MIC22400

4A Integrated Switch Synchronous Buck Regulator with Frequency Programmable up to 4 MHz

Features

- Input Voltage Range: 2.6V to 5.5V
- Output Voltage Adjustable Down to 0.7V
- Output Load Current Up to 4A
- Full Sequencing and Tracking Ability
- Power-On-Reset (POR)
- Efficiency >90% Across a Broad Load Range
- Programmable Frequency 300 kHz to 4 MHz
- Easy Ramp Control (RC) Compensation
- Ultra-Fast Transient Response
- 100% Maximum Duty Cycle
- Fully Integrated MOSFET Switches
- Micropower Shutdown
- Thermal-Shutdown and Current-Limit Protection
- 20-Pin 3 mm x 4 mm VQFN
- –40°C to +125°C Junction Temperature Range

Applications

- High Power Density Point-of-Load Conversion
- Servers and Routers
- DVD Recorders
- Computing Peripherals
- Base Stations
- FPGAs, DSP, and Low-Voltage ASIC Power

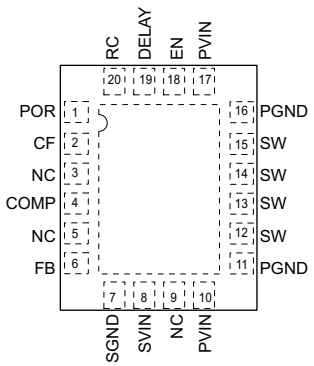
General Description

MIC22400 is a high-efficiency, 4A integrated switch synchronous buck (step-down) regulator. MIC22400 is optimized for highest efficiency, achieving over 90% efficiency while still switching at 1 MHz over a broad load range. The ultra high-speed control loop keeps the output voltage within regulation even under extreme transient load swings commonly found in FPGAs and low-voltage ASICs. The output voltage can be adjusted down to 0.7V to address all low-voltage power needs. MIC22400 gives a full range of sequencing and tracking options. The EN/DLY pin combined with the Power-On-Reset (POR) pin allows multiple outputs to be sequenced in any way on turn-on and turn-off. The Ramp Control (RC) pin allows the device to be connected to another MIC22400 family of products to keep the output voltages within a certain ΔV on start-up.

MIC22400 is available in a 20-pin 3 mm x 4 mm VQFN with a junction operating range from –40°C to +125°C.

Package Types

MIC22400
20-Lead VQFN (ML)
(Top View)



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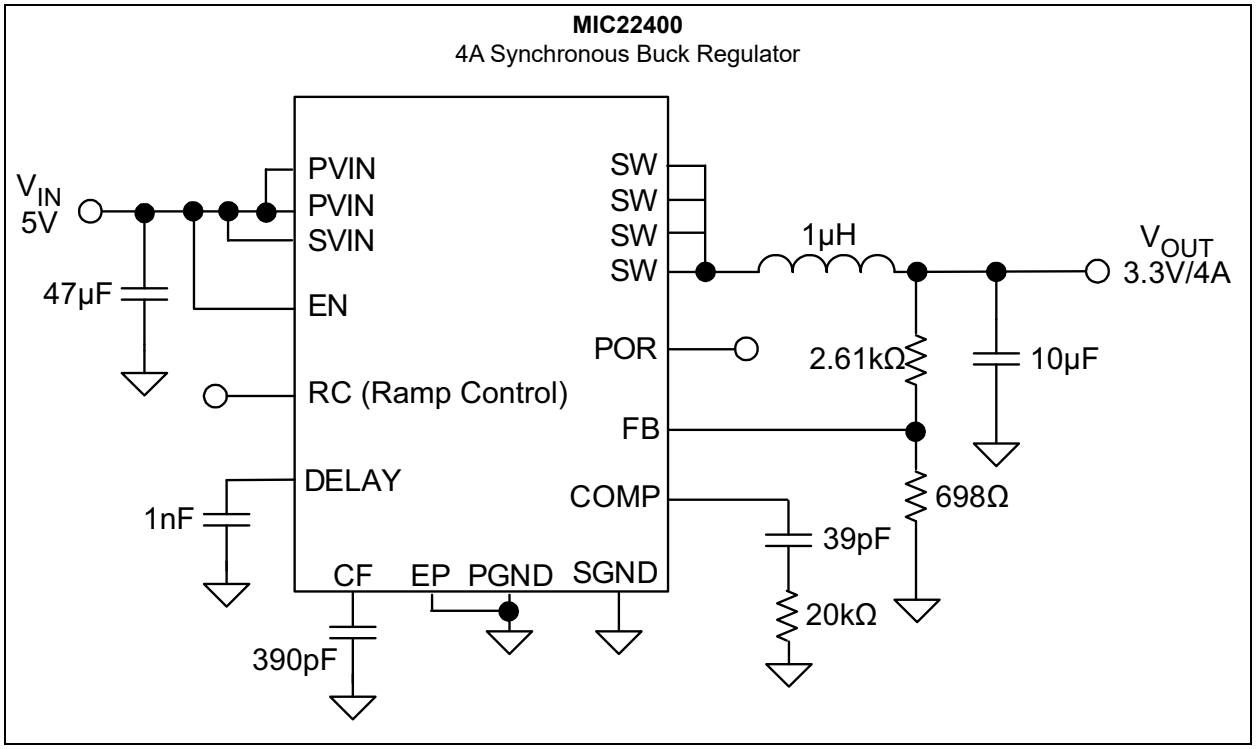
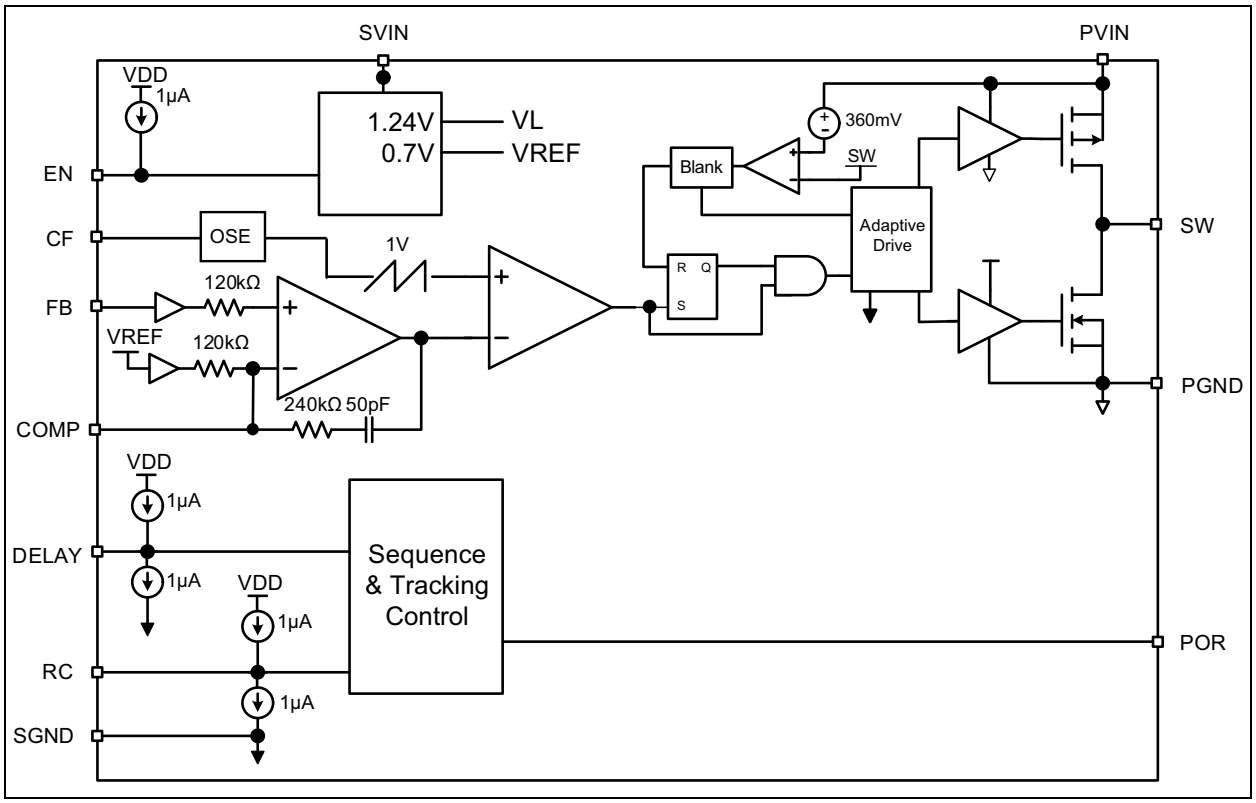
Typical Application Circuit



Functional Block Diagram



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1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings†

PV_{IN} to PGND ..... –0.3V to +6V
SV_{IN} to PGND ..... –0.3V to PGND
V_{SW} to PGND ..... –0.3V to PV_{IN}
$V_{EN/DLY}$ to PGND ..... –0.3V to PV_{IN}
V_{PG} to PGND ..... –0.3V to PV_{IN}
ESD Rating ..... Note 1

Operating Ratings‡

Supply Voltage (V_{IN}) ..... +2.6V to +5.5V

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

† **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.

