MICROCHIP

MIC4684

30V Input, 2A High Efficiency Buck Regulator

Features

- Up to 2A Continuous Output Current
- Up to 85% Efficiency
- Fixed 200 kHz PWM Operation
- Wide 4V to 30V Input Voltage Range
- Output Voltage Adjustable to 1.235V
- Internally Compensated with Fast Transient Response
- Overcurrent Protection
- Frequency Foldback Short-Circuit Protection
- Thermal Shutdown

Applications

- High-Efficiency Step-Down Regulator
- On-Card Switching Regulator

General Description

The MIC4684 is a high-efficiency 200 kHz step-down (buck) switching regulator. The MIC4684 achieves up to 2A of continuous current in an 8-lead SOIC (small outline) package at 60°C ambient temperature.

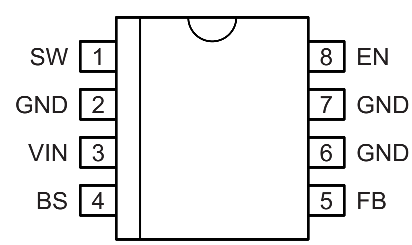
As a result of high efficiency, no external heat sink is required. The MIC4684, packaged in an SOIC-8, can replace larger TO-220 and TO-263 packages in many applications.

The MIC4684 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 overcurrent protection, frequency foldback short-circuit protection, and thermal shutdown. The MIC4684 folds the switching frequency back during a hard short-circuit condition to reduce the energy per cycle and protect the device.

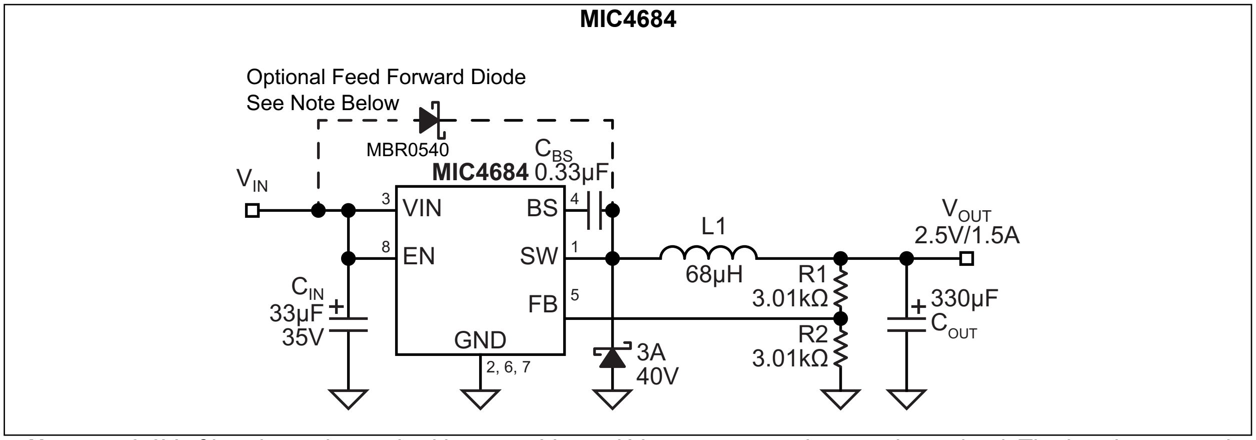
The MIC4684 is available in an 8-lead SOIC package with a junction temperature range of –40°C to +125°C.

Package Type

MIC4684
8-Lead SOIC (M)

