MIC4685

3A SPAK SuperSwitcher™ Buck Regulator

General Description

The MIC4685 is a high-efficiency 200kHz stepdown (buck) switching regulator. Power conversion efficiency of above 85% is easily obtainable for a wide variety of applications. The MIC4685 achieves 3A of continuous current in the 7-pin SPAK package.

The thermal performance of the SPAK allows it to replace TO-220s and TO-263s (D^2PAKs) in many applications. The SPAK saves board space with a 36% smaller footprint than TO-263.

High-efficiency is maintained over a wide output current range by utilizing a boost capacitor to increase the voltage available to saturate the internal power switch. As a result of this high-efficiency, only the ground plane of the PCB is needed for a heat sink.

The MIC4685 allows for a high degree of safety. It has a wide input voltage range of 4V to 30V (34V transient), allowing it to be used in applications where input voltage transients may be present. Built-in safety features include over-current protection, frequency-foldback short-circuit protection, and thermal shutdown.

The MIC4685 is available in a 7-pin SPAK package with a junction temperature range of –40°C to +125°C.

Data sheets and support documentation can be found on Micrel's web site at www.micrel.com.

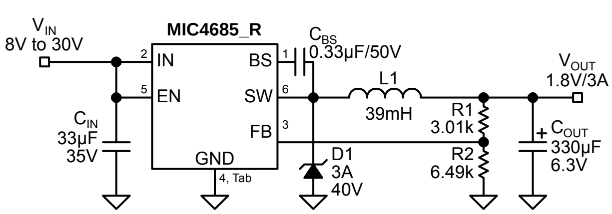
Features

- Low 2mm profile SPAK package
- 3A continuous output current
- Wide 4V to 30V input voltage range (34V transient)
- Fixed 200kHz PWM operation
- Over 85% efficiency
- Output voltage adjustable to 1.235V
- All surface mount solution
- Internally compensated with fast transient response
- Over-current protection
- Frequency foldback short-circuit protection
- Thermal shutdown

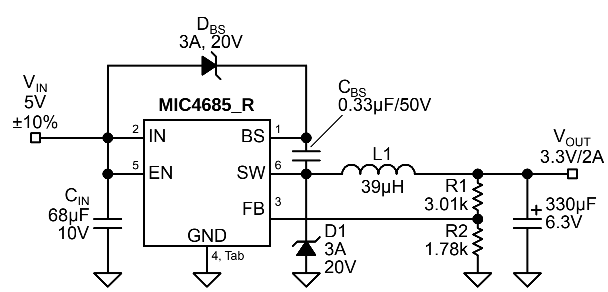
Applications

- Point-of-load power supplies
- Simple high-efficiency step-down regulators
- 5V to 3.3V/2A conversion
- 12V to 5V/3.3V/2.5V/1.8V 3A conversion
- Dual-output ±5V conversion
- Base stations
- LCD power supplies
- Battery chargers

Typical Application



1.8V Output Converter



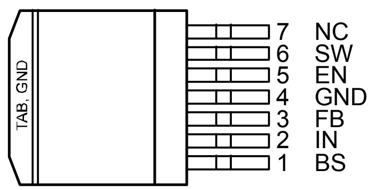
5V to 3.3V Converter

Ordering Information

Part Number		Voltage	Junction Temp. Range	Package
Standard	RoHS Compliant*			
MIC4685BR	MIC4685WR	Adj.	–40° to +125°C	7-Pin SPAK
	MIC4685WR EV	Adj.		Evaluation Board

* RoHS compliant with 'high-melting solder' exemption.

Pin Configuration



7-Pin SPAK (R)

Pin Description

Pin Number	Pin Name	Pin Function
1	BS	Bootstrap Voltage Node (External Component): Connect to external boost capacitor.
2	IN	Supply (Input): Unregulated +4V to 30V supply voltage (34V transient)
3	FB	Feedback (Input): Outback voltage feedback to regulator. Connect to 1.235V tap of resistive divider.
4, Tab	GND	Ground
5	EN	Enable (Input): Logic high = enable; logic low = shutdown
6	SW	Switch (Output): Emitter of NPN output switch. Connect to external storage inductor and Schottky diode.
7	NC	No Connect. Tie this pin-to-ground.

Detailed Pin Description

Switch (SW, Pin 6)

The switch pin is tied to the emitter of the main internal NPN transistor. This pin is biased up to the input voltage, minus the V_{SAT}, of the main NPN pass element. The emitter is also driven negative when the output inductor's magnetic field collapses at turn-off. During the OFF time, the SW pin is clamped by the output Schottky diode typically to a –0.5V.

Ground (GND, Pin 4, Tab)

There are two main areas of concern when it comes to the ground pin, EMI and ground current. In a buck regulator or any other non-isolated switching regulator, the output capacitor(s) and diode(s) ground is referenced back to the switching regulator's or controller's ground pin. Any resistance between these reference points causes an offset voltage/IR drop proportional to load current and poor load regulation. This is why it's important to keep the output grounds placed as close as possible to the switching regulator's ground pin. To keep radiated EMI to a minimum, it is necessary to place the input capacitor ground lead as close as possible to the switching regulator's ground pin.

Input Voltage (V_{IN}, Pin 2)

The V_{IN} pin is the collector of the main NPN pass element. This pin is also connected to the internal regulator. The output diode or clamping diode should have its cathode as close as possible to this point to avoid voltage spikes adding to the voltage across the collector.

Bootstrap (BS, Pin 1)

The bootstrap pin, in conjunction with the external bootstrap capacitor, provides a bias voltage higher than the input voltage to the MIC4685's main NPN pass element. The bootstrap capacitor sees the dv/dt of the switching action at the SW pin as an AC voltage. The bootstrap capacitor then couples the AC voltage back to the BS pin, plus the dc offset of V_{IN} where it is rectified and used to provide additional drive to the main switch; in this case, a NPN transistor.

This additional drive reduces the NPN's saturation voltage and increases efficiency, from a V_{SAT} of 1.8V, and 75% efficiency to a V_{SAT} of 0.5V and 88% efficiency respectively.