ELECTRICAL CHARACTERISTICS

Electrical Characteristics: T_A = +25°C with V_{IN} = V_{EN} = 3.3V; V_{OUT} = 1.2V, C_F = 400 pF, unless otherwise specified. **Bold** values valid for –40°C ≤ T_J ≤ +125°C. Note 1

Parameter	Sym.	Min.	Typ.	Max.	Units	Conditions
Supply Voltage Range		**2.6**	—	**5.5**	V	—
Undervoltage Lockout Threshold		**2.4**	2.5	**2.6**	V	Turn-on
UVLO Hysteresis		—	280	—	mV	—
Quiescent Current, PWM Mode		—	1.3	**2.0**	mA	V_{EN} ≥ 1.34V; V_{FB} = 0.9V (not switching)
Shutdown Current	I_{SHDN}	—	5	**10**	µA	V_{EN} = 0V
Adjustable Feedback Voltage	V_{FB}	0.693	0.7	0.707	V	±1%
		0.686	0.7	**0.714**		±2% (over temperature)
Oscillator Frequency		**0.8**	1	**1.2**	MHz	—
FB Pin Input Current	I_{IN}	—	1	—	nA	—
Current Limit	I_{LIM}	**4**	7	**10**	A	V_{FB} = 0.5V
Output Voltage Line Regulation		—	0.2	—	%	V_{OUT} = 1.2V; V_{IN} = 2.6 to 5.5V, I_{LOAD} = 100 mA
Output Voltage Load Regulation		—	0.2	—	%	100 mA < I_{LOAD} < 4000 mA, V_{IN} = 3.3V
Maximum Duty Cycle		100	—	—	%	V_{FB} ≤ 0.5V
Switch ON-Resistance PFET		—	0.060	—	Ω	I_{SW} = 1000 mA; V_{FB} = 0.5V
Switch ON-Resistance NFET		—	0.035	—	Ω	I_{SW} = 1000 mA; V_{FB} = 0.9V
EN/DLY Threshold Voltage		**1.14**	1.24	**1.34**	V	—
EN/DLY Source Current		**0.7**	1	**1.3**	µA	V_{IN} = 2.6 to V_{IN} = 5.5V
RC Pin I_{RAMP}		**0.7**	1	**1.3**	µA	Ramp Control Current

Note 1: Specification for packaged product only.

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ELECTRICAL CHARACTERISTICS (CONTINUED)

Electrical Characteristics: T_A = +25°C with V_{IN} = V_{EN} = 3.3V; V_{OUT} = 1.2V, C_F = 400 pF, unless otherwise specified. **Bold** values valid for –40°C ≤ T_J ≤ +125°C. Note 1

Parameter	Sym.	Min.	Typ.	Max.	Units	Conditions
POR $I_{POR(LEAK)}$		—	—	1	µA	V_{PORH} = 5.5V; POR = High
		—	—	**2**		
POR $V_{POR(LO)}$		—	135	—	mV	Output Logic Low Voltage (undervoltage condition), I_{POR} = 5 mA
POR V_{POR}		**7.5**	10	**12.5**	%	Threshold, Percent of V_{OUT} below nominal
		—	2.7	—	%	Hysteresis
Overtemperature Shutdown		—	150	—	°C	—
Overtemperature Shutdown Hysteresis		—	10	—	°C	—

Note 1: Specification for packaged product only.

TEMPERATURE SPECIFICATIONS

Parameters	Sym.	Min.	Typ.	Max.	Units	Conditions
Temperature Ranges						
Junction Temperature Range	T_J	–40	—	+125	°C	—
Storage Temperature Range	T_S	–65	—	+150	°C	—
Lead Temperature	—	—	—	+260	°C	—
Package Thermal Resistance						
Thermal Resistance, VQFN 20-Ld	θ_{JA}	—	45	—	°C/W	—

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.

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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.

