MIC22400

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

General Description

The Micrel MIC22400 is a high-efficiency, 4A integrated switch synchronous buck (step-down) regulator. The MIC22400 is optimized for highest efficiency, achieving over 90% efficiency while still switching at 1MHz 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. The 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.

The MIC22400 is available in a 20-pin 3mm x 4mm MLF® and thermally enhanced 20-pin e-TSSOP with a junction operating range from –40°C to +125°C.

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

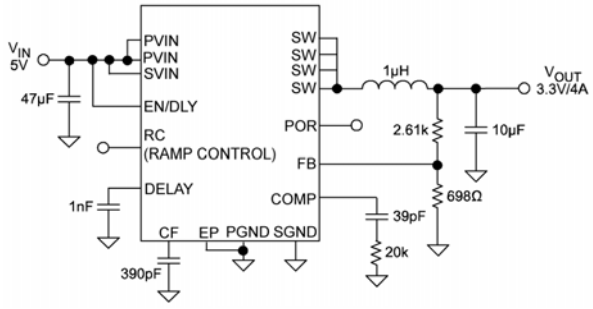
Features

- 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 300kHz to 4MHz
- 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 3mm x 4mm MLF®
- 20-pin e-TSSOP
- –40°C to +125°C junction temperature range

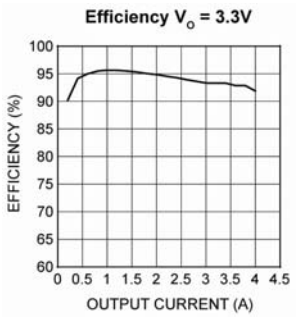
Applications

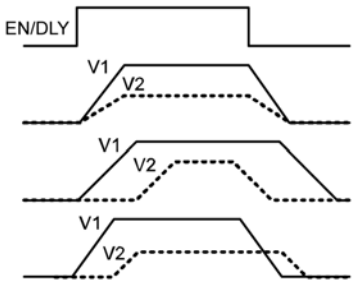
- High power density point-of-load conversion
- Servers and routers
- DVD recorders
- Computing peripherals
- Base stations
- FPGAs, DSP and low-voltage ASIC power

Typical Application



MIC22400 4A Synchronous Buck Regulator





Sequencing & Tracking

Ramp Control is a trademark of Micrel, Inc.
MLF and *Micro*LeadFrame are registered trademarks of Amkor Technology, Inc.

Ordering Information

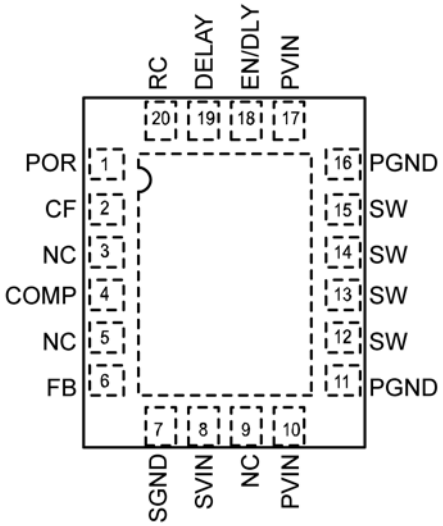
Part Number	Voltage	Junction Temperature Range	Package	Lead Finish
MIC22400YML	Adjustable	–40° to +125°C	20-Pin 3x4 MLF®*	Pb-Free
MIC22400YTSE**	Adjustable	–40° to +125°C	20-Pin e-TSSOP	Pb-Free

Notes:

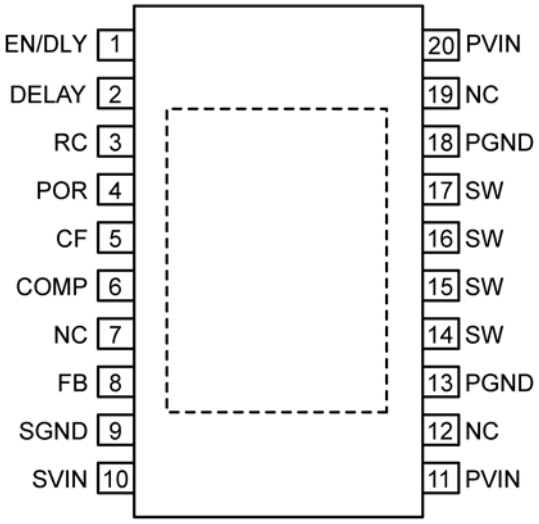
***** MLF is a Green RoHS compliant package. Lead finish is NiPdAu. Mold compound is Halogen Free.

****** Contact Micrel Marketing for YTSE availability.

Pin Configuration



20-Pin 3mm x 4mm MLF® (ML)



20-Pin e-TSSOP (TS)

Pin Description

Pin Number MLF-20	Pin Number e-TSSOP-20	Pin Name	Description
1	4	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	5	CF	Adjustable frequency with external capacitor. Refer to table on page 12.
3, 5, 9	7, 12, 19	NC	Not connected internally.
4	6	COMP	Compensation pin (Input): Place a RC to GND to compensate the device, see applications section.
6	8	FB	Feedback (Input): Input to the error amplifier, connect to the external resistor divider network to set the output voltage.
7	9	SGND	Signal Ground (Signal): Ground
8	10	SVIN	Signal Power Supply Voltage (Input): Requires bypass capacitor to GND.
10, 17	11, 20	PVIN	Power Supply Voltage (Input): Requires bypass capacitor to GND.
11, 16	13, 18	PGND	Power Ground (Signal): Ground
12, 13, 14, 15	14, 15, 16, 17	SW	Switch (Output): Internal power MOSFET output switches.

Pin Description (Continued)

Pin Number MLF-20	Pin Number e-TSSOP-20	Pin Name	Description
18	1	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 1µA 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	2	DELAY	Delay (Input): Capacitor-to-ground sets internal delay timer. Timer delays POR output at turn-on and ramp down at turn-off.
20	3	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	EP	GND	Exposed Pad (Power): Must make a full connection to a GND plane.