Feedback (FB, Pin 3)

The feedback pin is tied to the inverting side of an error amplifier. The noninverting side is tied to a 1.235V bandgap reference. An external resistor voltage divider is required from the output-to-ground, with the center tied to the feedback pin. See Tables 1 and 2 for recommended resistor values.

Enable (EN, Pin 5)

The enable (EN) input is used to turn on the regulator and is TTL compatible. Note: connect the enable pin to the input if unused. A logic-high enables the regulator. A logic-low shuts down the regulator and reduces the stand-by quiescent input current to typically 150µA. The enable pin has an up-per threshold of 2.0V minimum and lower threshold of 0.8V maximum. The hysterisis provided by the upper and lower thresholds acts as an UVLO and prevents unwanted turn on of the regulator due to noise.

Absolute Maximum Ratings[1]

Supply Voltage (V_{IN}) [1] ....+34V
Enable Voltage (V_{EN})....................–0.3V to V_{IN}
Steady-State Output Switch Voltage (V_{SW})..........–1V to V_{IN}
Feedback Voltage (V_{FB}) ....+12V
Storage Temperature (T_s) ....–65°C to +150°C
EDS Rating[3]....................2kV

Operating Ratings[2]

Supply Voltage (V_{IN}) [4] ....+4V to +30V
Junction Temperature (T_J) ....–40°C to +125°C
Package Thermal Resistance
SPAK-7 (θ_{JA})....................11.8°C/W
SPAK-7 (θ_{JC})....................2.2°C/W

Electrical Characteristics

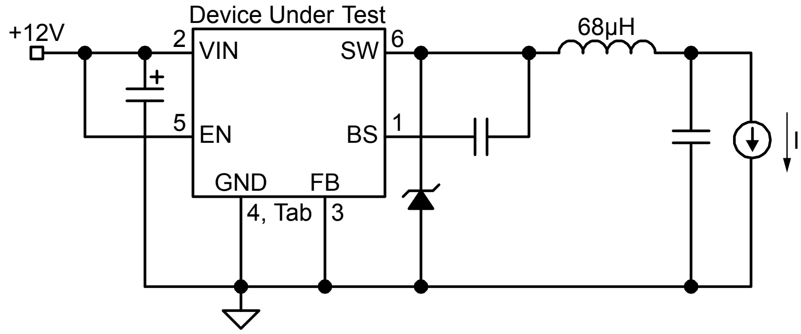
$V_{IN} = V_{EN} = 12V$; V_{OUT} 5V; $I_{OUT} = 500mA$; $T_A = 25°C$, **bold** values indicate $–40°C \le T_J \le +125°C$, unless noted.

Parameter	Condition	Min	Typ	Max	Units
MIC4685 [Adjustable]					
Feedback Voltage	(±2%) (±3%)	1.210 **1.198**	1.235	1.260 **1.272**	V V
	$8V \le V_{IN} \le 30V$, $0.1A \le I_{LOAD} \le 1A$, $V_{OUT} = 5V$, **Note 4**	1.186 **1.173**	1.235	1.284 **1.297**	V V
Feedback Bias Current			50		nA
Maximum Duty Cycle	$V_{FB} = 1.0V$		94		%
Output Leakage Current	$V_{IN} = 30V$, $V_{EN} = 0V$, $V_{SW} = 0V$		5	500	µA
	$V_{IN} = 30V$, $V_{EN} = 0V$, $V_{SW} = 1V$		1.4	20	mA
Quiescent Current	$V_{FB} = 1.5V$		6	12	mA
Bootstrap Drive Current	$V_{FB} = 1.5V$, $V_{SW} = 0V$	250	380		mA
Bootstrap Voltage	$I_{BS} = 10mA$, $V_{FB} = 1.5V$, $V_{SW} = 0V$	5.5	6.2		V
Frequency Fold Back	$V_{FB} = 0V$	30	70	120	kHz
Oscillator Frequency		180	200	225	kHz
Saturation Voltage	$I_{OUT} = 1A$		0.59		V
Short Circuit Current Limit	$V_{FB} = 0V$, *See Test Circuit*	3.5		6	A
Shutdown Current	$V_{EN} = 0V$		150	200	µA
Enable Input Logic Level	regulator on	2			V
	regulator off			0.8	V
Enable Pin Input Current	$V_{EN} = 0V$ (regulator off)		16	50	µA
	$V_{EN} = 0V$ (regulator on)	–1	–0.83		mA
Thermal Shutdown @ T_J			160		°C

Notes:

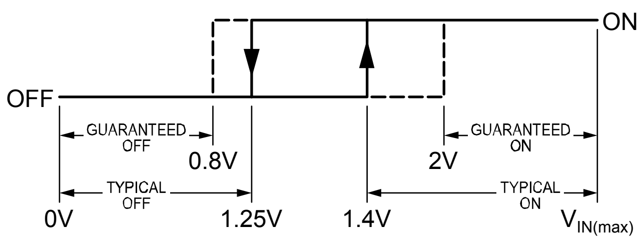
1. Exceeding the absolute maximum rating may damage the device.
2. The device is not guaranteed to function outside its operating rating.
3. Devices are ESD sensitive. Handling precautions recommended. Human body model, 1.5kΩ in series with 100pF.
4. 2.5V of headroom is required between V_{IN} and V_{OUT}. The headroom can be reduced by implementing a bootstrap diode as seen on the 5V to 3.3V circuit on page 1.

