MIC23050

4 MHz PWM Buck Regulator with HyperLight Load® Switching Scheme

Features

- Input Voltage: 2.7V to 5.5V
- 600 mA Output Current
- Fixed Output Voltage from 0.72V to 3.3V
- Ultra-Fast Transient Response
- 20 µA Typical Quiescent Current
- 4 MHz in PWM in Constant-Current Mode
- 0.47 µH to 2.2 µH Inductor
- Low Voltage Output Ripple
  - 25 mV_{PP} in HyperLight Load Mode
  - 3 mV Output Voltage Ripple in Full PWM Mode
- >93% Efficiency
- ~89% Efficiency @ 1 mA
- Micropower Shutdown
- Available in 8-Lead 2 mm x 2 mm VDFN
- –40°C to +125°C Junction Temperature Range

Applications

- Cellular Phones
- Digital Cameras
- Portable Media Players
- Wireless LAN Cards
- WiFi/WiMax/WiBro Modules
- USB-Powered Devices

General Description

The MIC23050 is a high-efficiency, 600 mA, PWM, synchronous buck (step-down) regulator featuring the HyperLight Load® patented switching scheme that offers best-in-class light load efficiency and transient performance while providing very-small external components and low output ripple at all loads.

The MIC23050 also has a very low typical quiescent current draw of 20 µA and can achieve over 89% efficiency even at 1 mA. The device allows operation with a tiny inductor ranging from 0.47 µH to 2.2 µH and uses a small output capacitor that enables a sub-1 mm height.

In contrast to traditional light load schemes, the HyperLight Load architecture does not need to trade off control speed to obtain low standby currents and in doing so the device only needs a small output capacitor to absorb the load transient as the powered device goes from light load to full load.

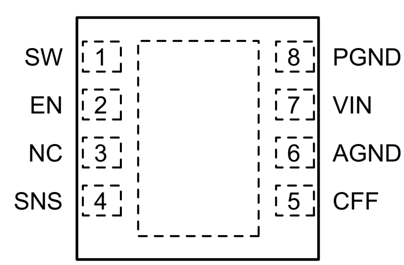
At higher loads the MIC23050 provides a constant switching frequency of greater than 4 MHz while providing peak efficiencies greater than 93%.

The MIC23050 comes in fixed output voltage options from 0.72V to 3.3V eliminating external feedback components.

The MIC23050 is available in an 8-lead 2 mm x 2 mm VDFN with a junction operating range from –40°C to +125°C.

Package Type

MIC23050
8-Lead 2 mm x 2 mm VDFN (ML)
(Top View)



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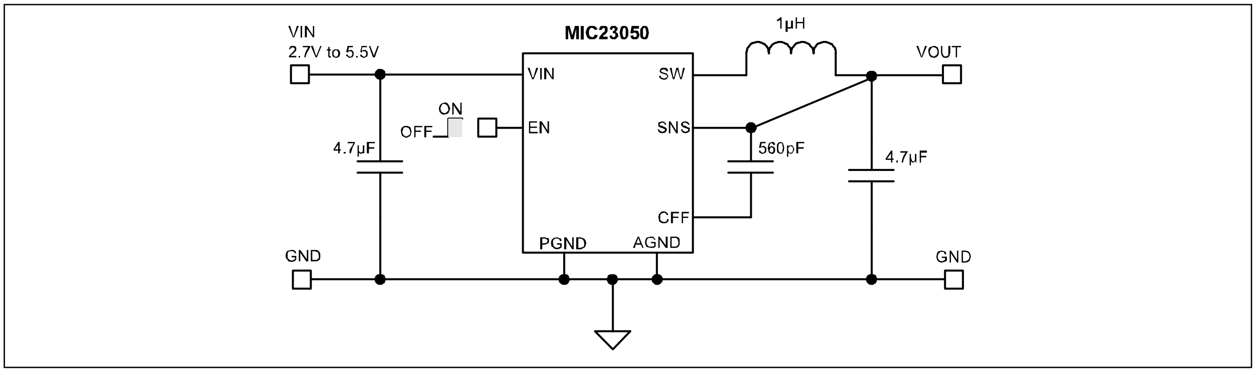
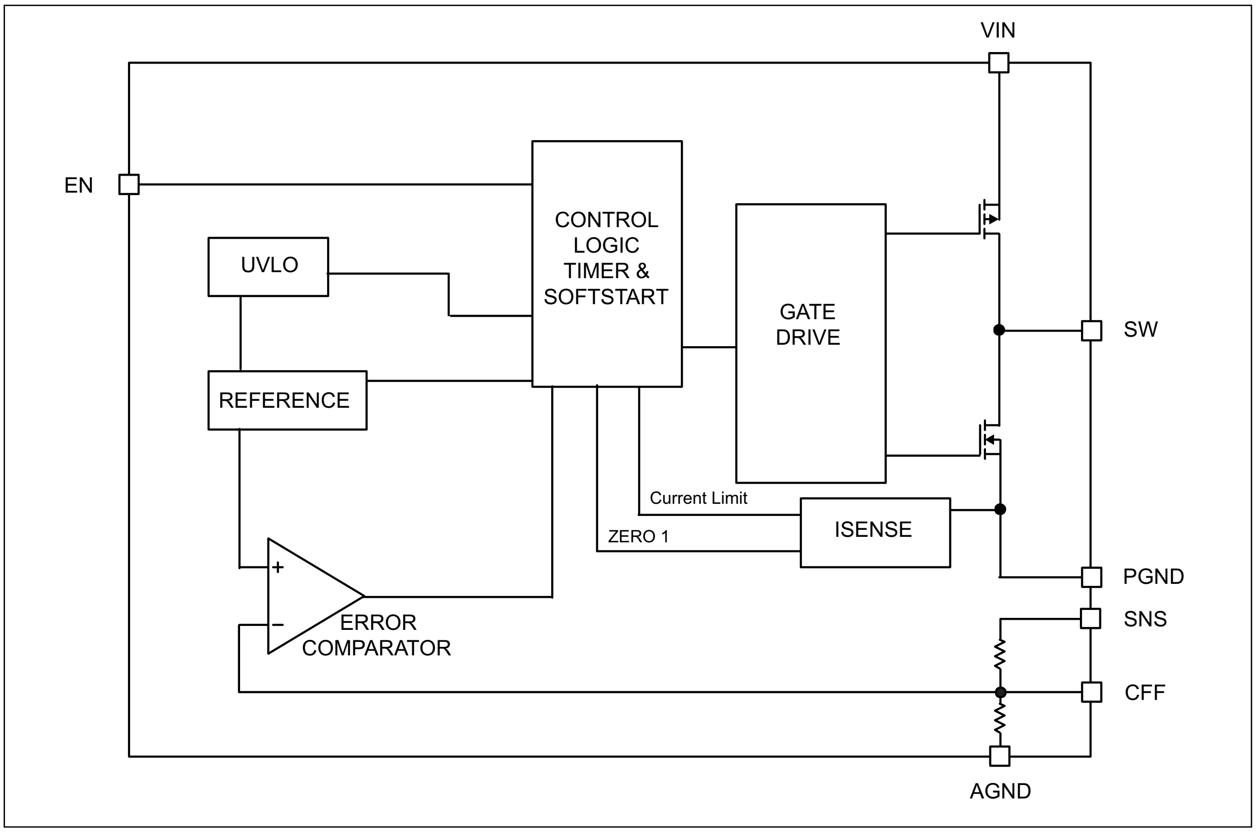
Typical Application Circuit