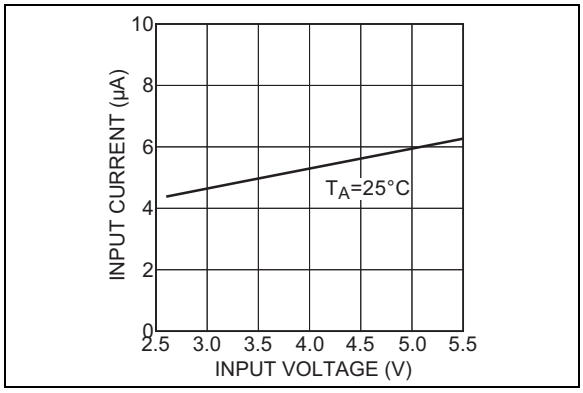

FIGURE 2-1: *Shutdown Current vs. Input Voltage.*

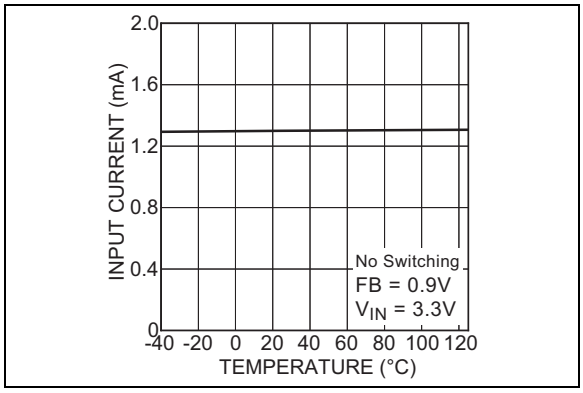

FIGURE 2-4: *Quiescent Current vs. Temperature.*

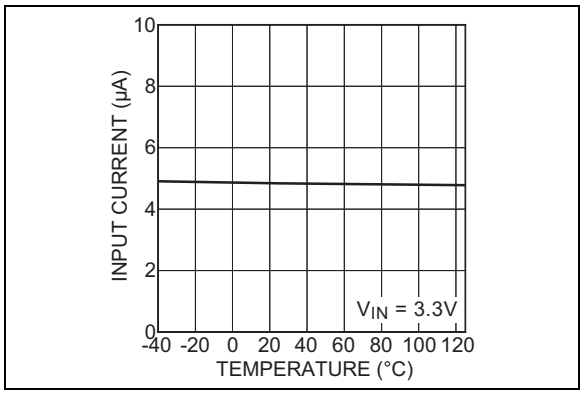

FIGURE 2-2: *Shutdown Current vs. Temperature.*

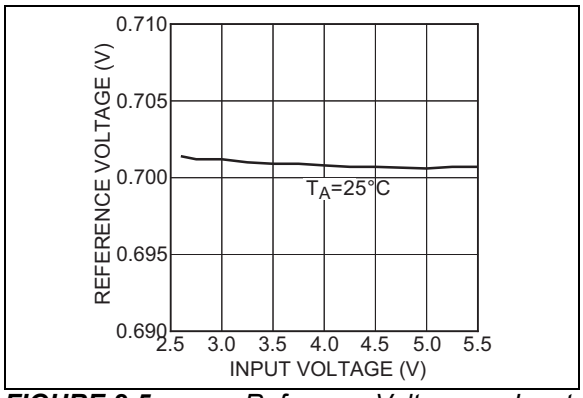

FIGURE 2-5: *Reference Voltage vs. Input Voltage.*

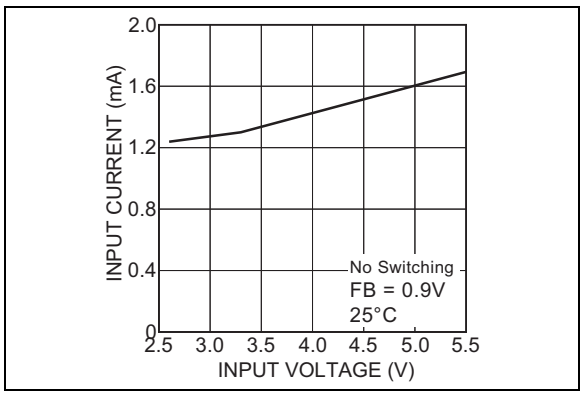

FIGURE 2-3: *Quiescent Current vs. Input Voltage.*

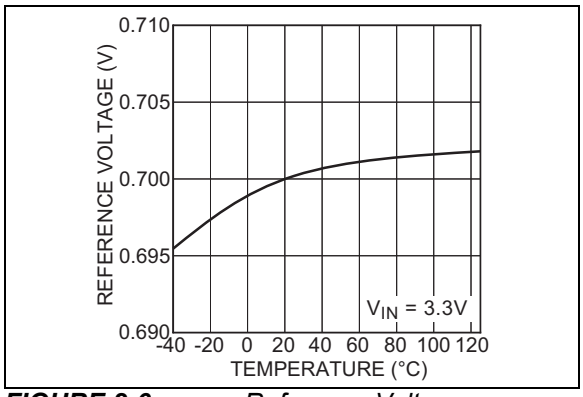

FIGURE 2-6: *Reference Voltage vs. Temperature.*

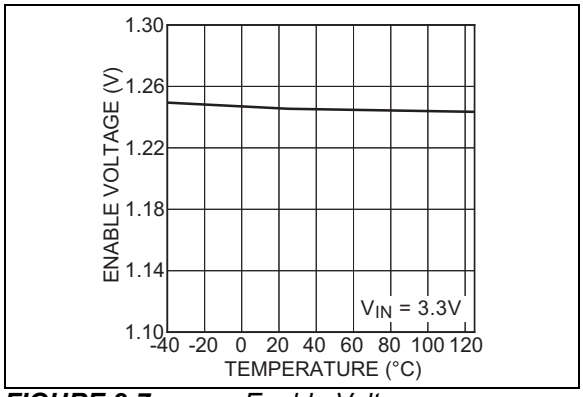

FIGURE 2-7: *Enable Voltage vs. Temperature.*

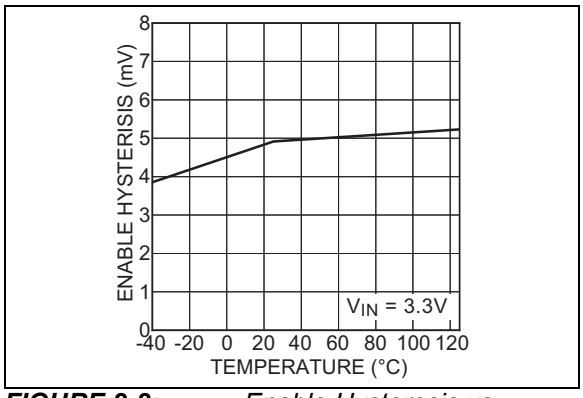

FIGURE 2-8: *Enable Hysteresis vs. Temperature.*

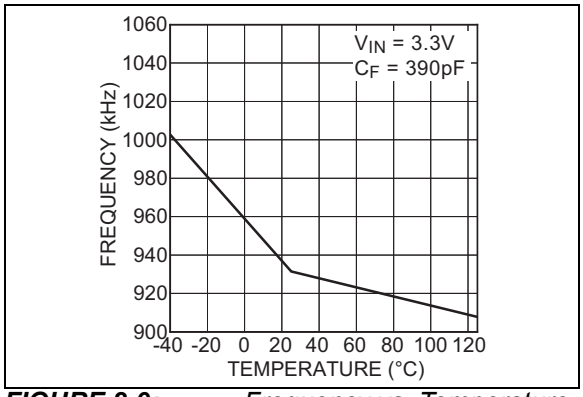

FIGURE 2-9: *Frequency vs. Temperature.*

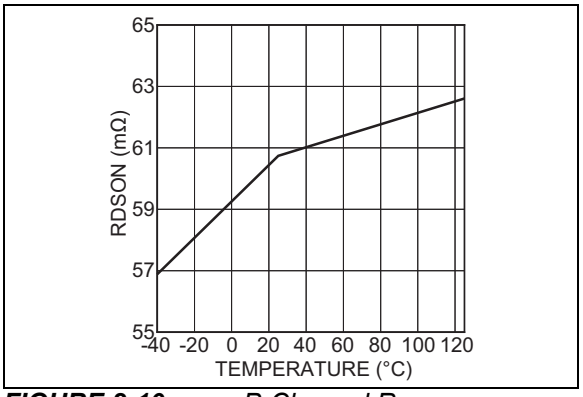

FIGURE 2-10: *P-Channel $R_{DS(ON)}$ vs. Temperature.*

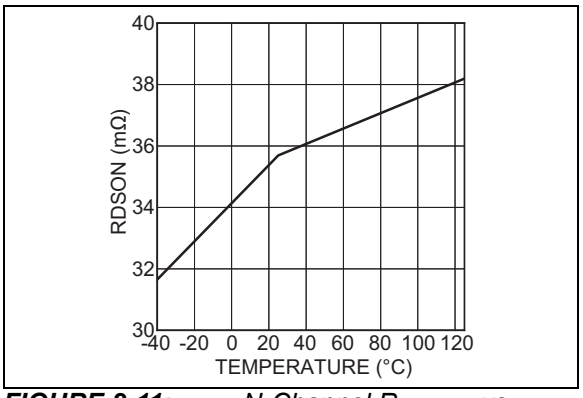

FIGURE 2-11: *N-Channel $R_{DS(ON)}$ vs. Temperature.*

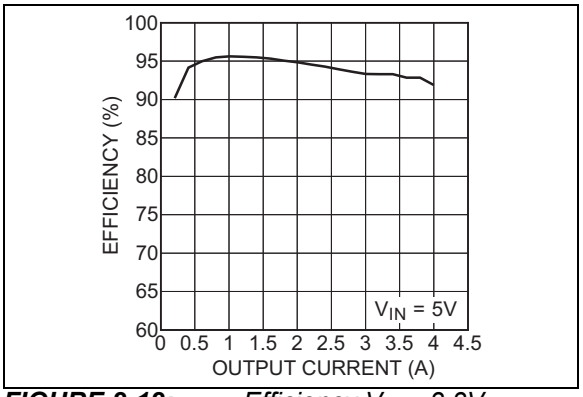

FIGURE 2-12: *Efficiency V_O = 3.3V.*

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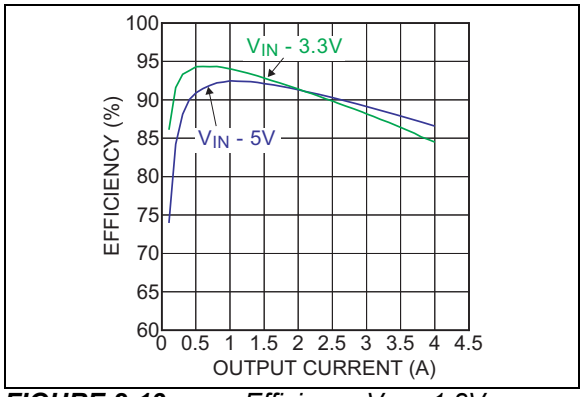