Absolute Maximum Ratings[1]

Supply Voltage (V_{IN}) 6V
Output Switch Voltage (V_{SW}) 6V
Output Switch Current (I_{SW}) 6A
Logic Input Voltage (V_{EN}, V_{LQ}) ..... V_{IN} to –0.3V
Lead Temperature ..... 260°C
Storage Temperature (T_s) ..... –65°C to +150°C
ESD Rating ..... Note 3

Operating Ratings[2]

Supply Voltage (V_{IN}) ..... 2.6V to 5.5V
Junction Temperature (T_J) ..... –40°C ≤ T_J ≤ +125°C
Thermal Resistance
3x4 MLF-20 (θ_{JA}) ..... 45°C/W
e-TSSOP-20 (θ_{JA}) ..... 32.2°C/W

Electrical Characteristics[4]

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

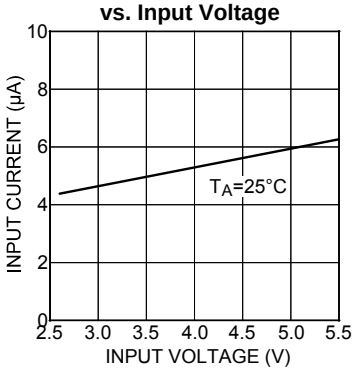
Parameter	Condition	Min.	Typ.	Max.	Units
Supply Voltage Range		**2.6**		**5.5**	V
Undervoltage Lockout Threshold	(turn-on)	**2.4**	2.5	**2.6**	V
UVLO Hysteresis			280		mV
Quiescent Current, PWM Mode	V_{EN} ≥1.34V; V_{FB} = 0.9V (not switching)		1.3	**2.0**	mA
Shutdown Current	V_{EN} = 0V		5	**10**	µA
[Adjustable] Feedback Voltage	± 1% ± 2% (over temperature)	0.693 **0.686**	0.7	0.707 **0.714**	V V
Oscillator Frequency		**0.8**	1	**1.2**	MHz
FB Pin Input Current			1		nA
Current Limit	V_{FB} = 0.5V	**4**	7	**10**	A
Output Voltage Line Regulation	V_{OUT} 1.2V; V_{IN} = 2.6 to 5.5V, I_{LOAD}= 100mA		0.2		%
Output Voltage Load Regulation	100mA < I_{LOAD} < 4000mA, V_{IN} = 3.3V		0.2		%
Maximum Duty Cycle	V_{FB} ≤ 0.5V	100			%
Switch ON-Resistance PFET Switch ON-Resistance NFET	I_{SW} = 1000mA; V_{FB}=0.5V I_{SW} = 1000mA; V_{FB}=0.9V		0.060 0.035		Ω Ω
EN/DLY Threshold Voltage		**1.14**	1.24	**1.34**	V
EN/DLY Source Current	V_{IN} = 2.6 to V_{IN} = 5.5V	**0.7**	1	**1.3**	µA
RC Pin I_{RAMP}	Ramp Control Current	**0.7**	1	**1.3**	µA
POR $I_{PG(LEAK)}$	V_{PORH} = 5.5V; POR = High			1 **2**	µA µA
POR $V_{PG(LO)}$	Output Logic-Low Voltage (undervoltage condition), I_{POR} = 5mA		135		mV
POR V_{PG}	Threshold, % of V_{OUT} below nominal	**7.5**	10	**12.5**	%
	Hysteresis		2.7		%
Over-Temperature Shutdown			150		°C
Over-Temperature Shutdown Hysteresis			10		°C

Notes:

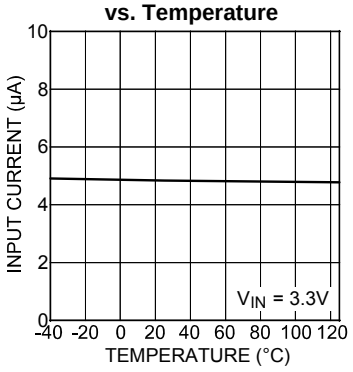
1. Exceeding the absolute maximum rating may damage the device.
2. The device is not guaranteed to function outside its operating rating.
3. Devices are ESD sensitive. Handling precautions recommended.
4. Specification for packaged product only.