Functional Block Diagram



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1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

Supply Voltage (V_{IN}) .... +6V
Output Switch Voltage (V_{SW}) .... +6V
Output Switch Current (I_{SW}) 2A
Logic Input Voltage (V_{EN}, V_{LQ}) .... V_{IN} to –0.3V
ESD Rating (Note 1) .... 3 kV

Operating Ratings ‡

Supply Voltage (V_{IN}) .... +2.7V to +5.5V
Logic Input Voltage (V_{EN}) .... 0V to V_{IN}

† 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: Device is ESD sensitive. Handling precautions are recommended. Human body model, 1.5 kΩ in series with 100 pF.

ELECTRICAL CHARACTERISTICS

T_A = +25°C with V_{IN} = V_{EN} = 3.6V; L = 1 µH; C_{FF} = 560 pF; C_{OUT} = 4.7 µF; I_{OUT} = 20 mA unless otherwise specified. **Bold** values valid for –40°C ≤ T_J ≤ +125°C. Note 1

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions
Supply Voltage Range	V_{IN}	2.7	—	5.5	V	—
Undervoltage Lockout Threshold	$UVLO_{STRT}$	2.45	2.55	2.65	V	Turn-on
UVLO Hysteresis	$UVLO_{HYS}$	—	100	—	mV	—
Quiescent Current, HyperLight Load Mode	I_{Q_HLL}	—	20	**32**	µA	I_{OUT} = 0 mA, V_{SNS} > 1.2 x V_{OUT} nominal
Shutdown Current	I_{Q_SHDN}	—	0.01	**4**	µA	V_{IN} = 5.5V; V_{EN} = 0V
Output Voltage Accuracy	—	**–2.5**	—	**2.5**	%	V_{IN} = 3.0V, I_{LOAD} = 20 mA
Current Limit in PWM Mode	I_{MAX}	**0.65**	1	**1.7**	A	SNS = 0.9 x V_{NOM}
Output Voltage Line Regulation	—	—	0.5	—	%/V	V_{IN} = 3.0V to 5.5V, I_{LOAD} = 20 mA
Output Voltage Load Regulation	—	—	0.3	—	%	20 mA < I_{LOAD} < 500 mA
Maximum Duty Cycle	DC_{MAX}	**80**	89	—	%	SNS ≤ V_{NOM}
PWM Switch ON-Resistance	$R_{DS(ON)}$	—	0.45	—	Ω	I_{SW} = 100 mA PMOS
		—	0.5	—		I_{SW} = −100 mA NMOS
Switching Frequency	f_{SW}	**3.4**	4	**4.6**	MHz	I_{LOAD} = 120 mA
Soft-Start Time	t_{SS}	—	650	—	µs	V_{OUT} = 90%
Enable Threshold	V_{IH}	**0.5**	0.8	**1.2**	V	Turn-on
Enable Hysteresis	—	—	35	—	mV	—
Enable Input Current	I_{ENLK}	—	0.1	**2**	µA	—
Overtemperature Shutdown	T_{SD}	—	165	—	°C	—
Overtemperature Shutdown Hysteresis	T_{SDHYS}	—	20	—	°C	—

Note 1: Specification for packaged product only.

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TEMPERATURE SPECIFICATIONS

Parameters	Sym.	Min.	Typ.	Max.	Units	Conditions
Temperature Ranges						
Maximum Junction Temperature	$T_{J(MAX)}$	—	—	+150	°C	—
Storage Temperature Range	T_S	–65	—	+150	°C	—
Junction Temperature Range	T_J	–40	—	+125	°C	—
Package Thermal Resistances						
Thermal Resistance, 8-Ld VDFN	θ_{JA}	—	90	—	°C/W	—
	θ_{JC}	—	45	—	°C/W	—

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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.