Test Circuit



Current Limit Test Circuit

Shutdown Input Behavior

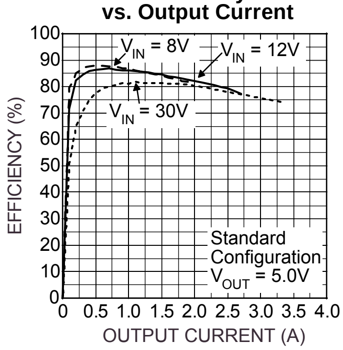


Enable Hysteresis

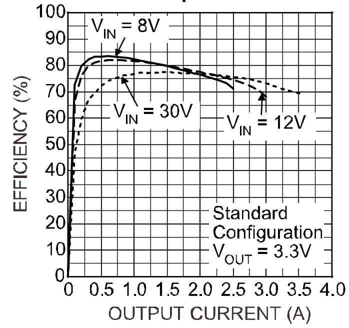
Typical Characteristics

(TA = 25°C unless otherwise noted)

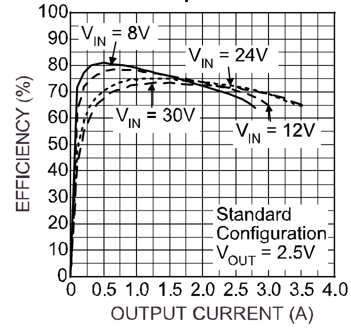
Efficiency vs. Output Current



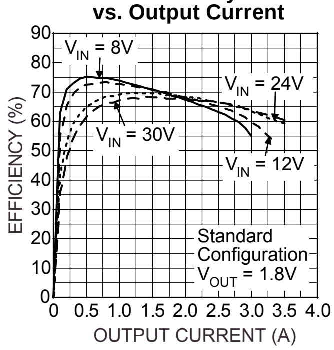
Efficiency vs. Output Current



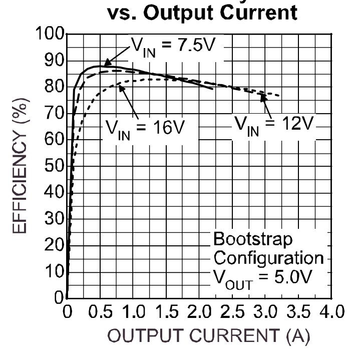
Efficiency vs. Output Current



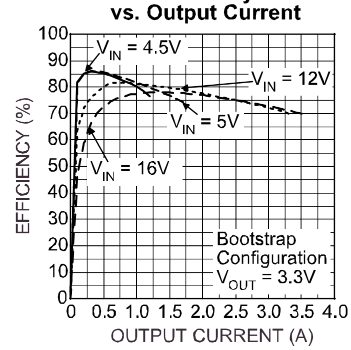
Efficiency vs. Output Current



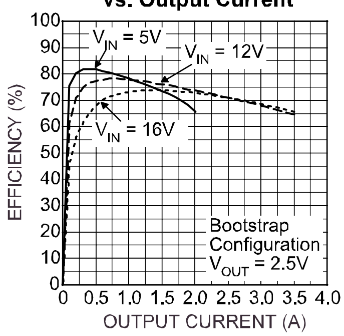
Efficiency vs. Output Current



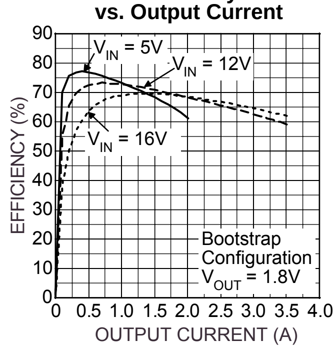
Efficiency vs. Output Current



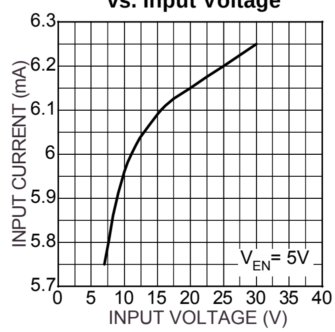
Efficiency vs. Output Current



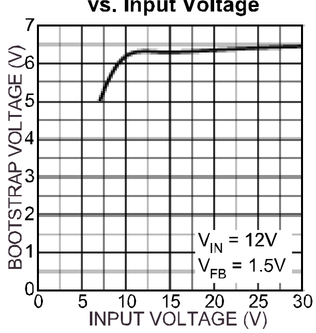
Efficiency vs. Output Current



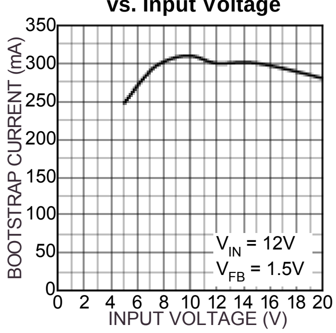
Quiescent Current vs. Input Voltage



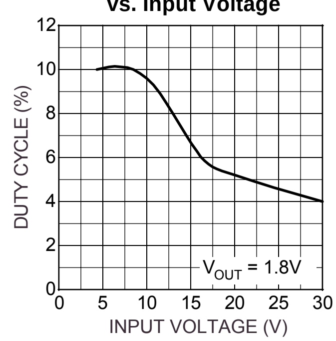
Bootstrap Voltage vs. Input Voltage



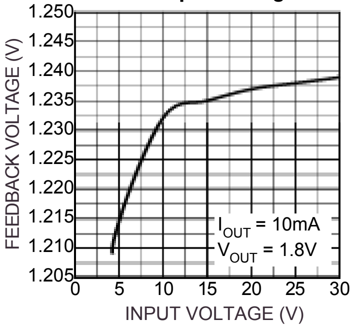
Bootstrap Drive Current vs. Input Voltage



