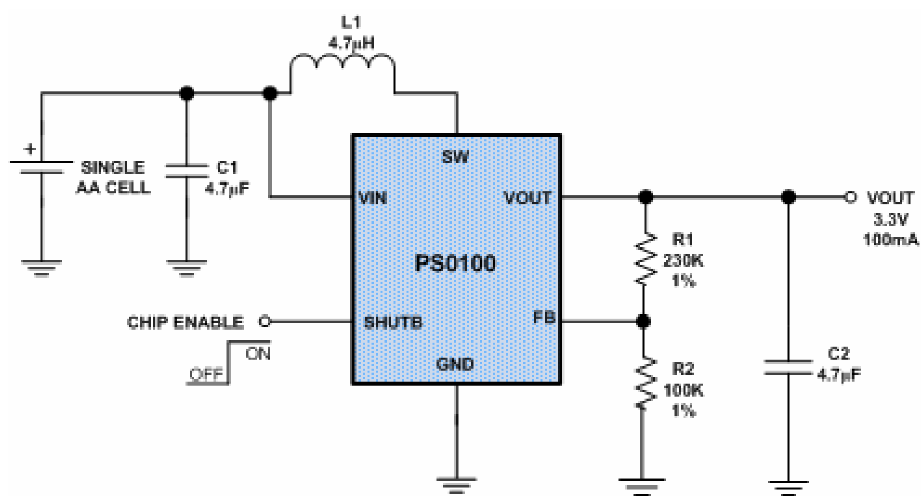
Synchronous Boost Converter with Output Disconnect

APPLICATION NOTE

INTRODUCTION

This design is intended to be used in portable applications where the input power source is provided by one or two AAA or AA cells. The cells might be normal dry cell or rechargeable (Ni-MH, 1.2V) and where the output voltage is 3.3V. The user can adjust the output voltage through the resistor network at feedback node. When the input battery is fully charged (the input voltage is above 2.4V) or when the battery is near fully discharged (the input voltage is below 1V); in both the cases PS0100 is capable of generating a 3.3V, 100mA regulated output with a typical quiescent current of 250µA. Input voltage ranges from 0.5V to 4.4V and efficiency is above 92%. It has a special feature that is the output is totally disconnected during shutdown, drawing zero current from the input.
To reduce power consumption, some applications need to be cycled between active and shutdown modes. In shutdown mode, the quiescent current of the system is dominated by the power supply. Current must be as low as possible and PS0100 has less than 1 µA because it is impossible to turn off the power supply, as it must remain active to supply some parts of the system.

TYPICAL APPLICATION CIRCUIT



DETAILED DESCRIPTION

The PS0100 is a compact, high-efficiency, synchronous boost converter in a 6-leads SOT-26 package designed for space-restricted applications. The parts are available with adjustable output voltages ranging from 2.5V to 5.0V. They are able to start up with input voltages as low as 0.8V and operate with input voltages down to 0.5V. With its internal synchronous rectifier and low on-resistance of the internal NMOS switch, the devices maintain high efficiency over a wide range of load current. As shown in the Block Diagram, the PS0100 consists of accurate band gap core, error amplifier, start-up oscillator and control logic unit along with PMOS and NMOS switches. With current mode PWM control, the PS0100 has ultra-fast line and improved load regulation. Moreover, the PS0100 provides real shutdown circuitry, which disconnects the output from the input in shutdown and results in discharge of the output to ground.
The PS0100 will start up typically at 0.8V. When it is turned-on, the device gets its start up bias from Vin. A start-up oscillator, which runs typically at 650 KHz, brings the output voltage high enough so that Vout exceeds Vin. Once Vout exceeds Vin, internal bias switches from Vin to Vout by an internal bias-select circuit. Thus, once started (i.e. Vout exceeds Vin), internal circuit bias is completely independent of Vin. The start-up oscillator runs at 66% duty cycle around 650kHz. Once Vout exceeds Vin (typically 1.9V), the start-up oscillator is disabled and the normal fixed Ton PWM operation takes over.
The PS0100 features a 0.45Ω NMOS switch and a 0.6Ω PMOS switch. In normal operation these switches are

alternatively turned-on and thus initiate charging of the inductor from Vin and then discharging of it to the ou tput capacitor and the load. However, between the event of one switch turning-off and the other turning-on, a dead time is provided to avoid huge in-rush current from output to ground via switches. In the dead time, both switches remain off and the inductor discharges via body diode of the PMOS switch to the output.
The PS0100A features a user-adjustable output through an external feedback network. A voltage divider from Vout to ground programs the output voltage via FB from 2.5V to 5V using the following equation:

$$V_{out}=V_{ref}*[1+(R1/R2)]$$

Where, $V_{ref}=1V$

DC-DC Converter Tutorial

Switching power supplies offer higher efficiency than traditional linear power supplies. They can step-up, step-down, and invert. Some designs can isolate output voltage from the input such as PS0100.