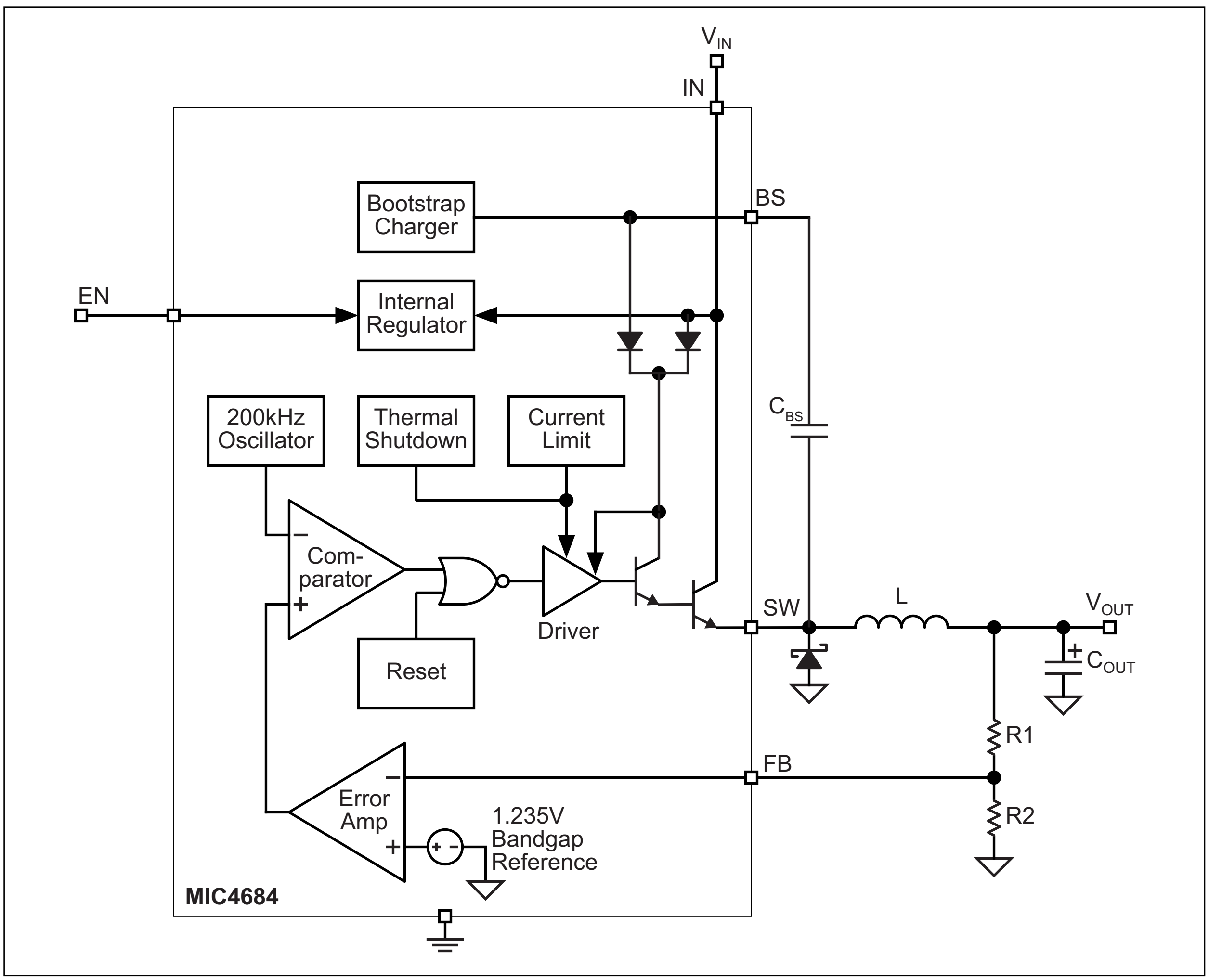


Typical Application Circuit



Note: 3.0V of headroom is required between V_{IN} and V_{OUT} at start-up into maximum load. The headroom can be reduced by implementing a feed-forward diode.

Functional Block Diagram



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

Supply Voltage (V_{IN}) .... +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
ESD Rating .... Note 1

Operating Ratings ‡

Supply Voltage (V_{IN}) (Note 2) .... +4V to +30V

† Notice: Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational sections of this specification is not intended. Exposure to maximum rating conditions for extended periods may affect device reliability.

‡ Notice: The device is not guaranteed to function outside its operating ratings.

Note 1: Devices are ESD sensitive. Handling precautions recommended.

2: 3.0V of headroom is required between V_{IN} and V_{OUT} at start-up into maximum load. The headroom can be reduced by implementing a feed-forward diode, as shown in the Typical Application Circuit.

TABLE 1-1: ELECTRICAL CHARACTERISTICS

Electrical Characteristics: V_{IN} = V_{EN} = 12V, V_{OUT} = 5V; I_{OUT} = 500 mA; T_A = +25°C, unless otherwise noted. **Bold** values are valid for –40°C ≤ T_J ≤ +125°C.

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions
Feedback Voltage	V_{FB}	1.210	1.235	1.260	V	±2%
		1.198	—	**1.272**		±3% over temperature
		1.186	1.235	1.284		8V ≤ V_{IN} ≤ 30V, 0.1A ≤ I_{LOAD} ≤ 1A, V_{OUT} = 5V
		1.173	—	**1.297**		—
Feedback Bias Current	I_{FB}	—	50	—	nA	—
Maximum Duty Cycle	D_{MAX}	—	94	—	%	V_{FB} = 1.0V
Output Leakage Current	$\|I_{OZ}\|$	—	5	500	µA	V_{IN} = 30V, V_{EN} = 0V, V_{SW} = 0V
		—	1.4	20	mA	V_{IN} = 30V, V_{EN} = 0V, V_{SW} = –1V
Quiescent Current	I_Q	—	6	**12**	mA	V_{FB} = 1.5V
Bootstrap Drive Current	I_{BS}	250	380	—	mA	V_{FB} = 1.5V, V_{SW} = 0V
Bootstrap Voltage	V_{BS}	5.5	6.2	—	V	I_{BS} = 10 mA, V_{FB} = 1.5V, V_{SW} = 0V
Frequency Foldback		30	50	120	kHz	V_{FB} = 0V
Oscillator Frequency	f_O	180	200	225	kHz	—
Saturation Voltage	V_{SAT}	—	0.59	—	V	I_{OUT} = 1A
Short-Circuit Current-Limit	I_{LIM}	2.2	—	—	A	V_{FB} = 0V, See Test Circuit
Shutdown Current	I_{SHDN}	—	150	—	µA	V_{EN} = 0V
Enable Input Logic Level	V_{EN}	2	—	—	V	Regulator on
		—	—	0.8		Regulator off
Enable Pin Input Current	I_{EN}	—	16	50	µA	V_{EN} = 0V (regulator off)
		–1	–0.83	—	mA	V_{EN} = 12V (regulator on)
Thermal Shutdown at T_J	T_{SHDN}	—	160	—	°C	—

Test Circuit

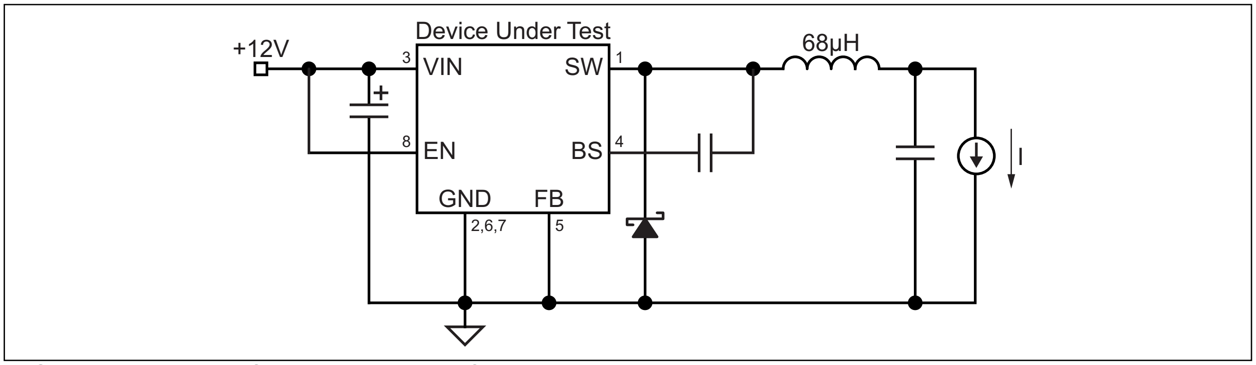


FIGURE 1-1: Current-Limit Test Circuit.

