MIC27600

36V, 7A Hyper Speed Control® Synchronous DC/DC Buck Regulator

Features

- Hyper Speed Control® Architecture Enables:
  - High Delta V Operation (V_{IN} = 36V and V_{OUT} = 0.8V)
  - Small Output Capacitance
- 4.5V to 36V Voltage Input
- Adjustable Output from 0.8V to 5.5V (V_{HSD} ≤ 28V)
- Adjustable Output from 0.8V to 3.6V (V_{HSD} ≤ 36V)
- ±1% FB Accuracy
- Any Capacitor™ Stable: Zero-ESR to High-ESR
- 7A Output Current Capability, Up to 95% Efficiency
- 300 kHz Switching Frequency
- Internal Compensation, 6 ms Internal Soft-Start
- Foldback Current-Limit and “Hiccup” Mode Short-Circuit Protection
- Thermal Shutdown
- Supports Safe Start-Up into a Pre-Biased Load
- –40°C to +125°C Junction Temperature Range
- 28-Lead, 5 mm x 6 mm VQFN Package

Applications

- Distributed Power Systems
- Communications/Networking Infrastructure
- Set-Top Boxes, Gateways, and Routers
- Printers, Scanners, Graphic Cards, and Video Cards

General Description

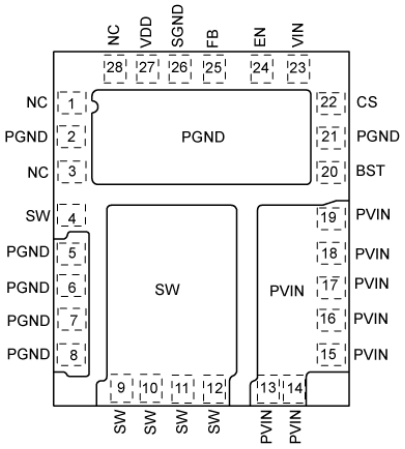
The MIC27600 is a constant-frequency, synchronous buck regulator that features a unique digitally modified adaptive on-time control architecture. The MIC27600 operates over an input supply range of 4.5V to 36V and provides a regulated output current of up to 7A. The output voltage is adjustable down to 0.8V with an ensured accuracy of ±1%, and the device operates at a switching frequency of 300 kHz.

Microchip’s Hyper Speed Control® architecture allows for ultra-fast transient response while reducing the output capacitance and also makes (High V_{IN})/(Low V_{OUT}) operation possible. This digitally modified adaptive t_{ON} ripple control architecture combines the advantages of fixed-frequency operation and fast transient response in a single device.

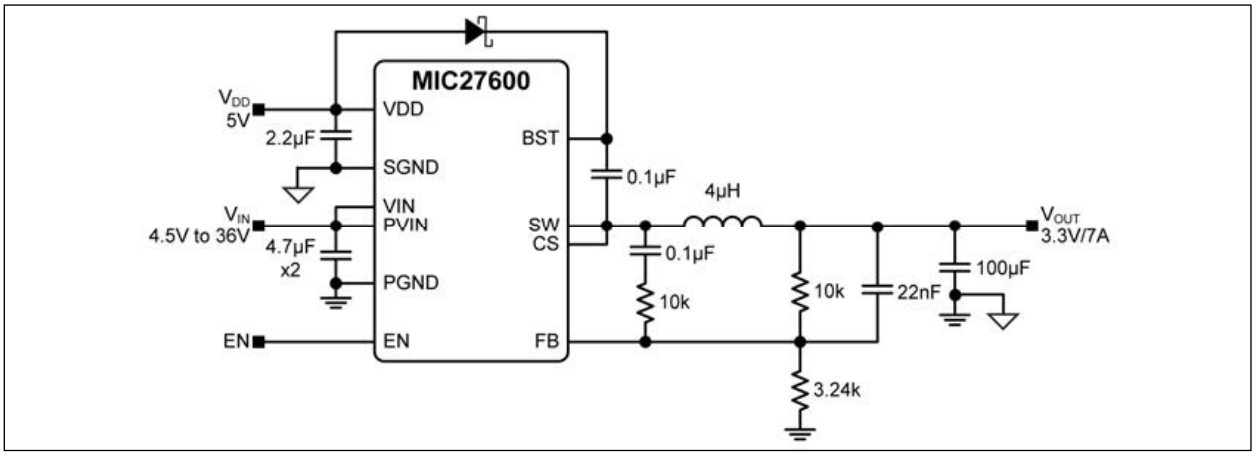
The MIC27600 offers a full suite of protection features to ensure protection of the IC during fault conditions. These include undervoltage lockout to ensure proper operation under power-sag conditions, internal soft-start to reduce inrush current, foldback current limit, “hiccup” mode short-circuit protection, and thermal shutdown.

Package Type

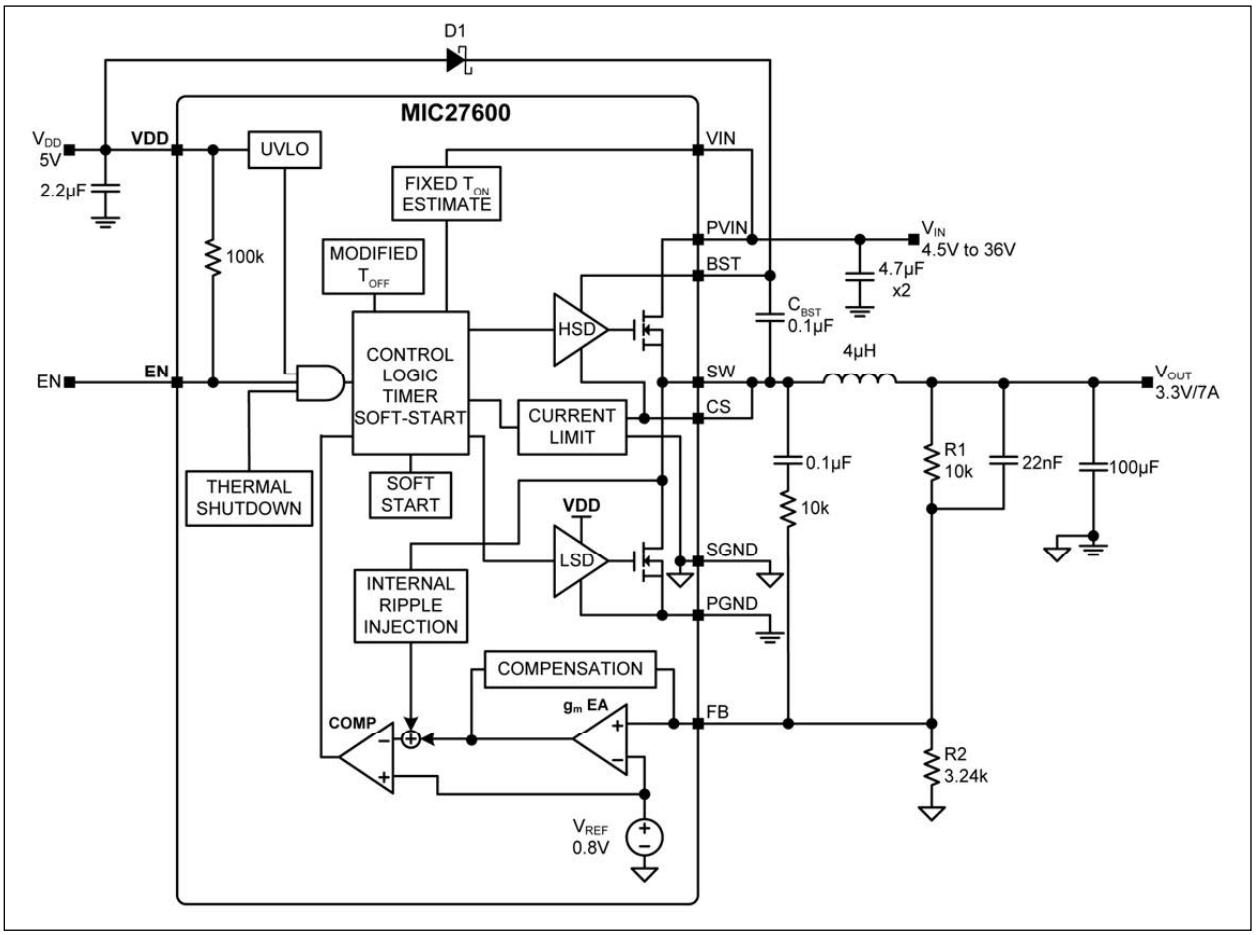
MIC27600
28-Lead 5 mm x 6 mm VQFN
(Top View)



Typical Application Circuit



Functional Block Diagram



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

PV_{IN} to PGND ..... –0.3V to +38V
V_{IN} to PGND ..... –0.3V to PV_{IN}
V_{DD} to PGND ..... –0.3V to +6V
V_{SW}, V_{CS} to PGND ..... –0.3V to (PV_{IN} + 0.3V)
V_{BST} to V_{SW} ..... –0.3V to +6V
V_{BST} to PGND ..... –0.3V to +44V
V_{EN} to PGND ..... –0.3V to (V_{DD} + 0.3V)
V_{FB} to PGND ..... –0.3V to (V_{DD} + 0.3V)
PGND to SGND ..... –0.3V to +0.3V

Operating Ratings ‡

Supply Voltage (PV_{IN}, V_{IN}) ..... +4.5V to +36V
Bias Voltage (V_{DD}) ..... +4.5V to +5.5V
Enable Input Voltage (V_{EN}) ..... 0V to V_{DD}
Maximum Power Dissipation ..... Note 1

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

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

Note 1: $P_{D(MAX)} = (T_{J(MAX)} – T_A)/\theta_{JA}$, where θ_{JA} depends upon the printed circuit layout. See the Application Information section.

ELECTRICAL CHARACTERISTICS

$PV_{IN} = V_{IN}$ = 12V, V_{DD} = 5V; $V_{BST} – V_{SW}$ = 5V; T_A = +25°C, unless noted. **Bold** values valid for –40°C ≤ T_J ≤ +125°C. Note 1

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions
Power Supply Input						
Input Voltage Range	V_{IN}, PV_{IN}	**4.5**	—	**36**	V	—
V_{DD} Bias Voltage						
Operating Bias Voltage	V_{DD}	**4.5**	5	**5.5**	V	—
Undervoltage Lockout Trip Level		**2.4**	2.7	**3.2**	V	V_{DD} rising
UVLO Hysteresis		—	50	—	mV	—
Quiescent Supply Current	I_Q	—	1.3	**3**	mA	V_{FB} = 1.5V
Shutdown Supply Current	I_{SHDN}	—	0.8	**2**	mA	V_{DD} = V_{BST} = 5.5V, V_{IN} = 36V, SW = unconnected, V_{EN} = 0V
Reference						
Feedback Reference Voltage	V_{REF}	**0.792**	0.8	**0.808**	V	0°C ≤ T_J ≤ +85°C (±1.0%)
		0.788	0.8	**0.812**		–40°C ≤ T_J ≤ +125°C (±1.5%)
Load Regulation		—	0.2	—	%	I_{OUT} = 0A to 7A
Line Regulation		—	0.1	—	%	V_{IN} = (V_{OUT} + 3.0V) to 36V
FB Bias Current	I_{FB}	—	5	—	nA	V_{FB} = 0.8V
DC/DC Converter						
Output Voltage Range	V_{OUT}	**0.8**	—	**5.5**	V	3.0V ≤ V_{IN} ≤ 36V

ELECTRICAL CHARACTERISTICS (CONTINUED)

PV_{IN} = V_{IN} = 12V, V_{DD} = 5V; V_{BST} – V_{SW} = 5V; T_A = +25°C, unless noted. **Bold** values valid for –40°C ≤ T_J ≤ +125°C. Note 1

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions
Enable Control						
EN Logic Level High	V_{IH}	**1.2**	0.85	—	V	4.5V < V_{DD} < 5.5V
EN Logic Level Low	V_{IL}	—	0.78	**0.4**	V	4.5V < V_{DD} < 5.5V
EN Bias Current	I_{EN}	—	54.6	—	µA	V_{EN} = 0V
Oscillator						
Switching Frequency	f_{SW}	**225**	300	**375**	kHz	Note 2
Maximum Duty Cycle	DC_{MAX}	—	87	—	%	V_{FB} = 0V, Note 3
Minimum Duty Cycle	DC_{MIN}	—	0	—	%	V_{FB} > 0.8V
Minimum OFF Time	$t_{OFF(MIN)}$	—	360	—	ns	—
Soft-Start						
Soft-Start Time	t_{SS}	—	6	—	ms	—
Short-Circuit Protection						
Current-Limit Threshold	I_{LIM}	**7.7**	18.4	—	A	V_{FB} = 0.8V
Short-Circuit Current	I_{SC}	—	6	—	A	V_{FB} = 0V
Internal FETs						
Top-MOSFET $R_{DS(ON)}$		—	20.1	—	mΩ	I_{SW} = 1A
Bottom-MOSFET $R_{DS(ON)}$		—	7.2	—	mΩ	I_{SW} = 1A
SW Leakage Current		—	45	**60**	µA	V_{IN} = 36V, V_{SW} = 36V, V_{EN} = 0V, V_{BST} = 41V
V_{IN} Leakage Current		—	15	**25**	µA	V_{IN} = 36V, V_{SW} = 0V, V_{EN} = 0V, V_{BST} = 41V
Thermal Protection						
Overtemperature Shutdown		—	155	—	°C	T_J rising
Overtemperature Shutdown Hysteresis		—	10	—	°C	—

Note 1: Specification for packaged product only.