What Is a Switching Regulator?

A switching regulator is a circuit that uses a power switch, an inductor, and a diode to transfer energy from input to output. **But instead of diode there is a PMOS in PS0100**. The power switch was the key to practical switching regulators. The inductor's main function is to limit the current slew rate through the power switch. This limits the otherwise high-peak current that would be limited by the switch resistance alone. The key advantage for using an inductor in switching regulators: when the inductor is used to drop voltage, it stores energy. This energy is can be expressed in Joules as a function of the current by:

$E= ½ * L * I^2$

A linear regulator uses a resistive voltage drop to regulate the voltage, losing energy (voltage drop times the current) in the form of heat. A switching regulator's inductor does have a voltage drop and an associated current but the current is 90 degrees out of phase with the voltage, so the energy is stored and can be recovered in the discharge phase of the switching cycle. This results in a much higher efficiency and much less heat.

The Basic design of a step-up (boost) converter is shown in **Fig-1**. Feedback and control circuitry can be carefully nested around these circuits to regulate the energy transfer and maintain a constant output within normal operating conditions.

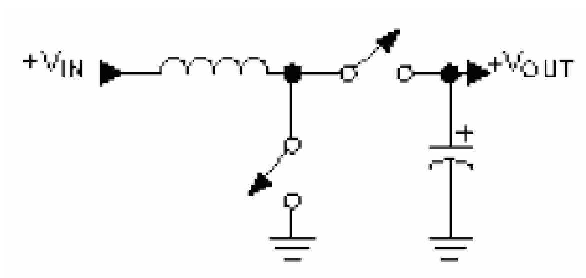


Fig-1: Simple Boost Converter

Why Use a Switching Regulator?

Switching regulators offer three main advantages compared to a linear regulators. First, switching efficiency can be much better than linear. Second, because less energy is lost in the transfer, smaller components and less thermal management are required. Third, the energy stored by switchers can be transformed to output voltages that can be greater than input (boost).
Given the advantages of switching regulators, one might wonder where would you use a linear regulator? Linear can provide lower noise and higher bandwidth; their simplicity can sometimes offer a less expensive solution. There are, admittedly, disadvantages with switchers: they can be noisy and require energy management in the form of a control loop. Fortunately the solution to these control problems is found integrated in modern switching-mode controller chips.

Charge Phase

A basic boost configuration is shown in **Fig-2**. Assuming that the SW1 has been open and Sw2 has been close for a long time, the voltage across the capacitor is equal to the input voltage. When the Sw1 closes and Sw2 opens, the input voltage, $+V_{IN}$, is impressed across the inductor and the Sw2 prevents the capacitor from discharging $+V_{OUT}$ to ground, because there is no conductive path through the body of the PMOS. Though the input voltage is DC, current through the inductor rises linearly with time at a rate proportional to the input voltage divided by the inductance.

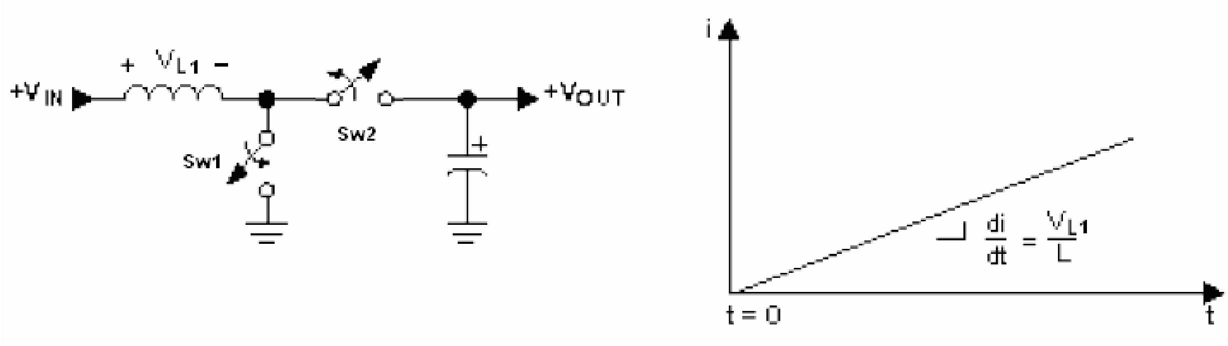


Fig-2: Charging phase: when the switch closes, current ramps up through the inductor.

Discharge Phase

Fig-3 shows the discharge phase. When the Sw1 opens again and Sw2 closes, the inductor current continues to flow and charge the output. As the output voltage rises, the slope of the current, di/dt, though the inductor reverses. The output voltage rises until equilibrium is reached or:

$V_L = L * di/dt$

In other words, the higher the inductor voltage, the faster inductor current drops.