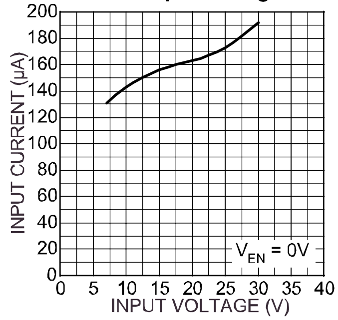
Minimum Duty Cycle vs. Input Voltage



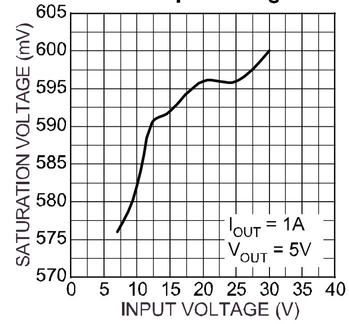
Feedback Voltage vs. Input Voltage



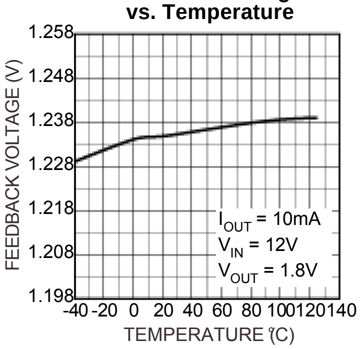
Shutdown Current vs. Input Voltage



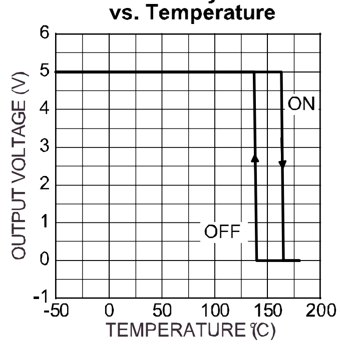
Saturation Voltage vs. Input Voltage



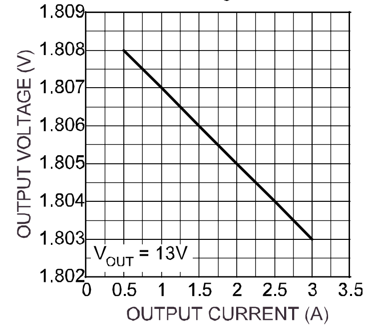
Feedback Voltage vs. Temperature



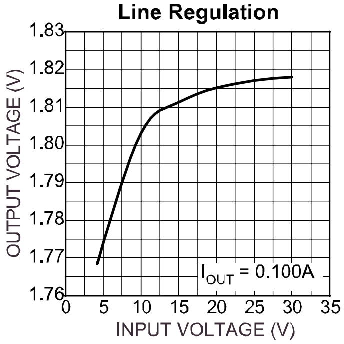
Shutdown Hysteresis vs. Temperature



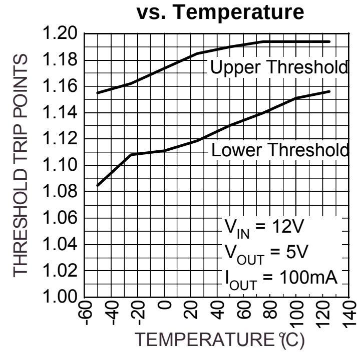
Load Regulation



Line Regulation



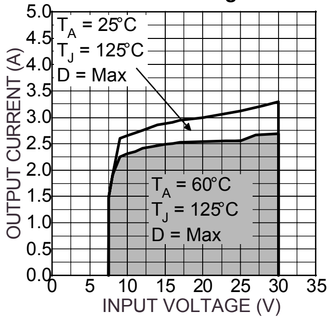
Enable Threshold vs. Temperature



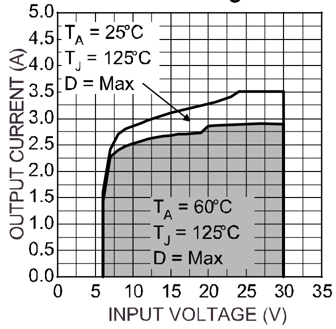
Typical Safe Operating Area (SOA)

(SOA measured on the MIC4685 Evaluation Board*)