2: Measured in test mode.

3: The maximum duty cycle is limited by the fixed mandatory OFF-time (t_{OFF}) of 360 ns typically.

TEMPERATURE SPECIFICATIONS

Parameters	Sym.	Min.	Typ.	Max.	Units	Conditions
Temperature Ranges						
Operating Junction Temp. Range	T_J	–40	—	+125	°C	—
Absolute Maximum Junction Temp.	$T_{J(MAX)}$	—	—	+150	°C	—
Absolute Maximum Storage Temp.	T_S	–65	—	+150	°C	—
Absolute Maximum Lead Temp.	T_{LEAD}	—	—	+260	°C	Soldering, 10 sec.
Package Thermal Resistances						
Thermal Resistance, VQFN 28-Ld	θ_{JA}	—	36	—	°C/W	—

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.

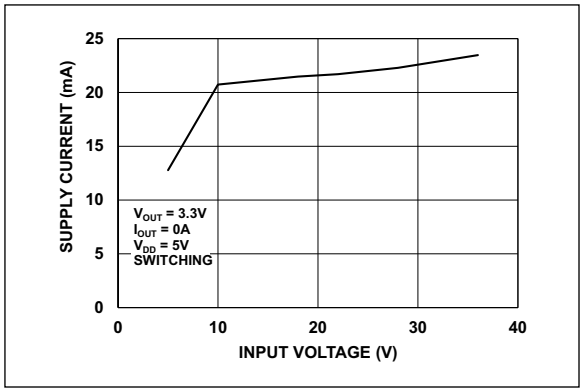


FIGURE 2-1: *V_{IN} Operating Supply Current vs. Input Voltage.*

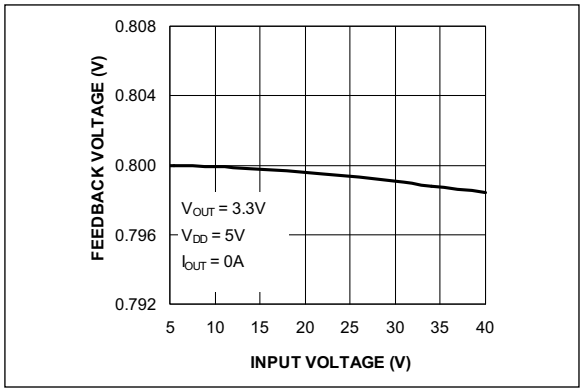


FIGURE 2-4: *Feedback Voltage vs. Input Voltage.*

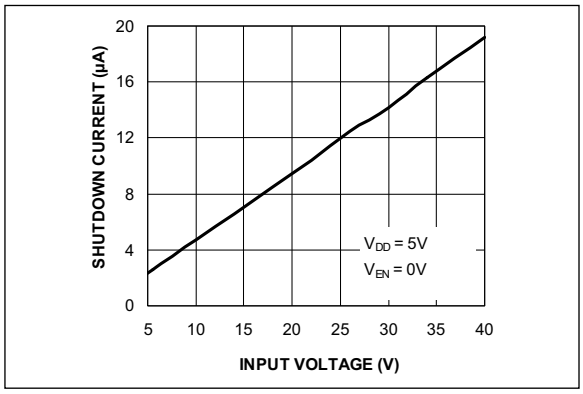


FIGURE 2-2: *V_{IN} Shutdown Current vs. Input Voltage.*

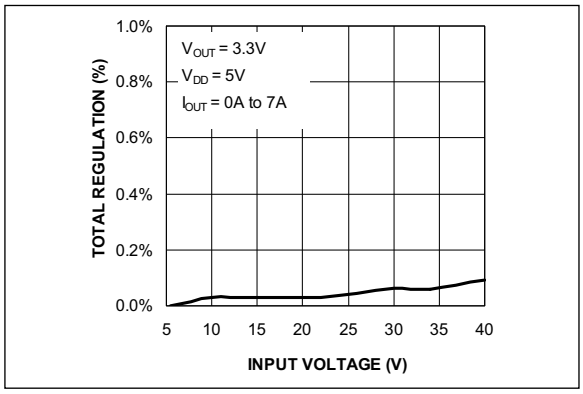


FIGURE 2-5: *Total Regulation vs. Input Voltage.*

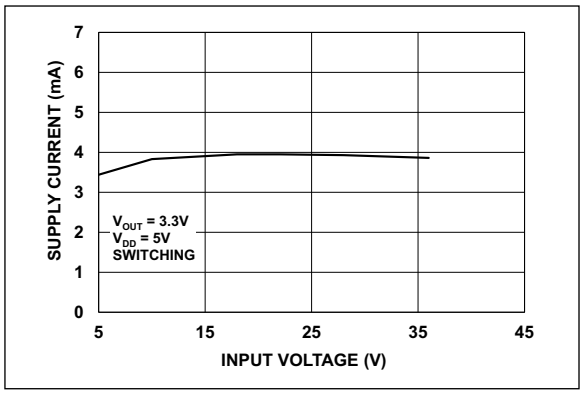


FIGURE 2-3: *V_{DD} Operating Supply Current vs. Input Voltage.*

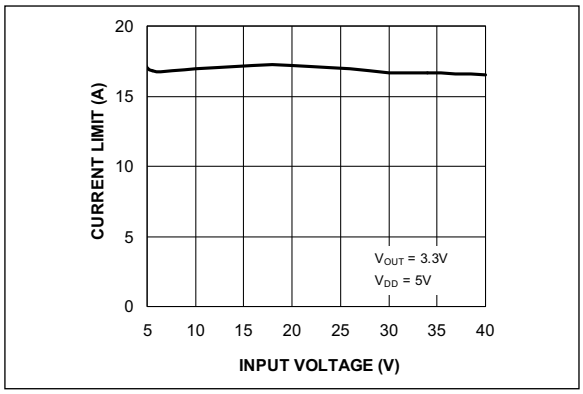


FIGURE 2-6: *Current Limit vs. Input Voltage.*

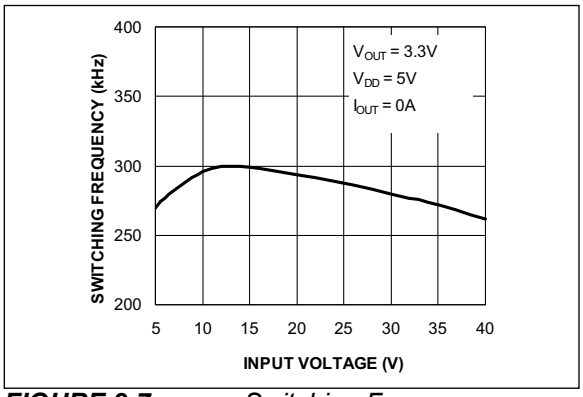


FIGURE 2-7: *Switching Frequency vs. Input Voltage.*

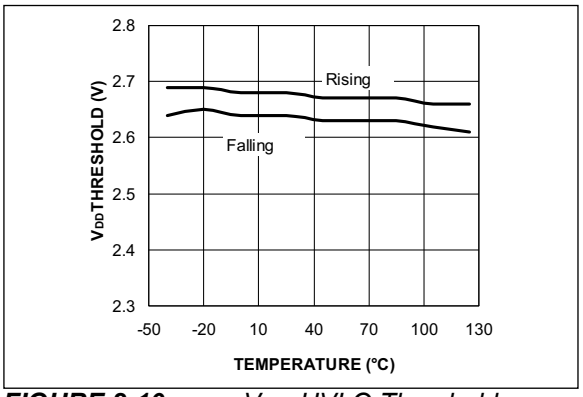


FIGURE 2-10: *V_{DD} UVLO Threshold vs. Temperature.*

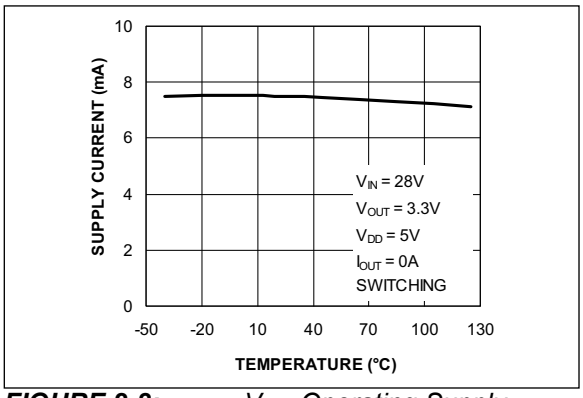


FIGURE 2-8: *V_{DD} Operating Supply Current vs. Temperature.*

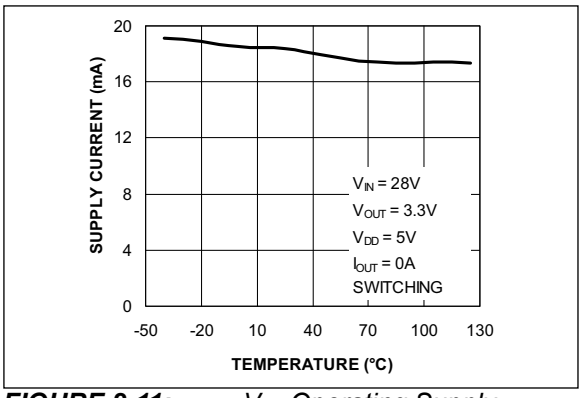


FIGURE 2-11: *V_{IN} Operating Supply Current vs. Temperature.*

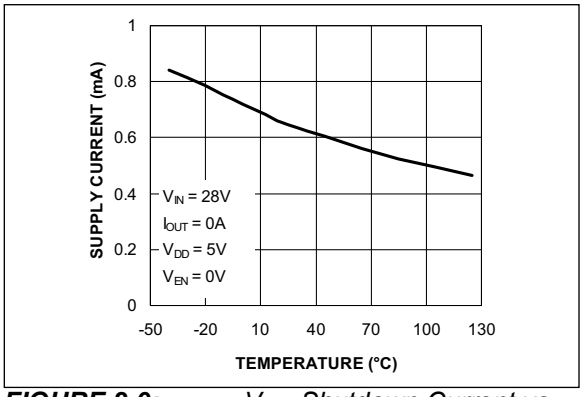