Shutdown Input Behavior

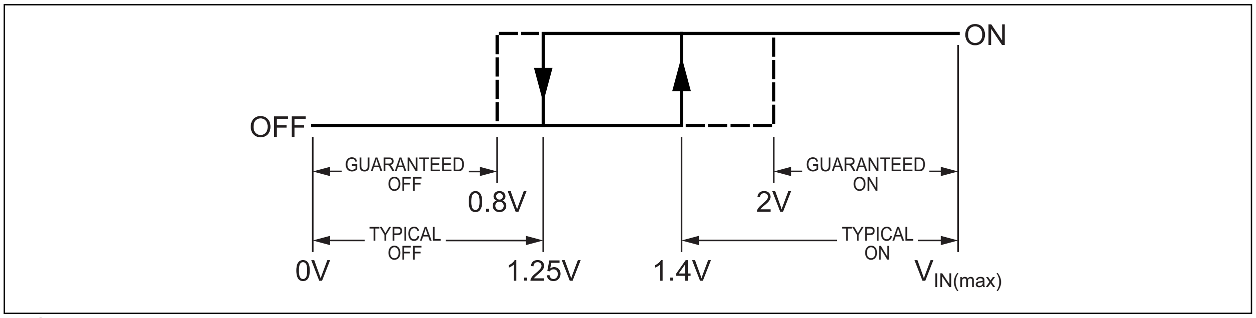


FIGURE 1-2: Enable Hysteresis.

TEMPERATURE SPECIFICATIONS (Note 1)

Parameters	Sym.	Min.	Typ.	Max.	Units	Conditions
Temperature Ranges						
Maximum Storage Temperature Range	T_S	–65	—	+150	°C	—
Junction Operating Temperature Range	T_J	–40	—	+125	°C	—
Ambient Operating Temperature Range	T_A	–40	—	+85	°C	—
Package Thermal Resistances						
Thermal Resistance SOIC-8	θ_{JA}	—	75	—	°C/W	Note 2
	θ_{JC}	—	25	—	°C/W	Note 2

Note 1: The maximum allowable power dissipation is a function of ambient temperature, the maximum allowable junction temperature and the thermal resistance from junction to air (i.e., T_A, T_J, θ_{JA}). Exceeding the maximum allowable power dissipation will cause the device operating junction temperature to exceed the maximum +125°C rating. Sustained junction temperatures above +125°C can impact the device reliability.

2: Measured on 1” square of 1 oz. copper FR4 printed circuit board connected to the device ground leads.

2.0 TYPICAL PERFORMANCE CURVES

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore outside the warranted range.

T_A = +25°C unless otherwise noted.

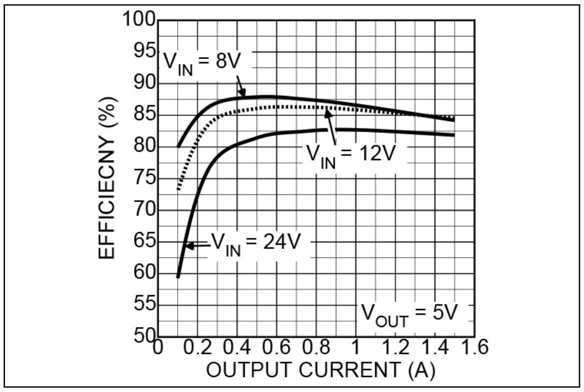


FIGURE 2-1: 5V_{OUT} Efficiency without Feed Forward Diode.

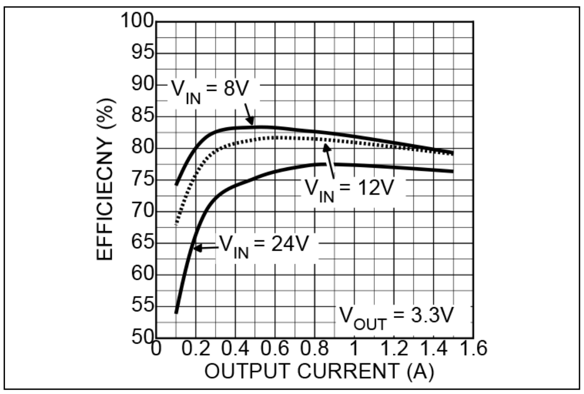


FIGURE 2-2: 3.3V_{OUT} Efficiency without Feed Forward Diode.

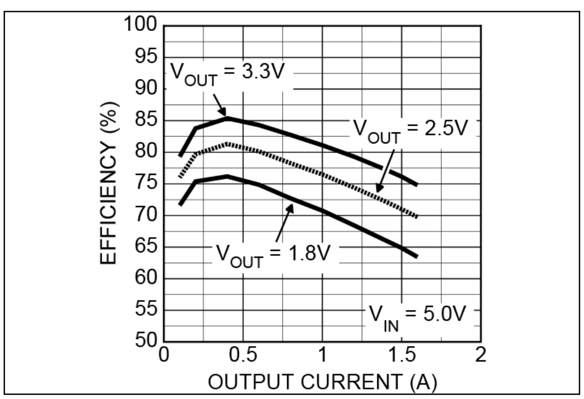


FIGURE 2-3: 5V_{OUT} Efficiency with Feed Forward Diode.

