MP1570

3A, 23V, 340KHz Synchronous Rectified Step-Down Converter

The Future of Analog IC Technology™

DESCRIPTION

The MP1570 is a monolithic synchronous buck regulator. The device integrates 100mΩ MOSFETS that provide 3A continuous load current over a wide operating input voltage of 4.75V to 23V. Current mode control provides fast transient response and cycle-by-cycle current limit.

An adjustable soft-start prevents inrush current at turn-on. In shutdown mode, the output is actively discharged by transferring energy in the output capacitor to the input capacitor, dropping the supply current to 1μA.

This device, available in an 8-pin SOIC package, provides a very compact system solution with minimal reliance on external components.

EVALUATION BOARD REFERENCE

Board Number	Dimensions
EV1570DN-00A	2.0”X x 1.5”Y x 0.5”Z

FEATURES

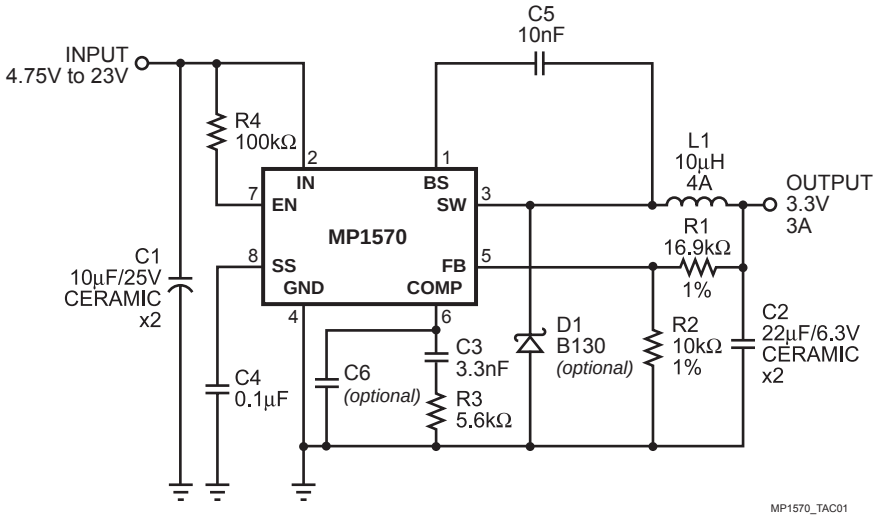
- 3A Output Current
- Wide 4.75V to 23V Operating Input Range
- Integrated 100mΩ Power MOSFET Switches
- Output Adjustable from 1.23V to 20V
- Up to 95% Efficiency
- Programmable Soft-Start
- Stable with Low ESR Ceramic Output Capacitors
- Fixed 340KHz Frequency
- Cycle-by-Cycle Over Current Protection
- Input Under Voltage Lockout
- Thermally Enhanced 8-Pin SOIC Package

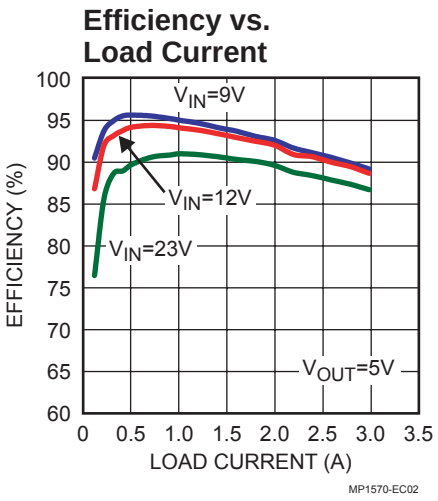
APPLICATIONS

- Distributed Power Systems
- Pre-Regulator for Linear Regulators
- Notebook Computers

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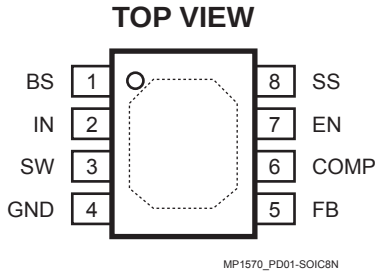
TYPICAL APPLICATION





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PACKAGE REFERENCE



Part Number*	Package	Temperature
MP1570DN	SOIC8N (Exposed Pad)	–40° to +85°C

* For Tape & Reel, add suffix –Z (eg. MP1570DN–Z)
For Lead Free, add suffix –LF (eg. MP1570DN–LF–Z)

ABSOLUTE MAXIMUM RATINGS (1)

Supply Voltage V_{IN} ..... –0.3V to +26V
Switch Voltage V_{SW} ..... –1V to V_{IN} + 0.3V
Boost Voltage V_{BS} ..... V_{SW} – 0.3V to V_{SW} + 6V
All Other Pins ..... –0.3V to +6V
Junction Temperature ..... 150°C
Lead Temperature ..... 260°C
Storage Temperature ..... –65°C to +150°C

Recommended Operating Conditions (2)

Input Voltage V_{IN} ..... 4.75V to 23V
Output Voltage V_{OUT} ..... 1.23V to 20V
Ambient Operating Temperature ... –40°C to +85°C

Thermal Resistance (3)

	θ_{JA}	θ_{JC}
SOIC8N	50	10 °C/W

Notes:
1) Exceeding these ratings may damage the device.
2) The device is not guaranteed to function outside of its operating conditions.
3) Measured on approximately 1" square of 1 oz copper.

