropower Linear Regulators with Supervisor	<a href="#">Free Samples</a>
<a href="#">MAX6771</a>	Automotive Micropower Linear Regulators with Supervisor	<a href="#">Free Samples</a>
<a href="#">MAX6772</a>	Automotive Micropower Linear Regulators with Supervisor	<a href="#">Free Samples</a>
<a href="#">MAX6773</a>	Automotive Micropower Linear Regulators with Supervisor	<a href="#">Free Samples</a>
<a href="#">MAX6774</a>	Automotive Micropower Linear Regulators with	

Supervisor

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<a href="#">MAX828</a>	Switched-Capacitor Voltage Inverters	<a href="#">Free Samples</a>
<a href="#">MAX889</a>	High-Frequency, Regulated, 200mA, Inverting Charge Pump	<a href="#">Free Samples</a>

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