FIGURE 2-13: *Efficiency V_O = 1.8V.*

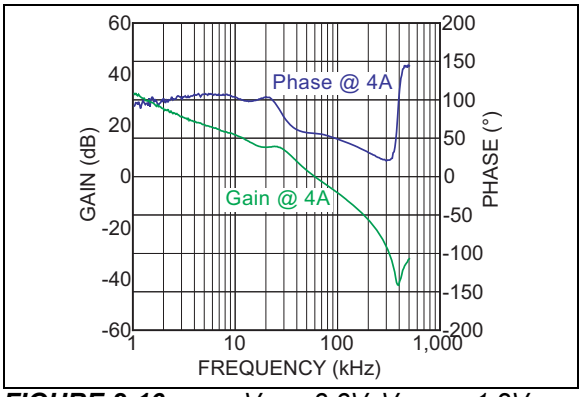

FIGURE 2-16: *V_{IN} = 3.3V, V_{OUT} = 1.2V.*

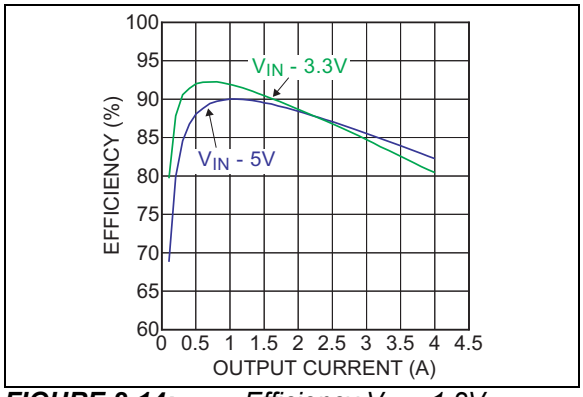

FIGURE 2-14: *Efficiency V_O = 1.2V.*

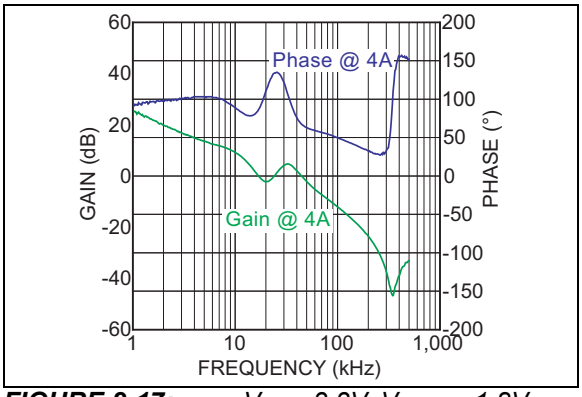

FIGURE 2-17: *V_{IN} = 3.3V, V_{OUT} = 1.8V.*

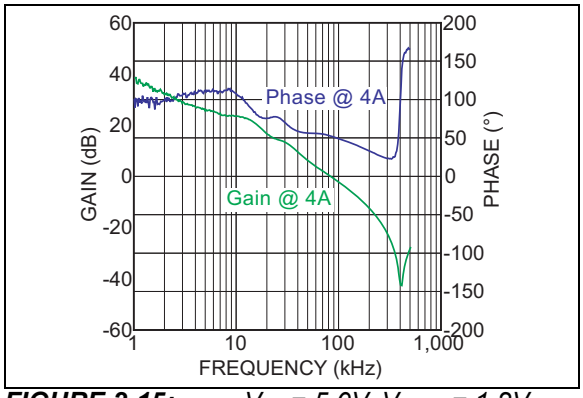

FIGURE 2-15: *V_{IN} = 5.0V, V_{OUT} = 1.2V.*

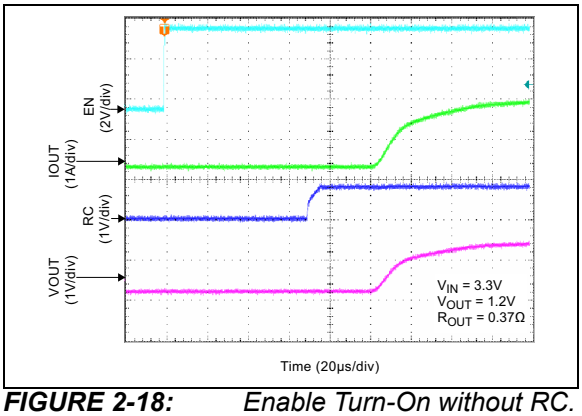

FIGURE 2-18: *Enable Turn-On without RC.*

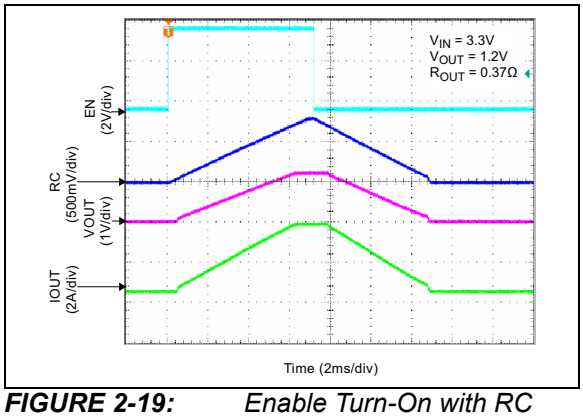

FIGURE 2-19: *Enable Turn-On with RC (10 nF).*

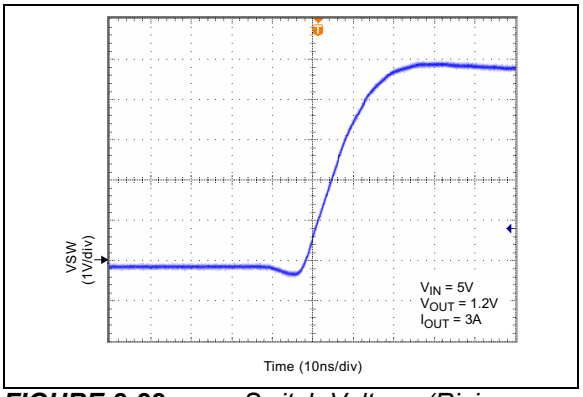

FIGURE 2-22: *Switch Voltage (Rising Edge).*

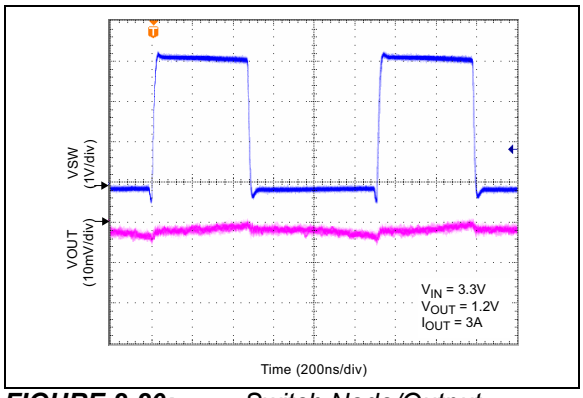

FIGURE 2-20: *Switch Node/Output Voltage.*

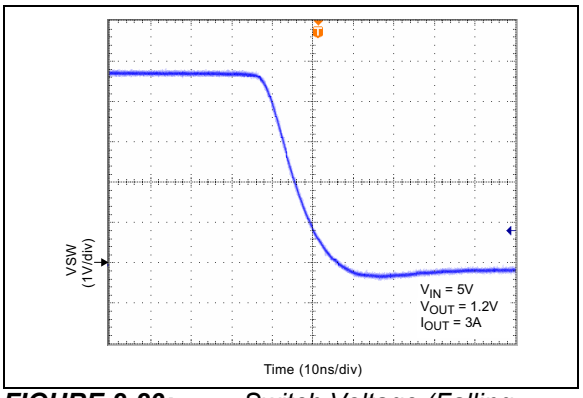

FIGURE 2-23: *Switch Voltage (Falling Edge).*

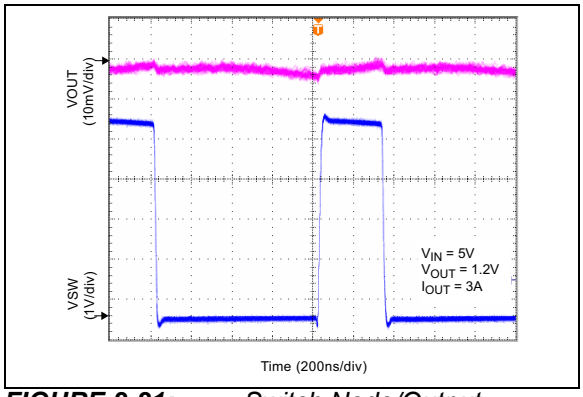

FIGURE 2-21: *Switch Node/Output Voltage.*

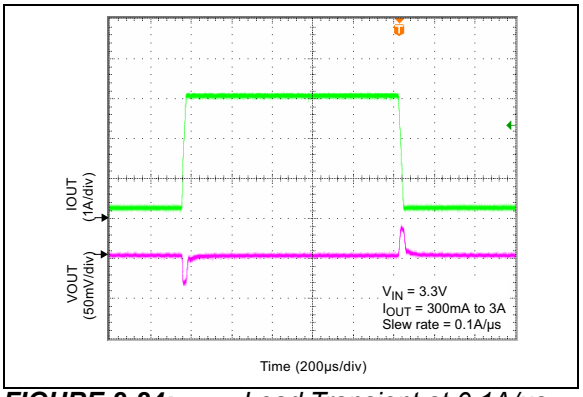

FIGURE 2-24: *Load Transient at 0.1A/µs.*

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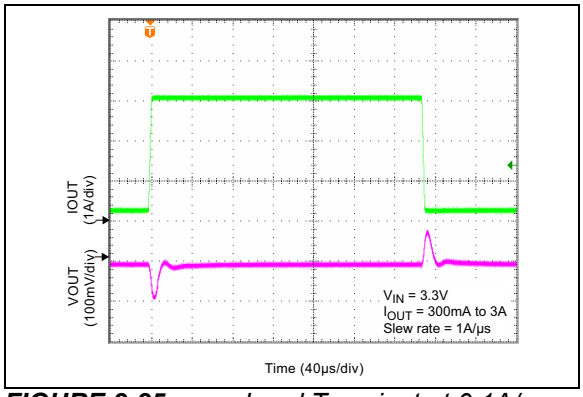

FIGURE 2-25: *Load Transient at 0.1A/µs.*

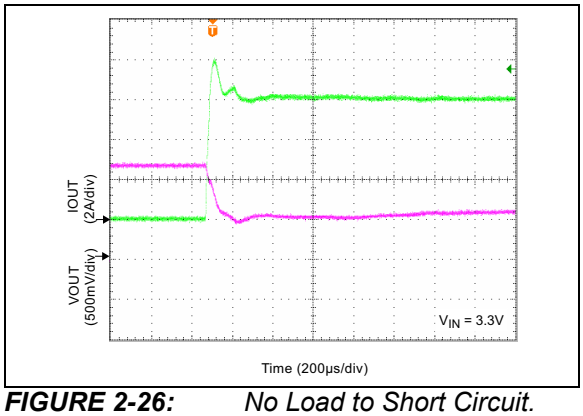

FIGURE 2-26: *No Load to Short Circuit.*

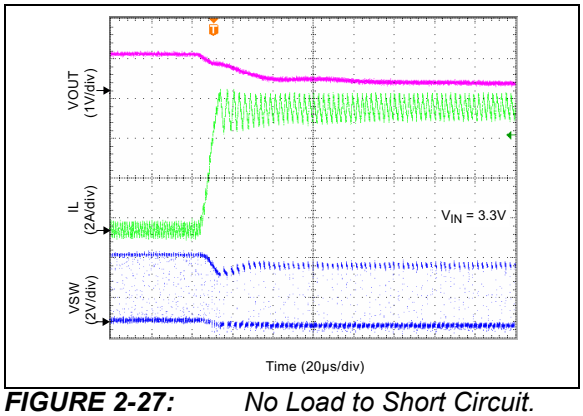

FIGURE 2-27: *No Load to Short Circuit.*

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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 VQFN-20	Pin Name	Description
1	POR	Power-On-Reset (Output): Open-drain output device indicates when the output is out of regulation and is active after the delay set by the DELAY pin.
2	CF	Adjustable frequency with external capacitor. Refer to table on page 12.
3, 5, 9	NC	Not connected internally.
4	COMP	Compensation pin (Input): Place a RC to GND to compensate the device, see applications section.
6	FB	Feedback (Input): Input to the error amplifier, connect to the external resistor divider network to set the output voltage.
7	SGND	Signal Ground (Signal): Ground
8	SVIN	Signal Power Supply Voltage (Input): Requires bypass capacitor to GND.
10, 17	PVIN	Power Supply Voltage (Input): Requires bypass capacitor to GND.
11, 16	PGND	Power Ground (Signal): Ground
12, 13, 14, 15	SW	Switch (Output): Internal power MOSFET output switches.
18	EN/DLY	Enable (Input): When this pin is pulled higher than the enable threshold, the part will start up. Below this voltage the device is in its low quiescent current mode. The pin has a 1 µA current source charging it to VDD. By adding a capacitor to this pin a delay may easily be generated. The enable function will not operate with an input voltage lower than the min specified.
19	DELAY	Delay (Input): Capacitor-to-ground sets internal delay timer. Timer delays POR output at turn-on and ramp down at turn-off.
20	RC	Ramp Control: Capacitor to ground from this pin determines slew rate of output voltage during start-up. This can be used for tracking capability as well as soft start.
EP	GND	Exposed Pad (Power): Must make a full connection to a GND plane.

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4.0 FUNCTIONAL DESCRIPTION

4.1 PVIN, SVIN

PVIN is the input supply to the internal 60 mΩ P-Channel Power MOSFET. This should be connected externally to the SVIN pin. The supply voltage range is from 2.6V to 5.5V. A 22 µF ceramic is recommended for bypassing each PVIN supply.

4.2 EN/DLY

This pin is internally fed with a 1 µA current source to VIN. A delayed turn on is implemented by adding a capacitor to this pin. The delay is proportional to the capacitor value. The internal circuits are held off until EN/DLY reaches the enable threshold of 1.24V.

4.3 RC

RC allows the slew rate of the output voltage to be programmed by the addition of a capacitor from RC to ground. RC is internally fed with a 1 µA current source and V_{OUT} slew rate is proportional to the capacitor and the 1 µA source.

4.4 DELAY

Adding a capacitor to this pin allows the delay of the POR signal.

When V_{OUT} reaches 90% of its nominal voltage, the DELAY pin current source (1 µA) starts to charge the external capacitor. At 1.24V, POR is asserted high.

4.5 COMP

The MIC22400 uses an internal compensation network containing a fixed frequency zero (phase lead response) and pole (phase lag response) which allows the external compensation network to be much simplified for stability. The addition of a single capacitor and resistor will add the necessary pole and zero for voltage mode loop stability using low value, low ESR ceramic capacitors.

4.6 FB

The feedback pin provides the control path to control the output. A resistor divider connecting the feedback to the output is used to adjust the desired output voltage. Refer to the “Feedback” section in Applications Information for more detail.

4.7 POR

This is an open-drain output. A 47 kΩ resistor can be used for a pull-up to this pin. POR is asserted high when output voltage reaches 90% of nominal set voltage and after the delay set by C_{DELAY}. POR is asserted low without delay when enable is set low or when the output goes below the –10% threshold. For a Power-On-Reset (POR) function, the delay can be set to a minimum. This can be done by removing the DELAY pin capacitor.

4.8 SW

This is the connection to the drain of the internal P-Channel MOSFET and drain of the N-Channel MOSFET. This is a high-frequency high-power connection; therefore traces should be kept as short and as wide as practical.

4.9 CF

Adding a capacitor to this pin can adjust switching frequency from 800 kHz to 4 MHz. By adding an additional resistor from CF to ground, the frequency range can be extended down to 300 kHz (refer to Table 5-1).

4.10 SGND

Internal signal ground for all low power sections.