ELECTRICAL CHARACTERISTICS

V_{IN} = 12V, T_A = +25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Shutdown Supply Current		V_{EN} = 0V		0.3	3.0	µA
Supply Current		V_{EN} = 2.7V, V_{FB} = 1.4V		1.3	1.5	mA
Feedback Voltage	V_{FB}	4.75V ≤ V_{IN} ≤ 23V, V_{COMP} < 2V	1.202	1.230	1.258	V
Feedback Overvoltage Threshold			1.4	1.5	1.6	V
Error Amplifier Voltage Gain (4)	A_{EA}			400		V/V
Error Amplifier Transconductance	G_{EA}	ΔI_C = ±10µA	550	820	1100	µA/V
High Side Switch On Resistance (4)	$R_{DS(ON)1}$			100		mΩ
Low Side Switch On Resistance (4)	$R_{DS(ON)2}$			100		mΩ
High Side Switch Leakage Current		V_{EN} = 0V, V_{SW} = 0V		0	10	µA
Upper Switch Current Limit			4.0	5.8	7.6	A
Lower Switch Current Limit		From Drain to Source		0.9		A
COMP to Current Sense Transconductance	G_{CS}		4.0	5.4	6.8	A/V
Oscillation Frequency	F_{osc1}		300	340	380	KHz
Short Circuit Oscillation Frequency	F_{osc2}	V_{FB} = 0V		110		KHz
Maximum Duty Cycle	D_{MAX}	V_{FB} = 1.0V		90		%
Minimum On Time (4)				220		ns
EN Shutdown Threshold Voltage		V_{EN} Rising	1.1	1.5	2.0	V
EN Shutdown Threshold Voltage Hysteresis				220		mV

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ELECTRICAL CHARACTERISTICS *(continued)*

V_{IN} = 12V, T_A = +25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
EN Lockout Threshold Voltage			2.2	2.5	2.7	V
EN Lockout Hysteresis				210		mV
Input Under Voltage Lockout Threshold		V_{IN} Rising	3.80	4.05	4.30	V
Input Under Voltage Lockout Threshold Hysteresis				210		mV
Soft-Start Current		V_{SS} = 0V		6		µA
Soft-Start Period		C_{SS} = 0.1µF		20		ms
Thermal Shutdown (4)				160		°C

Note:

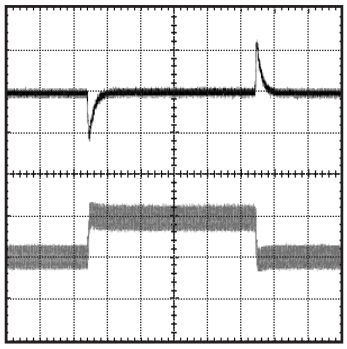
4) Guaranteed by design, not tested.

TYPICAL PERFORMANCE CHARACTERISTICS

V_{IN} = 12V, V_{OUT} = 3.3V, T_A = +25°C, unless otherwise noted.

