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MP1410

2A Step Down DC to DC Converter

Functional Description

The MP1410 is a current-mode step-down switch-mode regulator. It regulates input voltages from 4.75V to 15V down to an output voltage as low as 1.22V, and is able to supply up to 2A of load current. The MP1410 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 error amplifier. The output current of the transconductance error amplifier is presented at COMP where a network compensates the regulation control system. The voltage at COMP is compared to the switch current measured internally to control the output voltage.

The converter uses an internal n-channel MOSFET switch to step down the input voltage to the regulated output voltage. Since the MOSFET requires a gate voltage greater than the input voltage, a boost capacitor connected between SW and BS drives the gate. The capacitor is internally charged while the switch is off. An internal 10Ω switch from SW to GND is used to insure that SW is pulled to GND when the switch is off to fully charge the BS capacitor.

Application Information

The output voltage is set using a resistive voltage divider from the output voltage to FB (see Figure 3). The voltage divider divides the output voltage down by the ratio:

$$V_{FB} = V_{OUT} * R3 / (R2 + R3)$$

Thus the output voltage is:

$$V_{OUT} = 1.222 * (R2 + R3) / R3$$

R3 can be as high as 100KΩ, but a typical value is 10KΩ. Using that value, R2 is determined by:

$$R2 \sim= 8.18 * (V_{OUT} - 1.222)\ (K\Omega)$$

For example, for a 3.3V output voltage, R3 is 10KΩ, and R2 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 results in less ripple current that in turn results in lower output ripple voltage. However, the larger value inductor has a larger physical size, higher series resistance, and/or lower saturation current. Choose an inductor that does not saturate under the worst-case load conditions. A good rule for determining the inductance is to allow the peak-to-peak ripple current in the inductor to be approximately 30% of the maximum load current. Also, make sure that the peak inductor current (the load current plus half the peak-to-peak inductor ripple current) is below the 2.4A minimum current limit. The inductance value can be calculated by the equation:

$$L = (V_{OUT}) * (V_{IN} - V_{OUT}) / V_{IN} * f * \Delta I$$

Where V_{OUT} is the output voltage, V_{IN} is the input voltage, f is the switching frequency, and ΔI is the peak-to-peak inductor ripple current. Table 2 lists a number of suitable inductors from various manufacturers.

Table 2: Inductor Selection Guide

Vendor/Model	Core Type	Core Material	Package Dimensions (mm) W	L	H
Sumida					
CR25	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	11.5	4.0
Coilcraft					
DO3308	Open	Ferrite	9.4	13.0	3.0
DO3316	Open	Ferrite	9.4	13.0	5.1

Input Capacitor

The input current to the step-down converter is discontinuous, and therefore an input capacitor C1 is required to supply the AC current to the step-down converter while maintaining the DC input voltage. A low ESR capacitor is required to keep the noise at the IC to a minimum. Ceramic capacitors are preferred, but tantalum or low-ESR electrolytic capacitors may also suffice.

The input capacitor value should be greater than 10µF. The capacitor can be electrolytic, tantalum or ceramic. However since it absorbs the input switching current it requires an adequate ripple current rating. Its RMS current rating should be greater than approximately 1/2 of the DC load current.

For insuring stable operation C2 should be placed as close to the IC as possible. Alternately a smaller high quality ceramic 0.1µF capacitor may be placed closer to the IC and a larger capacitor placed further away. If using this technique, it is recommended that the larger capacitor be a tantalum or electrolytic type. All ceramic capacitors should be placed close to the MP1410.

Output Capacitor

The output capacitor is required to maintain the DC output voltage. Low ESR capacitors are preferred to keep the output voltage ripple low. The characteristics of the output capacitor also affect the stability of the regulation control system. Ceramic, tantalum, or low ESR electrolytic capacitors are recommended. In the case of ceramic capacitors, the impedance at the switching frequency is dominated by the capacitance, and so the output voltage ripple is mostly independent of the ESR. The output voltage ripple is estimated to be:

$$V_{RIPPLE} \sim= 1.4 * V_{IN} * (f_{LC}/f_{SW})^2$$

Where V_{RIPPLE} is the output ripple voltage, V_{IN} is the input voltage, f_{LC} is the resonant frequency of the LC filter, f_{SW} is the switching frequency. In the case of tanatalum or low-ESR electrolytic capacitors, the ESR dominates the impedance at the switching frequency, and so the output ripple is calculated as:

$$V_{RIPPLE} \sim= \Delta I * R_{ESR}$$

Where V_{RIPPLE} is the output voltage ripple, ΔI is the inductor ripple current, and R_{ESR} is the equivalent series resistance of the output capacitors.