Typical Characteristics

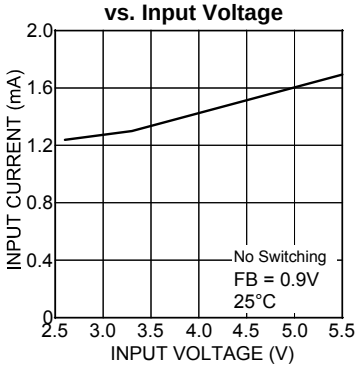
Shutdown Current vs. Input Voltage



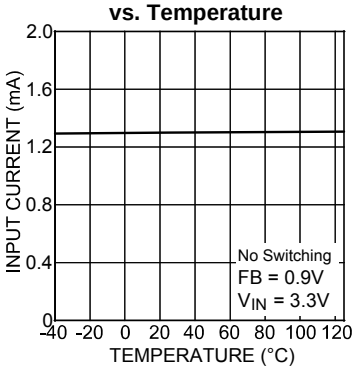
Shutdown Current vs. Temperature



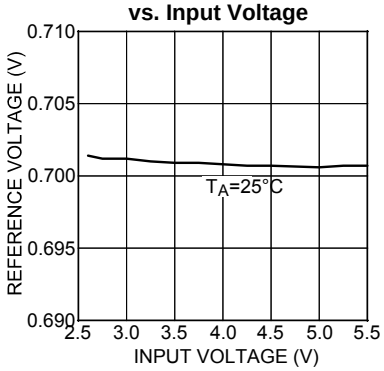
Quiescent Current vs. Input Voltage



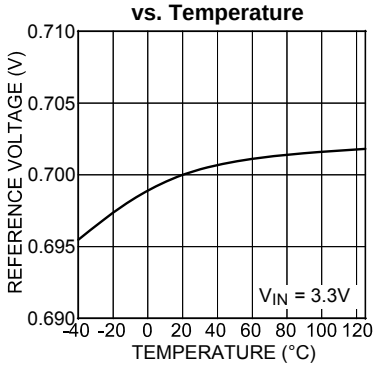
Quiescent Current vs. Temperature



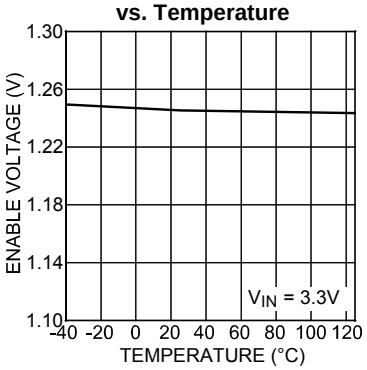
Reference Voltage vs. Input Voltage



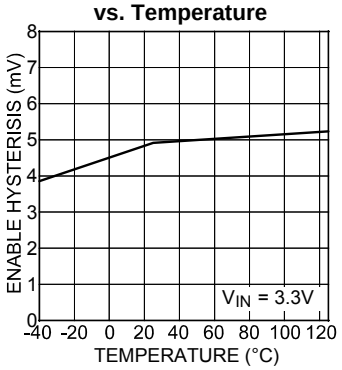
Reference Voltage vs. Temperature



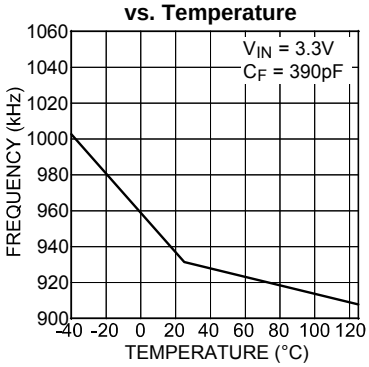
Enable Voltage vs. Temperature



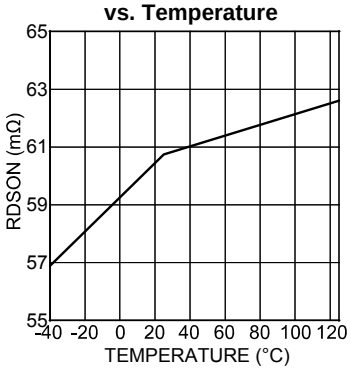
Enable Hysterisis vs. Temperature



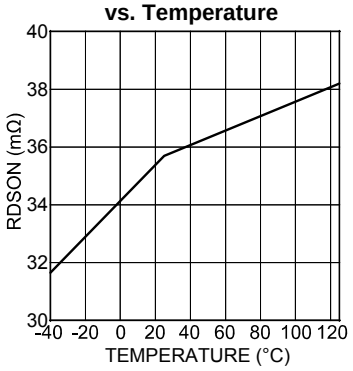
Frequency vs. Temperature



P-Channel RDS ON vs. Temperature

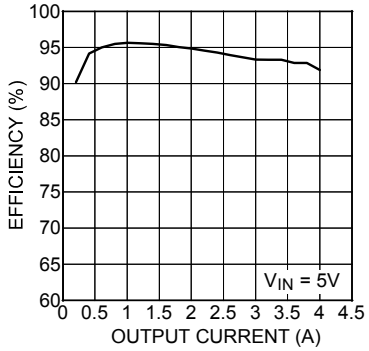


N-Channel RDS ON vs. Temperature

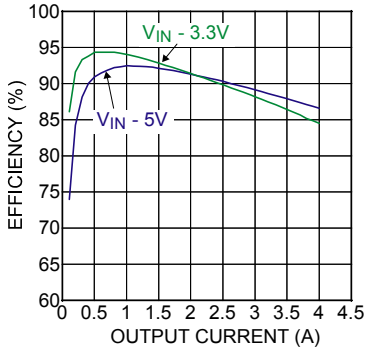


Typical Characteristics (Continued)