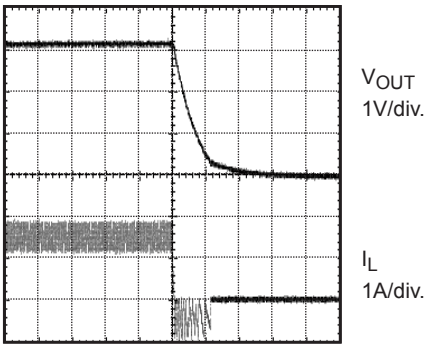
Load Transient Waveforms

1A - 2A STEP



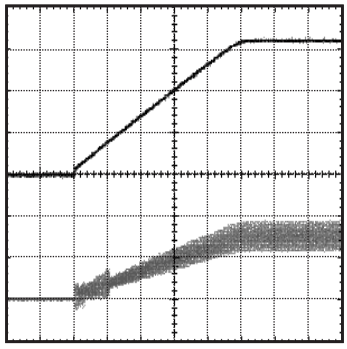
Turn Off Waveforms

R_{LOAD} = 2Ω



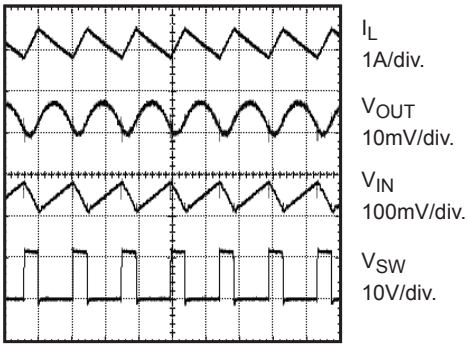
Soft-Start Waveforms

R_{LOAD} = 2Ω



Switching Waveforms

R_{LOAD} = 2Ω



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PIN FUNCTIONS

Pin #	Name	Description
1	BS	High-Side Gate Drive Boost Input. BS supplies the drive for the high-side N-Channel MOSFET switch. Connect a 0.01µF or greater capacitor from SW to BS to power the high side switch.
2	IN	Power Input. IN supplies the power to the IC, as well as the step-down converter switches. Drive IN with a 4.75V to 23V power source. Bypass IN to GND with a suitably large capacitor to eliminate noise on the input to the IC. See *Input Capacitor*.
3	SW	Power Switching Output. SW is the switching node that supplies power to the output. Connect the output LC filter from SW to the output load. Note that a capacitor is required from SW to BS to power the high-side switch.
4	GND	Ground (Connect Exposed Pad to Pin 4)
5	FB	Feedback Input. FB senses the output voltage to regulate that voltage. Drive FB with a resistive voltage divider from the output voltage. The feedback threshold is 1.230V. See *Setting the Output Voltage*.
6	COMP	Compensation Node. COMP is used to compensate the regulation control loop. Connect a series RC network from COMP to GND to compensate the regulation control loop. In some cases, an additional capacitor from COMP to GND is required. See *Compensation Components.*
7	EN	Enable Input. EN is a digital input that turns the regulator on or off. Drive EN high to turn on the regulator, drive it low to turn it off. Pull up with 100kΩ resistor for automatic startup.
8	SS	Soft-start Control Input. SS controls the soft-start period. Connect a capacitor from SS to GND to set the soft-start period. A 0.1µF capacitor sets the soft-start period to 20ms. To disable the soft-start feature, leave SS unconnected.