Output Rectifier Diode

The output rectifier diode supplies the current to the inductor when the high-side switch is off. To reduce losses due to the diode forward voltage and recovery times, use a Schottky rectifier.

Tables 3 provides the Schottky rectifier part numbers based on the maximum input voltage and current rating.

Table 3: Schottky Rectifier Selection Guide

V_{IN} (Max)	2A Load Current	
	Part Number	Vendor
15V	30BQ15	4
20V	B220	1
	SK23	6
	SR32	6

Table 4 lists some rectifier manufacturers.

Table 4: Schottky Diode Manufacturers

#	Vendor	Web Site
1	Diodes, Inc.	www.diodes.com
2	Fairchild Semiconductor	www.fairchildsemi.com
3	General Semiconductor	www.gensemi.com
4	International Rectifier	www.irf.com
5	On Semiconductor	www.onsemi.com
6	Pan Jit International	www.panjit.com.tw

Choose a rectifier who's maximum reverse voltage rating is greater than the maximum input voltage, and who's current rating is greater than the maximum load current.

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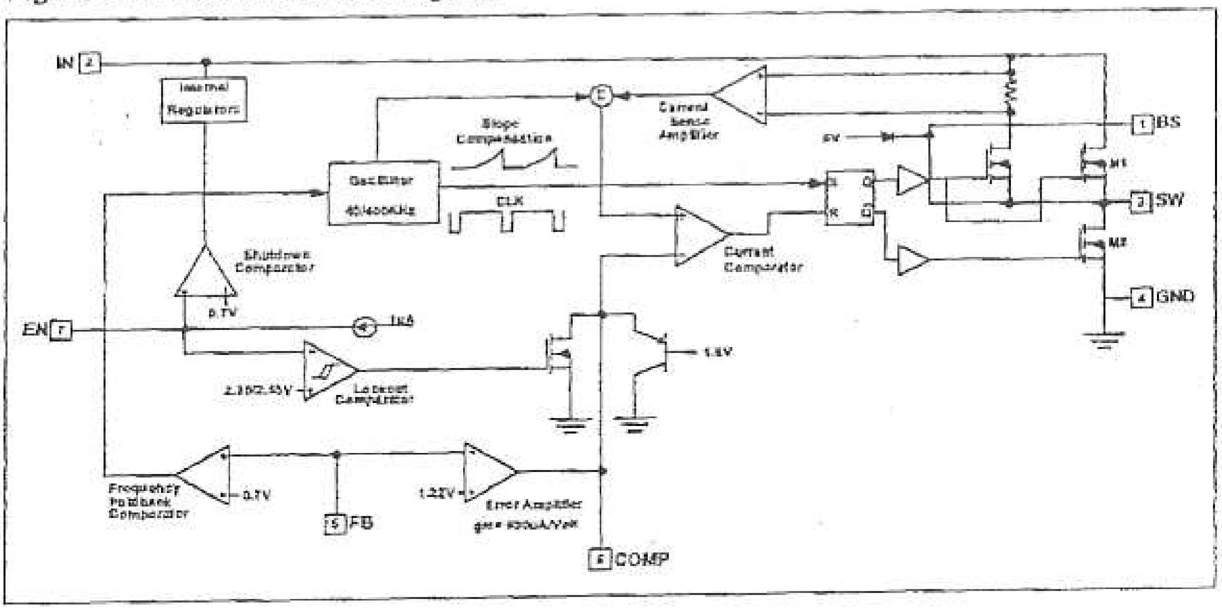
Table 1: Pin Designator

#	Name	Description
1	BS	High-Side Gate Drive Boost Input. BS supplies the drive for the high-side n-channel MOSFET switch. Connect a 10nF 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 15V 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.
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 1.22V. ***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. ***See Compensation.***
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. For automatic startup, leave EN unconnected.
8	N/C	No Connect

Figure 2: Functional Block Diagram



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Absolute Maximum Ratings (Note 1)

Input Voltage (V_{IN})	-0.3V to 16V
Switch Voltage (V_{SW})	-1V to V_{IN}+1V
Boot Strap Voltage (V_{BS})	V_{SW}-0.3V to V_{SW}+6V
All Other Pins	-0.3 to 6V
Junction Temperature	150°C
Lead Temperature	260°C
Storage Temperature	-65°C to 150°C