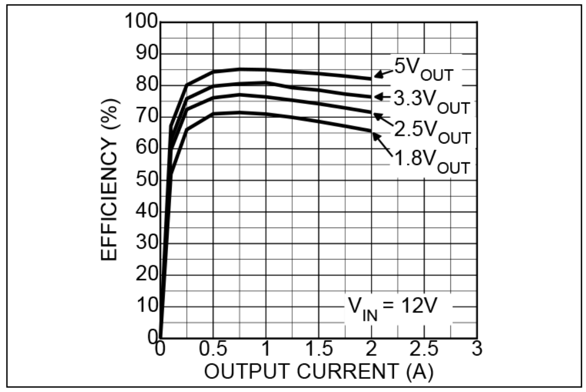


FIGURE 2-4: Efficiency vs. Output Current with Feed Forward Diode.

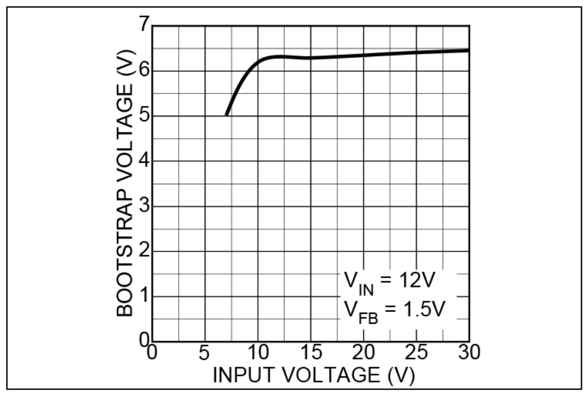


FIGURE 2-5: Bootstrap Voltage vs. Input Voltage.

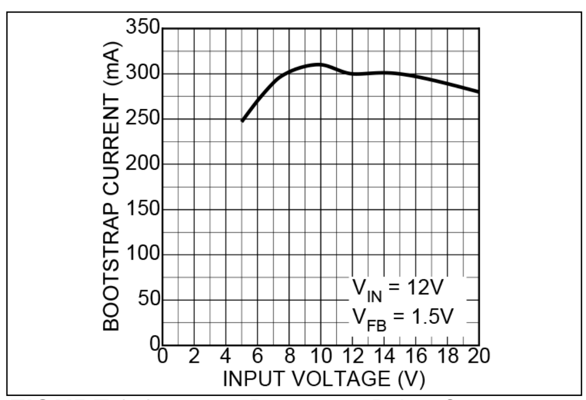


FIGURE 2-6: Bootstrap Drive Current vs. Input Voltage.