4.11 PGND

Internal ground connection to the source of the internal N-Channel MOSFETs.

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5.0 APPLICATION INFORMATION

The MIC22400 is a 4A synchronous step-down regulator IC with an adjustable switching frequency from 800 kHz to 4 MHz, voltage-mode PWM control scheme. The other features include tracking and sequencing control for controlling multiple output power systems, and Power-On-Reset.

5.1 Input Capacitor

A minimum 22 µF ceramic is recommended on each of the PVIN pins for bypassing. X5R or X7R dielectrics are recommended for the input capacitor. Do not use Y5V dielectrics. They lose most of their capacitance over temperature and become resistive at high frequencies. This reduces their ability to filter out high frequency noise.

5.2 Output Capacitor

The MIC22400 was designed specifically for the use of ceramic output capacitors. A 100 µF can be increased to improve transient performance. Because the MIC22400 is in voltage mode, the control loop relies on the inductor and output capacitor for compensation. For this reason, do not use excessively large output capacitors. The output capacitor requires either an X7R or X5R dielectric. Y5V and Z5U dielectric capacitors, aside from the undesirable effect of their wide variation in capacitance over temperature, become resistive at high frequencies. Using Y5V or Z5U capacitors can cause instability in the MIC22400.

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 MIC22400 is designed for use with a 0.47 µH to 4.7 µH inductor.

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% 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 that the peak current will not saturate the inductor. The ripple can add as much as 1.2A to the output current level. The RMS rating should be chosen to be equal or greater than the current limit of the MIC22400 to prevent overheating in a fault condition.

For best electrical performance, the inductor should be placed very close to the SW nodes of the IC. For this reason, the heat of the inductor is somewhat coupled to the IC, so it offers some level of protection if the inductor gets too hot. It is important to test all operating limits before settling on the final inductor choice.

The size requirements refer to the area and height requirements that are necessary to fit a particular design. Please refer to the inductor dimensions on their data sheet.

DC resistance is also important. While DCR is inversely proportional to size, DCR can represent a significant efficiency loss. Refer to the “Efficiency Considerations” section for a more detailed description.

5.4 EN/DLY Capacitor

EN/DLY pin sources 1 µA out of the IC to allow a startup delay to be implemented. The delay time is simply the time it takes 1 µA to charge $C_{EN/DLY}$ to 1.24V.

EQUATION 5-1:

$$t_{EN/\mathrm{DLY}} = \frac{1.24 \times C_{EN/\mathrm{DLY}}}{1.10^{-6}}$$

5.5 CF Capacitor

Adding a capacitor to this pin can adjust switching frequency from 800 kHz to 4 MHz. CF sources 400 µA out of the IC to charge the CF capacitor to set up the switching frequency. The switch period is simply the time it takes 400 µA to charge CF to 1.0V.

TABLE 5-1: CF VS. FREQUENCY

CF Capacitor	Frequency
56 pF	4.4 MHz
68 pF	4 MHz
82 pF	3.4 MHz
100 pF	2.8 MHz
150 pF	2.1 MHz
180 pF	1.7 MHz
220 pF	1.4 MHz
270 pF	1.2 MHz
330 pF	1.1 MHz
390 pF	1.05 MHz
470 pF	1 MHz

It is necessary to connect the CF capacitor between the CF pin and power ground.

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5.6 300kHz to 800kHz Operation

Additionally, the frequency range can be lowered by adding an additional resistor (R_{CF}) in parallel with the CF capacitor. This reduces the amount of current used to charge the capacitor, reducing the frequency. The following equation can be used to for frequencies between 800 kHz to 300 kHz.

EQUATION 5-2:

$$R_{CF} \times C_{CF} \times In\left(1 + \frac{1.0V}{400\mu A \times R_{CF}}\right) = t$$

$$R_{CF} > 2.9k\Omega$$

5.7 Efficiency Considerations

Efficiency is defined as the amount of useful output power, divided by the amount of power consumed.

EQUATION 5-3:

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

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

There are mainly two loss terms in switching converters: static losses and switching losses. Static losses are simply the power losses due to VI or I^2R. For example, 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 RMS switch current squared (I_{SW}^2). During the off cycle, the low-side N-Channel MOSFET conducts, also dissipating power. Similarly, the inductor's DCR and capacitor's ESR also contribute to the I^2R losses. Device operating current also reduces efficiency by the product of the quiescent (operating) current and the supply voltage. The current required to drive the gates on and in the frequency range from 800 kHz to 4 MHz and the switching transitions make up the switching losses.

Figure 5-1 shows an efficiency curve. The portion, from 0A to 0.2A, efficiency losses are dominated by quiescent current losses, gate drive, and transition losses. In this case, lower supply voltages yield greater efficiency in that they require less current to drive the MOSFETs and have reduced input power consumption.

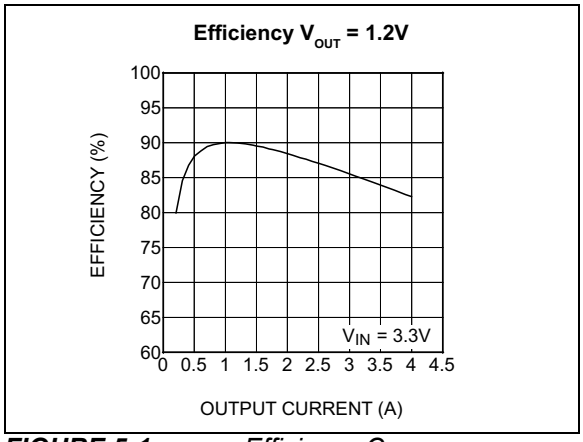

FIGURE 5-1: *Efficiency Curve.*

The region, 0.2A to 4A, efficiency loss is dominated by MOSFET $R_{DS(ON)}$ and inductor DC losses. Higher input supply voltages will increase the Gate-to-Source voltage 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 5-4:

$$L_{PD} = I_{OUT}^2 \times DCR$$

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

EQUATION 5-5:

$$Efficiency\ Loss = \left[1 - \left(\frac{V_{OUT} \times I_{OUT}}{(V_{OUT} \times I_{OUT}) + L_{PD}}\right)\right] \times 100$$

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.

Alternatively, under lighter loads, the ripple current due to the inductance becomes a significant factor. When light load efficiencies become more critical, a larger inductor value may be desired. Larger inductances

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reduce the peak-to-peak inductor ripple current, which minimize losses. Figure 5-2 illustrates the effects of inductance value at light load.

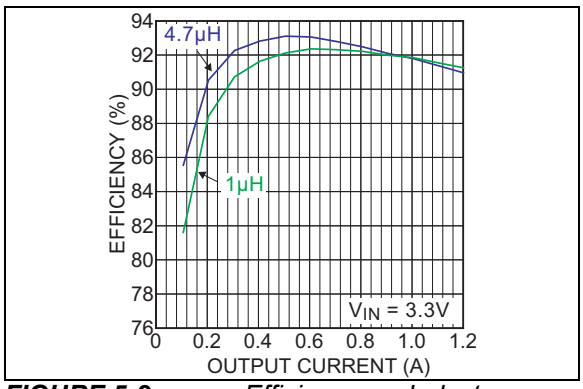

FIGURE 5-2: *Efficiency vs. Inductance.*

5.8 Compensation

The MIC22400 has a combination of internal and external stability compensation to simplify the circuit for small, high efficiency designs. In such designs, voltage mode conversion is often the optimum solution. Voltage mode is achieved by creating an internal 1 MHz ramp signal and using the output of the error amplifier to modulate the pulse width of the switch node, thereby maintaining output voltage regulation. With a typical gain bandwidth of 100 kHz to 200 kHz, the MIC22400 is capable of extremely fast transient responses.

The MIC22400 is designed to be stable with a typical application using a 1 µH inductor and a 47 µF ceramic (X5R) output capacitor. These values can be varied dependent upon the tradeoff between size, cost, and efficiency, keeping the LC natural frequency ideally less than 26 kHz to ensure stability can be achieved. The minimum recommended inductor value is 0.47 µH and minimum recommended output capacitor value is 22 µF. The tradeoff between changing these values is that with a larger inductor, there is a reduced peak-to-peak current that yields a greater efficiency at lighter loads. A larger output capacitor will improve transient response by providing a larger hold up reservoir of energy to the output.

The integration of one pole-zero pair within the control loop greatly simplifies compensation. The optimum values for C_{COMP} (in series with a 20 kΩ resistor) are shown in Table 5-2.

TABLE 5-2: COMPENSATION CAPACITOR SELECTION

C / L	22 µF to 47 µF	47 µF to 100 µF	100 µF to 470 µF
0.47 µH	0 pF* to 10 pF	22 pF	33 pF
1 µH	0 pF** to 15 pF	15 pF to 22 pF	33 pF
2.2 µH	15 pF to 33 pF	33 pF to 47 pF	100 pF to 220 pF

*V_{OUT} > 1.2V; **V_{OUT} > 1V.

For compensation values for various output voltages and inductor values refer to Table 5-4.

5.9 Feedback

The MIC22400 provides a feedback pin to adjust the output voltage to the desired level. This pin connects internally to an error amplifier. The error amplifier then compares the voltage at the feedback to the internal 0.7V reference voltage and adjusts the output voltage to maintain regulation. The resistor divider network for a desired V_{OUT} is given by the following equation.

EQUATION 5-6:

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

Where:
V_{REF} = 0.7V
V_{OUT} = The desired output voltage.

A 10 kΩ or lower resistor value from the output to the feedback is recommended because large feedback resistor values increase the impedance at the feedback pin, making the feedback node more susceptible to noise pick-up. A small capacitor (50 pF to 100 pF) across the lower resistor can reduce noise pick-up by providing a low impedance path to ground.

5.10 PWM Operation

The MIC22400 is a voltage mode, pulse width modulation (PWM) controller. By controlling the ratio of on-to-off time, or duty cycle, a regulated DC output voltage is achieved. As load or supply voltage changes, so does the duty cycle to maintain a constant output voltage. In cases where the input supply runs into a dropout condition, the MIC22400 will run at 100% duty cycle.