FIGURE 2-9: *V_{DD} Shutdown Current vs. Temperature.*

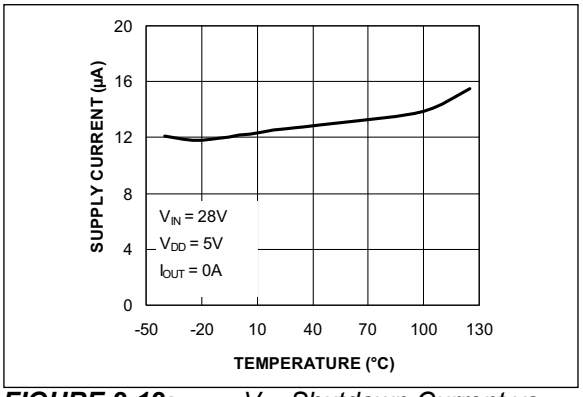


FIGURE 2-12: *V_{IN} Shutdown Current vs. Temperature.*

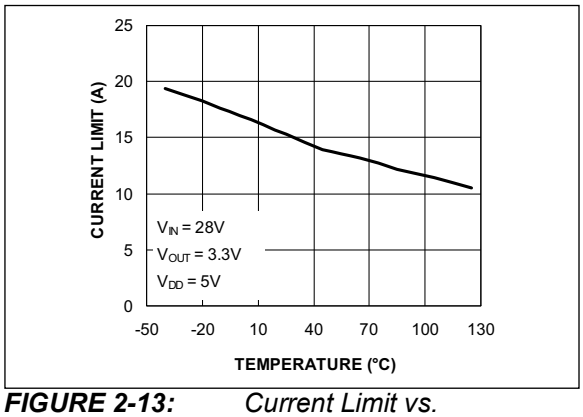


FIGURE 2-13: *Current Limit vs. Temperature.*

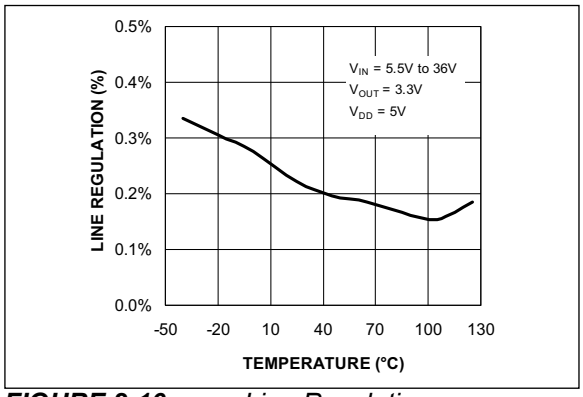


FIGURE 2-16: *Line Regulation vs. Temperature.*

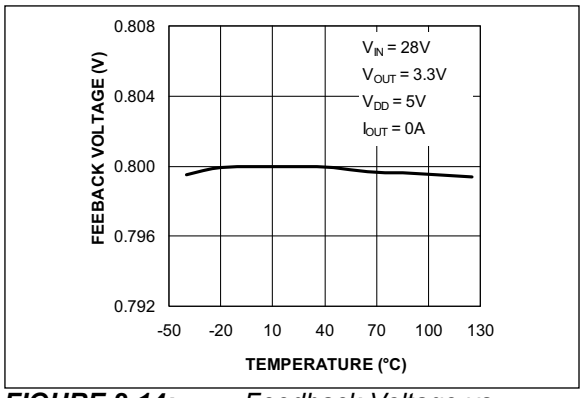


FIGURE 2-14: *Feedback Voltage vs. Temperature.*

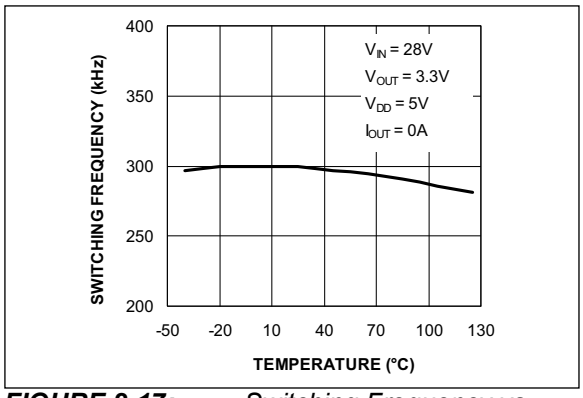


FIGURE 2-17: *Switching Frequency vs. Temperature.*

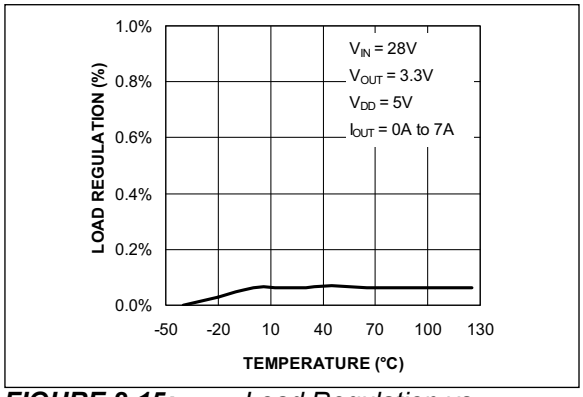


FIGURE 2-15: *Load Regulation vs. Temperature.*

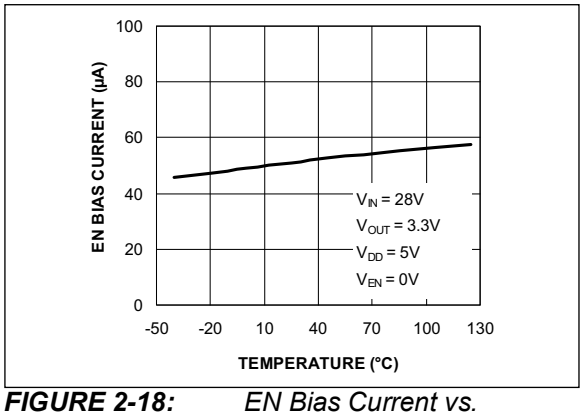


FIGURE 2-18: *EN Bias Current vs. Temperature.*

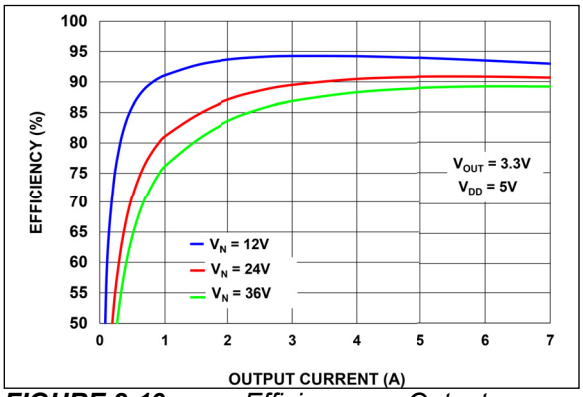


FIGURE 2-19: *Efficiency vs. Output Current.*

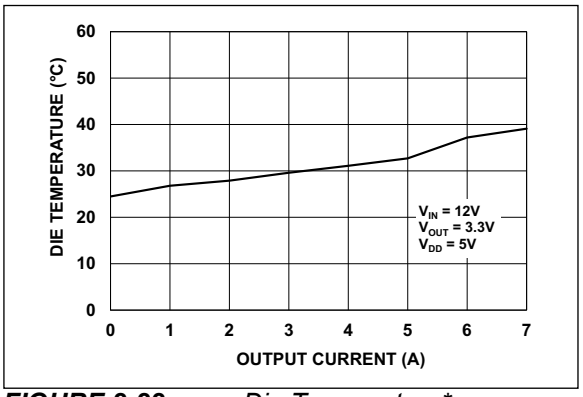


FIGURE 2-22: *Die Temperature* (V_{IN} = 12V) vs. Output Current.*

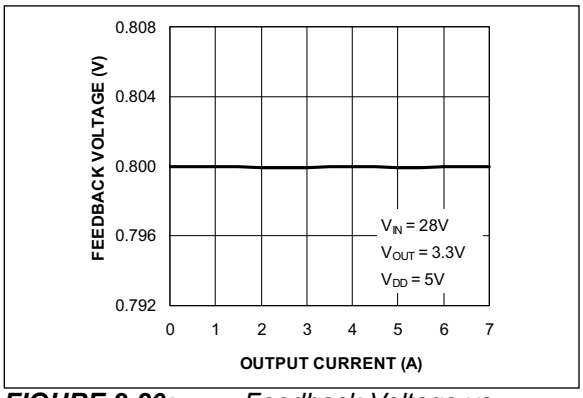


FIGURE 2-20: *Feedback Voltage vs. Output Current.*

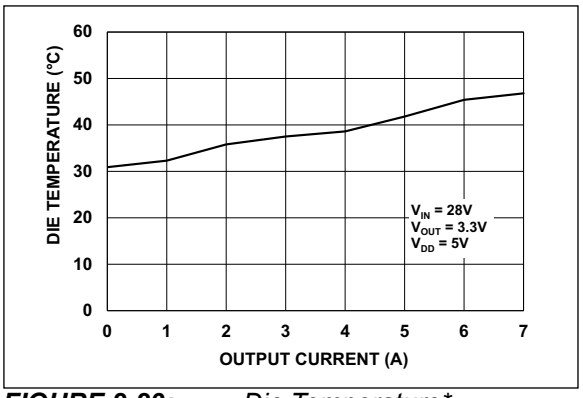


FIGURE 2-23: *Die Temperature* (V_{IN} = 28V) vs. Output Current.*

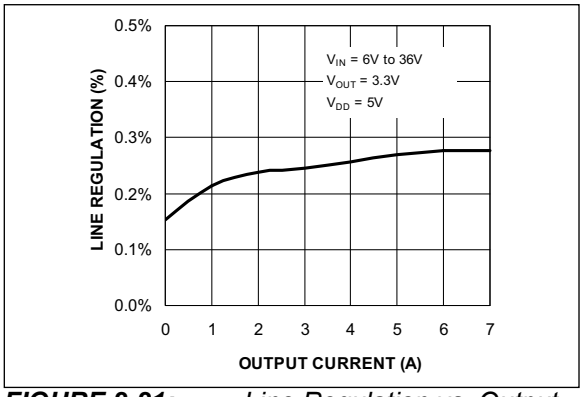


FIGURE 2-21: *Line Regulation vs. Output Current.*

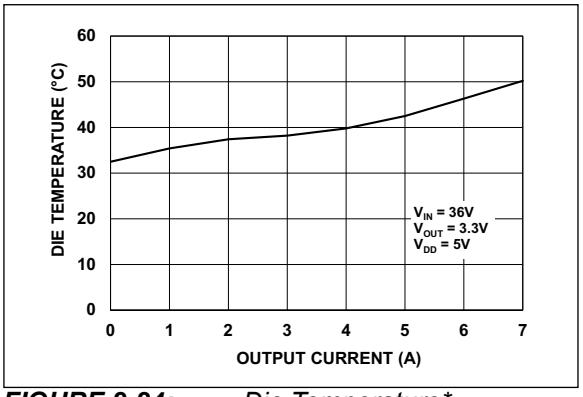


FIGURE 2-24: *Die Temperature* (V_{IN} = 36V) vs. Output Current.*

*** Die Temperature:** The temperature measurement was taken at the hottest point on the MIC27600 case mounted on a 5 square inch PCB, tested in ambient temperature of 23-25 degree in open space with no forced cooling. See the Thermal Measurement section. Actual results will depend upon the size of the PCB, ambient temperature, and proximity to other heat emitting components.