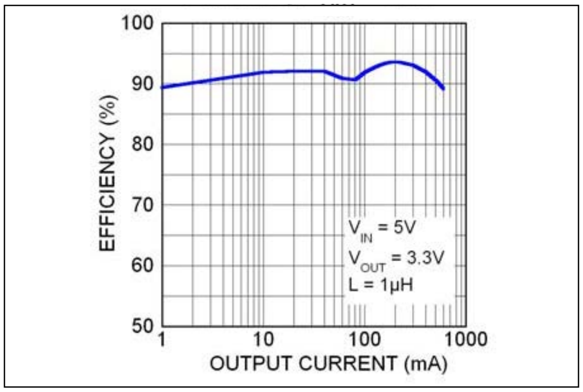

FIGURE 2-1: *Efficiency, V_{OUT} = 3.3V.*

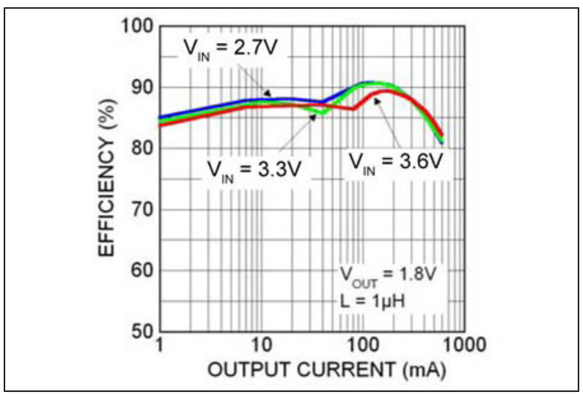

FIGURE 2-2: *Efficiency, V_{OUT} = 1.8V.*

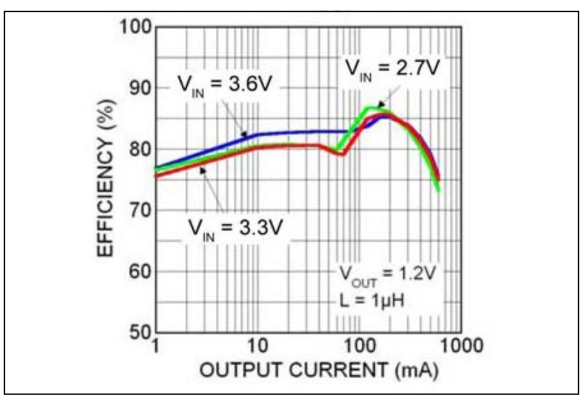

FIGURE 2-3: *Efficiency, V_{OUT} = 1.2V.*

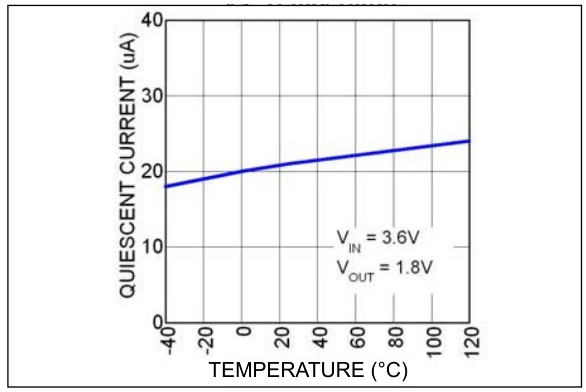

FIGURE 2-4: *Quiescent Current vs. Temperature.*

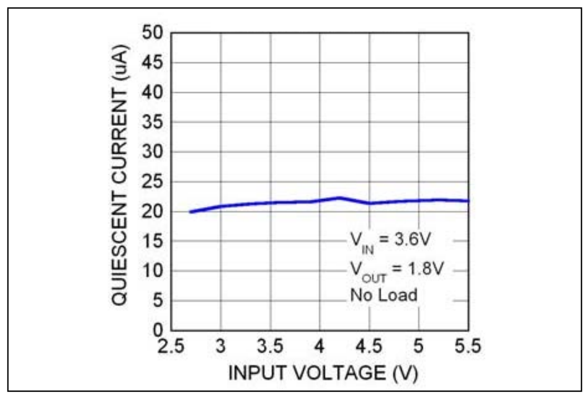

FIGURE 2-5: *Quiescent Current vs. Input Voltage.*

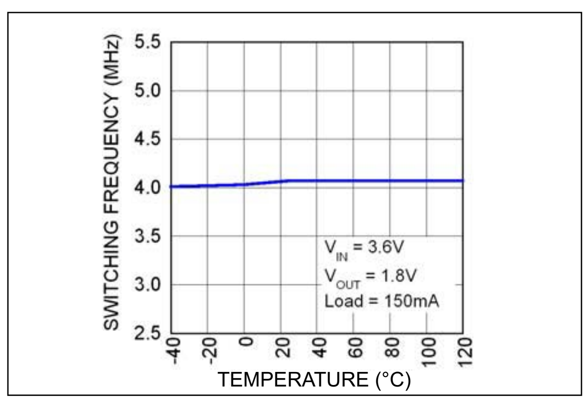

FIGURE 2-6: *Switching Frequency vs. Temperature.*

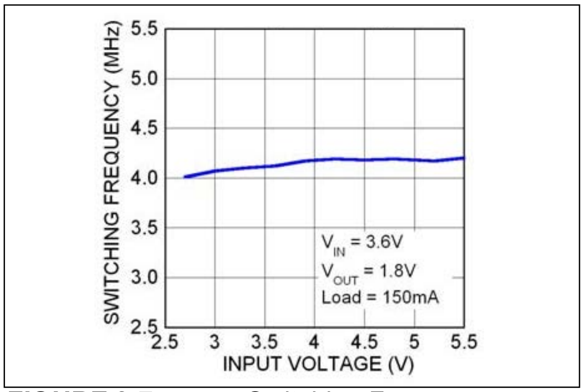

FIGURE 2-7: *Switching Frequency vs. Input Voltage.*

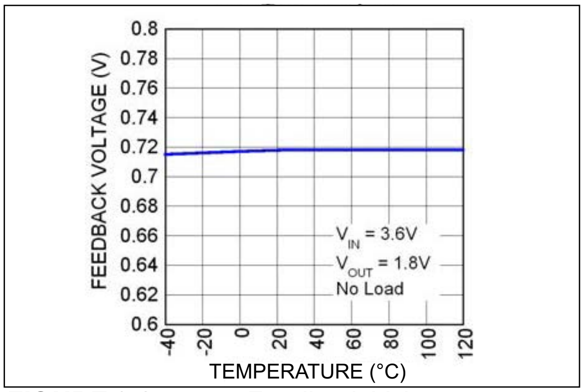

FIGURE 2-8: *Feedback Voltage vs. Temperature.*

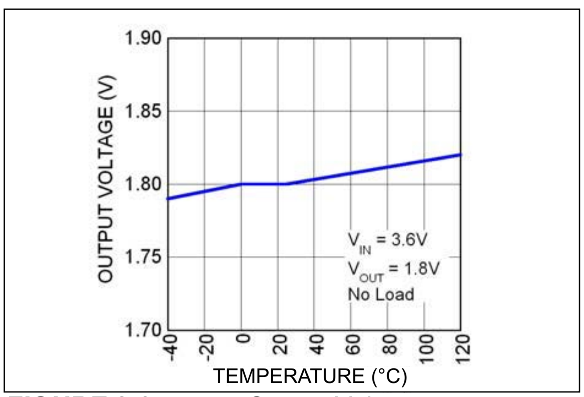

FIGURE 2-9: *Output Voltage vs. Temperature.*

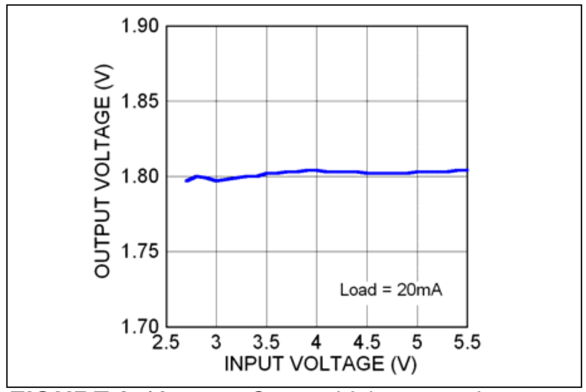

FIGURE 2-10: *Output Voltage vs. Input Voltage.*

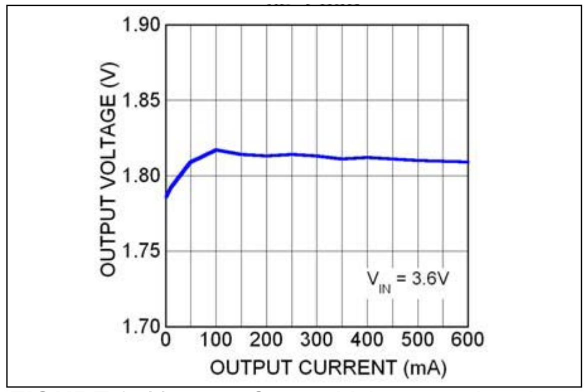

FIGURE 2-11: *Output Voltage vs. Load.*

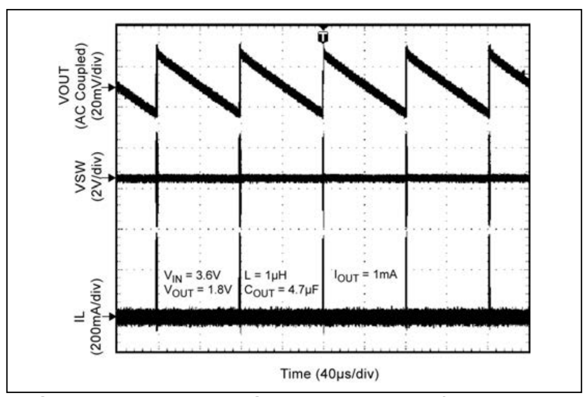

FIGURE 2-12: *Switching Waveform.*

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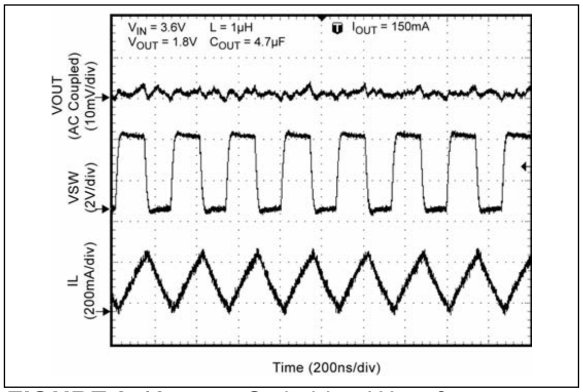