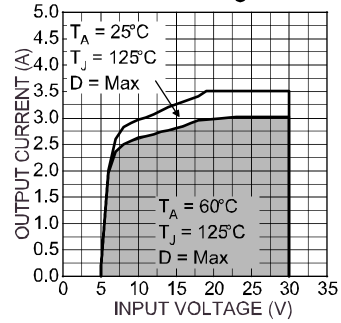
5V Output SOA Standard Configuration



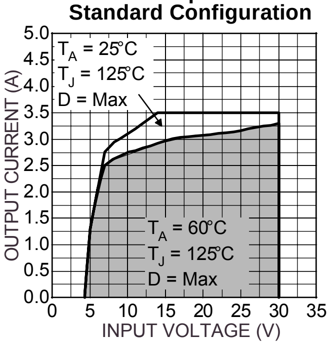
3.3V Output SOA Standard Configuration



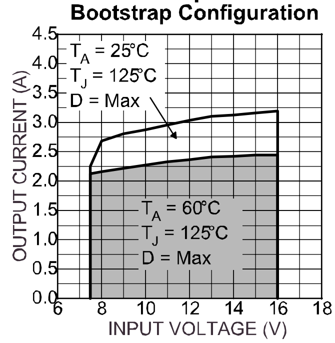
2.5V Output SOA Standard Configuration



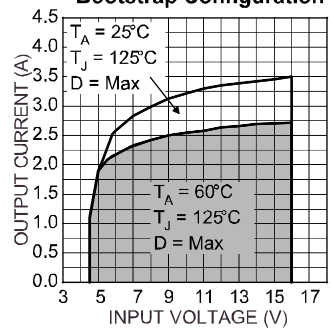
1.8V Output SOA Standard Configuration



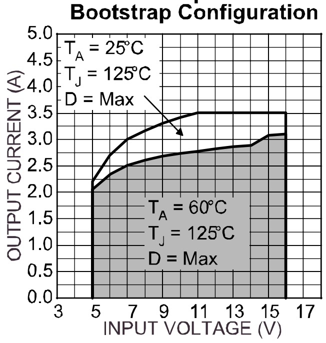
5.0V Output SOA Bootstrap Configuration



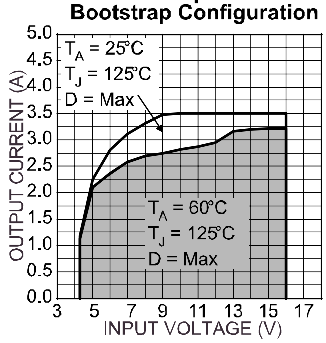
3.3V Output SOA Bootstrap Configuration



2.5V Output SOA Bootstrap Configuration

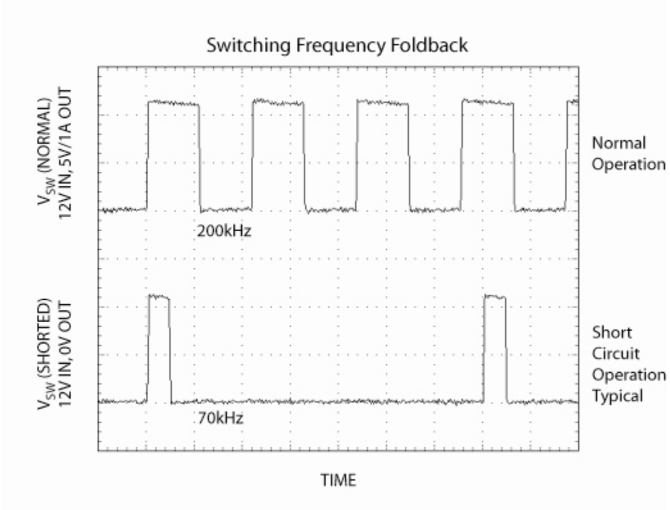


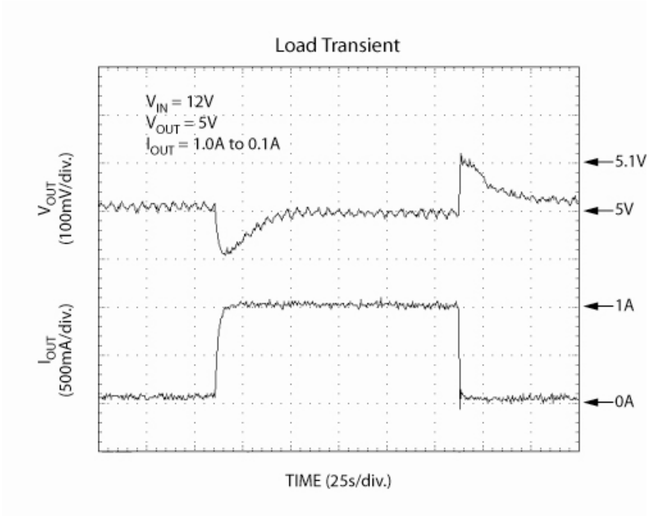
1.8V Output SOA Bootstrap Configuration



* I_{OUT} <3A, D1: Diode Inc. B340 (3A/40V)
I_{OUT} <3A, D1: SBM1040 (10A/40V)

Functional Characteristics





Frequency Foldback

The MIC4685 folds the switching frequency back during a hard short circuit condition to reduce the energy per cycle and protect the device.

Functional Diagram

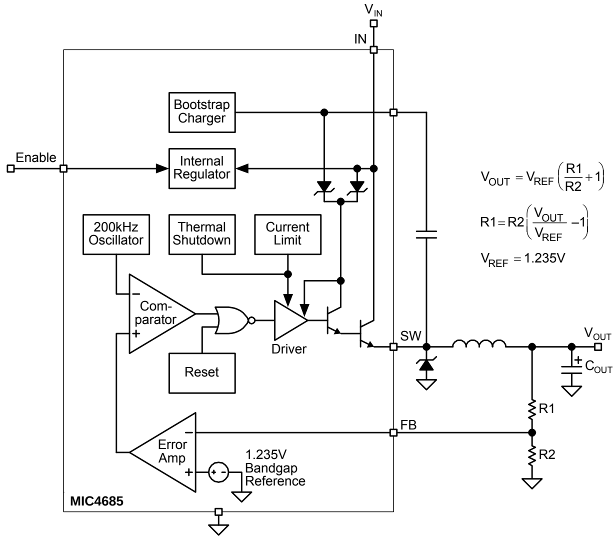


Figure 1. Adjustable Regulator

Functional Description

The MIC4685 is a variable duty cycle switch-mode regulator with an internal power switch. Refer to the above block diagram.

Supply Voltage

The MIC4685 operates from a +4V to +30V (34V transient) unregulated input. Highest efficiency operation is from a supply voltage around +12V. See the efficiency curves in the "*Typical Characteristics*" section on page 5.

Enable/Shutdown

The enable (EN) input is TTL compatible. Tie the input high if unused. A logic-high enables the regulator. A logic-low shuts down the internal regulator which reduces the current to typically 150µA when V_{EN} = 0V.

Feedback

In the adjustable version, an external resistive voltage divider is required from the output voltage to ground, center tapped to the FB pin. See Table 1 and Table 2 for recommended resistor values.

Duty Cycle Control

A fixed-gain error amplifier compares the feedback signal with a 1.235V bandgap voltage reference. The resulting error amplifier output voltage is compared to a 200kHz sawtooth waveform to produce a voltage controlled variable duty cycle output.

A higher feedback voltage increases the error amplifier output voltage. A higher error amplifier voltage (comparator inverting input) causes the comparator to detect only the peaks of the sawtooth, reducing the duty cycle of the comparator output. A lower feedback voltage increases the duty cycle. The MIC4685 uses a voltage-mode control architecture.

Output Switching

When the internal switch is ON, an increasing current flows from the supply V_{IN}, through external storage inductor L1, to output capacitor C_{OUT} and the load. Energy is stored in the inductor as the current increases with time.

When the internal switch is turned OFF, the collapse of the magnetic field in L1 forces current to flow through fast recovery diode D1, charging C_{OUT}.

Output Capacitor

External output capacitor C_{OUT} provides stabilization and reduces ripple.

Return Paths

During the ON portion of the cycle, the output capacitor and load currents return to the supply ground. During the OFF portion of the cycle, current is being supplied to the output capacitor and load by storage inductor L1, which means that D1 is part of the high-current return path.

Application Information

Adjustable Regulators

Adjustable regulators require a 1.235V feedback signal. Recommended voltage-divider resistor values for common output voltages are detailed in Table 1.

For other voltages, the resistor values can be determined using the following formulas:

$$V_{OUT} = V_{REF}\left(\frac{R1}{R2} + 1\right)$$

$$R1 = R2\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

V_{REF} = 1.235V

Thermal Considerations

The MIC4685 is capable of high current due to the thermally optimized SPAK package.

One limitation of the maximum output current on any MIC4685 design is the junction-to-ambient thermal resistance (θ_{JA}) of the design (package and ground plane).

Examining θ_{JA} in more detail:

$\theta_{JA} = (\theta_{JC} + \theta_{CA})$

where:

θ_{JC} = junction-to-case thermal resistance

θ_{CA} = case-to-ambient thermal resistance

θ_{JC} is a relatively constant 2.2°C/W for a 7-pin SPAK.

θ_{CA} is dependent upon layout and is primarily governed by the connection of pins 4, and Tab to the ground plane. The purpose of the ground plane is to function as a heat sink.