BLOCK DIAGRAM

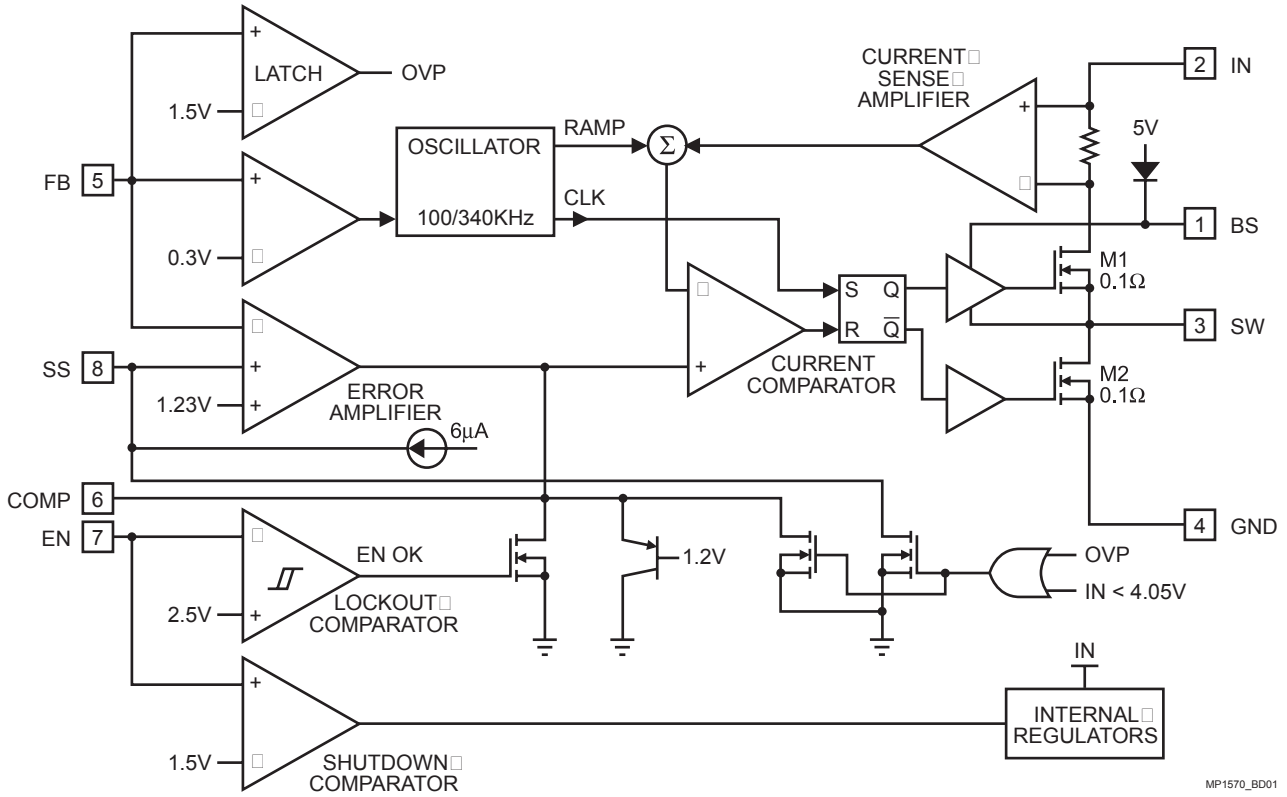


Figure 1—Functional Block Diagram

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OPERATION

FUNCTIONAL DESCRIPTION

The MP1570 is a synchronous rectified, current-mode, step-down regulator. It regulates input voltages from 4.75V to 23V down to an output voltage as low as 1.230V, and supplies up to 3A of load current.

The MP1570 uses current-mode control to regulate the output voltage. The output voltage is measured at FB through a resistive voltage divider and amplified through the internal transconductance error amplifier. The voltage at COMP pin is compared to the switch current measured internally to control the output voltage.

The converter uses internal N-Channel MOSFET switches to step-down the input voltage to the regulated output voltage. Since the high side MOSFET requires a gate voltage greater than the input voltage, a boost capacitor connected between SW and BS is needed to drive the high side gate. The boost capacitor is charged from the internal 5V rail when SW is low.

When the MP1570 FB pin exceeds 20% of the nominal regulation voltage of 1.230V, the over voltage comparator is tripped and latched; the COMP pin and the SS pin are discharged to GND, forcing the high-side switch off. Latch cannot be cleared unless the EN or IN pin is reset.

Following discharge, the MP1570 actively recycles the energy stored in the output capacitor. Initially the low-side synchronous rectifier turns on. Once the internal, negative 900mA current limit is reached, the low-side switch turns off, forcing inductor current to flow through the high-side switch body diode. The inductor current is recycled back into the input as an energy saving feature. This cycle continues until the output voltage is discharged below 10% of the initial regulation voltage (0.123V at FB), at which time the low-side switch turns off.

APPLICATIONS INFORMATION

COMPONENT SELECTION

Setting the Output Voltage

The output voltage is set using a resistive voltage divider from the output voltage to FB pin. The voltage divider divides the output voltage down to the feedback voltage by the ratio:

$$V_{FB} = V_{OUT} \frac{R2}{R1+R2}$$

Thus the output voltage is:

$$V_{OUT} = 1.23 \times \frac{R1+R2}{R2}$$

Where V_{FB} is the feedback voltage and V_{OUT} is the output voltage.

A typical value for R2 can be as high as 100kΩ, but a typical value is 10kΩ. Using that value, R1 is determined by:

$$R1 = 8.18 \times (V_{OUT} - 1.23)(k\Omega)$$

For example, for a 3.3V output voltage, R2 is 10kΩ, and R1 is 17kΩ.

Inductor

The inductor is required to supply constant current to the output load while being driven by the switched input voltage. A larger value inductor will result in less ripple current that will result in lower output ripple voltage. However, the larger value inductor will have a larger physical size, higher series resistance, and/or lower saturation current. A good rule for determining the inductance to use is to allow the peak-to-peak ripple current in the inductor to be approximately 30% of the maximum switch current limit. Also, make sure that the

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peak inductor current is below the maximum switch current limit. The inductance value can be calculated by:

$$L = \frac{V_{OUT}}{f_S \times \Delta I} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Where V_{IN} is the input voltage, f_S is the 340KHz switching frequency, and ΔI_L is the peak-to-peak inductor ripple current.

Choose an inductor that will not saturate under the maximum inductor peak current. The peak inductor current can be calculated by:

$$I_{LP} = I_{LOAD} + \frac{V_{OUT}}{2 \times f_S \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Where I_{LOAD} is the load current.

Table 1 lists a number of suitable inductors from various manufacturers. The choice of which style inductor to use mainly depends on the price vs. size requirements and any EMI requirement.