FIGURE 2-13: *Switching Waveform.*

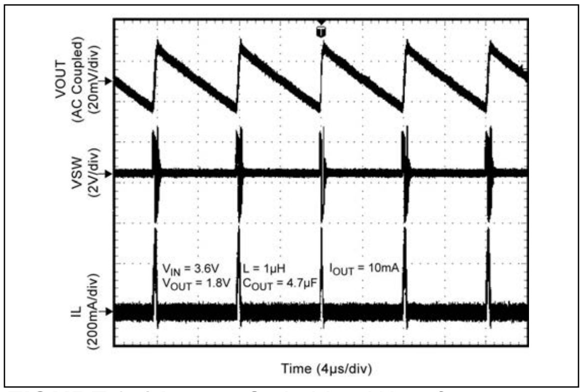

FIGURE 2-14: *Switching Waveform.*

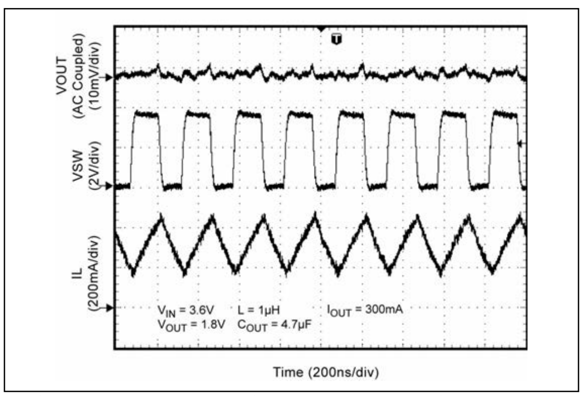

FIGURE 2-15: *Switching Waveform.*

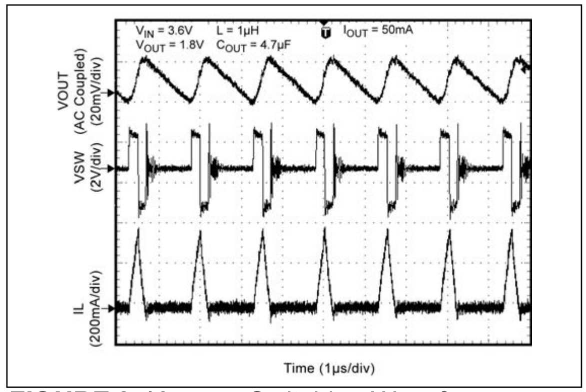

FIGURE 2-16: *Switching Waveform.*

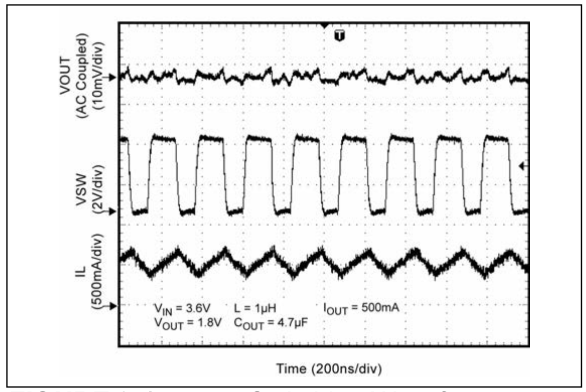

FIGURE 2-17: *Switching Waveform.*

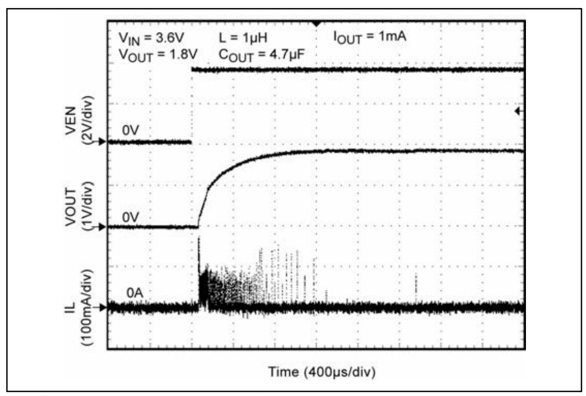

FIGURE 2-18: *Start-Up.*

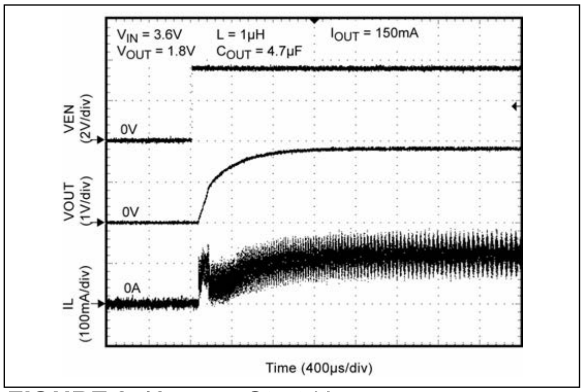

FIGURE 2-19: *Start-Up.*

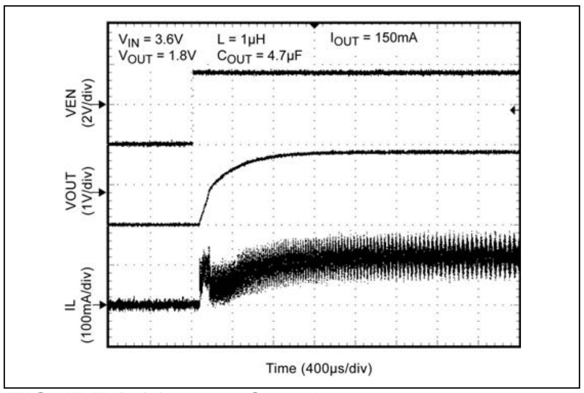

FIGURE 2-20: *Start-Up.*

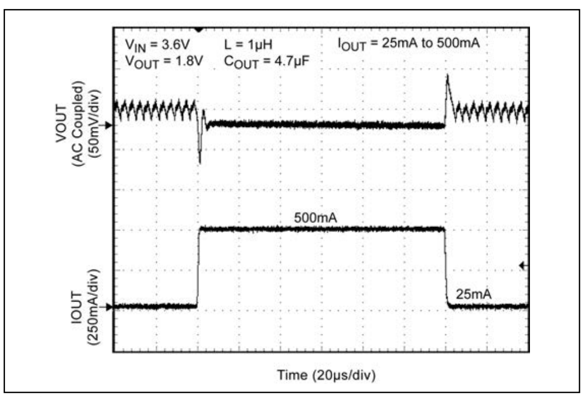

FIGURE 2-21: *Load Transient.*

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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): Internal power MOSFET output switches.
2	EN	Enable (Input): Logic low will shut down the device, reducing the quiescent current to less than 4 µA. Do not leave floating.
3	NC	No connect.
4	SNS	Connect to VOUT to sense the output voltage.
5	CFF	Feed-Forward Capacitor: Connect a 560 pF capacitor from VOUT to the CFF pin.
6	AGND	Analog Ground.
7	VIN	Supply Voltage (Input): Required bypass capacitor to GND.
8	PGND	Power Ground.

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4.0 FUNCTIONAL DESCRIPTION

4.1 VIN

VIN provides power to the MOSFETs for the switch mode regulator section and to the analog supply circuitry. Due to the high switching speeds, it is recommended that a 2.2 µF or greater capacitor be placed close to VIN and the power ground (PGND) pin for bypassing. Refer to the layout recommendations for details.

4.2 EN

The enable pin (EN) controls the on and off state of the device. A logic high on the enable pin activates the regulator, while a logic low deactivates it. MIC23050 features built-in soft-start circuitry that reduces in-rush current and prevents the output voltage from overshooting at start up. Do not leave this pin floating.

4.3 SW

The switch (SW) pin connects directly to the inductor and provides the switching current necessary to operate in PWM mode. Due to the high speed switching on this pin, the switch node should be routed away from sensitive nodes such as the CFF pin.

4.4 SNS

An inductor is connected from the SW pin to the SNS pin. The SNS pin is the output pin of the device and a minimum of 2.2 µF bypass capacitor should be connected in shunt. In order to reduce parasitic inductance it is good practice to place the output bypass capacitor as close to the inductor as possible.

4.5 CFF

The CFF pin is connected to the SNS pin of MIC23050 with a feed-forward capacitor of 560 pF. The CFF pin itself is compared with the internal reference voltage (V_{REF}) of the device and provides the control path to control the output. V_{REF} is equal to 0.72V. The CFF pin is sensitive to noise and should be placed away from the SW pin. Refer to the layout recommendations for details.

4.6 PGND

Power ground (PGND) is the ground path for the high current PWM mode. The current loop for the power ground should be as small as possible and separate from the Analog ground (AGND) loop. Refer to the layout recommendations for more details.

4.7 AGND

Signal ground (AGND) is the ground path for the biasing and control circuitry. The current loop for the signal ground should be separate from the Power ground (PGND) loop. Refer to the layout recommendations for more details.

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5.0 APPLICATION INFORMATION

5.1 Input Capacitor

A minimum of 2.2 µF ceramic capacitor should be placed close to the VIN pin and PGND pin for bypassing. X5R or X7R dielectrics are recommended for the input capacitor. Y5V dielectrics, aside from losing most of their capacitance over temperature, they also become resistive at high frequencies. This reduces their ability to filter out high frequency noise.