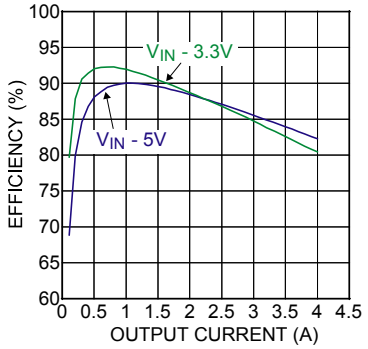
Efficiency V O = 3.3V



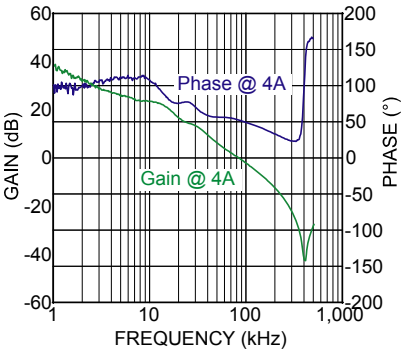
Efficiency V O = 1.8V



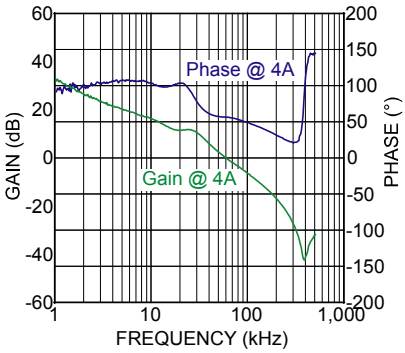
Efficiency V O = 1.2V



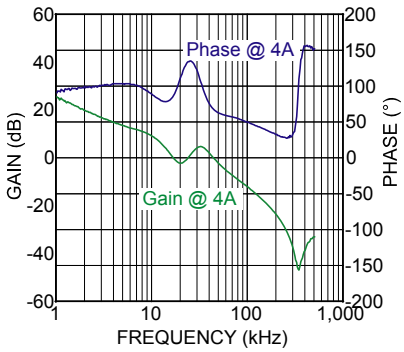
VIN = 5.0V, V OUT = 1.2V



VIN = 3.3V, V OUT = 1.2V

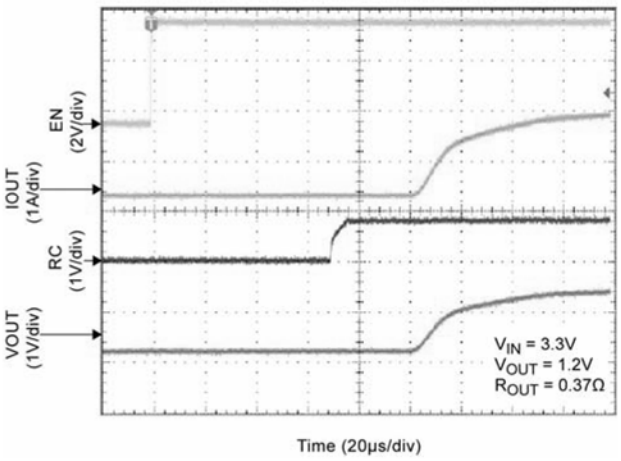


VIN = 3.3V, V OUT = 1.8V

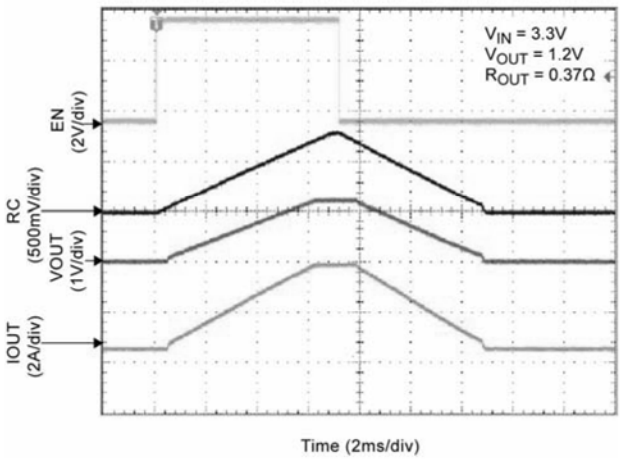


Functional Characteristics

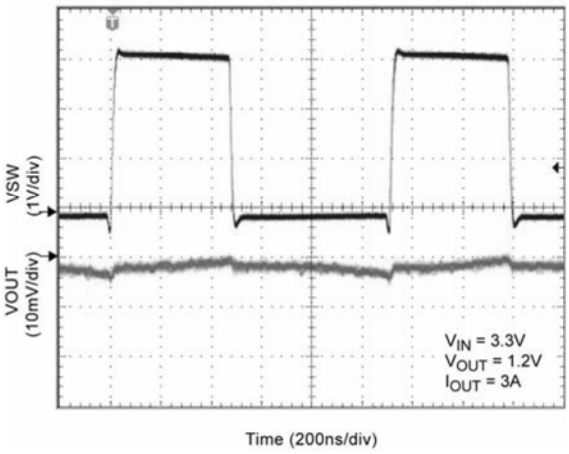
Enable Turn-On without RC



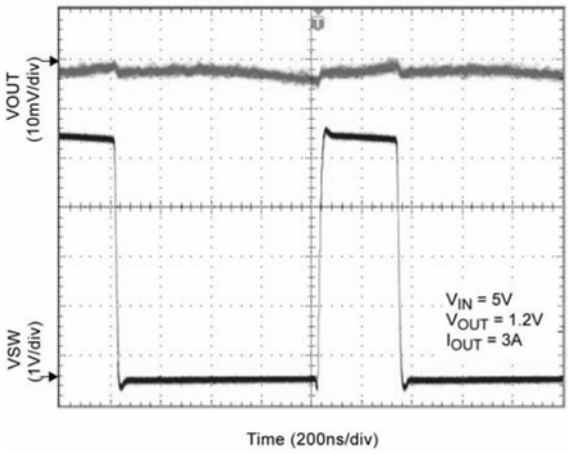
Enable Turn-On with RC (10nF)



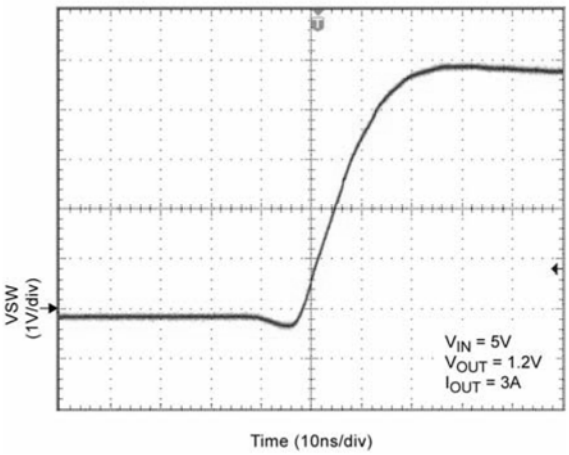
Switch Node / Output Voltage



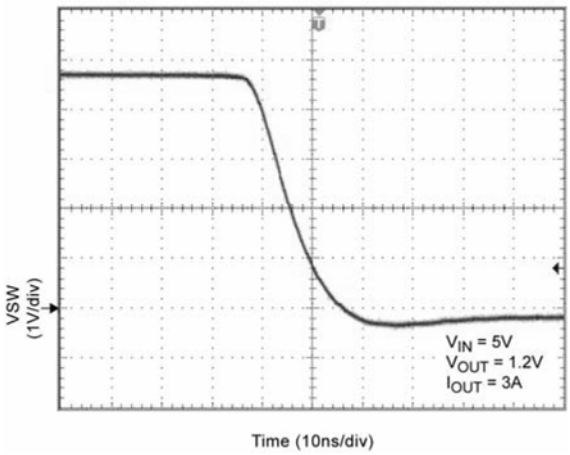
Switch Node / Output Voltage



Switch Voltage (Rising Edge)

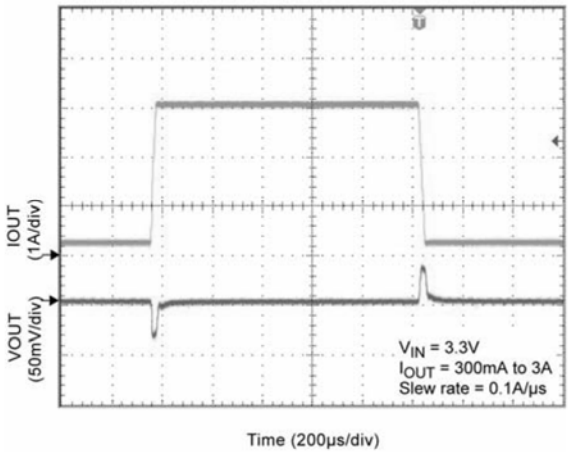


Switch Voltage (Rising Edge)

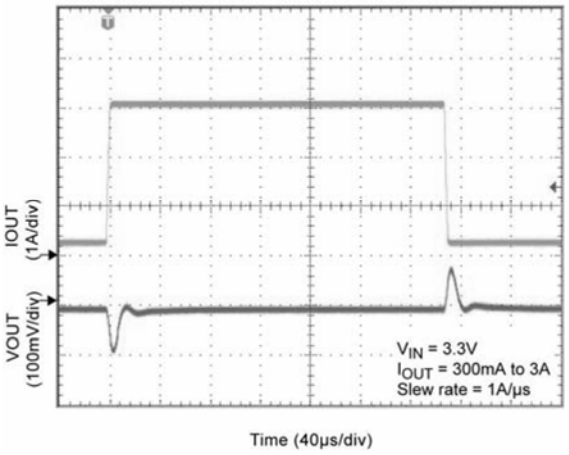


Functional Characteristics (Continued)