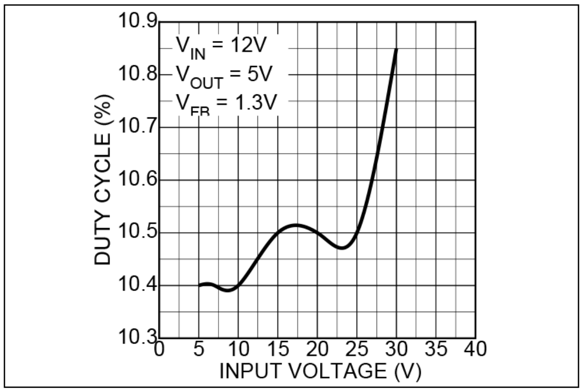


FIGURE 2-7: *Minimum Duty Cycle vs. Input Voltage.*

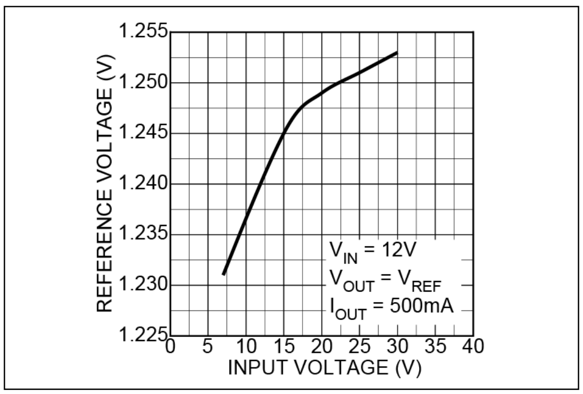


FIGURE 2-8: *Reference Voltage vs. Input Voltage.*

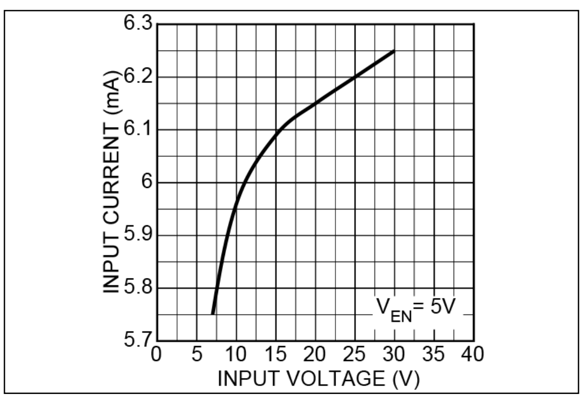


FIGURE 2-9: *Quiescent Current vs. Input Voltage.*

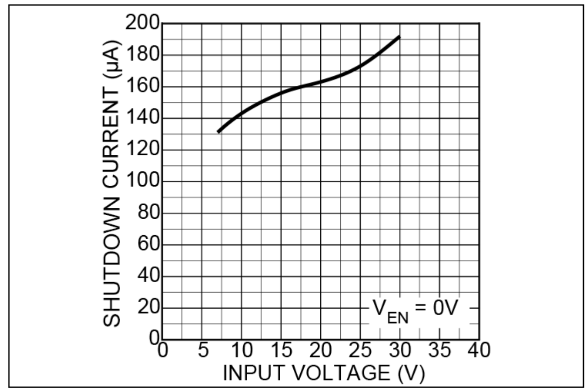


FIGURE 2-10: *Shutdown Current vs. Input Voltage.*

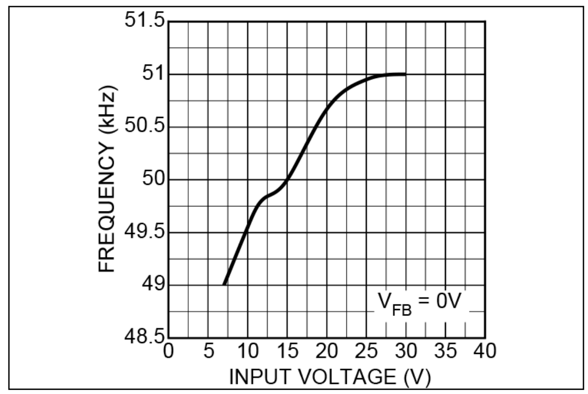


FIGURE 2-11: *Foldback Frequency vs. Input Voltage.*

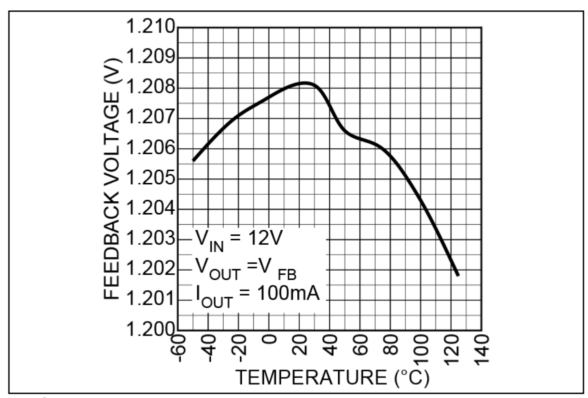


FIGURE 2-12: *Feedback Voltage vs. Temperature.*

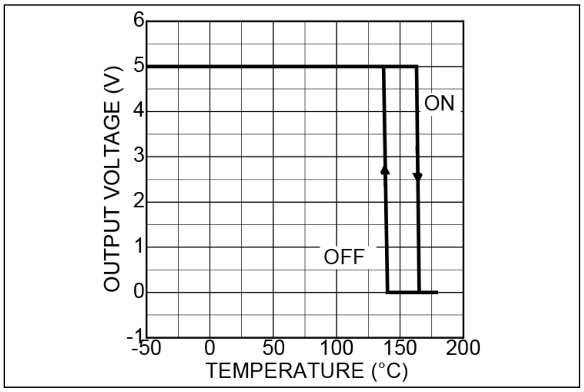


FIGURE 2-13: *Shutdown Hysteresis vs. Temperature.*

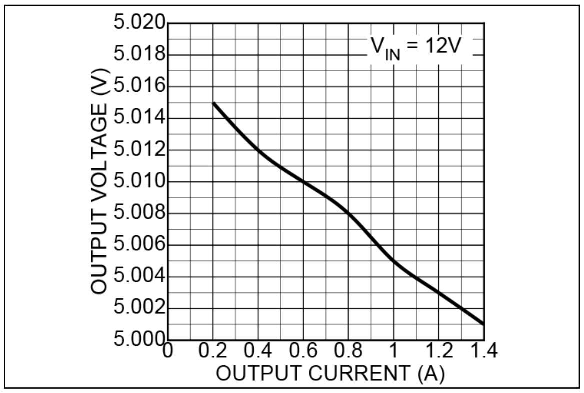


FIGURE 2-14: *Load Regulation.*

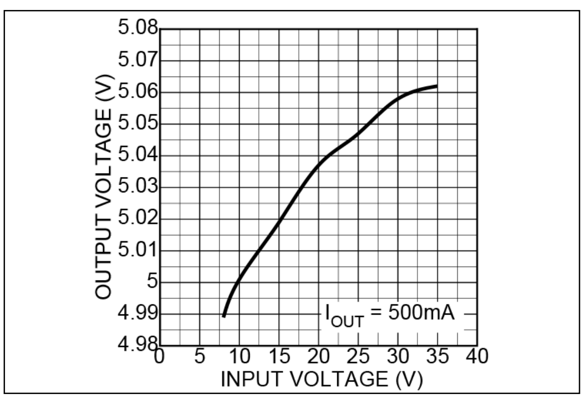


FIGURE 2-15: *Line Regulation.*

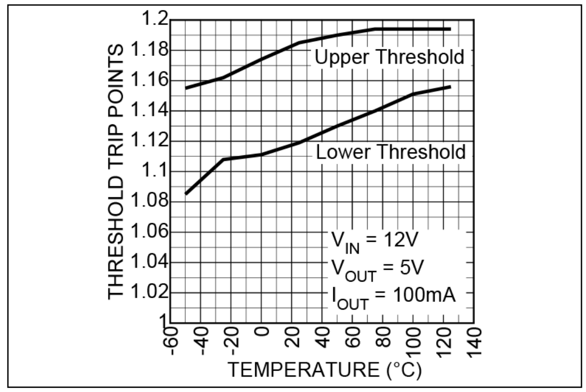


FIGURE 2-16: *Enable Threshold vs. Temperature.*

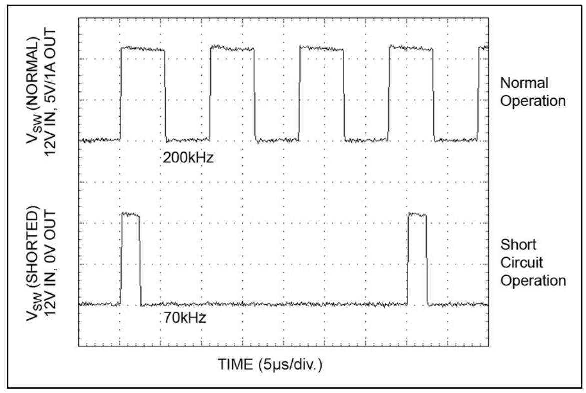


FIGURE 2-17: *Switching Frequency Foldback.*

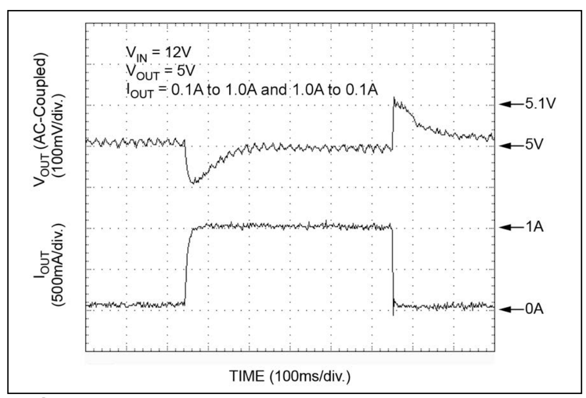


FIGURE 2-18: *Load Transient.*

3.0 PIN DESCRIPTIONS

The descriptions of the pins are listed in Table 3-1.

TABLE 3-1: PIN FUNCTION TABLE

Pin Number	Pin Name	Description
1	SW	Switch (Output): Emitter of NPN output switch. Connect to external storage inductor and Schottky diode. Connect this also to the C_{BS} capacitor.
2, 6, 7	GND	Ground pin.
3	VIN	Supply (Input): Unregulated +4V to +30V supply voltage (34V transient).
4	BS	Bootstrap Voltage Node: Connect to external bootstrap capacitor.
5	FB	Feedback (Input): Connect to center tap of resistive divider.
6	EN	Enable (Input): Logic-high = enable; logic-low = shutdown.

3.1 Detailed Pin Description

3.1.1 SWITCH (SW, PIN 1)

The switch pin is tied to the emitter of the main internal NPN transistor. This pin is biased up to the difference between the input voltage and the V_{SAT} of the main NPN switching 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 to a –0.5V typical voltage.

3.1.2 GROUND (GND, PINS 2, 6, 7)

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 its 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's necessary to place the input capacitor ground lead as close as possible to the switching regulators ground pin.

3.1.3 INPUT VOLTAGE (V_{IN}, PIN 3)

The VIN pin is the collector of the main NPN switching 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.

3.1.4 BOOTSTRAP (BS, PIN 4)

The bootstrap pin in conjunction with the external bootstrap capacitor provides a bias voltage higher than the input voltage to the MIC4684's main NPN switching 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 in addition to the DC offset of V_{IN} where it is rectified and used to provide the required drive to the main switch (the NPN transistor).

3.1.5 FEEDBACK (FB, PIN 5)

The feedback pin is tied to the inverting side of a g_M error amplifier. The non-inverting 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.

3.1.6 ENABLE (EN, PIN 8)