5.2 Output Capacitor

The MIC23050 is designed for use with a 2.2 µF or greater ceramic output capacitor. A low equivalent series resistance (ESR) ceramic output capacitor either X7R or X5R is recommended. Y5V and Z5U dielectric capacitors, aside from the undesirable effect of their wide variation in capacitance over temperature, become resistive at high frequencies.

5.3 Inductor Selection

Inductor selection will be determined by the following (not necessarily in the order of importance):

- Inductance
- Rated current value
- Size requirements
- DC resistance (DCR)

The MIC23050 is designed for use with an inductance range from 0.47 µH to 2.2 µH. Typically, a 1 µH inductor is recommended for a balance of transient response, efficiency and output ripple. For faster transient response a 0.47 µH inductor may be used. For lower output ripple, a 2.2 µH is recommended.

Maximum current ratings of the inductor are generally given in two methods; permissible DC current and saturation current. Permissible DC current can be rated either for a 40°C temperature rise or a 10% to 20% loss in inductance. Ensure the inductor selected can handle the maximum operating current. When saturation current is specified, make sure that there is enough margin so that the peak current of the inductor does not cause it to saturate. Peak current can be calculated as follows:

EQUATION 5-1:

$$I_{PK} = I_{OUT} + V_{OUT} \times (1 - V_{OUT}/V_{IN})/(2 \times f_{SW} \times L)$$

As shown by the previous calculation, the peak inductor current is inversely proportional to the switching frequency and the inductance; the lower the switching frequency or the inductance the higher the peak current. As input voltage increases the peak current also increases.

The size of the inductor depends on the requirements of the application. Refer to the Application Circuit and Bill of Material for details.

DC resistance (DCR) is also important. While DCR is inversely proportional to size, DCR can represent a significant efficiency loss. Refer to the Efficiency Considerations.

5.4 Compensation

The MIC23050 is designed to be stable with a 0.47 µH to 2.2 µH inductor with a 2.2 µF ceramic (X5R) output capacitor.

5.5 Efficiency Considerations

Efficiency is defined as the amount of useful output power, divided by the amount of power supplied:

EQUATION 5-2:

$$Efficiency\ \% = \left(\frac{V_{OUT} \times I_{OUT}}{V_{IN} \times I_{IN}}\right) \times 100$$

Maintaining high efficiency serves two purposes. It reduces power dissipation in the power supply, reducing the need for heat sinks and thermal design considerations and it reduces consumption of current for battery powered applications. Reduced current draw from a battery increases the devices operating time and is critical in hand held devices.

There are two types of losses in switching converters; DC losses and switching losses. DC losses are simply the power dissipation of I^2R. Power is dissipated in the high side switch during the on cycle. Power loss is equal to the high side MOSFET $R_{DS(ON)}$ multiplied by the square of the Switch Current. During the off cycle, the low side N-channel MOSFET conducts, also dissipating power. Device operating current also reduces efficiency. The product of the quiescent (operating) current and the supply voltage is another DC loss. The current required driving the gates on and off at a constant 4 MHz frequency and the switching transitions make up the switching losses.