Recommended Operating Conditions (Note 2)

Input Voltage (V_{IN})	4.75V to 15V
Operating Temperature	-20°C to +85°C

Package Thermal Characteristics (Note 3)

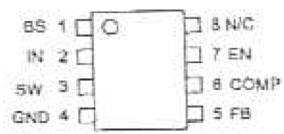
Thermal Resistance θ_{JA} (SOIC8)	105°C/W
Thermal Resistance θ_{JA} (PDIP8)	100°C/W

Electrical Characteristics (Unless otherwise specified refer to Circuit of Figure 1, V_{EN}=5V, V_{IN}=12V, T_A=25°C)

Parameters	Condition	Min	Typ	Max	Units
Feedback Voltage	4.75V ≤ V_{IN} ≤ 15V	1.184	1.222	1.258	V
Upper Switch On Resistance			0.22		Ω
Lower Switch On Resistance			10		Ω
Upper Switch Leakage	V_{EN}=0V; V_{SW}=0V			10	μA
Current Limit		2.4	2.95		A
Oscillator Frequency		320	380	440	KHz
Short Circuit Frequency	V_{FB} = 0V		42		KHz
Maximum Duty Cycle	V_{FB} = 1.0V		90		%
Minimum Duty Cycle	V_{FB} = 1.5V			0	%
Enable Threshold		0.7	1.0	1.3	V
Under Voltage Lockout Threshold High Going		2.0	2.5	3.0	V
Under Voltage Lockout Threshold Hysteresis			200		mV
Shutdown Supply current	V_{EN}=0V		25	50	μA
Operating Supply current	V_{EN}=0V; V_{FB}=1.4V		1.0	1.5	mA
Thermal Shutdown			160		°C

Note 1. Exceeding these ratings may damage the device.
Note 2. The device is not guaranteed to function outside its operating rating.
Note 3. Measured on 1" square of 1 oz. copper FR4 board.

Pin Description



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Compensation

The system stability is controlled through the COMP pin. COMP 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 loop gain is:

$$A_{VDC} = (V_{FB} / V_{OUT}) * A_{VEA} * G_{CS} * R_{LOAD}$$

Where:
V_{FB} is the feedback threshold voltage, 1.222V
V_{OUT} is the desired output regulation voltage
A_{VEA} is the transconductance error amplifier voltage gain, 400 V/V
G_{CS} is the current sense gain, (roughly the output current divided by the voltage at COMP), 1.95 A/V
R_{LOAD} is the load resistance (V_{OUT} / I_{OUT} where I_{OUT} is the output load current)

The system has 2 poles of importance, one is due to the compensation capacitor (C5), and the other is due to the output capacitor (C7). These are:

$$f_{P1} = G_{MEA} / (2\pi * A_{VEA} * C5)$$

Where P1 is the first pole, and G_{MEA} is the error amplifier transconductance (770µS).

and

$$f_{P2} = 1 / (2\pi * R_{LOAD} * C7)$$

The system has one zero of importance, due to the compensation capacitor (C5) and the compensation resistor (R1). The zero is:

$$f_{Z1} = 1 / (2\pi * R1 * C5)$$

If a large value capacitor (C7) with relatively high equivalent-series-resistance (ESR) is used, the zero due to the capacitance and ESR of the output capacitor can be compensated by a third pole set by R1 and C4. The pole is:

$$f_{P3} = 1 / (2\pi * R1 * C4)$$

The system crossover frequency (the frequency where the loop gain drops to 1, or 0dB) is important. A good rule of thumb is to set the crossover frequency to approximately 1/10 of the switching frequency. In this case, the switching frequency is 380KHz, so use a crossover frequency, f_C, of 40KHz. Lower crossover frequencies result in slower response and worse transient load recovery. Higher crossover frequencies can result in instability.

Table 5: Compensation Values for Typical Output Voltage/Capacitor Combinations

V_{OUT}	C7	R1	C3	C4
2.5V	22µF Ceramic	7.5KΩ	2.2nF	None
3.3V	22µF Ceramic	10KΩ	1.5nF	None
5V	22µF Ceramic	10KΩ	2.2nF	None
12V	22µF Ceramic	10KΩ	2.7nF	None
2.5V	560µF/6.3V (30mΩ ESR)	10KΩ	15nF	1.5nF
3.3V	560µF/6.3V (30mΩ ESR)	10KΩ	18nF	1.5nF
5V	470µF/10V (30mΩ ESR)	10KΩ	27nF	1.5nF
12V	220µF/25V (30mΩ ESR)	10KΩ	27nF	680pF

Choosing the Compensation Components

The values of the compensation components given in Table 5 yield a stable control loop for the output voltage and capacitor given.