Table 1—Inductor Selection Guide

Vendor/ Model	Core Type	Core Material	Package Dimensions (mm)		
			W	L	H
Sumida					
CR75	Open	Ferrite	7.0	7.8	5.5
CDH74	Open	Ferrite	7.3	8.0	5.2
CDRH5D28	Shielded	Ferrite	5.5	5.7	5.5
CDRH5D28	Shielded	Ferrite	5.5	5.7	5.5
CDRH6D28	Shielded	Ferrite	6.7	6.7	3.0
CDRH104R	Shielded	Ferrite	10.1	10.0	3.0
Toko					
D53LC Type A	Shielded	Ferrite	5.0	5.0	3.0
D75C	Shielded	Ferrite	7.6	7.6	5.1
D104C	Shielded	Ferrite	10.0	10.0	4.3
D10FL	Open	Ferrite	9.7	1.5	4.0
Coilcraft					
DO3308	Open	Ferrite	9.4	13.0	3.0
DO3316	Open	Ferrite	9.4	13.0	5.1

Optional Schottky Diode

During the transition between high-side switch and low-side switch, the body diode of the low-side power MOSFET conducts the inductor current. The forward voltage of this body diode is high. An optional Schottky diode may be paralleled between the SW pin and GND pin to improve overall efficiency. Table 2 lists example Schottky diodes and their Manufacturers.

Table 2—Diode Selection Guide

Part Number	Voltage/Current Rating	Vendor
B130	30V, 1A	Diodes, Inc.
SK13	30V, 1A	Diodes, Inc.
MBRS130	30V, 1A	International Rectifier

Input Capacitor

The input current to the step-down converter is discontinuous, therefore a capacitor is required to supply the AC current to the step-down converter while maintaining the DC input voltage. Use low ESR capacitors for the best performance. Ceramic capacitors are preferred, but tantalum or low-ESR electrolytic capacitors may also suffice. Choose X5R or X7R dielectrics when using ceramic capacitors.

Since the input capacitor (C1) absorbs the input switching current it requires an adequate ripple current rating. The RMS current in the input capacitor can be estimated by:

$$I_{C1} = I_{LOAD} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)}$$

The worst-case condition occurs at $V_{IN} = 2V_{OUT}$, where:

$$I_{C1} = \frac{I_{LOAD}}{2}$$

For simplification, choose the input capacitor whose RMS current rating greater than half of the maximum load current.

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The input capacitor can be electrolytic, tantalum or ceramic. When using electrolytic or tantalum capacitors, a small, high quality ceramic capacitor, i.e. 0.1μF, should be placed as close to the IC as possible. When using ceramic capacitors, make sure that they have enough capacitance to provide sufficient charge to prevent excessive voltage ripple at input. The input voltage ripple caused by capacitance can be estimated by:

$$\Delta V_{IN} = \frac{I_{LOAD}}{f_S \times C1} \times \frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Output Capacitor

The output capacitor is required to maintain the DC output voltage. Ceramic, tantalum, or low ESR electrolytic capacitors are recommended. Low ESR capacitors are preferred to keep the output voltage ripple low. The output voltage ripple can be estimated by:

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_S \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times \left(R_{ESR} + \frac{1}{8 \times f_S \times C2}\right)$$

Where C2 is the output capacitance value and R_{ESR} is the equivalent series resistance (ESR) value of the output capacitor.

In the case of ceramic capacitors, the impedance at the switching frequency is dominated by the capacitance. The output voltage ripple is mainly caused by the capacitance. For simplification, the output voltage ripple can be estimated by:

$$\Delta V_{OUT} = \frac{V_{OUT}}{8 \times f_S^{\,2} \times L \times C2} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

In the case of tantalum or electrolytic capacitors, the ESR dominates the impedance at the switching frequency. For simplification, the output ripple can be approximated to:

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_S \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times R_{ESR}$$

The characteristics of the output capacitor also affect the stability of the regulation system. The MP1570 can be optimized for a wide range of capacitance and ESR values.

Compensation Components

MP1570 employs current mode control for easy compensation and fast transient response. The system stability and transient response are controlled through the COMP pin. COMP pin is the output of the internal transconductance error amplifier. A series capacitor-resistor combination sets a pole-zero combination to control the characteristics of the control system.

The DC gain of the voltage feedback loop is given by:

$$A_{VDC} = R_{LOAD} \times G_{CS} \times A_{VEA} \times \frac{V_{FB}}{V_{OUT}}$$

Where A_{VEA} is the error amplifier voltage gain, 400V/V; G_{CS} is the current sense transconductance, 5.4A/V; R_{LOAD} is the load resistor value.

The system has 2 poles of importance. One is due to the compensation capacitor (C3) and the output resistor of error amplifier, and the other is due to the output capacitor and the load resistor. These poles are located at:

$$f_{P1} = \frac{G_{EA}}{2\pi \times C3 \times A_{VEA}}$$

$$f_{P2} = \frac{1}{2\pi \times C2 \times R_{LOAD}}$$

Where, G_{EA} is the error amplifier transconductance, 800μA/V.