The MIC22400 provides constant switching from 800 kHz to 4 MHz with synchronous internal MOSFETs. The internal MOSFETs include a 60 mΩ high-side P-Channel MOSFET from the input supply to the switch pin and a 35 mΩ N-Channel MOSFET from

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the switch pin-to-ground. Because the low-side N-Channel MOSFET provides the current during the off cycle, a freewheeling Schottky diode from the switch node-to-ground is not required.

PWM control provides fixed-frequency operation. By maintaining a constant switching frequency, predictable fundamental and harmonic frequencies are achieved. Other methods of regulation, such as burst and skip modes, have frequency spectrums that change with load that can interfere with sensitive communication equipment.

5.11 Sequencing and Tracking

The MIC22400 provides additional pins to provide up/down sequencing and tracking capability for connecting multiple voltage regulators together.

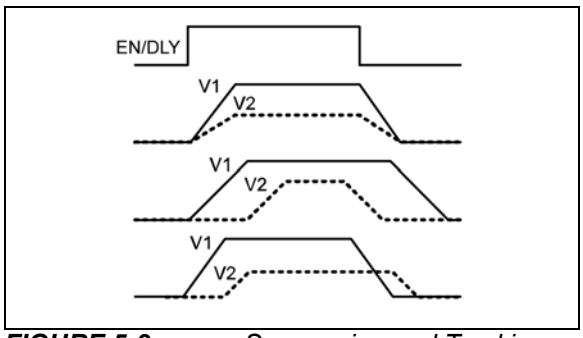

FIGURE 5-3: *Sequencing and Tracking.*

5.11.1 EN/DLY PIN

The EN/DLY pin contains a trimmed, 1 µA current source that can be used with a capacitor to implement a fixed delay in some sequenced power systems. The threshold level for power on is 1.24V with a hysteresis of 20 mV.

5.11.2 DELAY PIN

The DELAY pin also has a 1 µA trimmed current source and a 1 µA current sink that acts with an external capacitor to delay the operation of the Power-On-Reset (POR) output. This can be used also in sequencing outputs in a sequenced system, but with the addition of a conditional delay between supplies; allowing a first up, last down power sequence.

After EN/DLY is driven high, V_{OUT} will start to rise (rate determined by RC capacitor). As the FB voltage goes above 90% of its nominal set voltage, DELAY begins to rise as the 1 µA source charges the external capacitor. When the threshold of 1.24V is crossed, POR is asserted high and DELAY continues to charge to a voltage V_{DD}. When FB falls below 90% of nominal, POR is asserted low immediately. However, if EN/DLY is driven low, POR will fall immediately to the low state and DELAY will begin to fall as the external capacitor is discharged by the 1 µA current sink. When the threshold of V_{DD} – 1.24V is crossed, V_{OUT} will begin to fall at a rate determined by the RC capacitor. As the voltage change in both cases is 1.24V, both rising and falling delays are matched at the t_{POR} value calculated below.

EQUATION 5-7:

$$t_{POR} = \frac{1.24 \times C_{DELAY}}{1.10^{-6}}$$

5.11.3 RC PIN

The RC pin provides a trimmed 1 µA current source/sink similar to the DELAY pin for accurate ramp up (soft-start) and ramp down control. This allows the MIC22400 to be used in systems requiring voltage tracking or ratio-metric voltage tracking at startup.

There are two ways of using the RC pin:

1. Externally driven from a voltage source
2. Externally attached capacitor sets output ramp up/down rate

In the first case, driving RC with a voltage from 0V to V_{REF} will program the output voltage between 0% and 100% of the nominal set voltage.

In the second case, the external capacitor sets the ramp up and ramp down time of the output voltage. The time is given by:

EQUATION 5-8:

$$t_{RAMP} = \frac{0.7 \times C_{RC}}{1.10^{-6}}$$

Where:

t_{RAMP} = The time from 0% to 100% nominal output voltage.

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5.11.4 SEQUENCING AND TRACKING EXAMPLES

There are four distinct variations that are easily implemented using the MIC22400. The two sequencing variations are Windowed and Delayed. The two tracking variants are Normal and Ratio Metric. The following diagrams illustrate methods for connecting two MIC22400's to achieve these requirements:

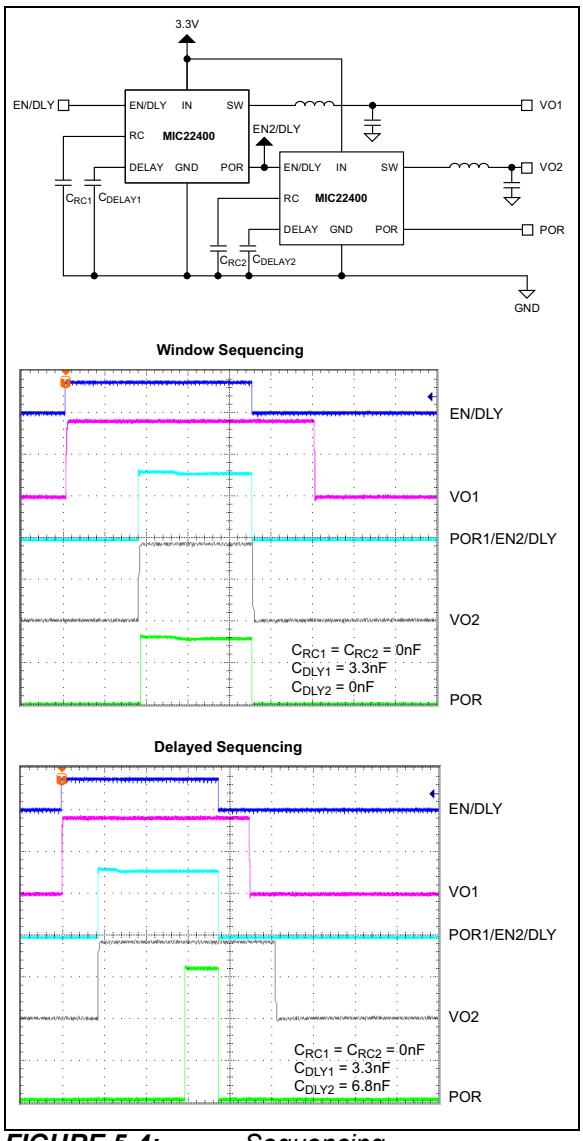

FIGURE 5-4: *Sequencing.*

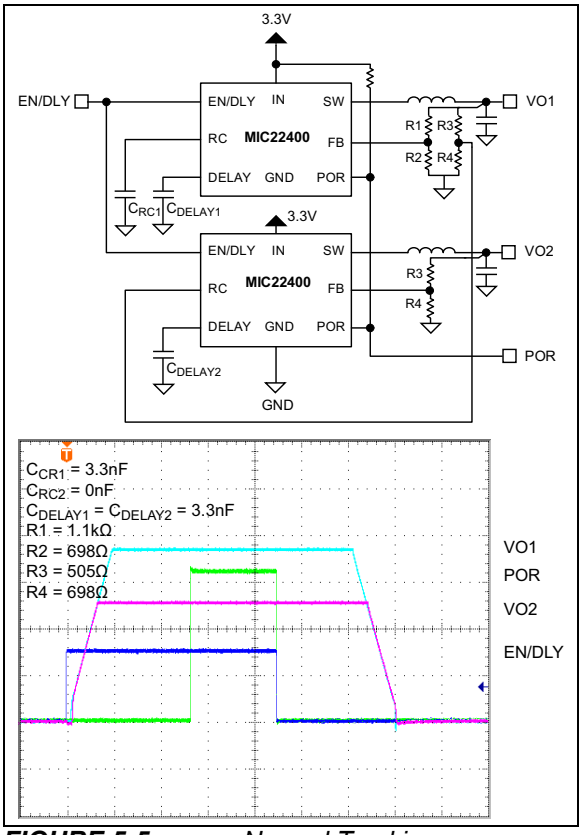

FIGURE 5-5: *Normal Tracking.*

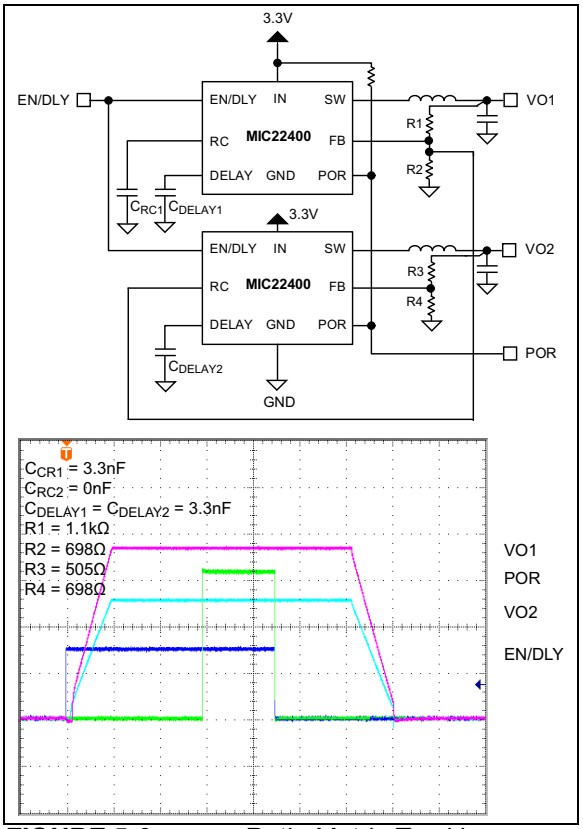

FIGURE 5-6: *Ratio Metric Tracking.*

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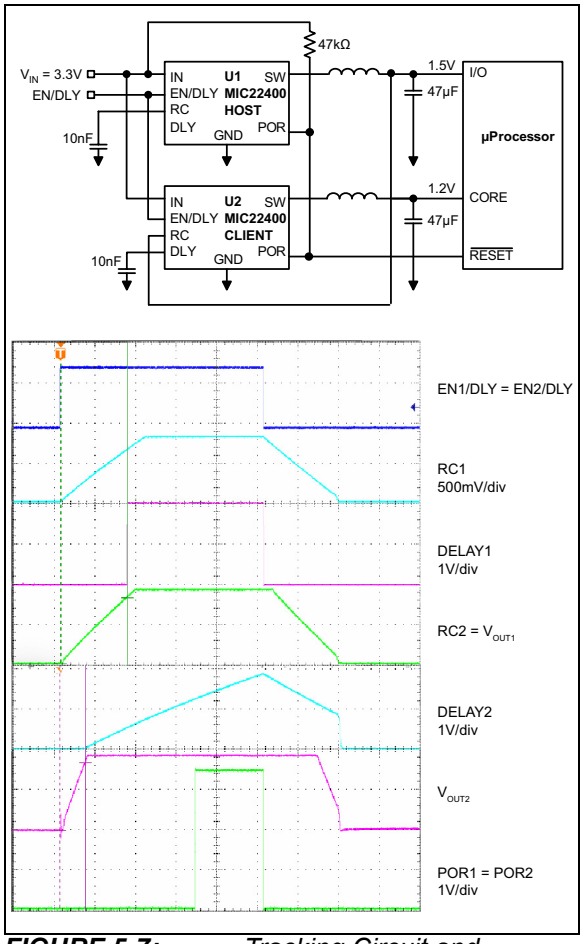