Checking the Maximum Junction Temperature:

For this example, with an output power (P_{OUT}) of 7.5W, (5V output at 1.5A with V_{IN} = 12V) and 60°C maximum ambient temperature, what is the junction temperature?

Referring to the "Typical Characteristics: 5V Output Efficiency" graph, read the efficiency (η) for 1.5A output current at V_{IN} = 12V or perform you own measurement.

η = 84%

The efficiency is used to determine how much of the output power (P_{OUT}) is dissipated in the regulator circuit (P_D).

$$P_D = \frac{P_{OUT}}{\eta} - P_{OUT}$$

$$P_D = \frac{7.5W}{0.84} - 7.5W$$

P_D = 1.43W

A worst-case rule of thumb is to assume that 80% of the total output power dissipation is in the MIC4685 ($P_{D(IC)}$) and 20% is in the diode-inductor-capacitor circuit.

$P_{D(IC)} = 0.8\ P_D$

$P_{D(IC)} = 0.8 \times 1.43W$

$P_{D(IC)}$ = 1.14W

Calculate the worst-case junction temperature:

$T_J = P_{D(IC)}\ \theta_{JC} + (T_C – T_A) + T_{A(max)}$

where:

T_J = MIC4685 junction temperature

$P_{D(IC)}$ = MIC4685 power dissipation

θ_{JC} = junction-to-case thermal resistance.

The θ_{JC} for the MIC4685's 7-pin SPAK is approximately 2.2°C/W.

T_C = "pin" temperature measurement taken at the Tab.

T_A = ambient temperature

$T_{A(max)}$ = maximum ambient operating temperature for the specific design.

Calculating the maximum junction temperature given a maximum ambient temperature of 60°C:

T_J = 1.14 × 2.2°C + (46°C – 25°C) + 60°C

T_J = 83.5°C

This value is within the allowable maximum operating junction temperature of 125°C as listed in *"Operating Ratings."* Typical thermal shutdown is 160°C and is listed in *"Electrical Characteristics."* Also refer to the *"Typical Safe Operating Area (SOA)"* graphs in this document.

Layout Considerations

Layout is very important when designing any switching regulator. Rapidly changing currents, through the printed circuit board traces and stray inductance, can generate voltage transients which can cause problems.

To minimize stray inductance and ground loops, keep trace lengths as short as possible. For example, keep D1 close to pin 6 and pin 4, and Tab, keep L1 away from sensitive node FB, and keep C_{IN} close to pin 2 and pin 4, and Tab. See "*Applications Information: Thermal Considerations*" for ground plane layout.

The feedback pin should be kept as far way from the switching elements (usually L1 and D1) as possible.

A circuit with sample layouts are provided. See Figure 6. Gerber files are available upon request.

Bootstrap Diode

The bootstrap diode provides an external bias source directly to the main pass element, this reduces V_{SAT} thus allowing the MIC4685 to be used in very low head-room applications i.e., $5V_{IN}$ to $3.3V_{OUT}$ with high efficiencies. Bootstrap diode not for use if V_{IN} exceeds 16V, V_{IN}. See Figure 2.

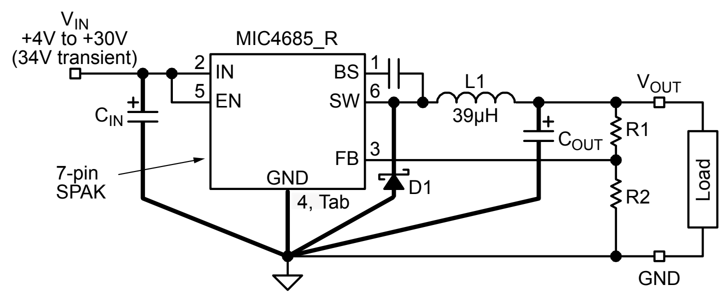


Figure 2. Critical Traces for Layout

Recommended Components for a Given Output Voltage (Bootstrap Configuration)

V_{OUT}	I_{OUT}*	R1	R2	V_{IN}	C1	D1	D2	L1	C4
5.0V	2.1A	3.01k	976Ω	7.5V – 16V	47µF, 20V Vishay-Dale 595D476X0020D2T	3A, 30V Schottky + Vishay B330A	1A, 20V Schottky B120-E3	39µH Sumida CDRH127R-390MC	330µF, 6.3V Vishay-Dale 594D337X06R3D2T
3.3V	2.2A	3.01k	1.78k	6.0V – 16V	47µF, 20V Vishay-Dale 595D476X0020D2T	3A, 30V Schottky B330A	1A, 20V Schottky B120-E3	39µH Sumida CDRH127R-390MC	330µF, 6.3V Vishay-Dale 594D337X06R3D2T
2.5V	2.0A	3.01k	2.94k	5.0V – 16V	47µF, 20V Vishay-Dale 595D476X0020D2T	3A, 30V Schottky B330A	1A, 20V Schottky B120-E3	39µH Sumida CDRH127R-390MC	330µF, 6.3V Vishay-Dale 594D337X06R3D2T
1.8V	2.0A	3.01k	6.49k	5.0V – 16V	47µF, 20V Vishay-Dale 595D476X0020D2T	3A, 30V Schottky + Vishay B330A	1A, 20V Schottky B120-E3	39µH Sumida CDRH127R-390MC	330µF, 6.3V Vishay-Dale 594D337X06R3D2T

* Maximum output current at minimum input voltage. See SOA curves for maximum output current vs. Input voltage.