The system has one zero of importance, due to the compensation capacitor (C3) and the compensation resistor (R3). This zero is located at:

$$f_{Z1} = \frac{1}{2\pi \times C3 \times R3}$$

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The system may have another zero of importance, if the output capacitor has a large capacitance and/or a high ESR value. The zero, due to the ESR and capacitance of the output capacitor, is located at:

$$f_{ESR} = \frac{1}{2\pi \times C2 \times R_{ESR}}$$

In this case (as shown in Figure 2), a third pole set by the compensation capacitor (C6) and the compensation resistor (R3) is used to compensate the effect of the ESR zero on the loop gain. This pole is located at:

$$f_{P3} = \frac{1}{2\pi \times C6 \times R3}$$

The goal of compensation design is to shape the converter transfer function to get a desired loop gain. The system crossover frequency where the feedback loop has the unity gain is important.

Lower crossover frequencies result in slower line and load transient responses, while higher crossover frequencies could cause system unstable. A good rule of thumb is to set the crossover frequency to approximately one-tenth of the switching frequency. Switching frequency for the MP1570 is 340KHz, so the desired crossover frequency is 34KHz.

Table 3 lists the typical values of compensation components for some standard output voltages with various output capacitors and inductors. The values of the compensation components have been optimized for fast transient responses and good stability at given conditions.

Table 3—Compensation Values for Typical Output Voltage/Capacitor Combinations

V_{OUT}	L	C2	R3	C3	C6
1.8V	4.7µH	100µF Ceramic	5.6kΩ	3.3nF	None
2.5V	4.7-6.8µH	47µF Ceramic	4.7kΩ	4.7nF	None
3.3V	6.8-10µH	22µFx2 Ceramic	5.6kΩ	3.3nF	None
5V	10-15µH	22µFx2 Ceramic	7.5kΩ	3.3nF	None
12V	15-22µH	22µFx2 Ceramic	10kΩ	1.2nF	None
1.8	4.7µH	100µF SP-CAP	10kΩ	2.2nF	100pF
2.5V	4.7-6.8µH	47µF SP-CAP	5.6kΩ	3.3nF	None
3.3V	6.8-10µH	47µF SP-CAP	6.8kΩ	2.2nF	None
5V	10-15µH	47µF SP CAP	10kΩ	2.2nF	None
2.5V	4.7-6.8µH	560µF Al. 30mΩ ESR	10kΩ	7.5nF	1.5nF
3.3V	6.8-10µH	560µF Al 30mΩ ESR	10kΩ	10nF	1.5nF
5V	10-15µH	470µF Al. 30mΩ ESR	15kΩ	7.5nF	1nF
12V	15-22µH	220µF Al. 30mΩ ESR	15kΩ	10nF	390pF

To optimize the compensation components for conditions not listed in Table 2, the following procedure can be used.

1. Choose the compensation resistor (R3) to set the desired crossover frequency. Determine the R3 value by the following equation:

$$R3 = \frac{2\pi \times C2 \times f_C}{G_{EA} \times G_{CS}} \times \frac{V_{OUT}}{V_{FB}}$$

Where f_C is the desired crossover frequency, 34KHz.

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2. Choose the compensation capacitor (C3) to achieve the desired phase margin. For applications with typical inductor values, setting the compensation zero, f_{Z1}, below one forth of the crossover frequency provides sufficient phase margin. Determine the C3 value by the following equation:

$$C3 > \frac{4}{2\pi \times R3 \times f_C}$$

3. Determine if the second compensation capacitor (C6) is required. It is required if the ESR zero of the output capacitor is located at less than half of the 340KHz switching frequency, or the following relationship is valid:

$$\frac{1}{2\pi \times C2 \times R_{ESR}} < \frac{f_S}{2}$$

is the case, then add the second compensation capacitor (C6) to set the pole f_{P3} at the location of the ESR zero. Determine the C6 value by the equation:

$$C6 = \frac{C2 \times R_{ESR}}{R3}$$

External Bootstrap Diode

It is recommended that an external bootstrap diode be added when the system has a 5V fixed input or the power supply generates a 5V output. This helps improve the efficiency of the regulator. The bootstrap diode can be a low cost one such as IN4148 or BAT54.

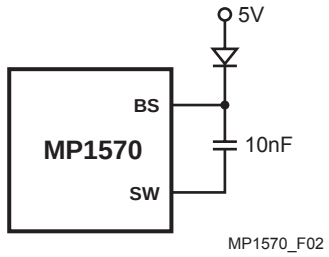


Figure 2—External Bootstrap Diode

This diode is also recommended for high duty cycle operation (when $\frac{V_{OUT}}{V_{IN}}$>65%) and high output voltage (V_{OUT}>12V) applications.