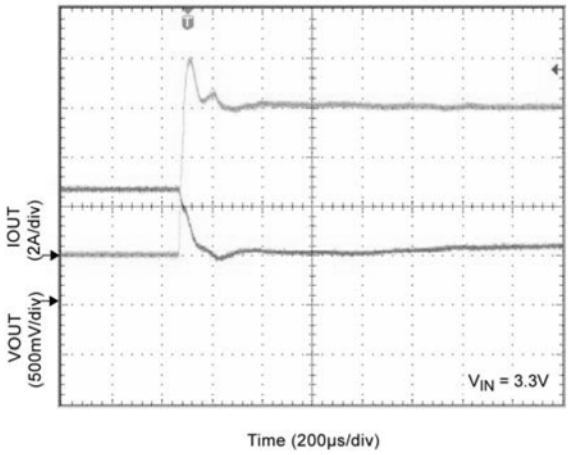
Load Transient @ 0.1A/µs



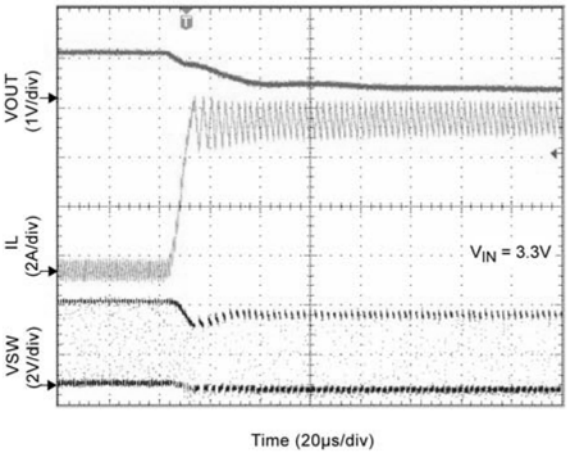
Load Transient @ 0.1A/µs



Load Shorted



Load Shorted



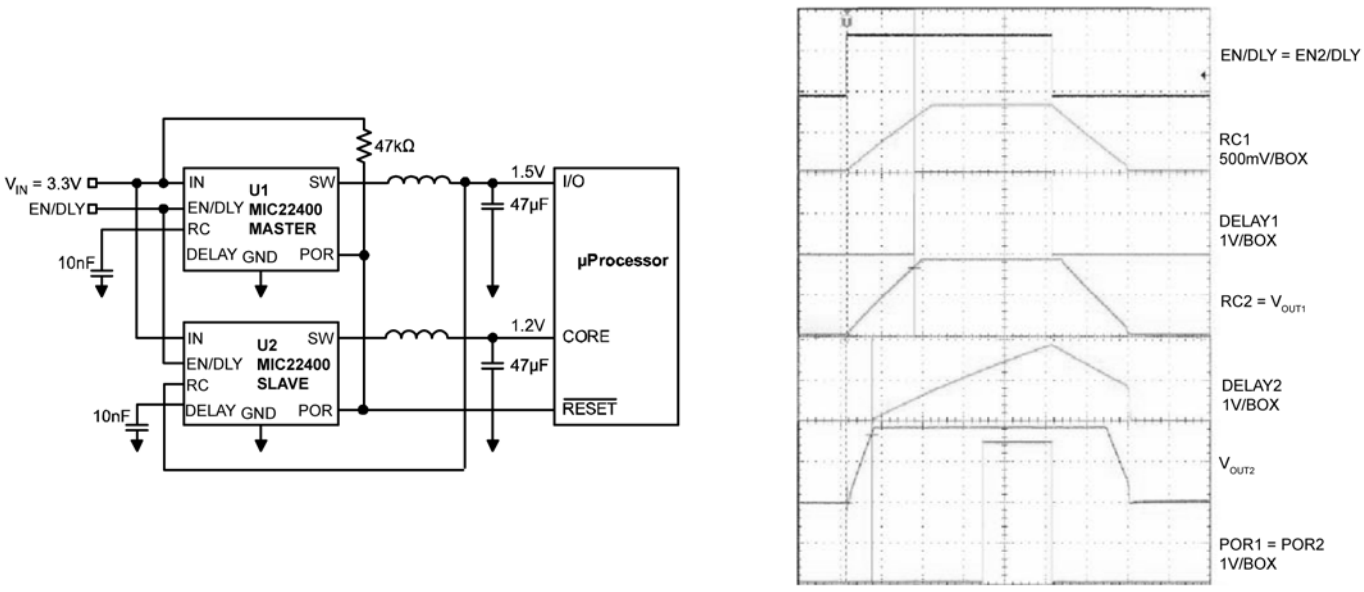


Figure 1. Tracking Circuit and Waveform

Functional Diagram

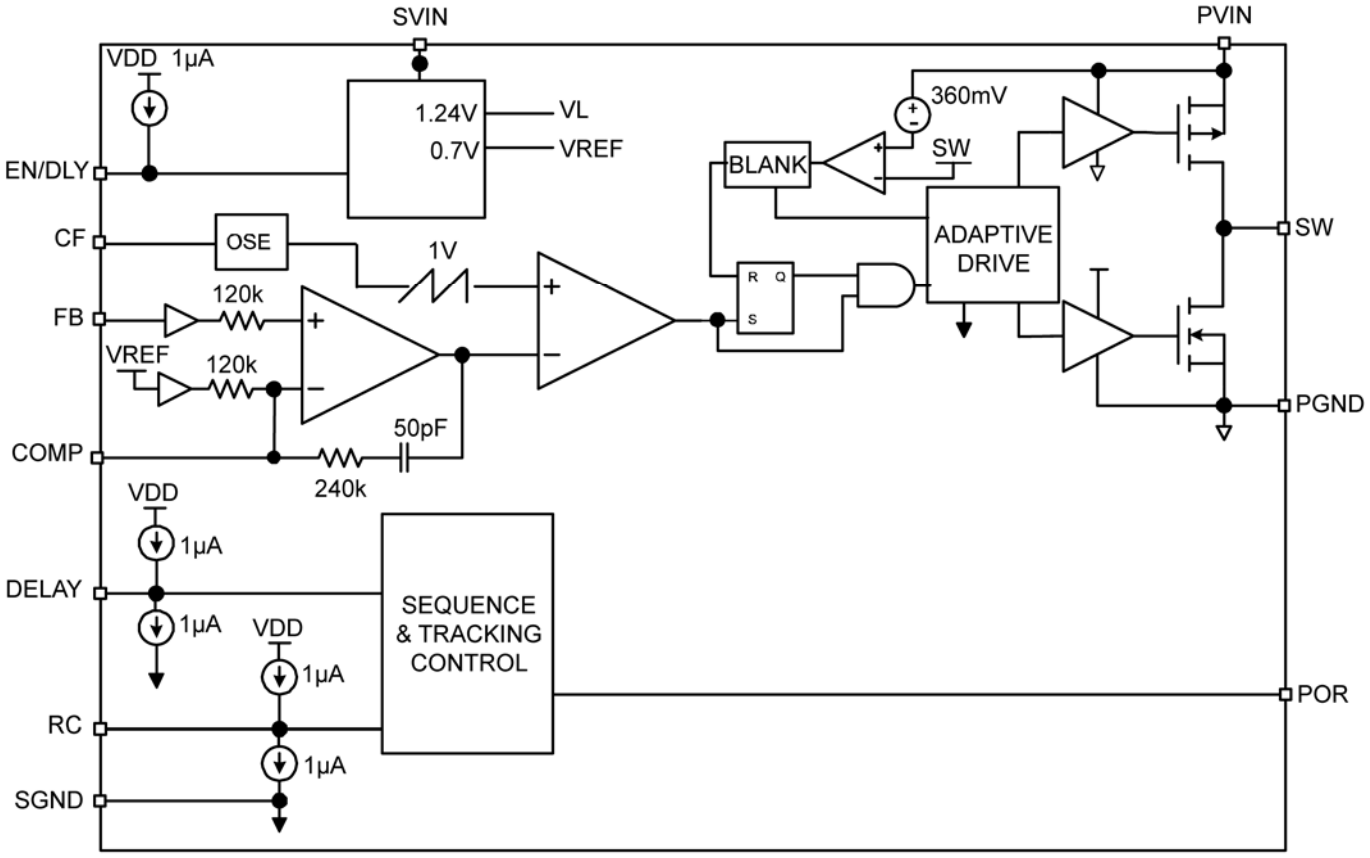


Figure 2. MIC22400 Block Diagram

Functional Description

PVIN, SVIN

PVIN is the input supply to the internal 60mΩ 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 22µF ceramic is recommended for bypassing each PVIN supply.

EN/DLY

This pin is internally fed with a 1µA 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.

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 1µA current source and V_{OUT} slew rate is proportional to the capacitor and the 1µA source.

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 (1µA) starts to charge the external capacitor. At 1.24V, POR is asserted high.

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.

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.

POR

This is an open drain output. A 47k 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 Good (PG) function, the delay can be set to a minimum. This can be done by removing the DELAY pin capacitor.

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.

CF

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

SGND

Internal signal ground for all low power sections.

PGND

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

Application Information

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

Component selection

Input Capacitor

A minimum 22µF 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.

Output Capacitor

The MIC22400 was designed specifically for the use of ceramic output capacitors. A 100µF can be increased to improve transient performance. Since 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.

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 0.47µH to 4.7µH 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 datasheet.

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.

EN/DLY Capacitor

EN/DLY pin sources 1µA out of the IC to allow a startup delay to be implemented. The delay time is simply the time it takes 1µA to charge $C_{EN/DLY}$ to 1.25V. Therefore:

$$T_{EN/DLY} = \frac{1.24 \cdot C_{EN/DLY}}{1.10^{-6}}$$

CF Capacitor

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

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

Table 1. CF vs. Frequency

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

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 800kHz to 300kHz.:

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

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

Efficiency Considerations

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

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

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 hand held 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 $RDS_{(ON)}$ 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 800kHz to 4MHz and the switching transitions make up the switching losses.

Figure 3 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.

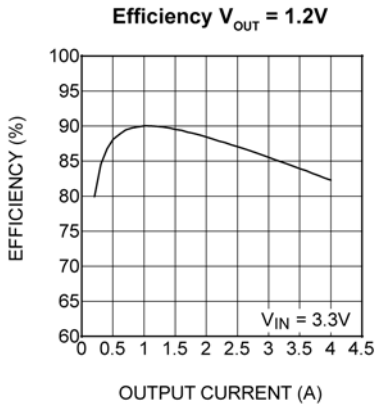


Figure 3. Efficiency Curve

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