The enable (EN) input is used to turn on the regulator and is TTL-compatible. 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 150 µA. The enable pin has an upper threshold of minimum 2.0V and lower threshold of maximum 0.8V. The hysteresis provided by the upper and lower thresholds acts as an UVLO and prevents unwanted turn on of the regulator due to noise.

4.0 FUNCTIONAL DESCRIPTION

The MIC4684 is a variable duty cycle switch-mode step-down regulator with an internal power switch. Refer to the Functional Block Diagram.

4.1 Supply Voltage

The MIC4684 operates from a +4V to +30V (34V transient) unregulated input. See the Typical Performance Curves section for highest efficiency operation.

4.2 Enable/Shutdown

The enable (EN) input is TTL-compatible. Connect the enable input high if this pin is unused. A logic-high enables the regulator. A logic-low shuts down the internal regulator which reduces the quiescent current to typically 150 µA.

4.3 Feedback

The MIC4684 only requires an external resistive voltage divider from the output voltage to ground, center tapped to the FB pin in order to regulate the output voltage to the calculated value below.

EQUATION 4-1:

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

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

$$V_{FB} = 1.235V$$

4.4 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 200 kHz 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 MIC4684 uses a voltage-mode control architecture.

4.5 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}.

4.6 Output Capacitor

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

4.7 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.

5.0 APPLICATION INFORMATION

5.1 Adjustable Regulators

Adjustable regulators require a 1.235V feedback signal.

5.2 Minimum Pulse Width

The minimum duty cycle of the MIC4684 is approximately 10%. See Figure 2-7. If this input-to-output voltage characteristic is exceeded, the MIC4684 will skip cycles to maintain a regulated V_{OUT}.

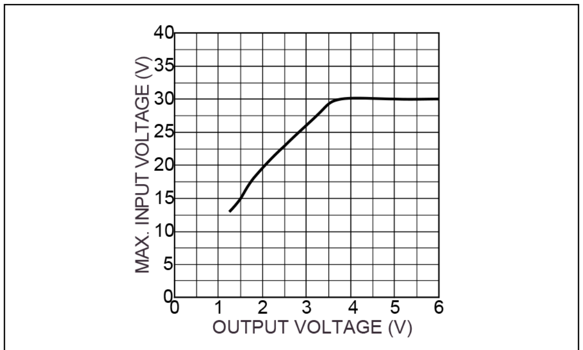


FIGURE 5-1: *Minimum Pulse Width Characteristic.*

5.3 Thermal Considerations

The MIC4684 SuperSwitcher™ features the power-SOIC-8. This package has a standard 8-lead small-outline package profile, but with much higher power dissipation than a standard SOIC-8. Microchip's MIC4684 SuperSwitcher™ family are the first DC-to-DC converters to take full advantage of this package.

The reason that the power SOIC-8 has higher power dissipation (lower thermal resistance) is that pins 2, 6, and 7 and the die-attach paddle are a single piece of metal. The die is attached to the paddle with thermally conductive adhesive. This provides a low thermal resistance path from the junction of the die to the ground pins. This design significantly improves package power dissipation by allowing an improved heat transfer through the ground leads to the printed circuit board.

One limitation of the maximum output current on any MIC4684 design is the junction-to-ambient thermal resistance (θ_{JA}) of the design (package and ground plane).