TYPICAL APPLICATION CIRCUITS

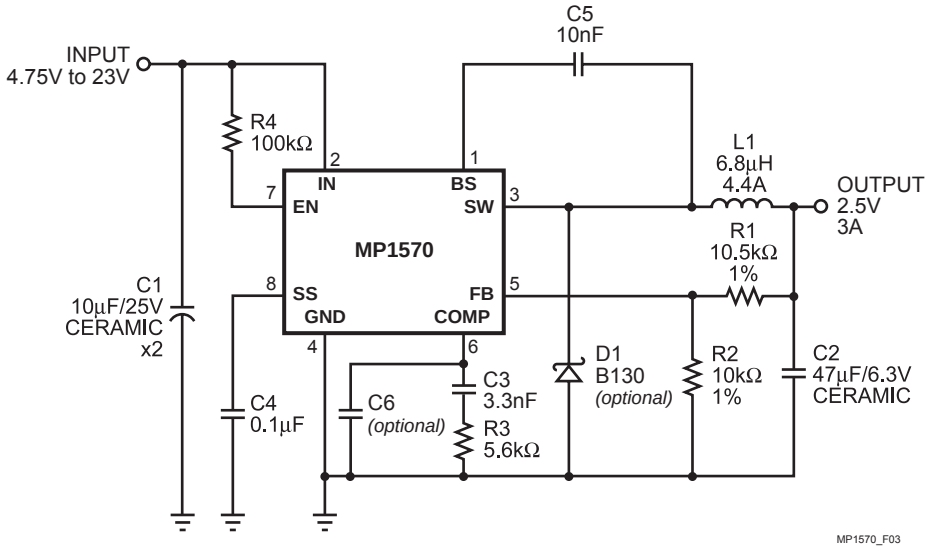


Figure 3—MP1570 with AVX 47µF, 6.3V Ceramic Output Capacitor

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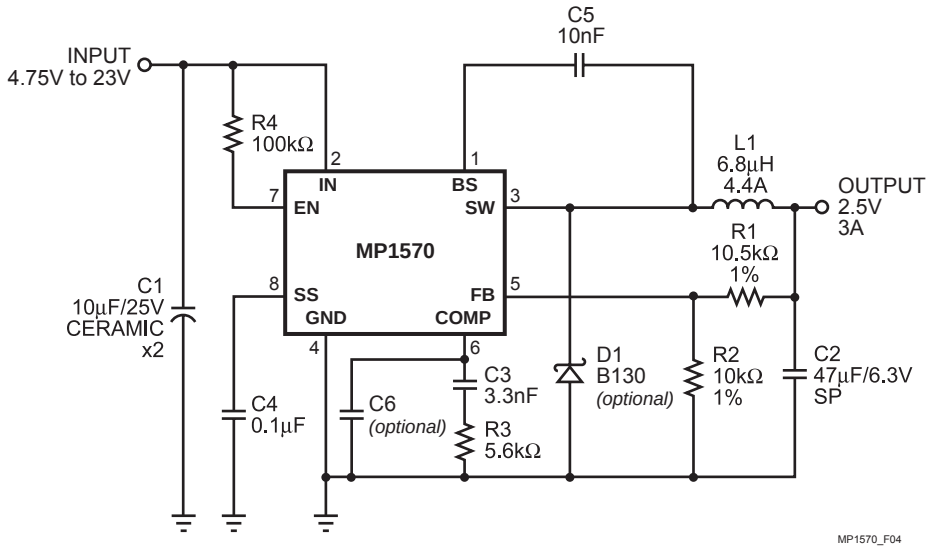