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

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

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

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 reduce the peak-to-peak inductor ripple current, which minimize losses. Figure 4 illustrates the effects of inductance value at light load.

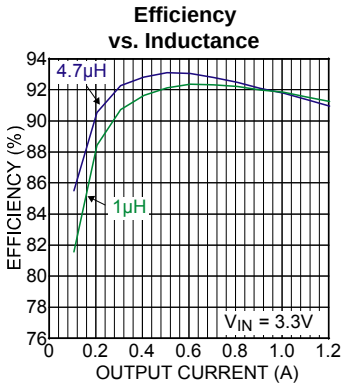


Figure 4. Efficiency vs. Inductance

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 1MHz 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 – 200kHz, the MIC22400 is capable of extremely fast transient responses.

The MIC22400 is designed to be stable with a typical application using a 1µH inductor and a 47µF ceramic (X5R) output capacitor. These values can be varied dependant upon the tradeoff between size, cost and efficiency, keeping the LC natural frequency ($\frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$) ideally less than 26 kHz to ensure stability can be achieved. The minimum recommended inductor value is 0.47µH and minimum recommended output capacitor value is 22µF. The tradeoff between changing these values is that with a larger inductor, there is a reduced peak-to-peak current which 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 20k resistor) are shown in Table 2.

C→ / L↓	22-47µF	47µF-100µF	100µF-470µF
0.47µH	0*-10pF	22pF	33pF
1µH	0†-15pF	15-22pF	33pF
2.2µH	15-33pF	33-47pF	100-220pF
* VOUT > 1.2V, † VOUT > 1V			

Table 2. Compensation Capacitor Selection

Note: For compensation values for various output voltages and inductor values refer to Table 4.

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:

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

where V_{REF} is 0.7V and V_{OUT} is the desired output voltage. A 10kΩ or lower resistor value from the output to the feedback is recommended since large feedback resistor values increase the impedance at the feedback pin, making the feedback node more susceptible to noise pick-up. A small capacitor (50pF – 100pF) across the lower resistor can reduce noise pick-up by providing a low impedance path to ground.

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 800kHz to 4MHz with synchronous internal MOSFETs. The internal MOSFETs include a 60mΩ high-side P-Channel MOSFET from the input supply to the switch pin and a 30mΩ N-Channel MOSFET from the switch pin-to-ground. Since 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.

Sequencing and Tracking

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

EN/DLY Pin

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

DELAY Pin

The DELAY pin also has a 1µA trimmed current source and a 1µA current sink which 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 pin begins to rise as the 1µA source charges the external capacitor. When the threshold of 1.24V is crossed, POR is asserted high and DELAY pin continues to charge to a voltage V_{DD}. When FB falls below 90% of nominal, POR is asserted low immediately. However, if EN/DLY pin is driven low, POR will fall immediately to the low state and DELAY pin will begin to fall as the external capacitor is discharged by the 1µA 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 $T_{POR} = \frac{1.24 \cdot C_{DELAY}}{1.10^{-6}}$.