Table 1. Recommended Components for Common Output Voltages

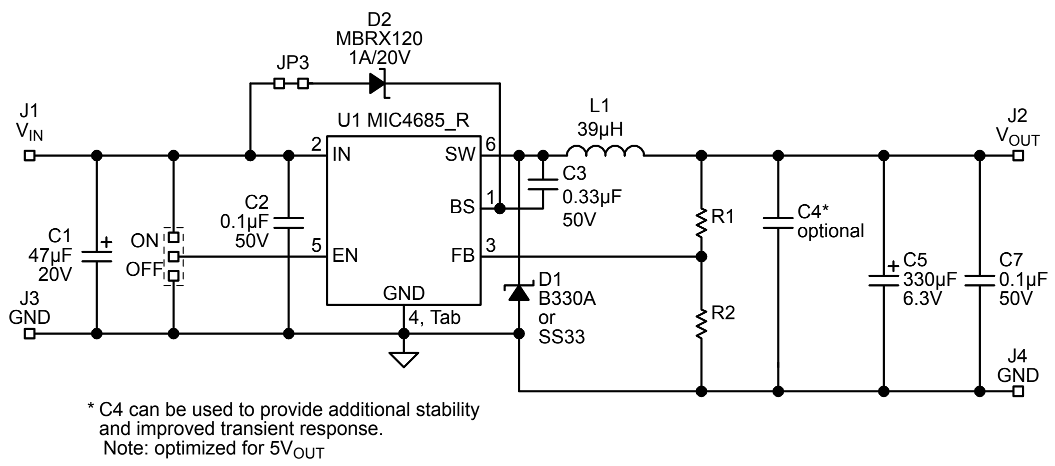


Figure 3. Schematic Diagram

Recommended Components for a Given Output Voltage (Standard Configuration)

V_{OUT}	I_{OUT}*	R1	R2	V_{IN}	C1	D1	L1	C5
5.0V	2.0A	3.01k	976Ω	8V – 30V	33µF, 35V Vishay-Dale 595D336X0035R2T	3A, 40V Schottky B340A-E3	39µH Sumida CDRH127-390MC	330µF, 6.3V Vishay-Dale 594D337X06R3D2T
3.3V	2.4A	3.01k	1.78k	8V – 26V	33µF, 35V Vishay-Dale 595D336X0035R2T	3A, 40V Schottky B340A-E3	39µH Sumida CDRH127-390MC	330µF, 6.3V Vishay-Dale 594D337X06R3D2T
2.5V	2.35A	3.01k	2.94k	7V – 23V	33µF, 35V Vishay-Dale 595D336X0035R2T	3A, 40V Schottky B340A-E3	39µH Sumida CDRH127-390MC	330µF, 6.3V Vishay-Dale 594D337X06R3D2T
1.8V	2.0A	3.01k	6.49k	6V – 16V	33µF, 35V Vishay-Dale 595D336X0035R2T	3A, 40V Schottky + Vishay B340A-E3	39µH Sumida CDRH127-390MC	330µF, 6.3V Vishay-Dale 594D337X06R3D2T

* Maximum output current at minimum input voltage. See SOA curves for maximum output current vs. Input voltage.