Figure 4—MP1570 with Panasonic 47µF, 6.3V Solid Polymer Output Capacitor

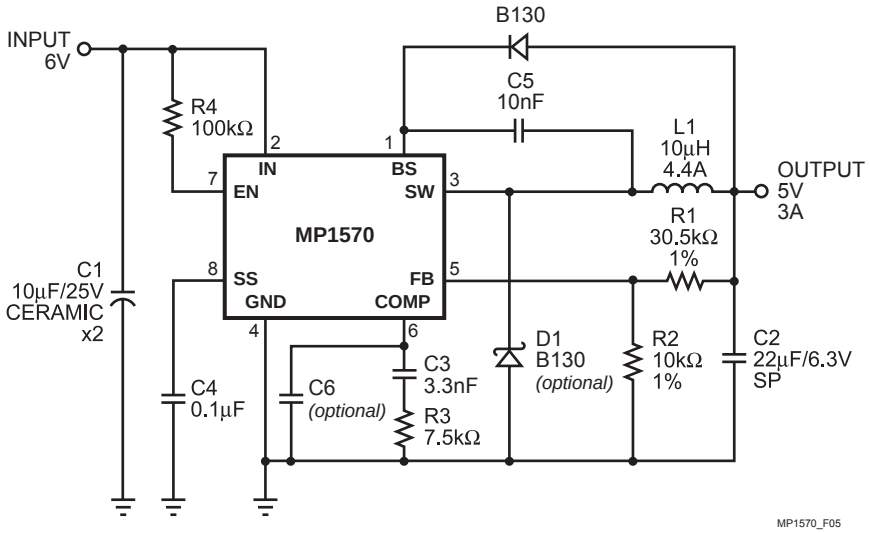
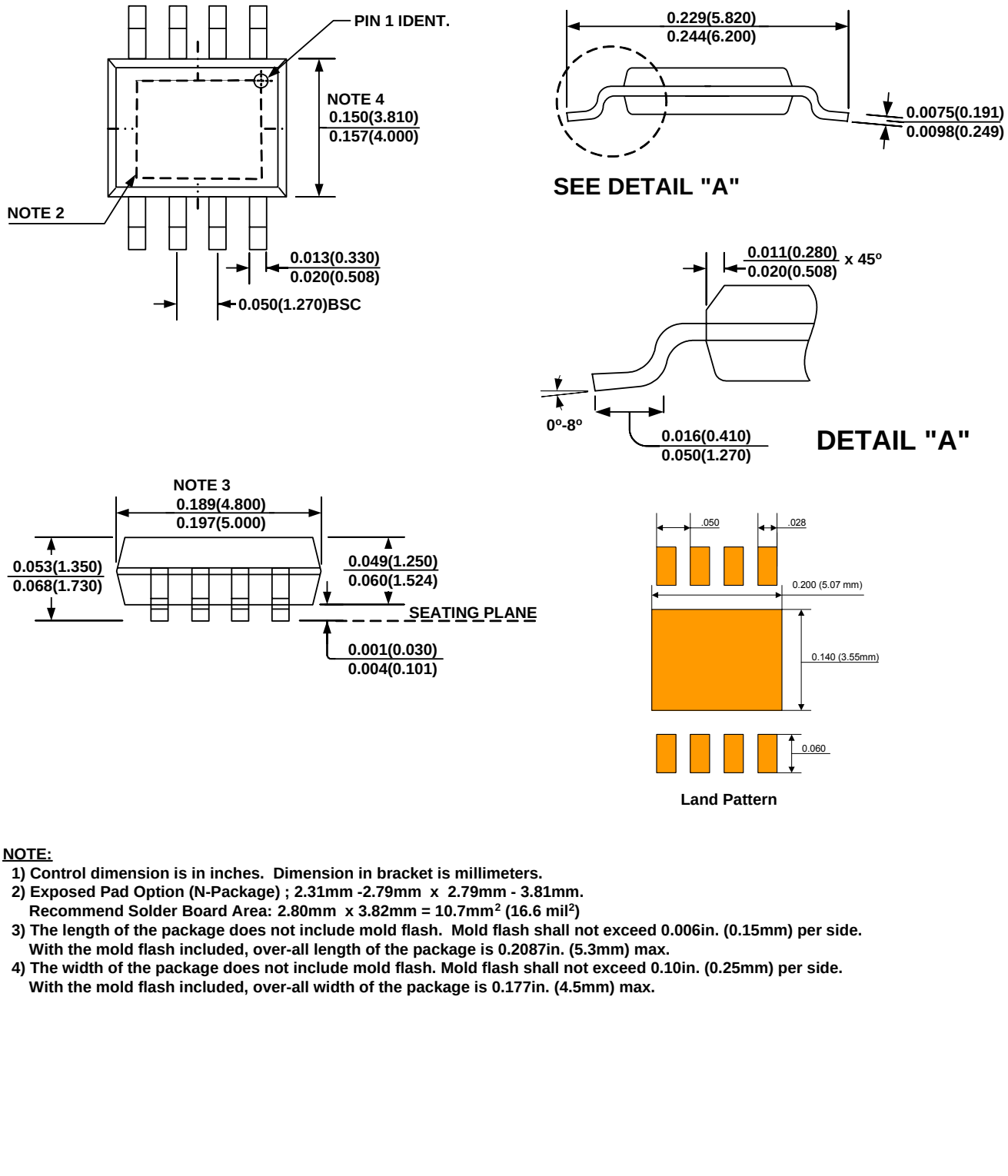


Figure 5—MP1570 Application Circuit with V_{IN} = 6V and V_O = 5V

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PACKAGE INFORMATION

SOIC8N (EXPOSED PAD)



NOTE:

1) Control dimension is in inches. Dimension in bracket is millimeters.
2) Exposed Pad Option (N-Package) ; 2.31mm -2.79mm x 2.79mm - 3.81mm.
   Recommend Solder Board Area: 2.80mm x 3.82mm = 10.7mm^2 (16.6 mil^2)
3) The length of the package does not include mold flash. Mold flash shall not exceed 0.006in. (0.15mm) per side.
   With the mold flash included, over-all length of the package is 0.2087in. (5.3mm) max.
4) The width of the package does not include mold flash. Mold flash shall not exceed 0.10in. (0.25mm) per side.
   With the mold flash included, over-all width of the package is 0.177in. (4.5mm) max.

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