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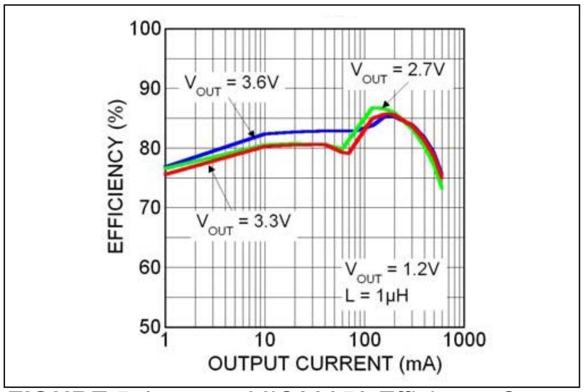

FIGURE 5-1: *MIC23050 Efficiency Curve.*

Figure 5-1 illustrates an efficiency curve for the MIC23050. From no load to 100 mA, efficiency losses are dominated by quiescent current losses, gate drive and transition losses. By using the HyperLight Load mode the MIC23050 is able to maintain high efficiency at low output currents.

Over 100 mA, efficiency loss is dominated by MOSFET $R_{DS(ON)}$ and inductor losses. Higher input supply voltages will increase the gate-to-source threshold on the internal MOSFETs, reducing the internal $R_{DS(ON)}$. This improves efficiency by reducing DC losses in the device. All but the inductor losses are inherent to the device. In which case, inductor selection becomes increasingly critical in efficiency calculations. As the inductors are reduced in size, the DC resistance (DCR) can become quite significant. The DCR losses can be calculated as follows:

EQUATION 5-3:

$$LP_D = I_{OUT}^2 \times DCR$$

From that, the loss in efficiency due to inductor resistance can be calculated as follows:

EQUATION 5-4:

$$\text{Eff. Loss} = \left[1 - \left(\frac{V_{OUT} \times I_{OUT}}{V_{OUT} \times I_{OUT} + LP_D}\right)\right] \times 100$$

Efficiency loss due to DCR is minimal at light loads and gains significance as the load is increased. Inductor selection becomes a trade-off between efficiency and size in this case.

5.6 HyperLight Load® Mode

MIC23050 uses a minimum on and off time proprietary control loop. When the output voltage falls below the regulation threshold, the error comparator begins a switching cycle that turns the PMOS on and keeps it on for the duration of the minimum-on-time. When the output voltage is over the regulation threshold, the error comparator turns the PMOS off for a minimum-off-time. The NMOS acts as an ideal rectifier that conducts when the PMOS is off. Using a NMOS switch instead of a diode allows for lower voltage drop across the switching device when it is on. The asynchronous switching combination between the PMOS and the NMOS allows the control loop to work in discontinuous mode for light load operations. In discontinuous mode MIC23050 works in pulse frequency modulation (PFM) to regulate the output. As the output current increases, the switching frequency increases. This improves the efficiency of MIC23050 during light load currents. As the load current increases, the MIC23050 goes into continuous conduction mode (CCM) at a constant frequency of 4 MHz. The equation to calculate the load when the MIC23050 goes into continuous conduction mode may be approximated by the following formula:

EQUATION 5-5:

$$I_{LOAD} = \frac{(V_{IN} - V_{OUT}) \times D}{2 \times L \times f_{sw}}$$

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6.0 APPLICATION CIRCUIT AND BILL OF MATERIALS

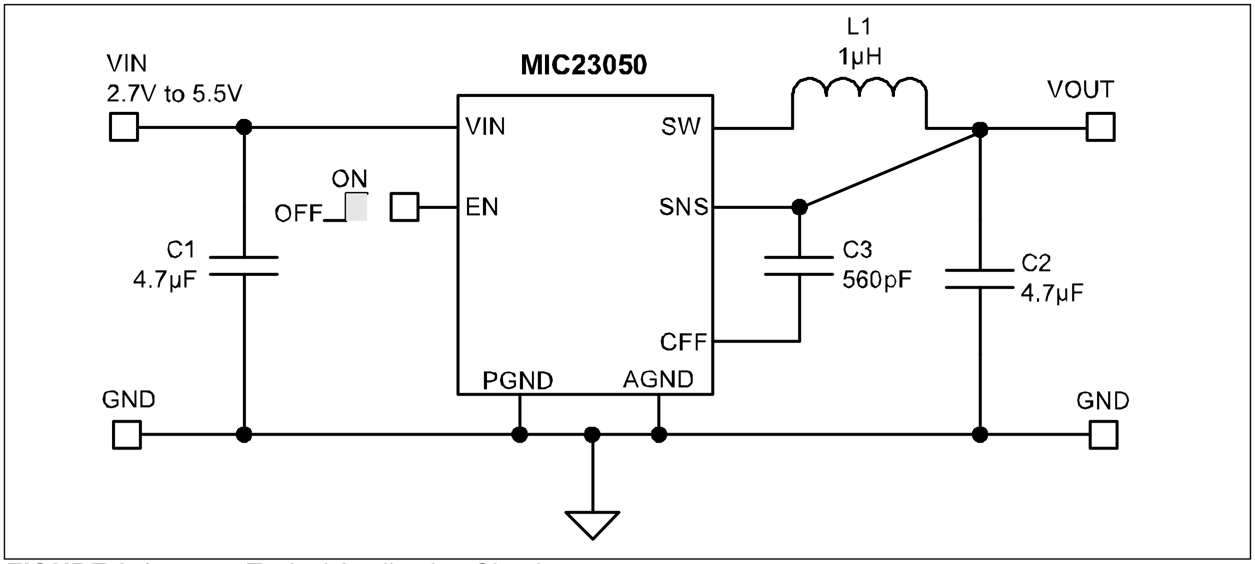

FIGURE 6-1: Typical Application Circuit.