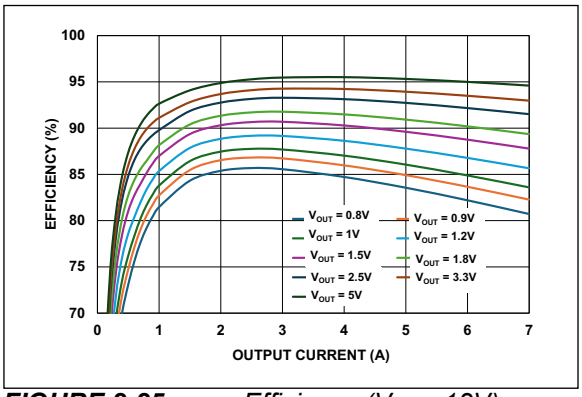


FIGURE 2-25: *Efficiency (V_{IN} = 12V) vs. Output Current.*

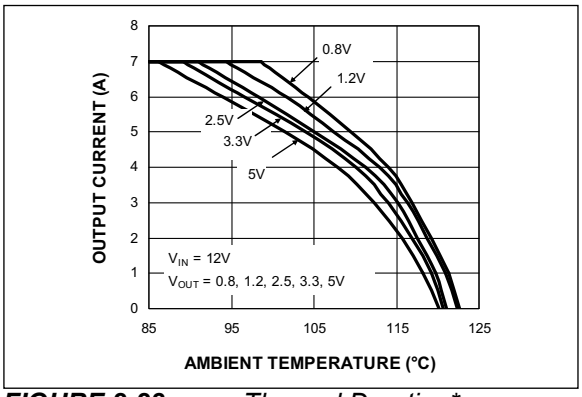


FIGURE 2-28: *Thermal Derating* vs. Ambient Temperature.*

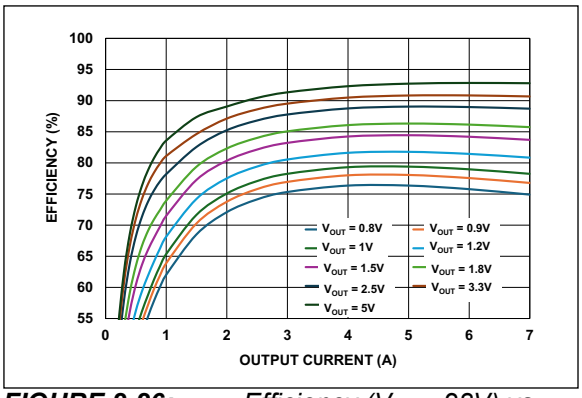


FIGURE 2-26: *Efficiency (V_{IN} = 28V) vs. Output Current.*

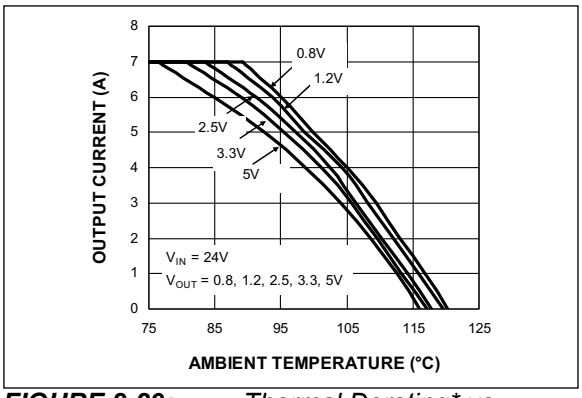


FIGURE 2-29: *Thermal Derating* vs. Ambient Temperature.*

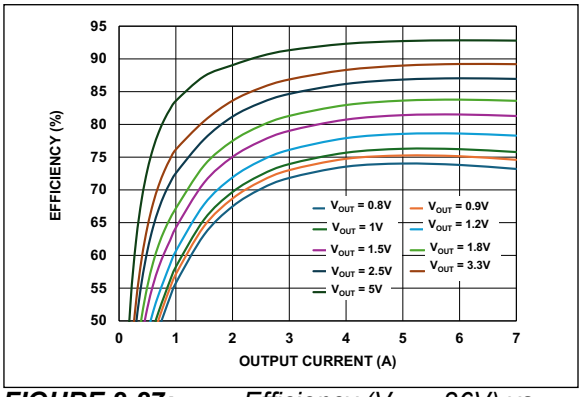


FIGURE 2-27: *Efficiency (V_{IN} = 36V) vs. Output Current.*

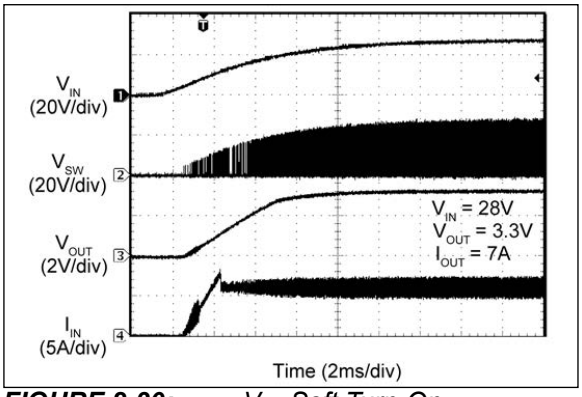


FIGURE 2-30: *V_{IN} Soft Turn-On.*

*** Die Temperature:** The temperature measurement was taken at the hottest point on the MIC27600 case mounted on a 5 square inch PCB, see the Thermal Measurement section. Actual results will depend upon the size of the PCB, ambient temperature, and proximity to other heat emitting components.