Examining θ_{JA} in more detail:

EQUATION 5-1:

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

Where:

θ_{JC}	= Junction-to-case thermal resistance.
θ_{CA}	= Case-to-ambient thermal resistance.

θ_{JC} is a relatively constant 25°C/W for a SOIC-8.

θ_{CA} is dependent on layout and is primarily governed by the connection of pins 2, 6, and 7 to the ground plane. The purpose of the ground plane is to function as a heat sink.

θ_{JA} is ideally 75°C/W, but will vary depending on the size of the ground plane to which the SOIC-8 is attached.

5.3.1 DETERMINING GROUND PLANE HEAT-SINK AREA

Make sure that MIC4684 pins 2, 6, and 7 are connected to a ground plane with a minimum area of 6 cm^2. This ground plane should be as close to the MIC4684 as possible. The area may be distributed in any shape around the package or on any PCB layer as long as there is good thermal contact to pins 2, 6, and 7. This ground plane area is more than sufficient for most designs.

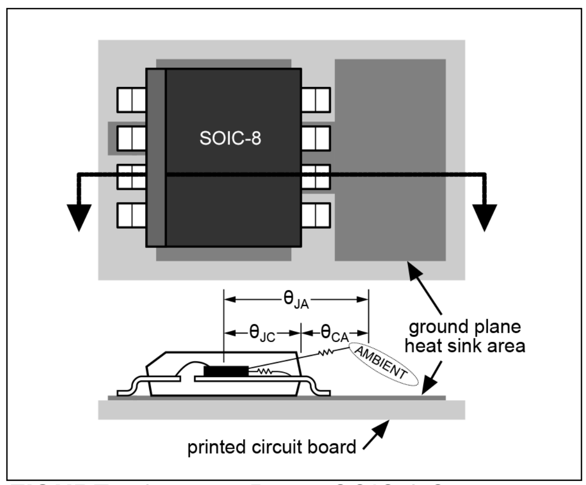


FIGURE 5-2: *Power SOIC-8 Cross Section.*

When designing with the MIC4684, it is a good practice to connect pins 2, 6, and 7 to the largest ground plane that is practical for the specific design.

5.3.2 CHECKING THE MAXIMUM JUNCTION TEMPERATURE

For this example, with an output power (P_{OUT}) of 5W, (5V output at 1A with V_{IN} = 12V) and 60°C maximum ambient temperature, what is the junction temperature?

Referring to Figure 2-1, read the efficiency (η) for 1A output current at V_{IN} = 12V or perform you own measurement.

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

EQUATION 5-2:

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

$$P_D = \frac{5W}{0.84} - 5W$$

$$P_D = 0.95W$$

A worst-case rule of thumb is to assume that 80% of the total output power dissipation is in the MIC4684 ($P_{D(IC)}$) and 20% is in the diode-inductor-capacitor circuit.

EQUATION 5-3:

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

$$P_{D(IC)} = 0.8 \times 0.95W$$

$$P_{D(IC)} = 0.76W$$

Calculate the worst-case junction temperature by using the following equation.

EQUATION 5-4:

$$T_J = P_{D(IC)} \times \theta_{JC} + (T_C - T_A) + T_{A(MAX)}$$

Where:

T_J	= Junction temperature.
$P_{D(IC)}$	= Power dissipation.
θ_{JC}	= Junction-to-case thermal resistance.
T_C	= Pin temperature measurement taken at the entry point of pin 2, 6, or 7.
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:

EQUATION 5-5:

$$T_J = 0.76 \times 25°C/W + (41°C - 25°C) + 60°C = 95°C$$

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 Table 1-1.

5.4 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 1 and pins 2, 6, and 7, keep L1 away from sensitive node FB, and keep C_{IN} close to pin 3 and pins 2, 6, and 7.

5.5 Feed Forward Diode

The feed forward (FF) diode provides an external bias source directly to the main switch element. This reduces V_{SAT} and allows the MIC4684 to be used in low headroom applications.

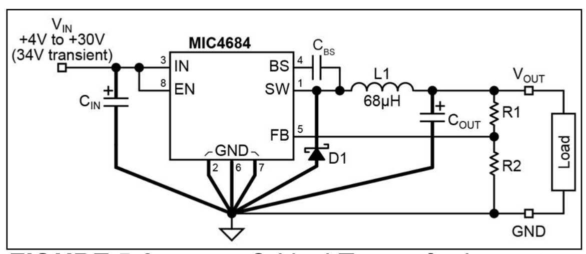
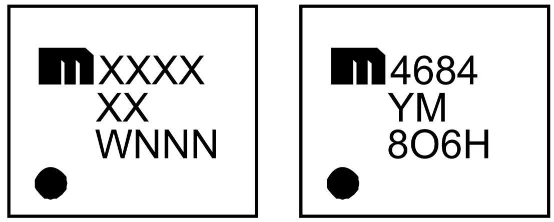


FIGURE 5-3: Critical Traces for Layout.

6.0 PACKAGING INFORMATION

6.1 Package Marking Information

8-Lead SOIC* Example



Legend:	XX...X	Product code or customer-specific information
	Y	Year code (last digit of calendar year)
	YY	Year code (last 2 digits of calendar year)
	WW	Week code (week of January 1 is week ‘01’)
	NNN	Alphanumeric traceability code
	(e3)	Pb-free JEDEC® designator for Matte Tin (Sn)
	*	This package is Pb-free. The Pb-free JEDEC designator ((e3)) can be found on the outer packaging for this package.
	●, ▲, ▼	Pin one index is identified by a dot, delta up, or delta down (triangle mark).

Note: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line, thus limiting the number of available characters for customer-specific information. Package may or may not include the corporate logo.