TABLE 6-1: BILL OF MATERIALS

Item	Part Number	Manufacturer	Description	Qty.
C1, C2	C1608X5R0J475K	TDK	4.7 µF Ceramic Capacitor, 6.3V, X5R, Size 0603	2
C3	C1608C0G1H561J	TDK	560 pF Ceramic Capacitor, 50V, NPO, Size 0603	1
L1	LQM21PN1R0MC0D	Murata	1 µH, 0.8A, 190 mΩ, L2 mm x W1.25 mm x H0.5 mm	1
	LQH32CN1R0M33	Murata	1 µH, 1A, 60 mΩ, L3.2 mm x W2.5 mm x H2.0 mm	
	LQM31PN1R0M00	Murata	1 µH, 1.2A, 120 mΩ, L3.2 mm x W1.6 mm x H0.95 mm	
	GLF251812T1R0M	TDK	1 µH, 0.8A, 100 mΩ, L2.5 mm x W1.8 mm x H1.35 mm	
	LQM31PNR47M00	Murata	0.47 µH, 1.4A, 80 mΩ, L3.2 mm x W1.6 mm x H0.85 mm	
	MIPF2520D1R5	FDK	1.5 µH, 1.5A, 70 mΩ, L2.5 mm x W2 mm x H1.0 mm	
U1	MIC23050-xYML	Microchip	4 MHz PWM Buck Regulator with HyperLight Load® Mode	1

7.0 PCB LAYOUT RECOMMENDATIONS

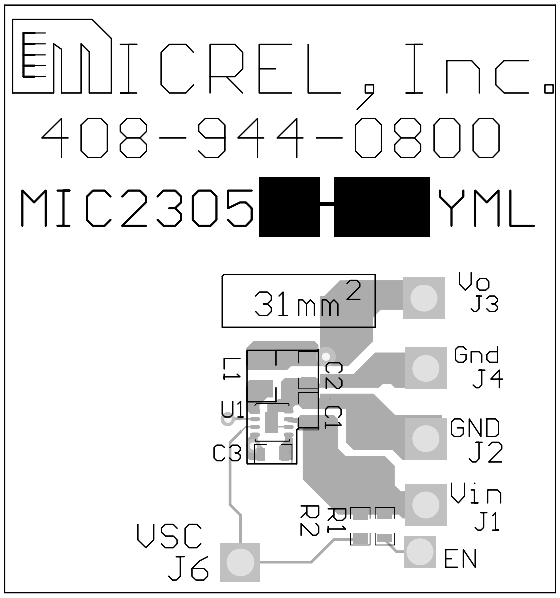

FIGURE 7-1: Top Layer.

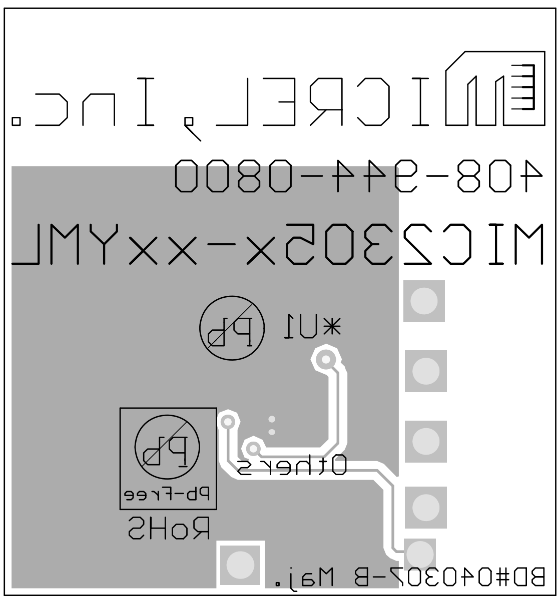

FIGURE 7-2: Bottom Layer.

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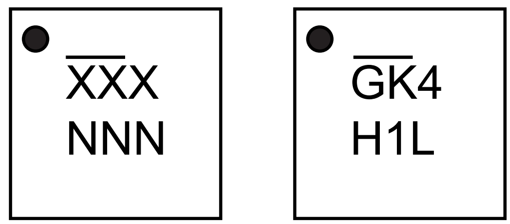
8.0 PACKAGING INFORMATION

8.1 Package Marking Information

8-Lead VDFN* 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

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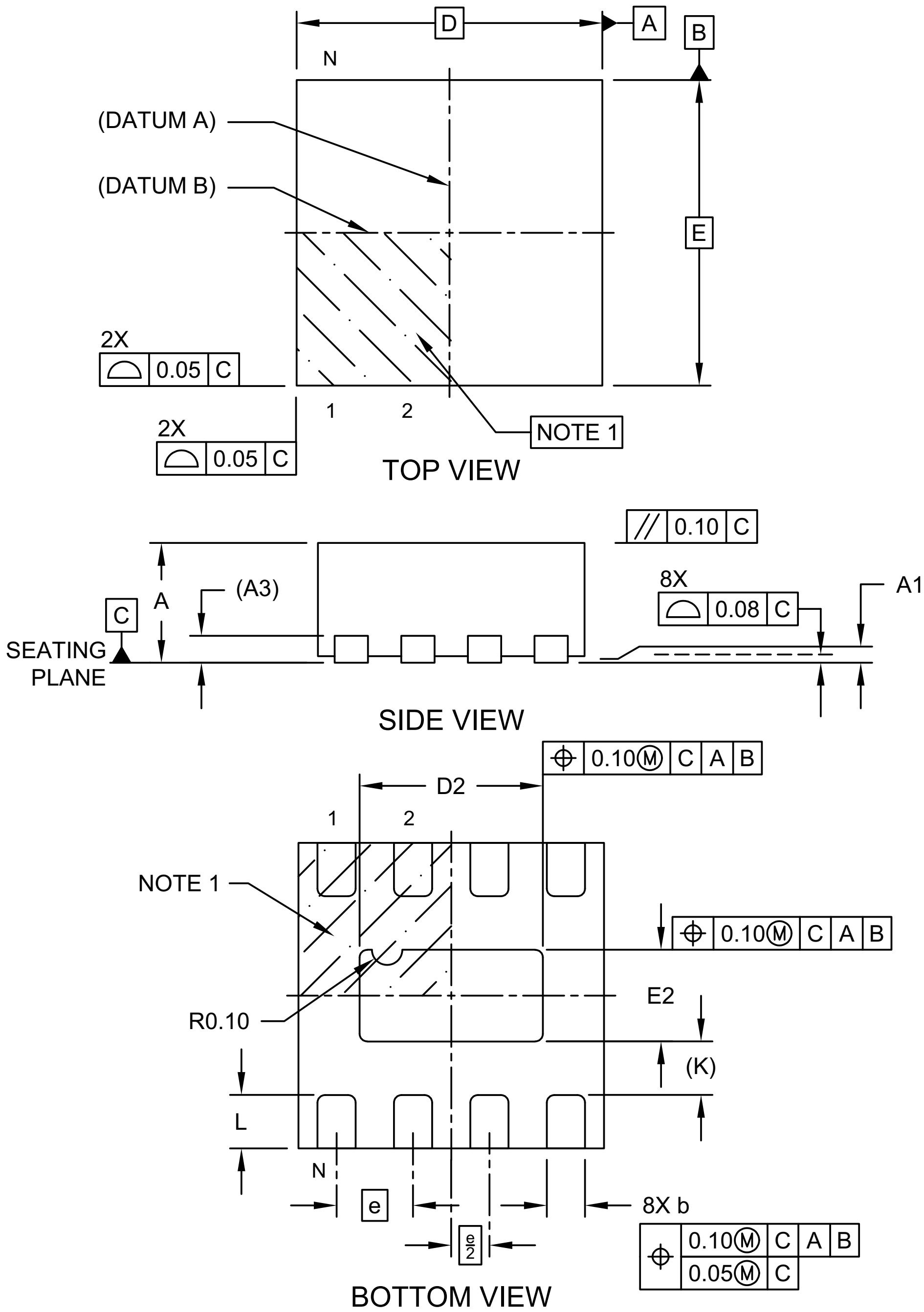
8-Lead Very Thin Plastic Dual Flat, No Lead Package (H2A) - 2x2x0.9 mm Body [VDFN] With 1.20x0.6 mm Exposed Pad

