

# A Unique Converter Configuration Provides Step-Up/Down Functions

## INTRODUCTION

The use of switching regulators in new portable equipment designs is becoming more pronounced over that of linear regulators. This is primarily due to the need for reductions in size and weight which dictate an ever-increasing demand for higher power conversion efficiency from a battery pack. When designing at the board level it sometimes becomes necessary to generate a constant output voltage that is less than that of the battery. The step-down circuit shown in Figure 1A will perform this function efficiently. However, as the battery discharges, its terminal voltage will eventually fall below the desired output, and in order to utilize the remaining battery energy the step-up circuit shown in Figure 1B will be required.

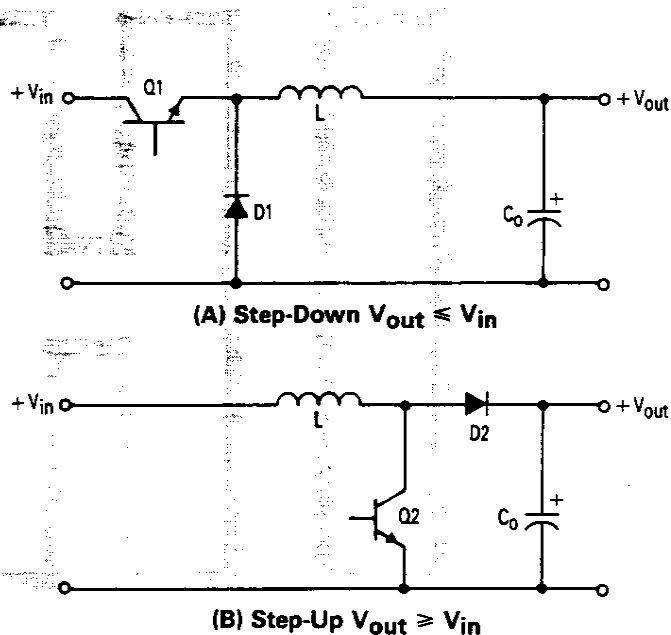


Figure 1. Basic Switching Regulator Configurations

## GENERAL APPLICATIONS

By combining circuits A and B a unique step-up/down configuration can be created (Figure 2) which still employs a *simple inductor* for the voltage transformation. Energy is stored in the inductor during the time that transistors Q1 and Q2 are in the 'on' state. Upon turn-off, the energy is transferred to the output filter capacitor and load forward biasing diodes D1 and D2. Note that during  $t_{on}$  this circuit is identical to the basic step-up, but during  $t_{off}$  the output voltage is derived only from the inductor and is with respect to ground instead of  $V_{in}$ . This allows the output voltage to be set to any value, thus it may be less than, equal to, or greater than that of the input. Current limit protection cannot be employed in the basic step-up circuit. If the output is severely overloaded or shorted L or D2 may be destroyed since they form a direct path from  $V_{in}$  to  $V_{out}$ . The step-up/down configuration allows the control circuit to implement current limiting because Q1 is now in series with  $V_{out}$ , as is in the step-down circuit.