To optimize the compensation components for conditions not listed in Table 5, use the following procedure:

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

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$$R1 = 2\pi * C7 * V_{OUT} * f_C / (G_{EA} * G_{CS} * V_{FB})$$

Putting in the know constants and setting the crossover frequency to the desired 40kHz:

$$R1 \approx 1.37x10^8 C7 * V_{OUT}$$

The value of R1 is limited to 10KΩ to prevent output overshoot at startup, so if the value calculated for R1 is greater than 10KΩ, use 10KΩ. In this case, the actual crossover frequency is less than the desired 40kHz, and is calculated by:

$$f_C = R1 * G_{EA} * G_{CS} * V_{FB} / (2\pi * C7 * V_{OUT})$$

or

$$f_C \approx 2.92 / (C7 * V_{OUT})$$

Choose the compensation capacitor to set the zero to ¼ of the crossover frequency. Determine the value by the following equation:

$$C5 = 2 / \pi * R1 * f_C \approx 1.59x10^{-5} / R1$$

if R1 is less than 10KΩ, or if R1 = 10KΩ use the following equation:

$$C5 = 4C7 * V_{OUT} / (R1^2 * G_{EA} * G_{CS} * V_{FB})$$

$$C5 \approx 2.2x10^{-5} C7 * V_{OUT}$$

Determine if the second compensation capacitor, C4 is required. It is required if the ESR zero of the output capacitor happens at less than four times the crossover frequency. Or:

$$8\pi * C7 * R_{ESR} * f_C \geq 1$$

where R_{ESR} is the equivalent series resistance of the output capacitor.

If this is the case, then add the second compensation resistor. Determine the value by the equation:

$$C4 = C7 * R_{ESR(max)} / R1$$

Where $R_{ESR(MAX)}$ is the maximum ESR of the output capacitor.

Example:

V_{OUT} =3.3V
C7 = 22µF Ceramic (ESR = 10mΩ)

R1 = (1.37 x 10^8) (22 x 10^{-6})(3.3V) = 9.9KΩ
Use the nearest standard value of 10KΩ.

C5 ≈ 1.59x10^{-5} / 10KΩ = 1.6nF. Use the nearest standard value of 1.5nF.

2π C7 R_{ESR} f_C = .055 which is less than 1, therefore no second compensation capacitor is required.

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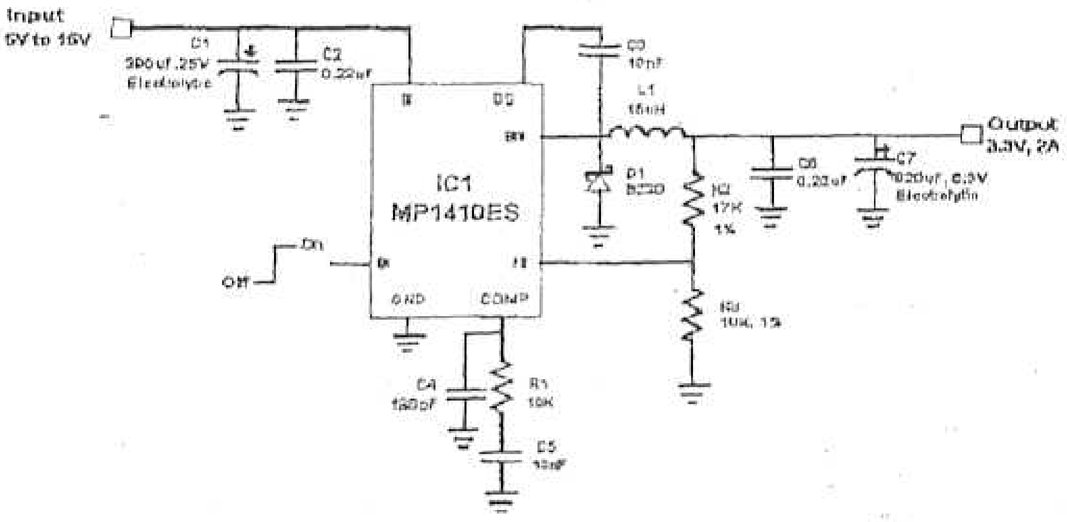
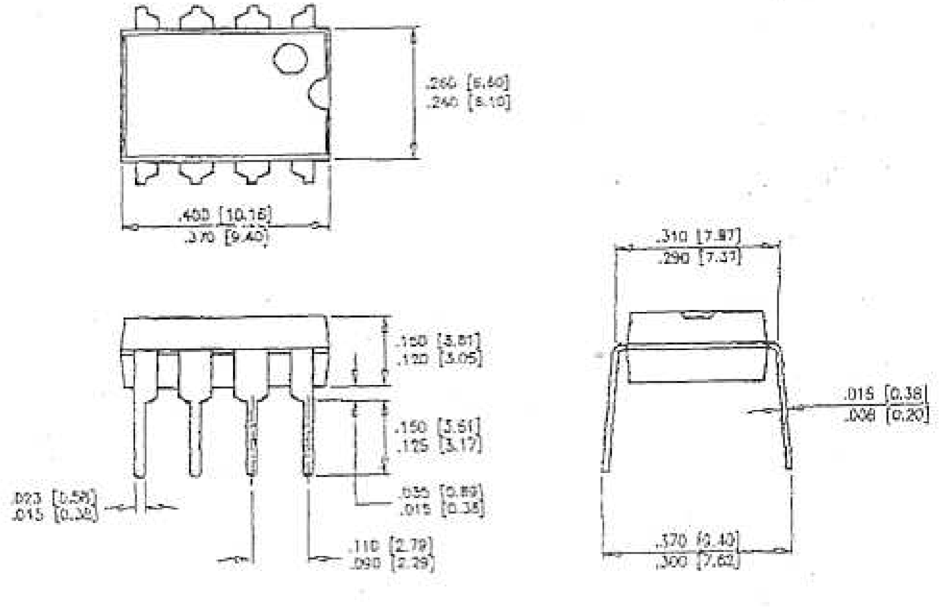
Figure 3. MP1410 Step Down from 15V to 3.3V @ 2A