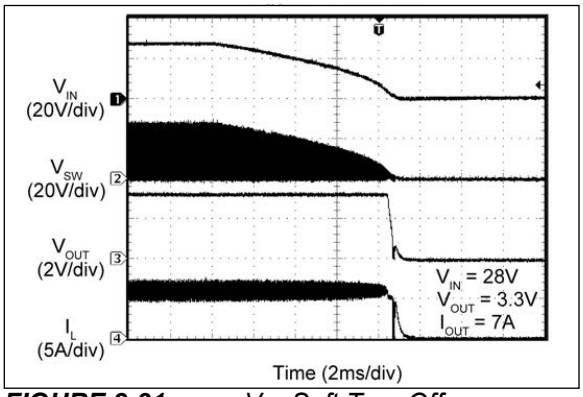


FIGURE 2-31: *V_{IN} Soft Turn-Off.*

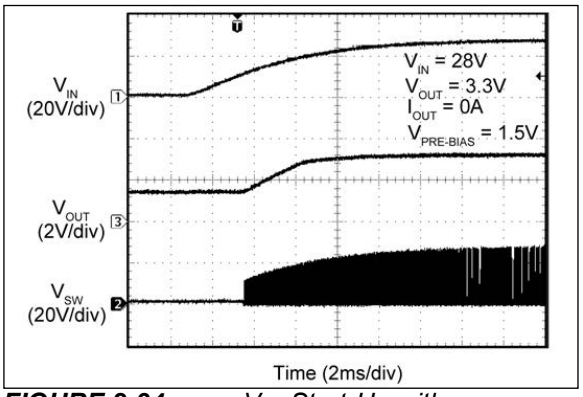


FIGURE 2-34: *V_{IN} Start-Up with Pre-Biased Output.*

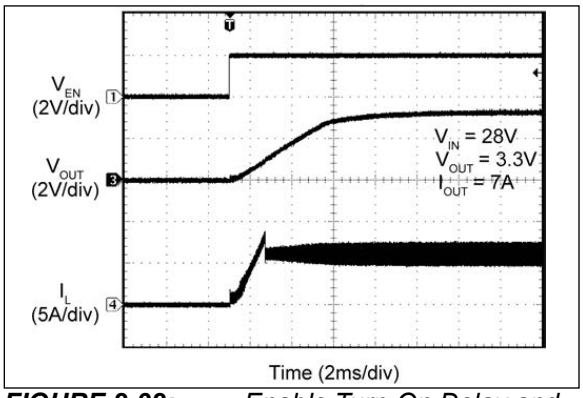


FIGURE 2-32: *Enable Turn-On Delay and Rise Time.*

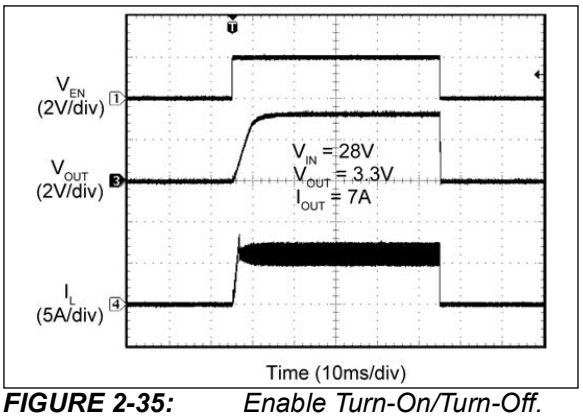


FIGURE 2-35: *Enable Turn-On/Turn-Off.*

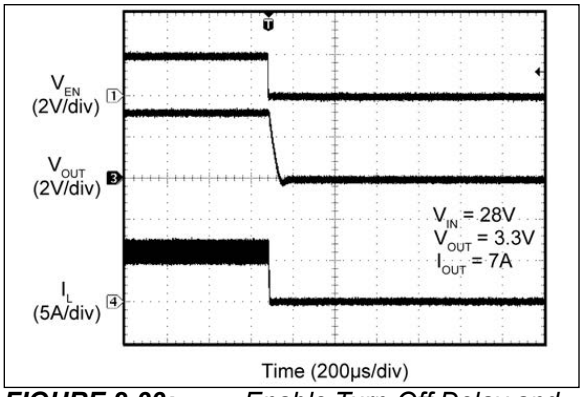


FIGURE 2-33: *Enable Turn-Off Delay and Fall Time.*

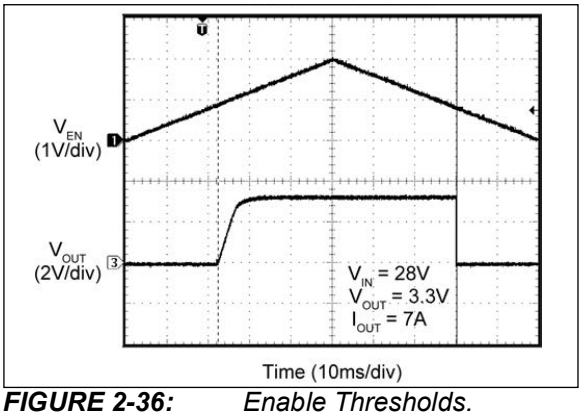


FIGURE 2-36: *Enable Thresholds.*

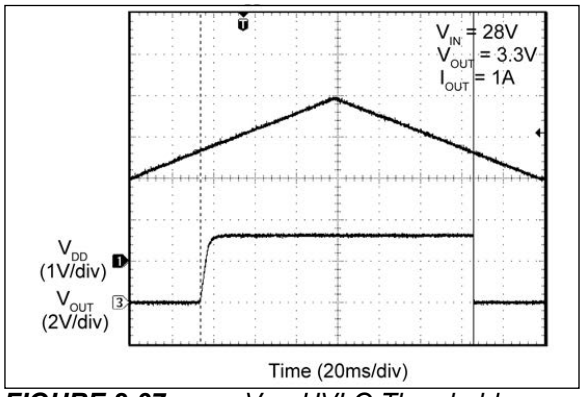


FIGURE 2-37: *V_{DD} UVLO Thresholds.*

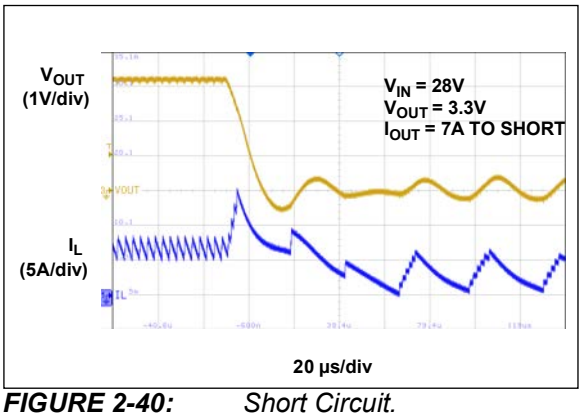


FIGURE 2-40: *Short Circuit.*

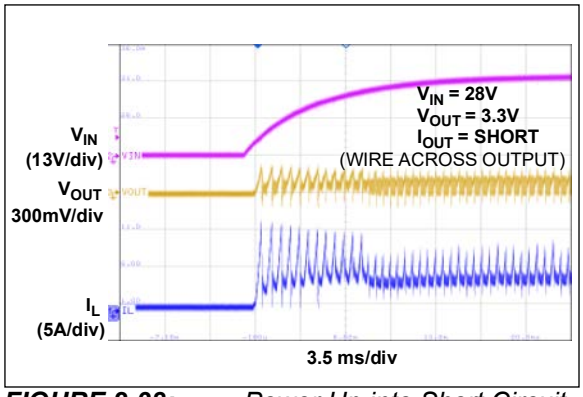


FIGURE 2-38: *Power-Up into Short Circuit.*

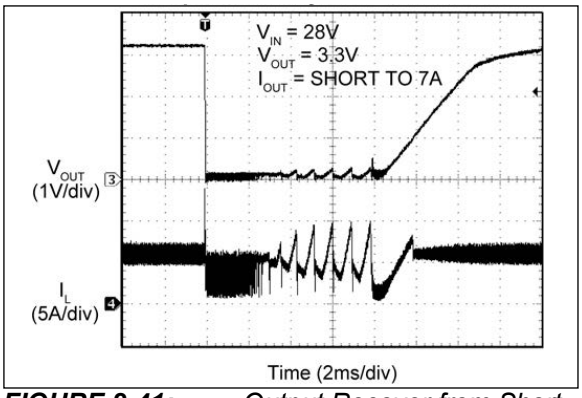


FIGURE 2-41: *Output Recover from Short Circuit.*

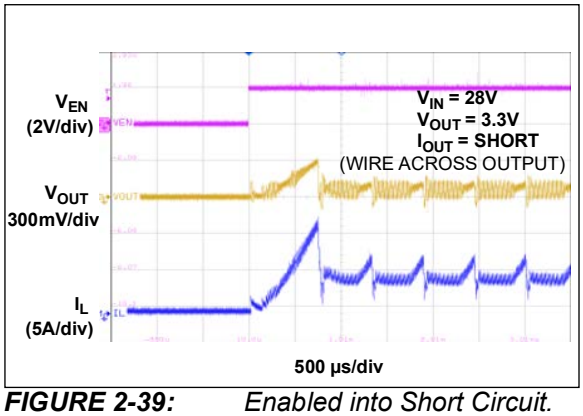


FIGURE 2-39: *Enabled into Short Circuit.*

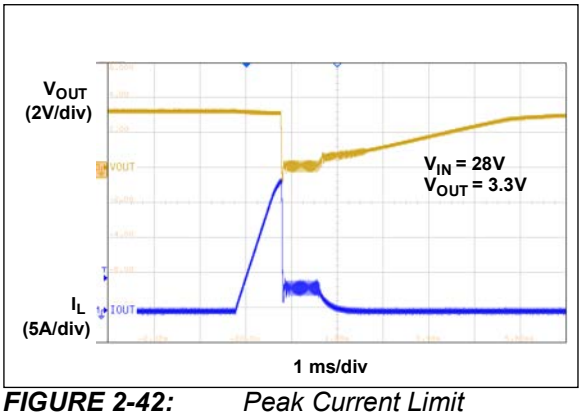


FIGURE 2-42: *Peak Current Limit Threshold.*

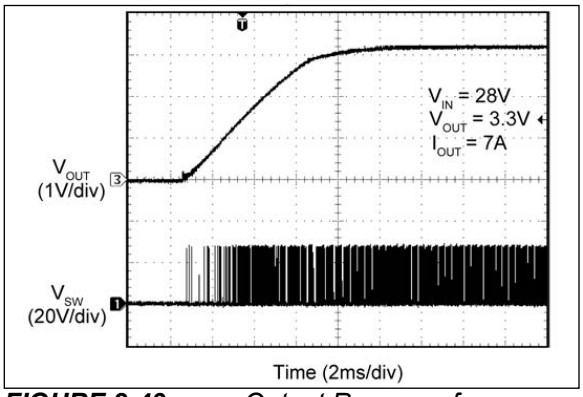


FIGURE 2-43: *Output Recovery from Thermal Shutdown.*

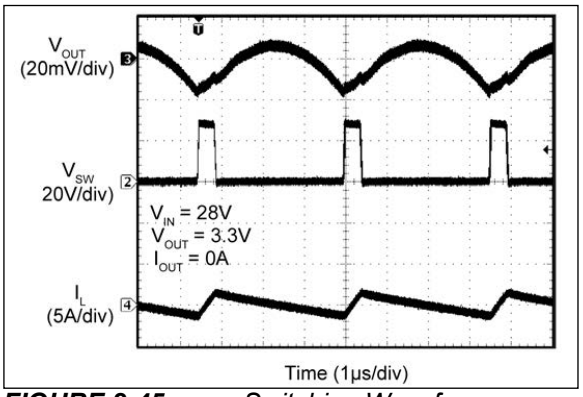


FIGURE 2-45: *Switching Waveforms; I_{OUT} = 0A.*

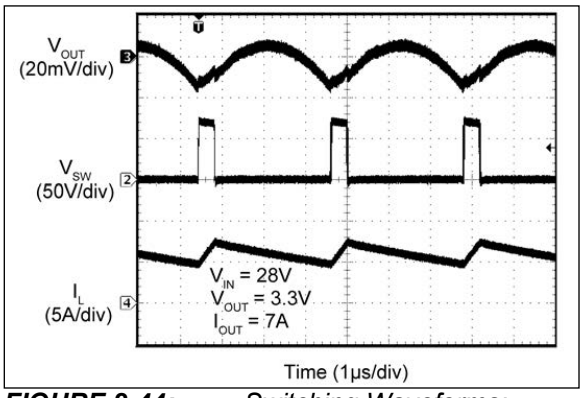


FIGURE 2-44: *Switching Waveforms; I_{OUT} = 7A.*

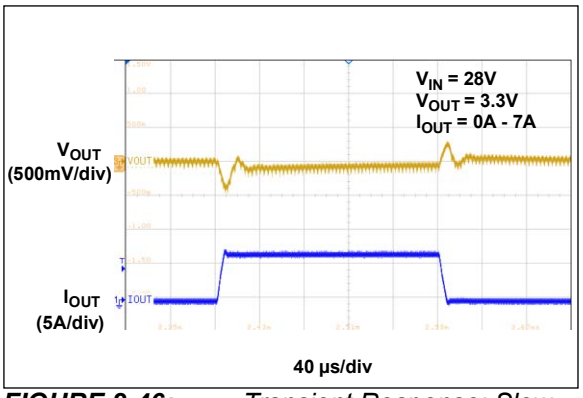


FIGURE 2-46: *Transient Response; Slew Rate = 1A/µs.*

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
13, 14, 15, 16, 17, 18, 19	PVIN	High-Side N-internal MOSFET Drain Connection (Input): The PV_{IN} operating voltage range is from 4.5V to 36V. Input capacitors between the PVIN pins and the power ground (PGND) are required and keep the connection short.
24	EN	Enable (Input): A logic level control of the output. The EN pin is CMOS-compatible. Logic high or floating = enable, logic low = shutdown. In the off state, the V_{DD} supply current of the device is reduced (typically 0.7 mA). Do not pull the EN pin above the V_{DD} supply.
25	FB	Feedback (Input): Input to the transconductance amplifier of the control loop. The FB pin is regulated to 0.8V. A resistor divider connecting the feedback to the output is used to adjust the desired output voltage.
26	SGND	Signal ground. SGND must be connected directly to the ground planes. Do not route the SGND pin to the PGND Pad on the top layer. See PCB layout guidelines for details.
27	VDD	V_{DD} Bias (Input): Power to the internal reference and control sections of the MIC27600. The V_{DD} operating voltage range is from 4.5V to 5.5V. A 2.2 µF ceramic capacitor from the VDD pin to the PGND pin must be placed next to the IC. VDD must be powered up at the same time or after VIN to make the soft-start function correctly.
2, 5, 6, 7, 8, 21	PGND	Power Ground. PGND is the ground path for the MIC27600 buck converter power stage. The PGND pin connects to the sources of low-side N-Channel internal MOSFETs, the negative terminals of input capacitors, and the negative terminals of output capacitors. The loop for the power ground should be as small as possible and separate from the signal ground (SGND) loop.
22	CS	Current Sense (Input): High current output driver return. The CS pin connects directly to the switch node. Due to the high-speed switching on this pin, the CS pin should be routed away from sensitive nodes. CS pin also senses the current by monitoring the voltage across the low-side internal MOSFET during OFF-time.
20	BST	Boost (Output): Bootstrapped voltage to the high-side N-channel internal MOSFET driver. A Schottky diode is connected between the VDD pin and the BST pin. A boost capacitor of 0.1 µF is connected between the BST pin and the SW pin.
4, 9, 10, 11, 12	SW	Switch Node (Output): Internal connection for the high-side MOSFET source and low-side MOSFET drain.
23	VIN	Power Supply Voltage (Input): Requires bypass capacitor to SGND.
1, 3, 28	NC	No Connect.

4.0 FUNCTIONAL DESCRIPTION

The MIC27600 is an adaptive ON-time synchronous step-down DC/DC regulator. It is designed to operate over a wide input voltage range, from 4.5V to 36V, and provides a regulated output voltage at up to 7A of output current. A digitally modified adaptive ON-time control scheme is employed to obtain a constant switching frequency and to simplify the control compensation. Overcurrent protection is implemented without using an external sense resistor. The device includes an internal soft-start function that reduces the power supply input surge current at start-up by controlling the output voltage rise time.

4.1 Theory of Operation

The Functional Block Diagram illustrates the control loop of the MIC27600. The output voltage is sensed by the MIC27600 feedback pin FB through the voltage divider R1 and R2. It is then compared to a 0.8V reference voltage V_{REF} at the error comparator through a low gain transconductance (g_m) amplifier. If the feedback voltage decreases and the output of the g_m amplifier is below 0.8V, the error comparator triggers the control logic and generates an ON-time period. The ON-time period length is predetermined by the "FIXED t_{ON} ESTIMATION" circuitry:

EQUATION 4-1:

$$t_{ON(ESTIMATED)} = \frac{V_{OUT}}{V_{IN} \times 300kHz}$$

Where:
V_{OUT} is the output voltage.
V_{IN} is the power stage input voltage.

At the end of the ON-time period, the internal high-side driver turns off the high-side MOSFET and the low-side driver turns on the low-side MOSFET. The OFF-time period length depends upon the feedback voltage in most cases. When the feedback voltage decreases and the output of the g_m amplifier is below 0.8V, the ON-time period is triggered and the OFF-time period ends. If the OFF-time period determined by the feedback voltage is less than the minimum OFF-time $t_{OFF(MIN)}$, which is about 360 ns, the MIC27600 control logic applies the $t_{OFF(MIN)}$ instead. $t_{OFF(MIN)}$ is required to maintain enough energy in the boost capacitor (C_{BST}) to drive the high-side MOSFET. The maximum duty cycle is obtained from the 360 ns $t_{OFF(MIN)}$:

EQUATION 4-2:

$$D_{MAX} = \frac{t_S - t_{OFF(MIN)}}{t_S} = 1 - \frac{360ns}{t_S}$$

Where:
t_S = 1/300 kHz = 3.3 µs

Microchip does not recommend using MIC27600 with an OFF-time close to $t_{OFF(MIN)}$ during steady-state operation. Also, as V_{OUT} increases, the internal ripple injection increases and reduces the line regulation performance. Therefore, the maximum output voltage of the MIC27600 should be limited to 5.5V. Please refer to the "Setting Output Voltage" section for more details.

The actual ON-time and resulting switching frequency varies with the part-to-part variation in the rise and fall times of the internal MOSFETs, the output load current, and variations in the V_{DD} voltage. Also, the minimum t_{ON} results in a lower switching frequency in high-V_{IN}-to-V_{OUT} applications, such as 26V to 1.0V. The minimum t_{ON} measured on the MIC27600 evaluation board is about 184 ns. During load transients, the switching frequency is changed due to the varying OFF-time.

To illustrate, the control loop operation will be analyzed in both steady-state and load transient scenarios. For easy analysis, the gain of the g_m amplifier is assumed to be 1. With this assumption, the inverting input of the error comparator is the same as the feedback voltage.

Figure 4-1 shows the MIC27600 control loop timing during steady-state operation. During steady-state, the g_m amplifier senses the feedback voltage ripple, which is proportional to the output voltage ripple and the inductor current ripple, to trigger the ON-time period. The ON-time is predetermined by the t_{ON} estimator. The termination of the OFF-time is controlled by the feedback voltage. At the valley of the feedback voltage ripple, which occurs when V_{FB} falls below V_{REF}, the OFF period ends and the next ON-time period is triggered through the control logic circuitry.