Table 2. Recommended Components for Common Output Voltages

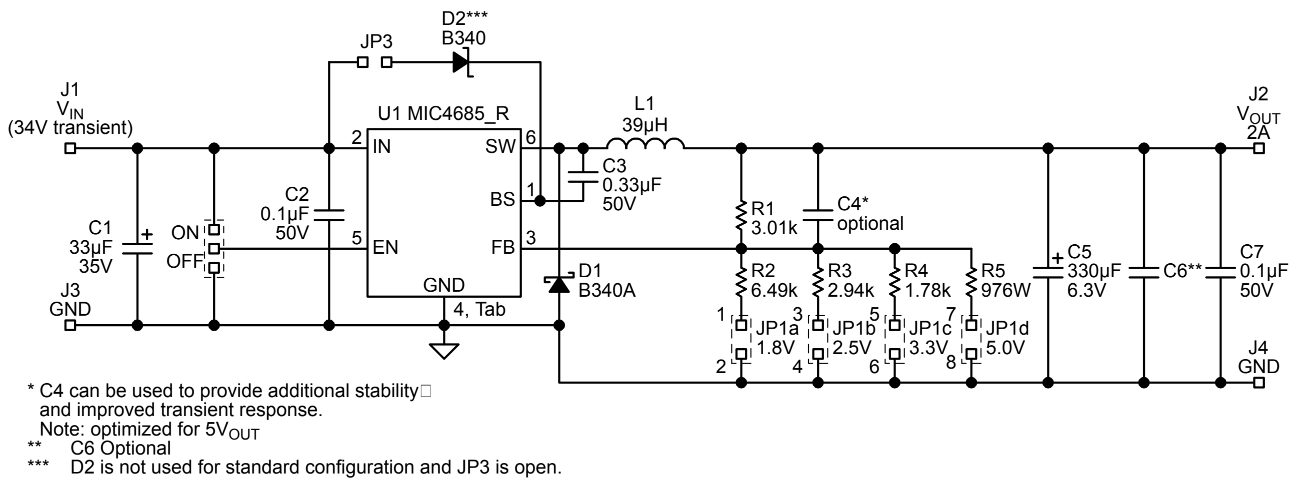


Figure 4. Evaluation Board Schematic Diagram

Printed Circuit Board

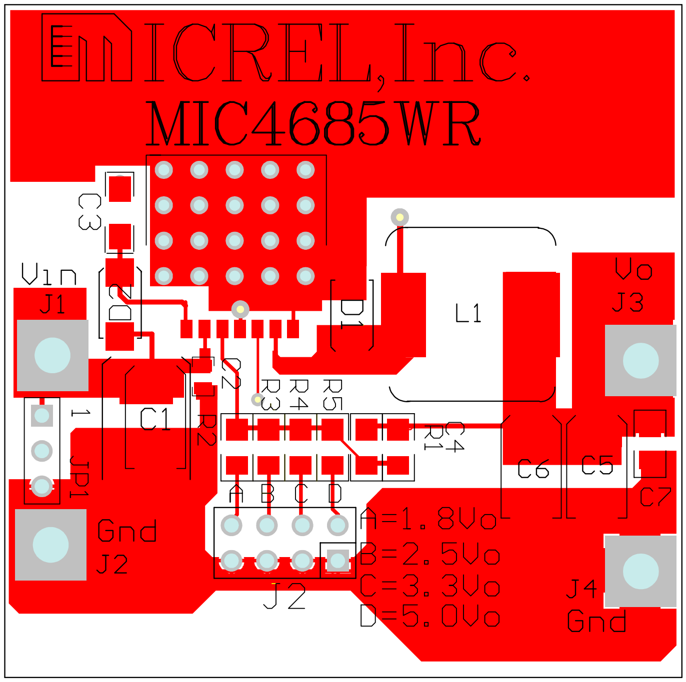


Figure 5a. Top Layer

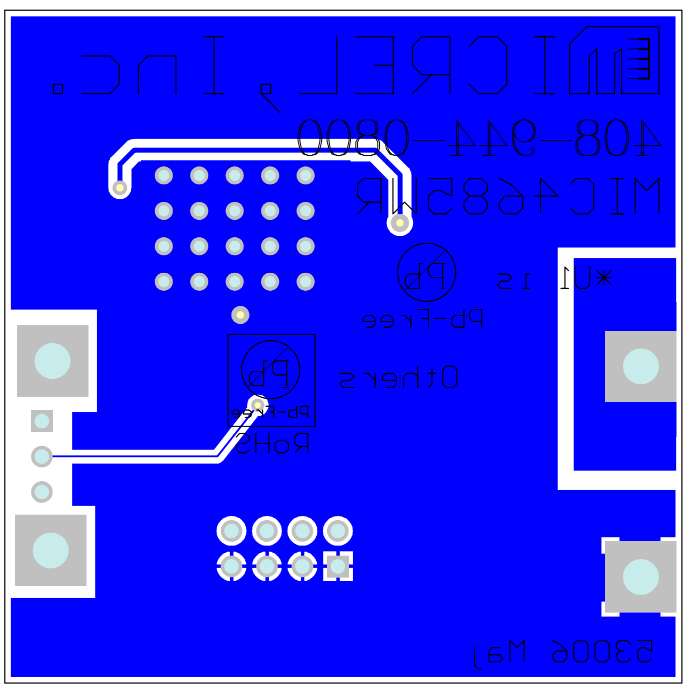


Figure 5b. Bottom Layer

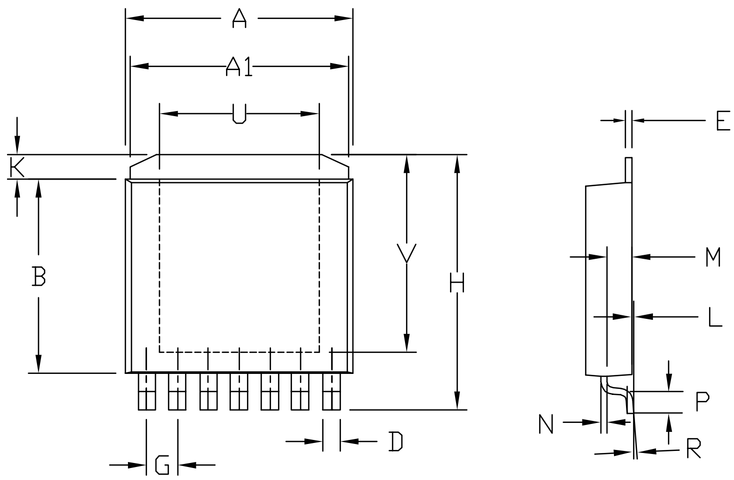
Abbreviated Bill of Materials (Critical Components)

Item	Part Number	Manufacturer	Description	Qty.
C1	594D336X0035R2T	Vishay Sprague(1)	33µF 35V	1
C2, C7	VJ0805Y104KXXAAB	Vitramon	0.1µF 50V	2
C3	GRM426X7R334K50	Murata(5)	0.33µF, 50V ceramic capacitor	
	VJ1206Y334KXXAAT	Vishay(1)	0.33µF, 50V ceramic capacitor	
C4*	Optional		1800pF, 50V ceramic	1
C5	594D337X06R3D2T	Vishay Sprague(1)	330µF, 6.3V, tantalum	1
D1	B340A	Diode Inc(2)	Schottky 3A 40V	1
	B340LA-EA	Vishay(1)	Schottky 3A 40V	1
	SSA34A	Vishay(1)	Schottky 3A 40V	1
	B340A	Vishay(1)	Schottky 3A 40V	1
D2	B120-EA	Vishay(1)	Schottky 3A 40V	1
	B340A	Diode Inc(2)	Schottky 3A 40V	1
	MBRX120	Micro Commercial Component(4)	Schottky 1A 20V	
L1	CDRH127-390MC	Sumida(3)	39µH	1
R1	CRCW08053011FKEY3	Vishay(1)	3K01, 1%, 1/10W, 805	1
R2	CRCW08056491FKEY3	Vishay(1)	6K49, 1%, 1/10W, 805	1
R3	CRCW08052941FKEY3	Vishay(1)	2K94, 1%, 1/10W, 805	1
R4	CRCW08051781FKEY3	Vishay(1)	1K78, 1%, 1/10W, 805	1
R5	CRCW08051781FKEY3	Vishay(1)	976Ω, 1%, 1/10W, 805	1
U1	**MIC4685BR/WR**	**Micrel, Inc.(6)**	**3A 200kHz SPAK Buck Regulator**	**1**

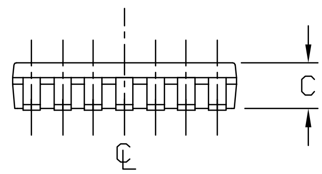
Notes:

1. Vishay Sprague, Inc.: www.vishay.com
2. Diodes Inc.: www.diodes.com
3. Sumida: www.sumida.com
4. Micro Commercial Component: www.mccsemi.com
5. Murata: www.murata.com
6. **Micrel, Inc.: www.website.com**

Package Information



	INCHES		MILLIMETERS	
A	0.365	0.375	9.27	9.52
A1	0.350	0.360	8.89	9.14
B	0.310	0.320	7.87	8.13
C	0.070	0.080	1.78	2.03
D	0.025	0.031	0.63	0.79
E	0.010	BSC	0.25	BSC
G	0.050	BSC	1.27	BSC
H	0.410	0.420	10.41	10.67
K	0.030	0.050	0.76	1.27
L	0.001	0.005	0.03	0.13
M	0.035	0.045	0.89	1.14
N	0.010	BSC	0.25	BSC
P	0.031	0.041	0.79	1.04
R	0°	6°	0°	6°
U	0.256	BSC	6.50	BSC
V	0.316	BSC	8.03	BSC



1. DIMENSION DOES NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
2. DIMENSION INCLUDES PLATING THICKNESS.

7-SPAK (R)

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