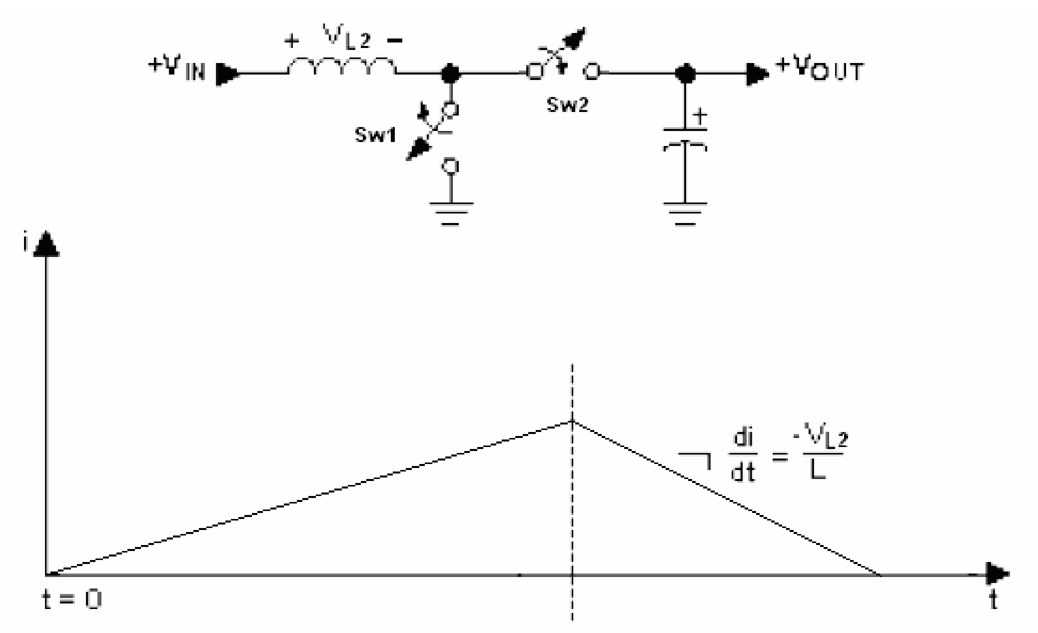


Fig-3: Discharge phase: when the Sw1 opens and Sw2 closes current flows to the load

In a steady-state operating condition the average voltage across the inductor over the entire switching cycle is zero. This implies that the average current through the inductor is also in steady state. This is an important rule governing all inductor-based switching topologies. Taking this one step further, we can establish that for a given charge time, t_{ON}, and a given input voltage and with the circuit in equilibrium, there is a specific discharge time, t_{OFF}, for an output voltage. Because the average inductor voltage in steady state must equal zero, we can calculate for the boost circuit:

During t_{ON} :

$V_{L1} = V_{IN}$

Energy stored by the inductor during on time = $V_{IN} * t_{ON}$

During t_{OFF} :

$V_{L2} = V_{OUT} - V_{IN}$

Energy released by the inductor during off time = $(V_{OUT} - V_{IN}) * t_{OFF}$

Since the energy stored during on time is equal to the energy released during off time, so we can establish the relationship:

$V_{IN} * t_{ON} = (V_{OUT} - V_{IN}) * t_{OFF}$

Resulting,

$V_{OUT} = V_{IN} * (1 + t_{ON}/t_{OFF})$

Also using the relationship for duty cycle (D):

$t_{ON} / (t_{ON} + t_{OFF}) = D$

Then for the Boost circuit:

$\mathbf{V_{OUT} = V_{IN} / (1 - D)}$

Capacitor selection

To achieve a low output ripple, all capacitors should be ceramic capacitors because of their low equivalent series resistance (ESR). The low ESR of the capacitors ensures minimum time constant when charging and discharging. The low ESR of C_{IN} and C_{OUT} is required to reduce the spikes that occur during the turnover from the transfer phase of one charge pump to that of the other. The lower the ESR of C_{OUT}, the lower is the output voltage spike. A 4.7-µF ceramic input and output capacitor is sufficient for most applications. Increasing this value provides better input-voltage filtering.

Inductor selection

The selection of the inductor value is very important. Depending on the application, inductor value 4.7µH is recommended. Beside this the user should keep in mind about the maximum inductor current capacity. It is recommended that the maximum inductor current capacity must be greater than the I_{LIM} (peak current limit) of PS0100. Otherwise the inductor might saturate and eventually be heated and may be permanently damaged. For using the PS0100 in any RF related equipments such as in cellular phones or wireless keyboard/mouse, it is recommended to use the shielded inductor.