Packaging
PDIP8



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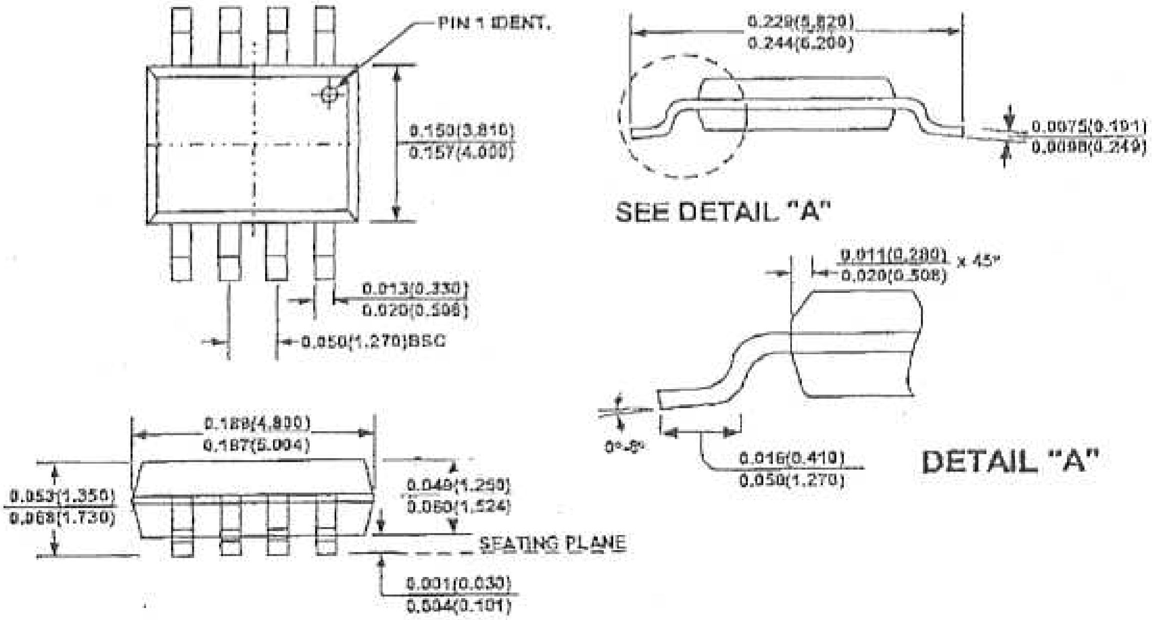
Packaging

SOIC8



NOTE:
1) Control dimension is in inches. Dimension in bracket is millimeters.