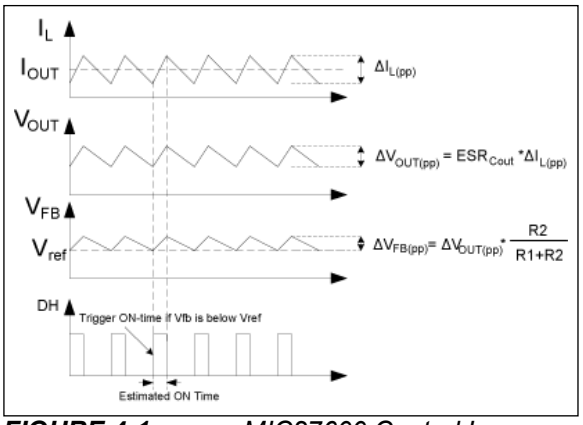


FIGURE 4-1: *MIC27600 Control Loop Timing.*

Figure 4-2 shows the operation of the MIC27600 during a load transient. The output voltage drops due to the sudden load increase, which causes the V_{FB} to be less than V_{REF}. This causes the error comparator to trigger an ON-time period. At the end of the ON-time period, a minimum OFF-time $t_{OFF(MIN)}$ is generated to charge C_{BST} because the feedback voltage is still below V_{REF}. Then, the next ON-time period is triggered by the low feedback voltage. Therefore, the switching frequency changes during the load transient, but returns to the nominal fixed frequency once the output has stabilized at the new load current level. With the varying duty cycle and switching frequency, the output recovery time is fast and the output voltage deviation is small in the MIC27600 converter.

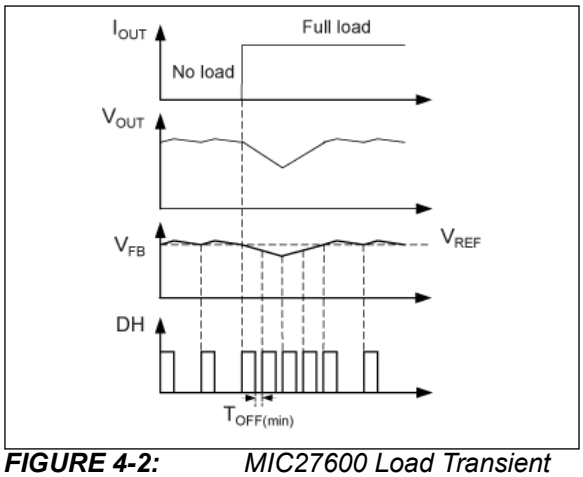


FIGURE 4-2: *MIC27600 Load Transient Response.*

Unlike true current-mode control, the MIC27600 uses the output voltage ripple to trigger an ON-time period. The output voltage ripple is proportional to the inductor current ripple if the ESR of the output capacitor is large enough. The MIC27600 control loop has the advantage of eliminating the need for slope compensation.

To meet the stability requirements, the MIC27600 feedback voltage ripple should be in phase with the inductor current ripple and large enough to be sensed by the g_m amplifier and the error comparator. The recommended feedback voltage ripple is 20 mV~100 mV. If a low-ESR output capacitor is selected, then the feedback voltage ripple may be too small to be sensed by the g_m amplifier and the error comparator. Also, the output voltage ripple and the feedback voltage ripple are not necessarily in phase with the inductor current ripple if the ESR of the output capacitor is very low. In these cases, ripple injection is required to ensure proper operation. Please refer to the Ripple Injection section for more details about the ripple injection technique.

4.2 Soft-Start

Soft-start reduces the power supply input surge current at start-up by controlling the output voltage rise time. The input surge appears while the output capacitor is charged up. A slower output rise time draws a lower input surge current.

The MIC27600 implements an internal digital soft-start by making the 0.8V reference voltage V_{REF} ramp from 0% to 100% in about 6 ms with 9.7 mV steps. Therefore, the output voltage is controlled to increase slowly by a stair-case V_{FB} ramp. After the soft-start cycle ends, the related circuitry is disabled to reduce current consumption. VDD must be powered up at the same time as VIN or after to make the soft-start function correctly.

4.3 Current Limit

The MIC27600 uses the $R_{DS(ON)}$ of the internal low-side power MOSFET to sense overcurrent conditions. This method avoids adding the cost, board space, and power losses taken by a discrete current sense resistor. The low-side MOSFET is used because it displays much lower parasitic oscillations during switching than the high-side MOSFET.

In each switching cycle of the MIC27600 converter, the inductor current is sensed by monitoring the low-side MOSFET in the OFF period. If the peak inductor current is greater than 15A, the MIC27600 turns off the high-side MOSFET and a soft-start sequence is triggered. This mode of operation is called “hiccup mode” and its purpose is to protect the downstream load in case of a hard short. The current-limit threshold has a foldback characteristic related to the feedback voltage, as shown in Figure 4-3.

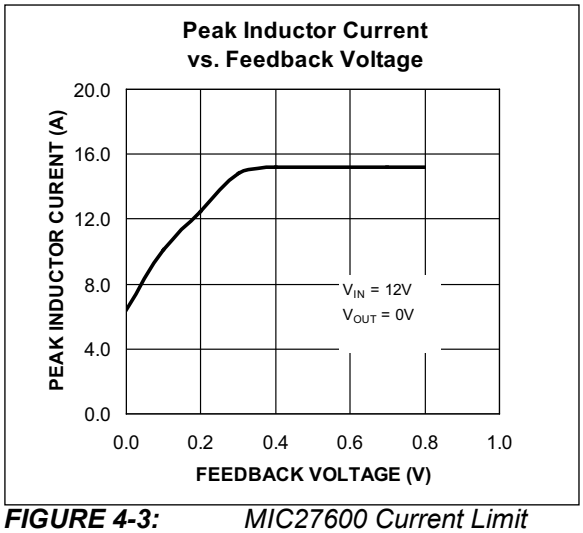


FIGURE 4-3: *MIC27600 Current Limit Foldback Characteristic.*

4.4 Internal MOSFET Gate Driver

The Functional Block Diagram shows a bootstrap circuit, consisting of D1 (a Schottky diode is recommended) and C_{BST}. This circuit supplies energy to the high-side drive circuit. Capacitor C_{BST} is charged, while the low-side MOSFET is on, and the voltage on the SW pin is approximately 0V. When the high-side MOSFET driver is turned on, energy from C_{BST} is used to turn the MOSFET on. As the high-side MOSFET turns on, the voltage on the SW pin increases to approximately V_{IN}. Diode D1 is reverse biased and C_{BST} floats high while continuing to keep the high-side MOSFET on. The bias current of the high-side driver is less than 10 mA so a 0.1 µF to 1 µF capacitor is sufficient to hold the gate voltage with minimal droop for the power stroke (high-side switching) cycle, that is ΔBST = 10 mA x 3.33 µs/0.1 µF = 333 mV. When the low-side MOSFET is turned back on, C_{BST} is recharged through D1. A small resistor (R_G), which is in series with C_{BST}, can be used to slow down the turn-on time of the high-side N-channel MOSFET.

The drive voltage is derived from the V_{DD} supply voltage. The nominal low-side gate drive voltage is V_{DD} and the nominal high-side gate drive voltage is approximately $V_{DD} – V_{DIODE}$, where V_{DIODE} is the voltage drop across D1. An approximate 30 ns delay between the high-side and low-side driver transitions is used to prevent current from simultaneously flowing unimpeded through both MOSFETs.

5.0 APPLICATION INFORMATION

5.1 Inductor Selection

Values for inductance, peak, and RMS currents are required to select the output inductor. The input and output voltages and the inductance value determine the peak-to-peak inductor ripple current. Generally, higher inductance values are used with higher input voltages. Larger peak-to-peak ripple currents increase the power dissipation in the inductor and MOSFETs. Larger output ripple currents also require more output capacitance to smooth out the larger ripple current. Smaller peak-to-peak ripple currents require a larger inductance value, and therefore a larger and more expensive inductor. A good compromise between size, loss, and cost is to set the inductor ripple current to be equal to 20% of the maximum output current. The inductance value is calculated by Equation 5-1:

EQUATION 5-1:

$$L = \frac{V_{OUT} \times (V_{IN(MAX)} - V_{OUT})}{V_{IN(MAX)} \times f_{SW} \times 20\% \times I_{OUT(MAX)}}$$

Where:

f_{SW} is the switching frequency of 300 kHz
20% is the ratio of AC ripple current to DC output current
$V_{IN(MAX)}$ is the maximum power stage input voltage

The peak-to-peak inductor current ripple is:

EQUATION 5-2:

$$\Delta I_{L(PP)} = \frac{V_{OUT} \times (V_{IN(MAX)} - V_{OUT})}{V_{IN(MAX)} \times f_{SW} \times L}$$

The peak inductor current is equal to the average output current plus one half of the peak-to-peak inductor current ripple.

EQUATION 5-3:

$$I_{L(PK)} = I_{OUT(MAX)} + 0.5 \times \Delta I_{L(PP)}$$

The RMS inductor current is used to calculate the I^2R losses in the inductor.

EQUATION 5-4:

$$I_{L(RMS)} = \sqrt{I_{OUT(MAX)}^2 + \frac{\Delta I_{L(PP)}^2}{12}}$$

Maximizing efficiency requires selecting the proper core material and minimizing the winding resistance. The high frequency operation of the MIC27600 requires the use of ferrite materials for all but the most cost-sensitive applications. Lower cost iron powder cores may be used but the increase in core loss reduces the efficiency of the power supply. This is especially noticeable at low output power. The winding resistance decreases efficiency at the higher output current levels. The winding resistance must be minimized, although this usually comes at the expense of a larger inductor. The power dissipated in the inductor is equal to the sum of the core and copper losses. At higher output loads, the core losses are usually insignificant and can be ignored. At lower output currents, the core losses can be a significant contributor. Core loss information is usually available from the magnetics vendor. Copper loss in the inductor is calculated by Equation 5-5:

EQUATION 5-5:

$$P_{INDUCTOR(CU)} = I_{L(RMS)}^2 \times R_{WINDING}$$

The resistance of the copper wire, $R_{WINDING}$, increases with the temperature. The value of the winding resistance used should be at the operating temperature:

EQUATION 5-6:

$$P_{WINDING(HI)} = R_{WINDING(20C)} \times (1 + 0.0042 \times [T_H - T_{20C}])$$

Where:

T_H is the temperature of wire under full load
T_{20C} is the ambient temperature
$R_{WINDING(20C)}$ is the room temperature winding resistance (usually specified by the manufacturer)

5.2 Output Capacitor Selection

The type of the output capacitor is usually determined by its equivalent series resistance (ESR). Voltage and RMS current capability are two other important factors in selecting the output capacitor. Recommended capacitor types are ceramic, low-ESR aluminum electrolytic, OS-CON, and POSCAP. The output capacitor's ESR is usually the main cause of the output ripple. The output capacitor ESR also affects the control loop from a stability point of view. The maximum value of ESR is calculated:

EQUATION 5-7:

$$ESR_{COUT} \leq \frac{\Delta V_{OUT(PP)}}{\Delta I_{L(PP)}}$$

Where:
$\Delta V_{OUT(PP)}$ is the peak-to-peak output voltage ripple
$\Delta I_{L(PP)}$ is the peak-to-peak inductor current ripple

The total output ripple is a combination of the ESR and output capacitance. The total ripple is calculated in Equation 5-8:

EQUATION 5-8:

$$\Delta V_{OUT(PP)} = \sqrt{\left(\frac{\Delta I_{L(PP)}}{C_{OUT} \times f_{SW} \times 8}\right)^2 + \left(\Delta I_{L(PP)} \times ESR_{COUT}\right)^2}$$

Where:
C_{OUT} is the output capacitance value
f_{SW} is the switching frequency

As described in the Theory of Operation section, the MIC27600 requires at least 20 mV peak-to-peak ripple at the FB pin to make the g_m amplifier and the error comparator behave properly. Also, the output voltage ripple should be in phase with the inductor current. Therefore, the output voltage ripple caused by the output capacitors value should be much smaller than the ripple caused by the output capacitor ESR. If low-ESR capacitors, such as ceramic capacitors, are selected as the output capacitors, a ripple injection method should be applied to provide the enough feedback voltage ripple. Please refer to the Ripple Injection section for more details.