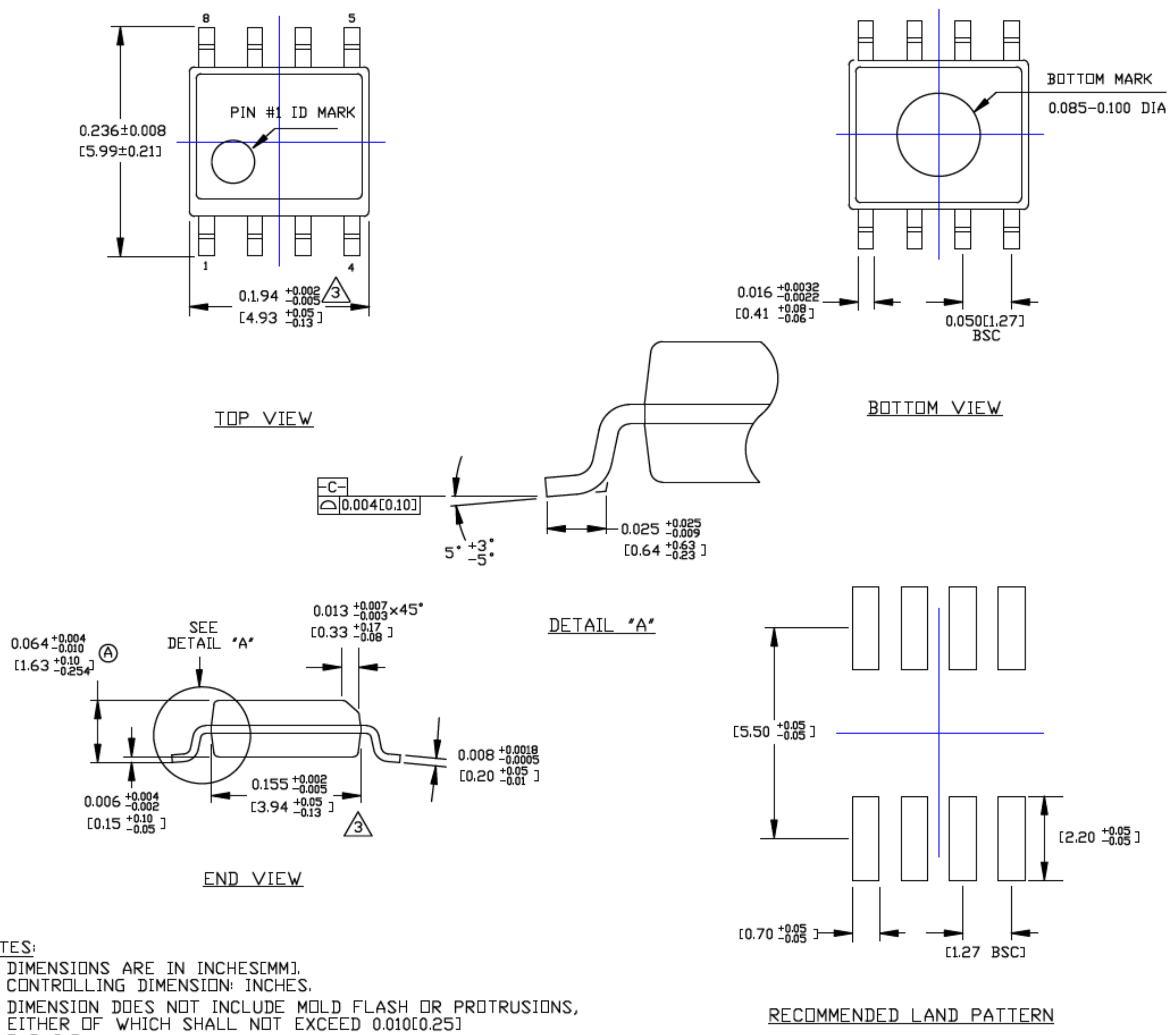
Underbar (_) and/or Overbar (‾) symbol may not be to scale.

Note: If the full seven-character YYWWNNN code cannot fit on the package, the following truncated codes are used based on the available marking space:
6 Characters = YWWNNN; 5 Characters = WWNNN; 4 Characters = WNNN; 3 Characters = NNN;
2 Characters = NN; 1 Character = N

8-Lead SOIC Package Outline and Recommended Land Pattern

TITLE
8 LEAD SOICN PACKAGE OUTLINE & RECOMMENDED LAND PATTERN

DRAWING #	SOICN-8LD-PL-1	**UNIT**	INCH [MM]



NOTES:
1. DIMENSIONS ARE IN INCHES[MM].
2. CONTROLLING DIMENSION: INCHES.
3. DIMENSION DOES NOT INCLUDE MOLD FLASH OR PROTRUSIONS, EITHER OF WHICH SHALL NOT EXCEED 0.010[0.25] PER SIDE.

Note:	For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging.

APPENDIX A: REVISION HISTORY

Revision A (July 2023)

- Converted Micrel document MIC4684 to Microchip data sheet DS20005970A.
- Minor text changes throughout.

NOTES:

PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, contact your local Microchip representative or sales office.

Device	X	X	-XX
Part No.	Junction Temp. Range	Package	Media Type

Device:	MIC4684:	2A High Efficiency Buck Regulator with Adjustable Output Voltage
Junction Temperature Range:	Y =	–40°C to +125°C
Package:	M =	8-Lead SOIC
Media Type:	<blank>= TR =	95/Tube 2,500/Reel

Examples:

a) MIC4684YM: MIC4684, –40°C to +125°C Junction Temp. Range, 8-Lead SOIC, 95/Tube

b) MIC4684YM-TR: MIC4684, –40°C to +125°C Junction Temp. Range, 8-Lead SOIC, 2,500/Reel

Note 1: Tape and Reel identifier only appears in the catalog part number description. This identifier is used for ordering purposes and is not printed on the device package. Check with your Microchip Sales Office for package availability with the Tape and Reel option.

NOTES:

ISBN: 978-1-6683-2845-3

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