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



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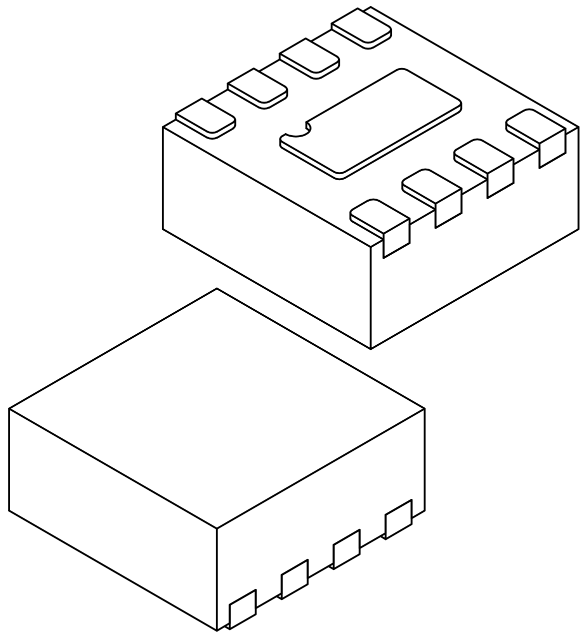
8-Lead Very Thin Plastic Dual Flat, No Lead Package (H2A) - 2x2x.9 mm Body [VDFN] With 1.20x0.6 mm Exposed Pad

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



Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Number of Terminals	N		8	
Pitch	e		0.50 BSC	
Overall Height	A	0.80	0.85	0.90
Standoff	A1	0.00	0.02	0.05
Terminal Thickness	A3		0.203 REF	
Overall Length	D		2.00 BSC	
Exposed Pad Length	D2	1.10	1.20	1.30
Overall Width	E		2.00 BSC	
Exposed Pad Width	E2	0.50	0.60	0.70
Terminal Width	b	0.20	0.25	0.30
Terminal Length	L	0.30	0.35	0.40
Terminal-to-Exposed-Pad	K		0.35 REF	

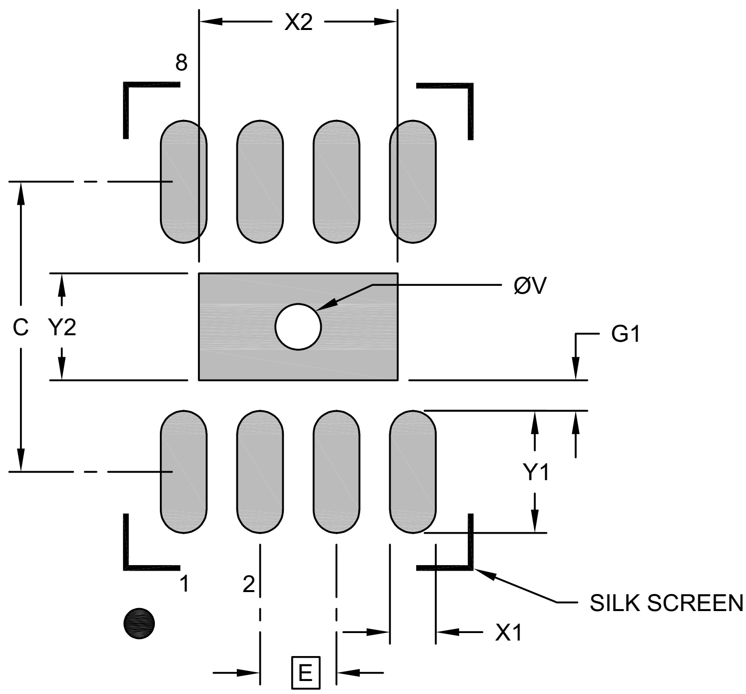
Notes:

1. Pin 1 visual index feature may vary, but must be located within the hatched area.
2. Package is saw singulated
3. Dimensioning and tolerancing per ASME Y14.5M
   BSC: Basic Dimension. Theoretically exact value shown without tolerances.
   REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-1247 Rev B Sheet 2 of 2

8-Lead Very Thin Plastic Dual Flat, No Lead Package (H2A) - 2x2 mm Body [VDFN] Micrel Legacy Package

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



RECOMMENDED LAND PATTERN

Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Contact Pitch	E		0.50 BSC	
Optional Center Pad Width	X2			1.30
Optional Center Pad Length	Y2			0.70
Contact Pad Spacing	C		1.90	
Contact Pad Width (X8)	X1			0.30
Contact Pad Length (X8)	Y1			0.80
Contact Pad to Center Pad (X8)	G1	0.20		
Thermal Via Diameter	V	0.27	0.30	0.33

Notes:

1. Dimensioning and tolerancing per ASME Y14.5M
   BSC: Basic Dimension. Theoretically exact value shown without tolerances.
2. For best soldering results, thermal vias, if used, should be filled or tented to avoid solder loss during reflow process

Microchip Technology Drawing C04-3247 Rev. B

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APPENDIX A: REVISION HISTORY

Revision A (August 2024)

- Converted Micrel document MIC23050 to Microchip data sheet DS20006903A.
- Minor text changes throughout.

NOTES:

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PRODUCT IDENTIFICATION SYSTEM

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

Part Number	-X	X	XX	-XX
Device	Nominal Output Voltage	Temperature Range	Package	Media Type

Device:	MIC23050:		4 MHz PWM Buck Regulator with HyperLight Load® Switching Scheme
Nominal Output Voltage:	C	=	1.0V
	4	=	1.2V
	G	=	1.8V
	S	=	3.3V
Temperature Range:	Y	=	–40°C to +125°C
Package:	ML	=	8-Lead 2 mm x 2 mm VDFN
Media Type:	TR	=	5,000/Reel

Examples:

a) MIC23050-CYML-TR: MIC23050, 1.0V Nom. Output Voltage, –40°C to +125°C Temp. Range, 8-Lead VDFN, 5,000/Reel

b) MIC23050-4YML-TR: MIC23050, 1.2V Nom. Output Voltage, –40°C to +125°C Temp. Range, 8-Lead VDFN, 5,000/Reel

c) MIC23050-GYML-TR: MIC23050, 1.8V Nom. Output Voltage, –40°C to +125°C Temp. Range, 8-Lead VDFN, 5,000/Reel

d) MIC23050-SYML-TR: MIC23050, 3.3V Nom. Output Voltage, –40°C to +125°C Temp. Range, 8-Lead VDFN, 5,000/Reel

Note: 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:

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