FIGURE 5-7: *Tracking Circuit and Waveform.*

An alternative method here shows an example of a V_{DDQ} and V_{TT} solution for a DDR memory power supply. Note that POR is taken from VO1 as POR_2 will not go high. This is because POR is set high when FB > 0.9 x V_{REF}. In this example, FB_2 is regulated to ½ V_{REF}.

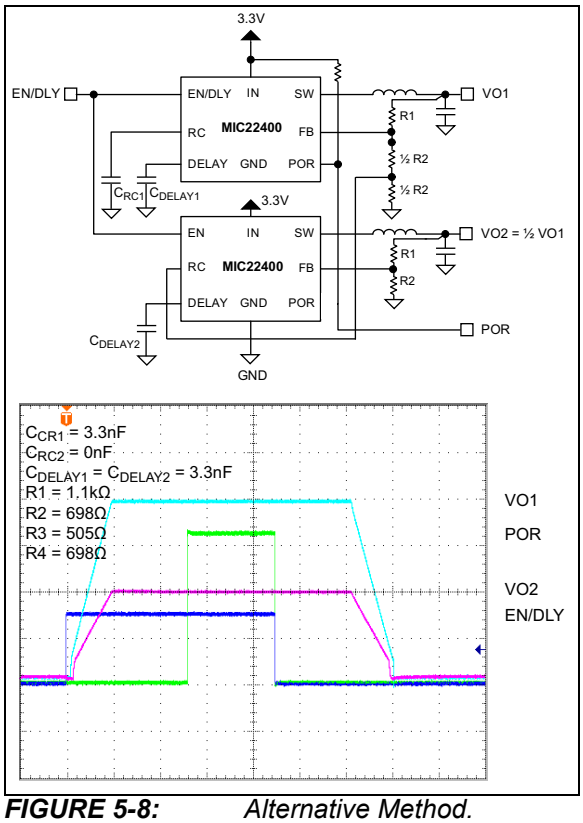

FIGURE 5-8: *Alternative Method.*

5.12 Current Limit

The MIC22400 is protected against overload in two stages. The first is to limit the current in the P-channel switch; the second is overtemperature shutdown.

Current is limited by measuring the current through the high-side MOSFET during its power stroke and immediately switching off the driver when the preset limit is exceeded.

Table 5-9 describes the operation of the current limit circuit. Because the actual $R_{DS(ON)}$ of the P-Channel MOSFET varies part-to-part, over temperature, and with input voltage, simple IR voltage detection is not employed. Instead, a smaller copy of the Power MOSFET (Reference FET) is fed with a constant current which is directly proportional to the factory set current limit. This sets the current limit as a current ratio and thus, is not dependent upon the $R_{DS(ON)}$ value. Current limit is set to 7A nominal. Variations in the scale factor K between the Power PFET and the reference PFET used to generate the limit threshold account for a relatively small inaccuracy.

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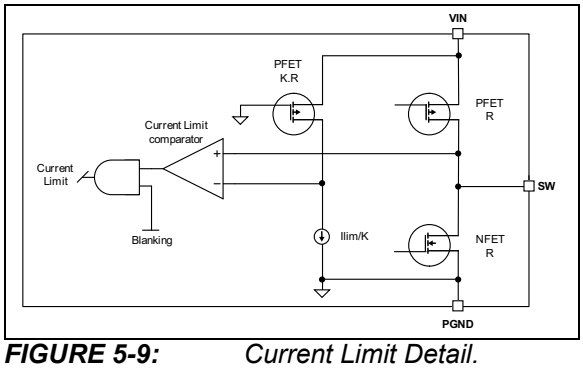

FIGURE 5-9: *Current Limit Detail.*

5.13 Thermal Considerations

The MIC22400 is packaged in the 3 mm x 4 mm VQFN, a package that has excellent thermal performance. This maximizes heat transfer from the junction to the exposed pad (ePad) that connects to the ground plane. The size of the ground plane attached to the exposed pad determines the overall thermal resistance from the junction to the ambient air surrounding the printed circuit board. The junction temperature for a given ambient temperature can be calculated using:

EQUATION 5-9:

$$T_J = T_{AMB} + P_{DISS} \times R\theta_{JA}$$

Where:
P_{DISS} = The power dissipated within the VQFN package and is typically 0.89W at 3A load. This has been calculated for a 1 µH inductor and details can be found in Table 5-3 for reference.
$R\theta_{JA}$ = A combination of junction-to-case thermal resistance ($R\theta_{JC}$) and case-to-ambient thermal resistance ($R\theta_{CA}$), because thermal resistance of the solder connection from the ePad to the PCB is negligible. $R\theta_{CA}$ is the thermal resistance of the ground plane to ambient, so $R\theta_{JA} = R\theta_{JC} + R\theta_{CA}$.
T_{AMB} = The ambient operating temperature.

TABLE 5-3: POWER DISSIPATION (W) FOR 4A OUTPUT

V_{OUT} at 3A	$3V_{IN}$	$3.5V_{IN}$	$4V_{IN}$	$4.5V_{IN}$	$5V_{IN}$
1V	0.732	0.689	0.672	0.668	0.670
1.2V	0.741	0.691	0.668	0.662	0.665
1.8V	0.825	0.764	0.732	0.720	0.720
2.5V	0.894	0.813	0.776	0.762	0.765
3.3V	—	0.817	0.816	0.801	0.800

Example:

To calculate the junction temperature for a 50°C ambient:

EQUATION 5-10:

$$T_J = T_{AMB} + P_{DISS} \times R\theta_{JA}$$

$$T_J = 50 + 0.894 \times 45$$

$$T_J = 90.2°C$$

This is below the maximum of 125°C.

TABLE 5-4: COMPENSATION SELECTION

V_{IN} = 5V								
V_{OUT}	L	C_{OUT}	C_{COMP}	R_{COMP}	C_{FF}	R_{FF}	C_{FB}	R_{FB}
4.2V	1.5 µH	2 x 47 µF	100 pF	20 kΩ	1 nF	4.7 kΩ	100 pF	953Ω

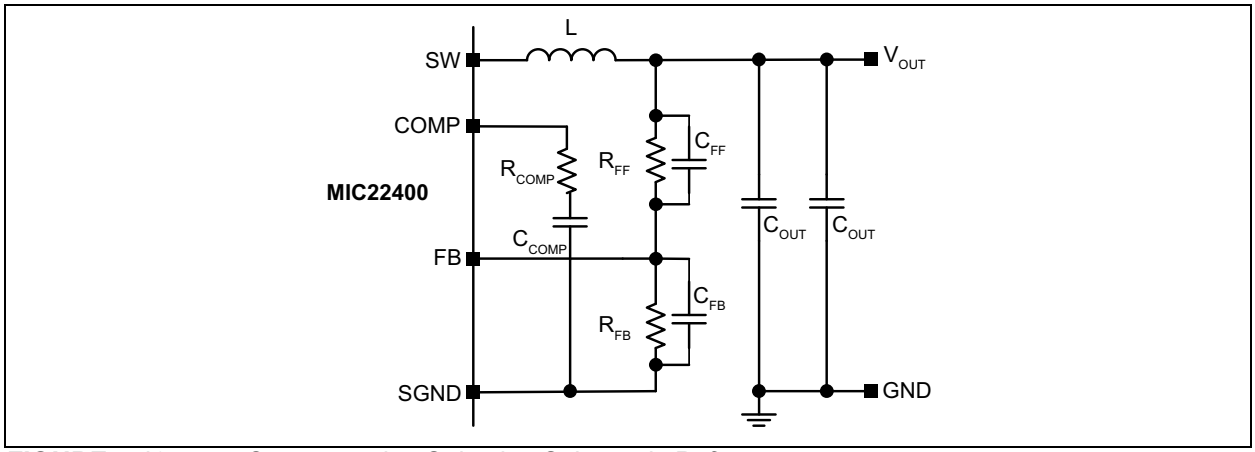

FIGURE 5-10: *Compensation Selection Schematic Reference.*

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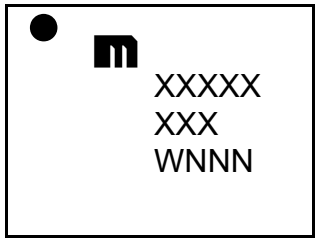
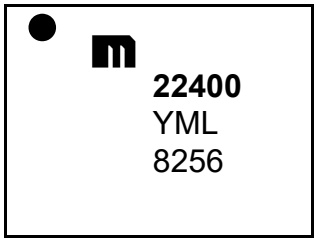
6.0 PACKAGING INFORMATION

6.1 Package Marking Information

20-Lead VQFN
(4 mm x 3 mm)