The voltage rating of the capacitor should be 20% greater for aluminum electrolytic or OS-CON. The output capacitor RMS current is calculated in Equation 5-9:

EQUATION 5-9:

$$I_{COUT(RMS))} = \frac{\Delta I_{L(PP)}}{\sqrt{12}}$$

The power dissipated in the output capacitor is:

EQUATION 5-10:

$$P_{DISS(COUT)} = I_{COUT(RMS)}^2 \times ESR_{COUT}$$

5.3 Input Capacitor Selection

The input capacitor for the power stage input V_{IN} should be selected for ripple current rating and voltage rating. Tantalum input capacitors may fail when subjected to high inrush currents, caused by turning the input supply on. A tantalum input capacitor's voltage rating should be at least two times the maximum input voltage to maximize reliability. Aluminum electrolytic, OS-CON, and multilayer polymer film capacitors can handle the higher inrush currents without voltage derating. The input voltage ripple primarily depends on the input capacitor's ESR. The peak input current is equal to the peak inductor current, so:

EQUATION 5-11:

$$\Delta V_{IN} = I_{L(PK)} \times C_{ESR}$$

The input capacitor must be rated for the input current ripple. The RMS value of input capacitor current is determined at the maximum output current. Assuming the peak-to-peak inductor current ripple is low:

EQUATION 5-12:

$$I_{CIN(RMS)} \approx I_{OUT(MAX)} \times \sqrt{D \times (1 - D)}$$

The power dissipated in the input capacitor is:

EQUATION 5-13:

$$P_{DISS(CIN)} = I_{CIN(RMS)}^2 \times C_{ESR}$$

5.4 Ripple Injection

The V_{FB} ripple required for the MIC27600 g_m amplifier and error comparator to operate properly is 20 mV to 100 mV. However, the output voltage ripple is generally designed as 1% to 2% of the output voltage. For a low output voltage, such as a 1V, the output voltage ripple is only 10 mV to 20 mV, and the feedback voltage ripple is less than 20 mV. If the feedback voltage ripple is so small that the g_m amplifier and error comparator can't sense it, then the MIC27600 will lose control and the output voltage is not regulated. In order to have some amount of V_{FB} ripple, a ripple injection method is applied for low output voltage ripple applications.

The applications are divided into three situations according to the amount of the feedback voltage ripple:

1. Enough ripple at the feedback voltage due to the large ESR of the output capacitors.

As shown in Figure 5-1, the converter is stable without any ripple injection.

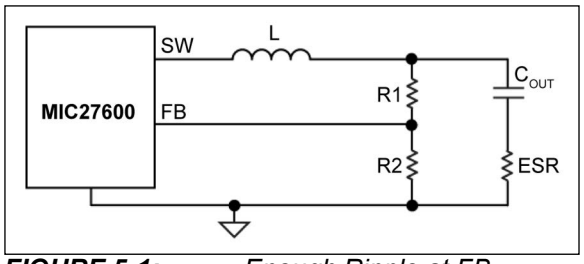


FIGURE 5-1: *Enough Ripple at FB.*

The feedback voltage ripple is:

EQUATION 5-14:

$$\Delta V_{FB(PP)} = \frac{R2}{R1 + R2} \times ESR_{COUT} \times \Delta I_{L(PP)}$$

Where:
$\Delta I_{L(PP)}$ is the peak-to-peak value of the inductor current ripple.

2. Inadequate ripple at the feedback voltage due to the small ESR of the output capacitors.

The output voltage ripple is fed into the FB pin through a feed-forward capacitor (C_{ff}) in this situation, as shown in Figure 5-2. The typical C_{ff} value is between 1 nF and 100 nF.

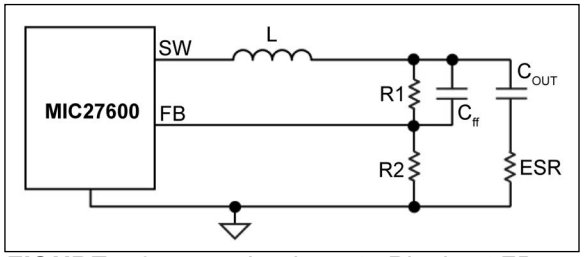


FIGURE 5-2: *Inadequate Ripple at FB.*

With the feed-forward capacitor, the feedback voltage ripple is very close to the output voltage ripple:

EQUATION 5-15:

$$\Delta V_{FB(PP)} \approx ESR \times \Delta I_{L(PP)}$$

3. Virtually no ripple at the FB pin voltage due to the very low ESR of the output capacitors.

In this situation, the output voltage ripple is less than 20 mV. Therefore, additional ripple is injected into the FB pin from the switching node (SW) via a resistor (R_{inj}) and a capacitor (C_{inj}), as shown in Figure 5-3.

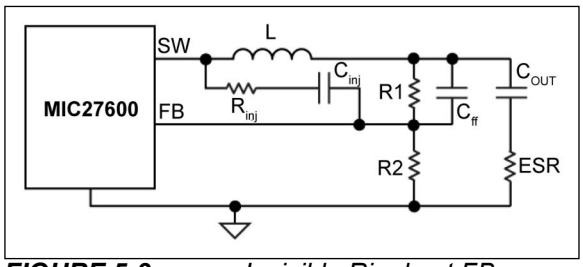


FIGURE 5-3: *Invisible Ripple at FB.*

The injected ripple is:

EQUATION 5-16:

$$\Delta V_{FB(PP)} = V_{IN} \times K_{DIV} \times D \times (1 - D) \times \frac{1}{f_{SW} \times \tau}$$

Where:
VIN is the power stage input voltage
D is the duty cycle
fSW is the switching frequency
τ (tau) is (R1//R2//R_{inj}) x C_{ff}

EQUATION 5-17:

$$K_{DIV} = \frac{R1//R2}{R_{inj} + R1//R2}$$

In Equation 5-16 and 5-17, it is assumed that the time constant associated with C_{ff} must be much greater than the switching period:

EQUATION 5-18:

$$\frac{1}{f_{SW} \times \tau} = \frac{1}{\tau} \ll 1$$

If the voltage divider resistors (R1 and R2) are in the kΩ range, a C_{ff} of 1 nF to 100 nF can easily satisfy the large time constant requirements. Also, a 100 nF injection capacitor (C_{inj}) is used in order to be considered as short for a wide range of frequencies.

The process of sizing the ripple injection resistor and capacitors is:

1. Select C_{ff} to feed all output ripples into the feedback pin and make sure the large time constant assumption is satisfied. Typical choice of C_{ff} is 1 nF to 100 nF if R1 and R2 are in the kΩ range.
2. Select R_{inj} according to the expected feedback voltage ripple using Equation 5-19:

EQUATION 5-19:

$$K_{DIV} = \frac{\Delta V_{FB(PP)}}{V_{IN}} \times \frac{f_{SW} \times \tau}{D \times (1 - D)}$$

Then the value of R_{inj} is obtained as:

EQUATION 5-20:

$$R_{inj} = (\mathrm{R1}//\mathrm{R2}) \times \left(\frac{1}{K_{DIV}} - 1\right)$$

3. Select C_{inj} as 100 nF, which could be considered as short for a wide range of the frequencies.

5.5 Setting Output Voltage

The MIC27600 requires two resistors to set the output voltage as shown in Figure 5-4.

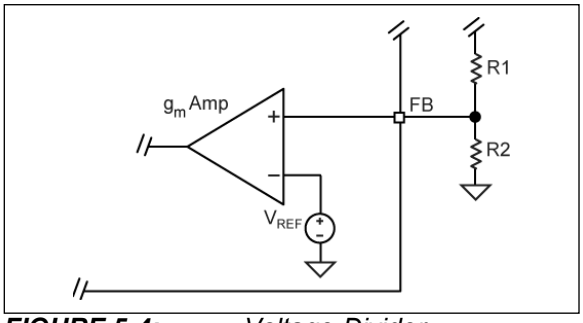


FIGURE 5-4: *Voltage-Divider Configuration.*

The output voltage is determined by Equation 5-21:

EQUATION 5-21:

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

Where:
V_{FB} = 0.8V

A typical value of R1 can be between 3 kΩ and 10 kΩ. If R1 is too large, it may allow noise to be introduced into the voltage feedback loop. If R1 is too small, it decreases the efficiency of the power supply, especially at light loads. After R1 is selected, R2 can be calculated using:

EQUATION 5-22:

$$R2 = \frac{V_{FB} \times R1}{V_{OUT} - V_{FB}}$$

In addition to the external ripple injection added at the FB pin, internal ripple injection is added at the inverting input of the comparator inside the MIC27600, as shown in Figure 5-5. The inverting input voltage (V_{INJ}) is clamped to 1.2V. As V_{OUT} increases, the swing of V_{INJ} will be clamped. The clamped V_{INJ} reduces the line regulation because it is reflected back as a DC error on the FB terminal. To avoid this line regulation problem, the maximum output voltage of MIC27600 should be limited to 5.5V for up to 28V V_{IN} and 3.6V for V_{IN} higher than 28V.

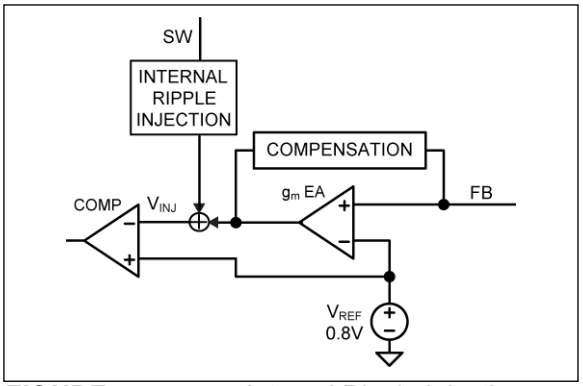


FIGURE 5-5: *Internal Ripple Injection.*

5.6 Thermal Measurements

It is a good idea to measure the IC's case temperature to make sure it is within its operating limits. Although this might seem like an elementary task, it is easy to get false results. The most common mistake is to use the standard thermal couple that comes with a thermal meter. This thermal couple wire gauge is large, typically 22 gauge, and behaves like a heatsink, which results in a lower case measurement.

There are two methods of temperature measurement: using a smaller thermal couple wire or using an infrared thermometer. If a thermal couple wire is used, it must be constructed of 36 gauge wire or higher (smaller wire size) to minimize the wire heat-sinking effect. In addition, the thermal couple tip must be covered in either thermal grease or thermal glue to ensure that the thermal couple junction makes good contact with the case of the IC. An Omega brand thermal couple (5SC-TT-K-36-36) is adequate for most applications.

Wherever possible, an infrared thermometer is recommended. The measurement spot size of most infrared thermometers is too large for an accurate reading on a small form factor ICs. However, an IR thermometer from Optris has a 1mm spot size, which makes it a good choice for measuring the hottest point on the case. An optional stand makes it easy to hold the beam on the IC for long periods of time.

5.7 PCB Layout Guidelines

PCB layout is critical to achieve reliable, stable, and efficient performance. A ground plane is required to control EMI and minimize the inductance in power, signal, and return paths.

Follow these guidelines to ensure proper operation and to minimize EMI and output noise of the MIC27600 converter.

IC

- The 2.2 µF ceramic capacitor, which is connected to the VDD pin, must be located right at the IC. The VDD pin is very noise sensitive, so placement of the capacitor is critical. Use wide traces to connect to the VDD and PGND pins.
- Connect the signal ground pin (SGND) directly to the ground planes. Do not route the SGND pin to the PGND Pad on the top layer.
- Place the IC close to the point of load (POL).
- Use fat traces to route the input and output power lines.
- Keep the signal and power grounds separate and connected at only one location.

Input Capacitor

- Place the input capacitor next.
- Place the input capacitors on the same side of the board and as close to the IC as possible.
- Keep both the PVIN pin and PGND connections short.
- Place several vias to the ground plane close to the input capacitor ground terminal.
- Use either X7R or X5R dielectric input capacitors. Do not use Y5V or Z5U type capacitors.
- Do not replace the ceramic input capacitor with any other type of capacitor. Any type of capacitor can be placed in parallel with the input capacitor.
- If a Tantalum input capacitor is placed in parallel with the input capacitor, it must be recommended for switching regulator applications. The operating voltage must be derated by 50%.
- In “Hot-Plug” applications, use a Tantalum or Electrolytic bypass capacitor to limit the overvoltage spike seen on the input supply when power is suddenly applied.

Inductor

- Keep the inductor connection to the switch node (SW) short.
- Do not route any digital lines underneath or close to the inductor.
- Keep the switch node (SW) away from the feedback (FB) pin.
- Connect the CS pin directly to the SW pin to accurately sense the voltage across the low-side MOSFET.
- To minimize noise, place a ground plane under the inductor.
- The inductor can be placed on the opposite side of the PCB with respect to the IC. It does not matter whether the IC or inductor is on the top or bottom as long as there is enough air flow to keep the power components within their temperature limits. Place the input and output capacitors on the same side of the board as the IC.