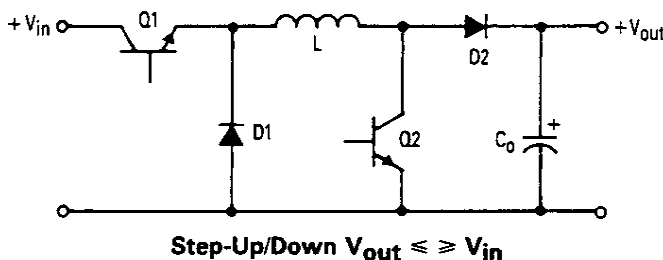
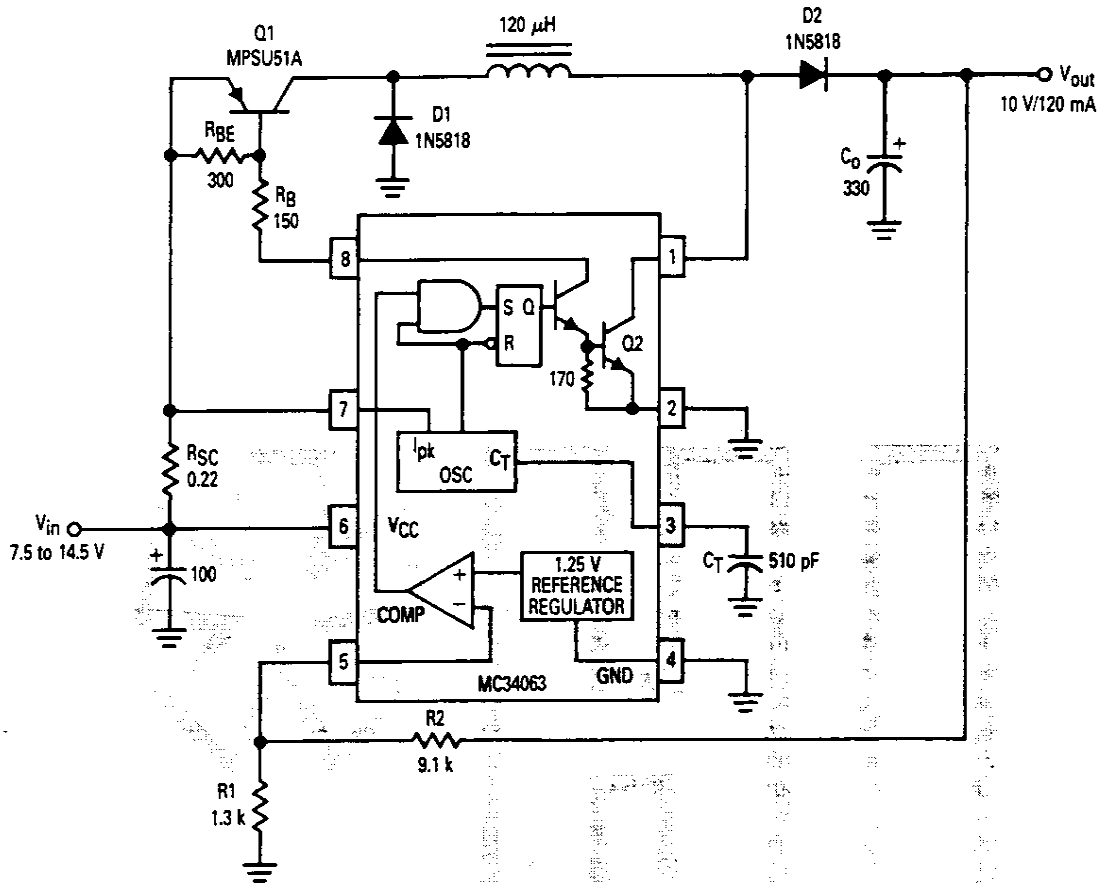


Figure 2. Combined Configuration





Test	Conditions	Results
Line Regulation	$V_{in} = 7.5 \text{ to } 14.5 \text{ V}$ , $I_{out} = 120 \text{ mA}$	$\Delta = 22 \text{ mV}$ or $\pm 0.11\%$
Load Regulation	$V_{in} = 12.6 \text{ V}$ , $I_{out} = 10 \text{ to } 120 \text{ mA}$	$\Delta = 3 \text{ mV}$ or $\pm 0.015\%$
Output Ripple	$V_{in} = 12.6 \text{ V}$ , $I_{out} = 120 \text{ mA}$	95 mV <sub>p-p</sub>
Short Circuit Current	$V_{in} = 12.6 \text{ V}$ , $R_L = 0.1 \Omega$	1.54 A
Efficiency	$V_{in} = 7.5 \text{ to } 14.5 \text{ V}$ , $I_{out} = 120 \text{ mA}$	74%

Figure 3. Step-Up/Down Switching Regulator Design Example

\*HI: This item is marked with the letters 'HI' to indicate that these documents are included for Historical Information only. This document was developed at a Design Centre strategically located throughout the global community and was originally written to support a local need. Whilst the basic concepts of this publication may have broad global applicability, specific Motorola semiconductor parts may be referred to that are currently available for limited distribution in a specific region and may only be supported by the country of origin of the document in which it is referenced. However, before attempting to design-in a device referenced, the user should contact the local Motorola supplier or sales office to confirm product availability and if application support is available.

A complete step-up/down switching regulator design example is shown in Figure 3. In order to implement a minimum component system, the Motorola MC34063 switching regulator subsystem was selected. This device features an on-chip 1.5 A switch transistor that was used to perform the function of Q2. This regulator was designed to operate from a standard 12 V battery pack with the following conditions:

$$\begin{aligned} V_{in} &= 7.5 \text{ to } 14.5 \text{ V} & V_{out} &= 10 \text{ V} \\ f_{min} &= 50 \text{ kHz} & I_{out} &= 120 \text{ mA} \\ V_{ripple} \text{ (p-p)} &= 1\% V_{out} \text{ or } 100 \text{ mV}_{p-p} \end{aligned}$$

The following design procedure is provided so that the user can select proper component values for his specific converter application.