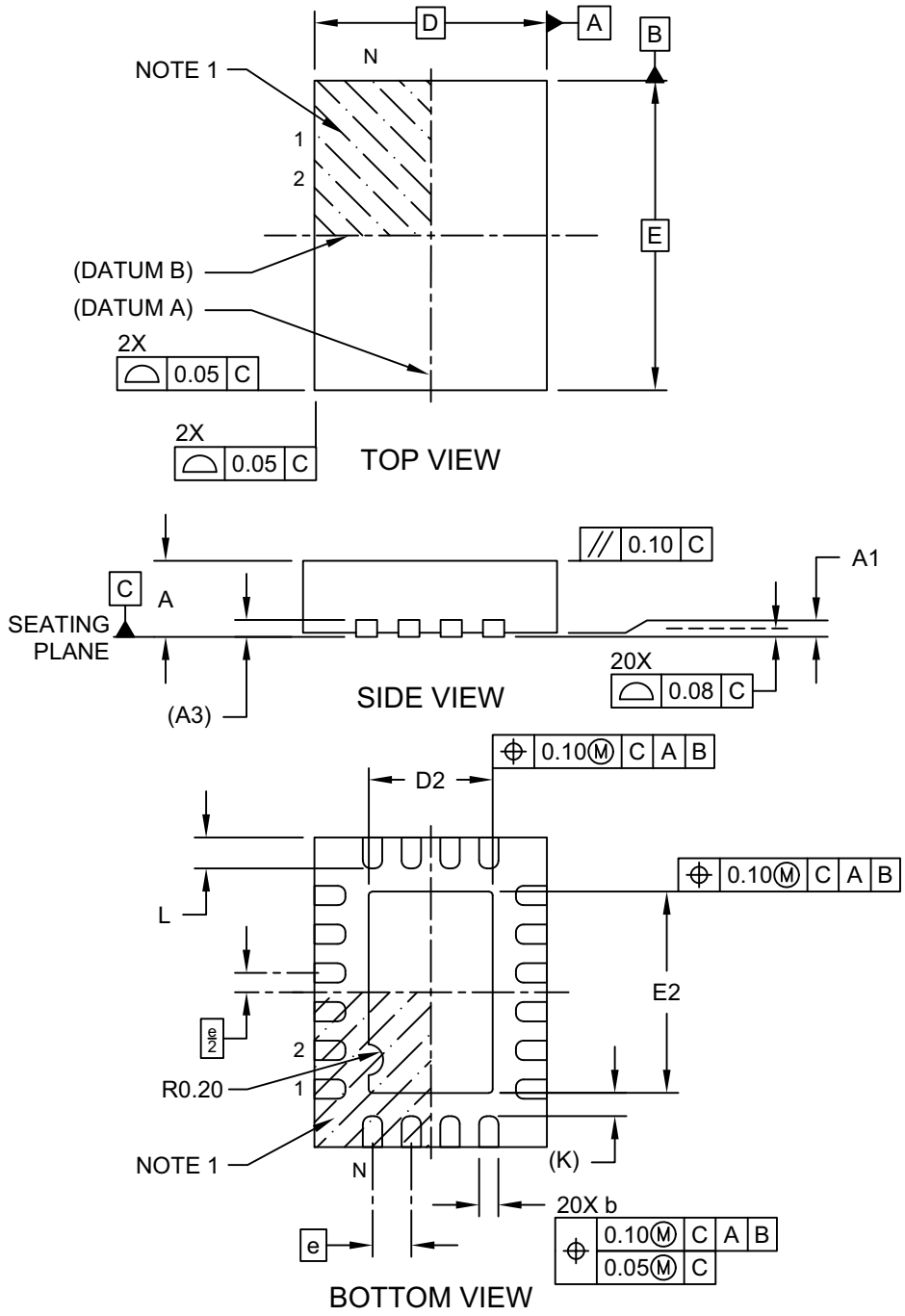
Example:



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.	

20-Lead Very Thin Plastic Quad Flat, No Lead Package (NQA) - 3x4 mm Body [VQFN] With 1.6x2.6 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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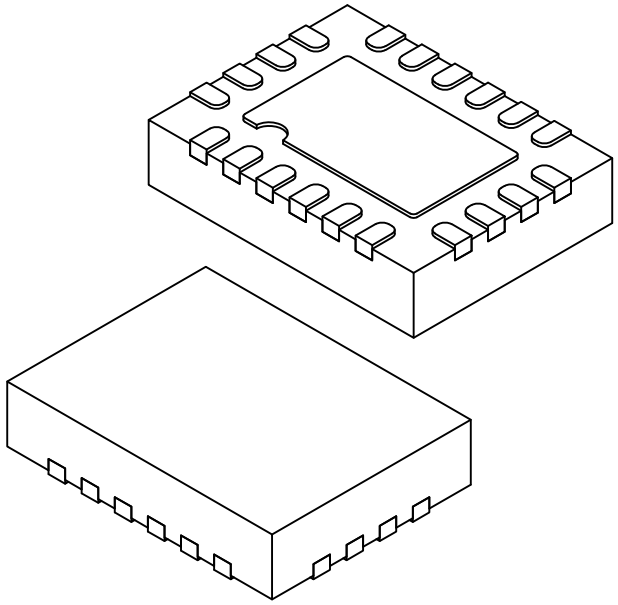
20-Lead Very Thin Plastic Quad Flat, No Lead Package (NQA) - 3x4 mm Body [VQFN] With 1.6x2.6 mm Exposed Pad

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		20	
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		3.00 BSC	
Exposed Pad Length	D2	1.55	1.60	1.65
Overall Width	E		4.00 BSC	
Exposed Pad Width	E2	2.55	2.60	2.65
Terminal Width	b	0.20	0.25	0.30
Terminal Length	L	0.35	0.40	0.45
Terminal-to-Exposed-Pad	K		0.20 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.

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20-Lead Very Thin Plastic Quad Flat, No Lead Package (NQA) - 3x4 mm Body [VQFN] With 1.6x2.6 mm Exposed Pad

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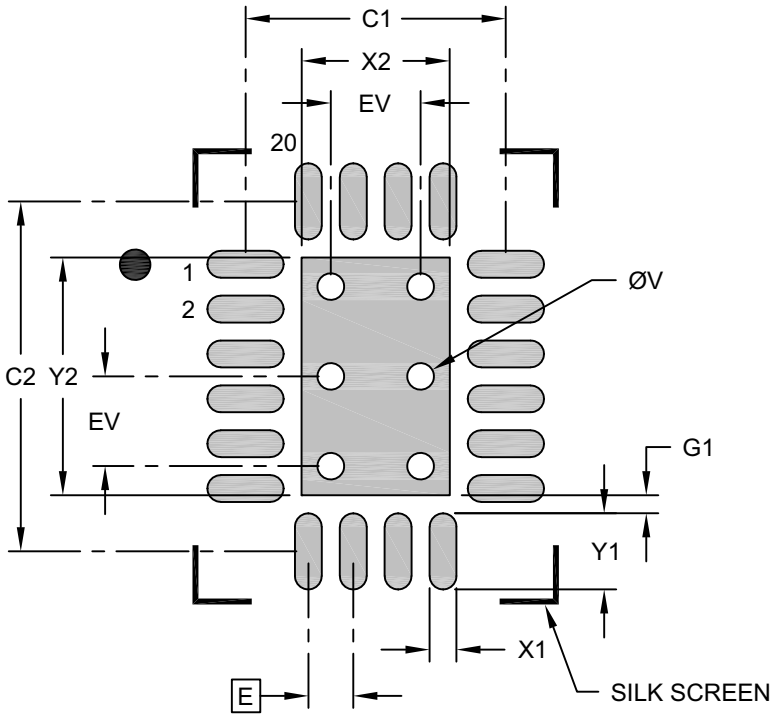

RECOMMENDED LAND PATTERN

Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Contact Pitch	E		0.50 BSC	
Center Pad Width	X2			1.65
Center Pad Length	Y2			2.65
Contact Pad Spacing	C1		2.90	
Contact Pad Spacing	C2		3.90	
Contact Pad Width (X20)	X1			0.30
Contact Pad Length (X20)	Y1			0.85
Contact Pad to Center Pad (X20)	G1	0.20		
Contact Pad to Contact Pad (X20)	G2	0.20		
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 C04-3106 Rev B

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APPENDIX A: REVISION HISTORY

Revision B (September 2022)

- Updated document layout.
- Made minor corrections for grammar.
- Updated Electrical Characteristics.
- Updated description of Figure 2-26 and Figure 2-27.
- Updated Equation 5-2.
- Section 4.0, “Tracking Circuit” was removed. Content was included in Section 5.11.4, Sequencing and Tracking Examples. Figure 4-1 became Figure 5-7.
- Updated Figure 5-7 to reflect Microchip terminology. The SPI standard uses the terminology “Master” and “Slave”. The equivalent Microchip terminology used in this document is “Host” and “Client” respectively.
- Updated **Section 6.0 “Packaging Information”**.
- Removed TSSOP package (mentioned in: Features, Package Types, Temperature Specifications, **Section 3.0 “Pin Descriptions”**, Section 5.13, Thermal Considerations, **Section 6.0 “Packaging Information”** and Product Identification System).

Revision A (August 2019)

- Converted Micrel document MIC22400 to Microchip data sheet template DS20006243A.
- Minor grammatical text changes throughout.
- Evaluation Board Schematic, BOM, and PCB Layout sections from original data sheet moved to the part’s Evaluation Board User’s Guide.

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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 NO.	X	XX	-XX
Device	Junction Temp. Range	Package	Media Type

Device:	MIC22400:		4A Integrated Switch Synchronous Buck Regulator with Frequency Programmable up to 4 MHz
Junction Temperature Range:	Y	=	–40°C to +125°C, RoHS-Compliant
Package:	ML	=	20-Lead 3 mm x 4 mm VQFN
Media Type:	TR	=	5,000/Reel (VQFN option)

Examples:

a) MIC22400YML-TR: MIC22400, Adj. Output Voltage, –40°C to +125°C Temp. Range, 20-Lead VQFN, 5,000/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.

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