Output Capacitor

- Use a wide trace to connect the output capacitor ground terminal to the input capacitor ground terminal.
- The phase margin changes as the output capacitor value and ESR changes. Contact the factory if the output capacitor is different from what is shown in the BOM.
- The feedback trace should be separate from the power trace and connected as close as possible to the output capacitor. Sensing a long high current load trace can degrade the DC load regulation.

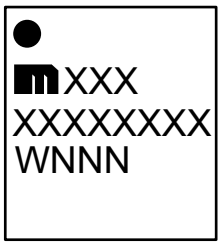
RC Snubber

- Place the RC snubber on either side of the board and as close to the SW pin as possible.

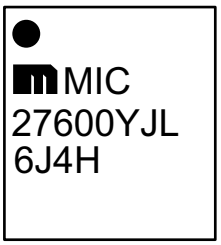
6.0 PACKAGING INFORMATION

6.1 Package Marking Information

28-Lead VQFN*



Example

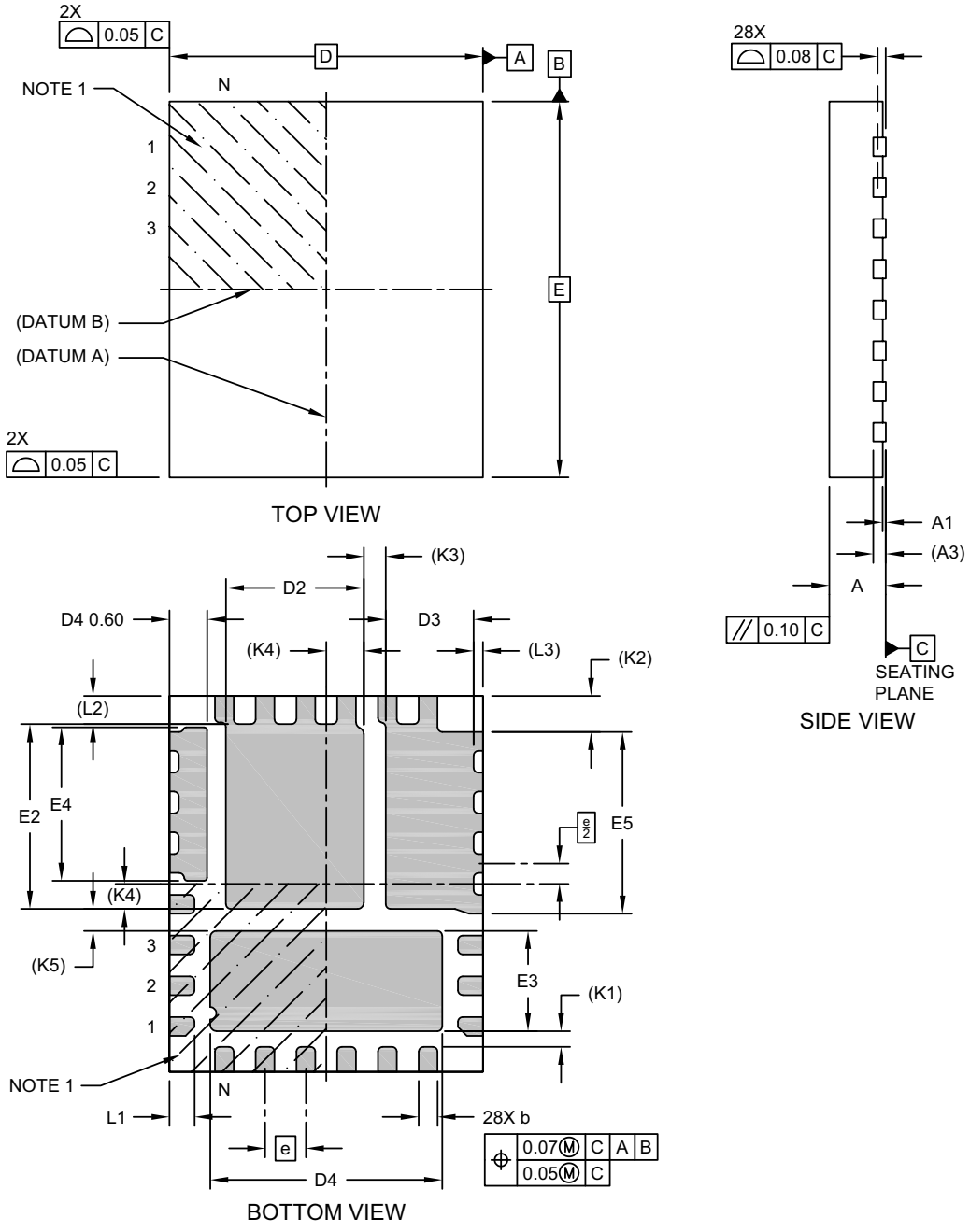


Legend:	XX...X	Product code or customer-specific information
	Y	Year code (last digit of calendar year)
	YY	Year code (last 2 digits of calendar year)
	WW	Week code (week of January 1 is week ‘01’)
	NNN	Alphanumeric traceability code
	(e3)	Pb-free JEDEC® designator for Matte Tin (Sn)
	*	This package 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

28-Lead Very Thin Plastic Quad Flat, No Lead Package (PKA) - 5x6x0.9 mm Body [VQFN] With Multiple Exposed Pads and Fused Terminals; Micrel Legacy QFN56-28LD-PL-1

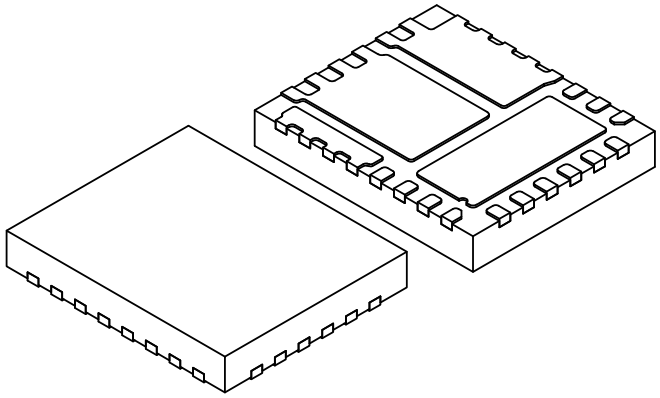
Note:	For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



Microchip Technology Drawing C04-1120 Rev A Sheet 1 of 2

28-Lead Very Thin Plastic Quad Flat, No Lead Package (PKA) - 5x6x0.9 mm Body [VQFN] With Multiple Exposed Pads and Fused Terminals; Micrel Legacy QFN56-28LD-PL-1

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		28	
Pitch	e		0.65 BSC	
Overall Height	A	0.00	0.02	0.05
Standoff	A1	0.80	0.85	0.85
Terminal Thickness	A3		0.20 REF	
Overall Length	D		5.00 BSC	
Exposed Pad Length	D2	2.15	2.20	2.25
Exposed Pad Length	D3	1.35	1.40	1.45
Exposed Pad Length	D4	3.65	3.70	3.75
Overall Width	E		6.00 BSC	
Exposed Pad Width	E2	2.90	2.95	3.00
Exposed Pad Width	E3	1.575	1.60	1.625
Exposed Pad Width	E4	2.40	2.45	2.50
Exposed Pad Width	E5	2.85	2.90	2.95
Terminal Width	b	0.25	0.30	0.35
Terminal Length	L1	0.35	0.40	0.45
Terminal Length	L2		0.45 REF	
Terminal Length	L3		0.15 REF	
Terminal to Exposed Pad	K1		0.25 REF	
Body Edge to Exposed Pad	K2		0.575 REF	
Exposed Pad to Exposed Pad	K3		0.035 REF	
Exposed Pad Offset	K4		0.40 REF	
Exposed Pad to Exposed Pad	K5		0.35 REF	

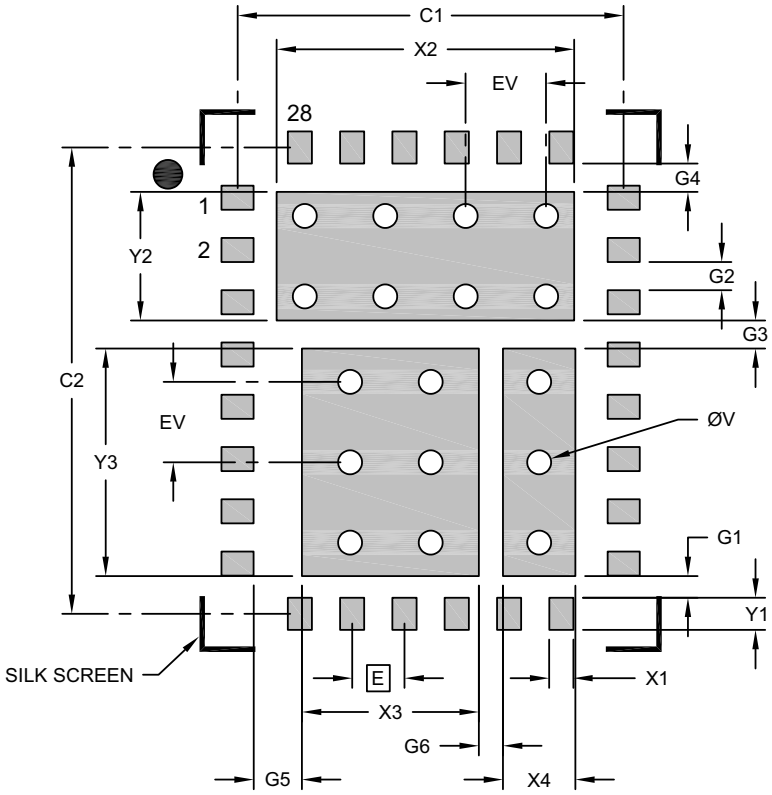
Notes:

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 C04-1120 Rev A Sheet 2 of 2

28-Lead Very Thin Plastic Quad Flat, No Lead Package (PKA) - 5x6x0.9 mm Body [VQFN] With Multiple Exposed Pads and Fused Terminals; Micrel Legacy QFN56-28LD-PL-1

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		0.65 BSC	
Center Pad Width	X2			3.70
Center Pad Width	X3			2.20
Center Pad Width	X4			0.90
Center Pad Length	Y2			1.60
Center Pad Length	Y3			2.83
Contact Pad Width	X1			0.30
Contact Pad Length	Y1			0.40
Contact Pad Spacing	C1		4.80	

Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Contact Pad Spacing	C2		5.80	
Contact Pad to Center Pad	G1	0.12		
Contact Pad to Contact Pad	G2	0.35		
Center Pad to Center Pad	G3	0.35		
Contact Pad to Center Pad	G4	0.35		
Contact Pad to Center Pad	G5	0.60		
Center Pad to Center Pad	G6	0.13		
Thermal Via Diameter	V		0.30	
Thermal Via Pitch	EV		1.00	

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 C04-3120 Rev A

NOTES:

APPENDIX A: REVISION HISTORY

Revision B (April 2025)

1. Updated values in the Electrical Characteristics and Temperature Specifications tables.
2. Updated Figures 2-1, 2-3, 2-19, 2-22, 2-23, 2-24, 2-25, 2-26, 2-27, 2-38, 2-39, 2-40 2-42 and 2-46.

Revision A (May 2024)

- Converted Micrel document MIC27600 to Microchip data sheet DS20006878A.
- Content related to the Schematic Diagram, Bill of Materials, and PCB Layout removed as that can be found in the MIC27600 User's Guide.
- 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.

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

Device:	MIC27600:		36V, 7A Hyper Speed Control® Synchronous DC/DC Buck Regulator
Output Voltage:	<blank>	=	Adjustable
Temperature Range:	Y	=	–40°C to +125°C
Package:	JL	=	28-Lead 5 mm x 6 mm VQFN
Media Type:	TR	=	1,000/Reel

Examples:

a) MIC27600YJL-TR: MIC27600, Adj. Output Voltage, –40°C to +125°C Temp. Range, 28-Lead VQFN, 1,000/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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ISBN: 979-8-3371-0957-2

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