- 1) Determine the ratio of switch conduction  $t_{on}$  versus diode conduction  $t_{off}$  time.

$$\begin{aligned} \frac{t_{on}}{t_{off}} &= \frac{V_{out} + V_{FD1} + V_{FD2}}{V_{in(min)} - V_{satQ1} - V_{satQ2}} \\ &= \frac{10 + 0.6 + 0.6}{7.5 - 0.8 - 0.8} \\ &= 1.9 \end{aligned}$$

- 2) The cycle time of the L-C network is equal to  $t_{on(max)} + t_{off}$ .

$$\begin{aligned} t_{on(max)} + t_{off} &= \frac{1}{f_{min}} \\ &= \frac{1}{50 \times 10^3} \\ &= 20 \mu\text{s per cycle} \end{aligned}$$

- 3) Next calculate  $t_{on}$  and  $t_{off}$  from the ratio of  $t_{on}/t_{off}$  in #1 and the sum of  $t_{on(max)} + t_{off}$  in #2.

$$\begin{aligned} t_{off} &= \frac{t_{on(max)} + t_{off}}{\frac{t_{on}}{t_{off}} + 1} \\ &= \frac{20 \times 10^{-6}}{1.9 + 1} \\ &= 6.9 \mu\text{s} \\ t_{on} &= 20 \mu\text{s} - 6.9 \mu\text{s} \\ &= 13.1 \mu\text{s} \end{aligned}$$

- 4) The maximum on-time is set by selecting a value for  $C_T$ .

$$\begin{aligned} C_T &= 4 \times 10^{-5} t_{on(max)} \\ &= 4 \times 10^{-5} (13.1 \times 10^{-6}) \\ &= 524 \text{ pF} \end{aligned}$$

Use a standard 510 pF capacitor.

- 5) The peak switch current is:

$$\begin{aligned} I_{pk(\text{switch})} &= 2I_{out} \left( \frac{t_{on}}{t_{off}} + 1 \right) \\ &= 2 (120 \times 10^{-3}) (1.9 + 1) \\ &= 696 \text{ mA} \end{aligned}$$

- 6) A minimum value of inductance can now be calculated since the maximum on-time and peak switch current are known.

$$\begin{aligned} L_{min} &= \left( \frac{V_{in(min)} - V_{satQ1} - V_{satQ2}}{I_{pk(\text{switch})}} \right) t_{on} \\ &= \left( \frac{7.5 - 0.8 - 0.8}{696 \times 10^{-3}} \right) 13.1 \times 10^{-6} \\ &= 111 \mu\text{H} \end{aligned}$$

A 120  $\mu\text{H}$  inductor was selected for  $L_{(min)}$ .

- 7) A value for the current limit resistor,  $R_{SC}$ , can be determined by using the current limit level of  $I'_{pk(\text{switch})}$  when  $V_{in} = 14.5 \text{ V}$ .

$$\begin{aligned} I'_{pk(\text{switch})} &= \left( \frac{V_{in} - V_{satQ1} - V_{satQ2}}{L_{(min)}} \right) t_{on(max)} \\ &= \left( \frac{14.5 - 0.8 - 0.8}{120 \times 10^{-6}} \right) 13.1 \times 10^{-6} \\ &= 1.41 \text{ A} \\ R_{SC} &= \frac{0.33}{I'_{pk(\text{switch})}} \\ &= \frac{0.33}{1.41} \\ &= 0.23 \Omega \end{aligned}$$

Use a standard 0.22  $\Omega$  resistor.

- 8) A minimum value for an *ideal* output filter capacitor is:

$$\begin{aligned} C_o &\approx \left( \frac{I_{out}}{V_{ripple(p-p)}} \right) t_{on} \\ &= \left( \frac{120 \times 10^{-3}}{100 \times 10^{-3}} \right) 13.1 \times 10^{-6} \\ &\approx 15.7 \mu\text{F} \end{aligned}$$

Ideally this would satisfy the design goal, however, even a solid tantalum capacitor of this value will have a typical ESR (equivalent series resistance) of  $0.3 \Omega$  which will contribute an additional 209 mV of ripple. Also there is a ripple component due to the gain of the comparator equal to:

$$\begin{aligned} V_{\text{ripple(p-p)}} &= \left( \frac{V_{\text{out}}}{V_{\text{Ref}}} \right) 1.5 \times 10^{-3} \\ &= \left( \frac{10}{1.25} \right) 1.5 \times 10^{-3} \\ &= 12 \text{ mV} \end{aligned}$$

The ripple components are not in phase, but can be assumed to be for a conservative design. From the above it becomes apparent that ESR is the dominant factor in the selection of an output filter capacitor. A  $330 \mu\text{F}$  with an ESR of  $0.12 \Omega$  was selected to satisfy this design example by the following:

$$\text{ESR} \approx \frac{V_{\text{ripple(p-p)}} - \left( \frac{I_{\text{out}}}{C_o} \right) t_{\text{on}} - \left( \frac{V_{\text{out}}}{V_{\text{Ref}}} \right) 1.5 \times 10^{-3}}{I_{\text{pk}}(\text{switch})}$$

- 9) The nominal output voltage is programmed by the R1, R2 resistor divider.

$$\begin{aligned} R2 &= R1 \left( \frac{V_{\text{out}}}{V_{\text{Ref}}} - 1 \right) \\ &= R1 \left( \frac{10}{1.25} - 1 \right) \\ &= 7 R1 \end{aligned}$$

If 1.3 k is chosen for R1, then R2 would be 9.1 k, both being standard resistor values.

- 10) Transistor Q1 is driven into saturation with a forced gain of approximately 20 at an input voltage of 7.5 V. The required base drive is:

$$\begin{aligned} I_B &= \frac{I_{\text{pk}}(\text{switch})}{\beta_F} \\ &= \frac{696 \times 10^{-3}}{20} \\ &= 35 \text{ mA} \end{aligned}$$

The value for the base-emitter turn-off resistor  $R_{BE}$  is determined by:

$$\begin{aligned} R_{BE} &= \frac{10 \beta_F}{I_{\text{pk}}(\text{switch})} \\ &= \frac{10 (20)}{696 \times 10^{-3}} \\ &= 287 \Omega \end{aligned}$$

A standard  $300 \Omega$  resistor was selected.

The additional base current required due to  $R_{BE}$  is:


$$\begin{aligned} I_{R_{BE}} &= \frac{V_{BEQ1}}{R_{BE}} \\ &= \frac{0.8}{300} \\ &= 3 \text{ mA} \end{aligned}$$

The base drive resistor for Q1 is equal to:

$$\begin{aligned} R_B &= \frac{V_{\text{in}}(\text{min}) - V_{\text{sat}}(\text{driver}) - V_{RSC} - V_{BEQ1}}{I_B + I_{R_{BE}}} \\ &= \frac{7.5 - 0.8 - 0.15 - 0.8}{(35 + 3) \times 10^{-3}} \\ &= 151 \Omega \end{aligned}$$

A standard  $150 \Omega$  resistor was used.

The circuit performance data shows excellent line and load regulation. There is some loss in conversion efficiency over the basic step-up or step-down circuits due to the added switch transistor and diode 'on' losses. However this unique converter demonstrates that with a simple inductor, a step-up/down converter with current limiting can be constructed. For a more in depth analysis of the MC34063 operation and the derivation of the above design equations, request Motorola Application Note AN920A.

Motorola reserves the right to make changes without further notice to any products herein. Motorola makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does Motorola assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation consequential or incidental damages. "Typical" parameters can and do vary in different applications. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. Motorola does not convey any license under its patent rights nor the rights of others. Motorola products are not designed, intended, or authorized for use as components in systems intended for surgical implant into the body, or other applications intended to support or sustain life, or for any other application in which the failure of the Motorola product could create a situation where personal injury or death may occur. Should Buyer purchase or use Motorola products for any such unintended or unauthorized application, Buyer shall indemnify and hold Motorola and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that Motorola was negligent regarding the design or manufacture of the part. Motorola and  are registered trademarks of Motorola, Inc. Motorola, Inc. is an Equal Opportunity/Affirmative Action Employer.

#### Literature Distribution Centers:

USA: Motorola Literature Distribution; P.O. Box 20912; Phoenix, Arizona 85036.

EUROPE: Motorola Ltd.; European Literature Centre; 88 Tanners Drive, Blakelands, Milton Keynes, MK14 5BP, England.

JAPAN: Nippon Motorola Ltd.; 4-32-1, Nishi-Gotanda, Shinagawa-ku, Tokyo 141, Japan.

ASIA PACIFIC: Motorola Semiconductors H.K. Ltd.; Silicon Harbour Center, No. 2 Dai King Street, Tai Po Industrial Estate, Tai Po, N.T., Hong Kong.



**MOTOROLA**

18761 PRINTED IN USA 7/93 MPS/POD

AN954/D