RC Pin

The RC pin provides a trimmed 1µA 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

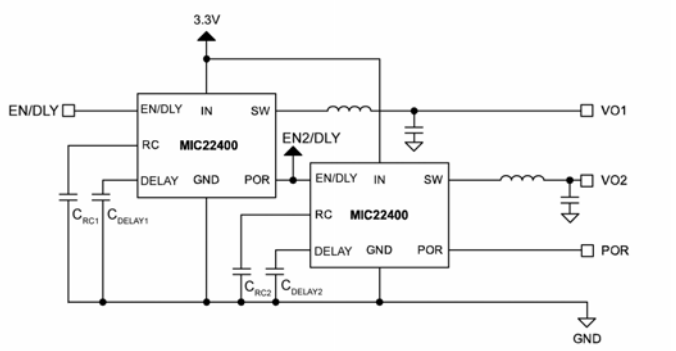
In the first case, driving RC with a voltage from 0V to V_{REF} will program the output voltage between 0 and 100% of the nominal set voltage.

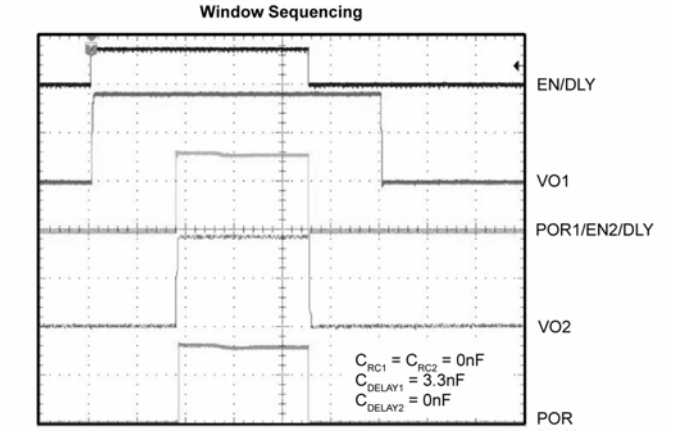
In the second case, the external capacitor sets the ramp up and ramp down time of the output voltage. The time is given by $T_{RAMP} = \frac{0.7 \cdot C_{RC}}{1.10^{-6}}$ where T_{RAMP} is the time from 0 to 100% nominal output voltage.

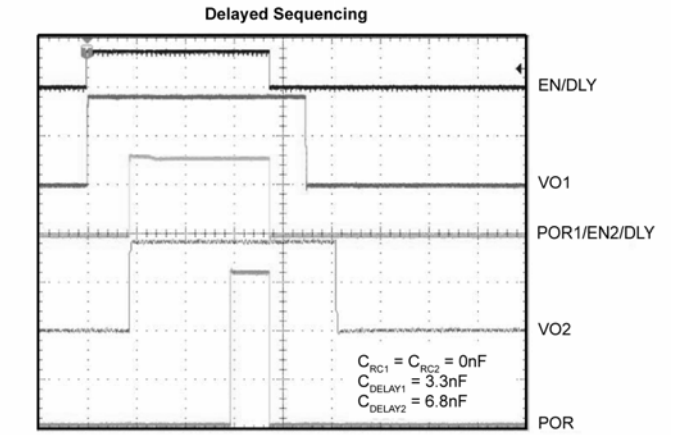
Sequencing and Tracking Examples

There are four distinct variations which 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:

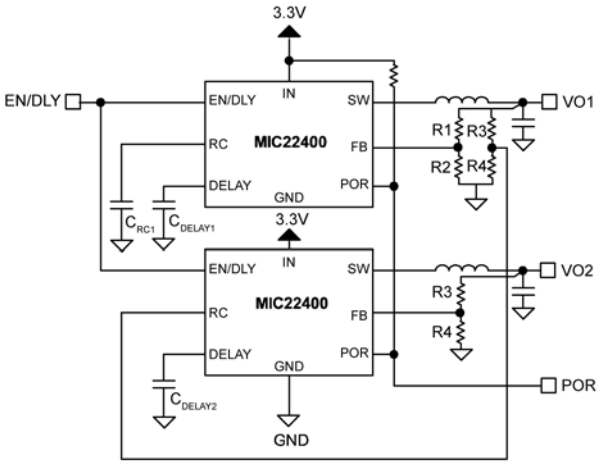
Sequencing:

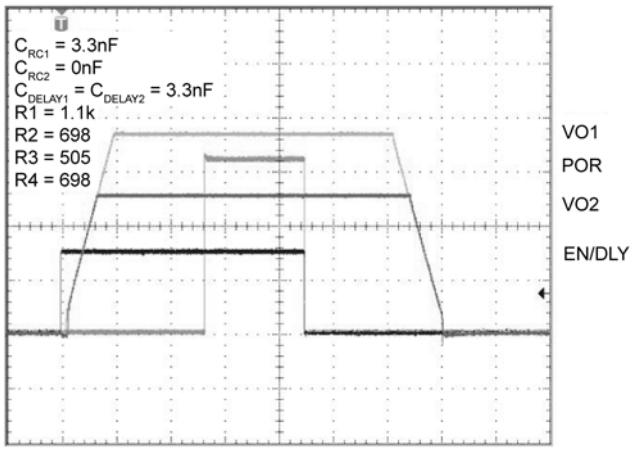




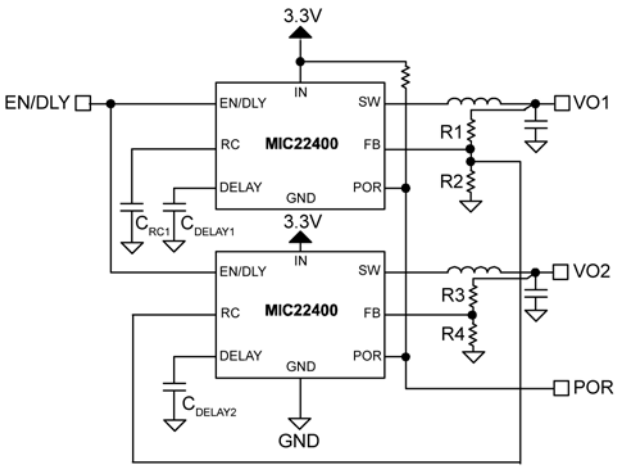


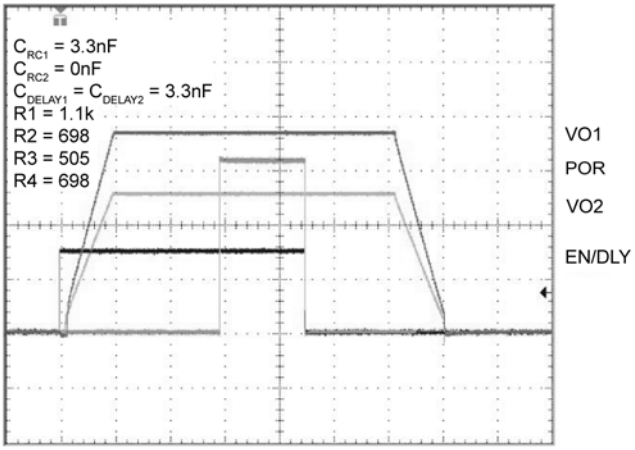
Normal Tracking:



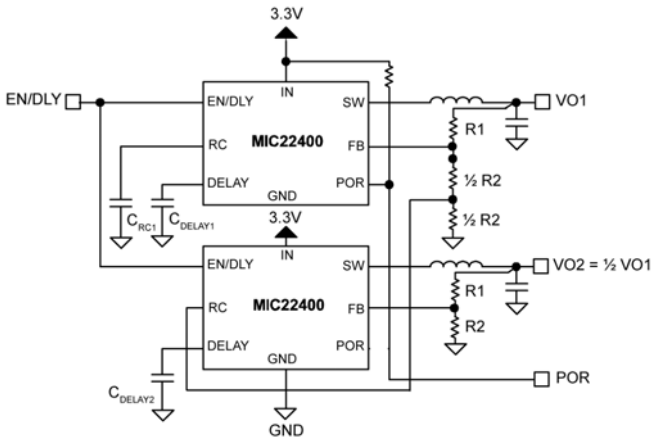


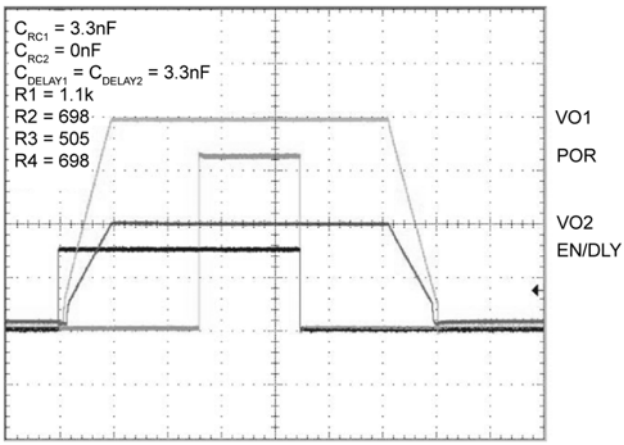
Ratio Metric Tracking:





An alternative method here shows an example of a V_{DDQ} & 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·V_{REF}. In this example, FB_2 is regulated to ½·V_{REF}.





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 over-temperature 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.

Figure 5 describes the operation of the current limit circuit. Since the actual RDS_{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 a directly proportional to the factory set current limit. This sets the current limit as a current ratio and thus, is not dependant upon the RDS_{ON} value. Current limit is set to 6A 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.

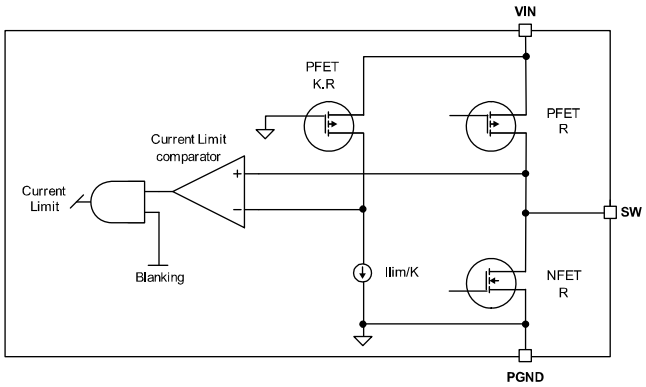


Figure 5. Current-Limit Detail

Thermal Considerations

The MIC22400 is packaged in the MLF® 3mm x 4mm, a package that has excellent thermal performance equaling that of the larger TSSOP packages. This maximizes heat transfer from the junction to the exposed pad (ePAD) which 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:

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

where:

- P_{DISS} is the power dissipated within the MLF® package and is typically 0.89W at 3A load. This has been calculated for a 1µH inductor and details can be found in Table 3 for reference.
- $R\theta_{JA}$ is a combination of junction to case thermal resistance ($R\theta_{JC}$) and case-to-ambient thermal resistance ($R\theta_{CA}$), since 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 $R\theta_{JA} = R\theta_{JC} + R\theta_{CA}$.

VIN→ / VOUT @3A↓	3	3.5	4	4.5	5
1	0.732	0.689	0.672	0.668	0.670
1.2	0.741	0.691	0.668	0.662	0.665
1.8	0.825	0.764	0.732	0.720	0.720
2.5	0.894	0.813	0.776	0.762	0.765
3.3	–	0.817	0.816	0.801	0.800

Table 3. Power Dissipation (W) for 4A Output

- T_{AMB} is the Operating Ambient temperature.

Example:

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

$$T_J = T_{AMB} + P_{DISS} \cdot R\theta_{JA}$$
$$T_J = 50 + 0.894 \times 45$$
$$T_J = 90.2°C$$

This is below the maximum of 125°C.

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

Table 4. Compensation Selection

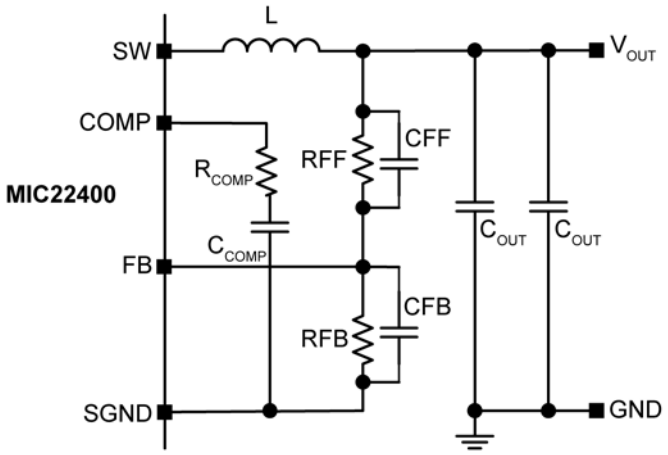


Figure 6. Table 4 Schematic Reference

Evaluation Board Schematic

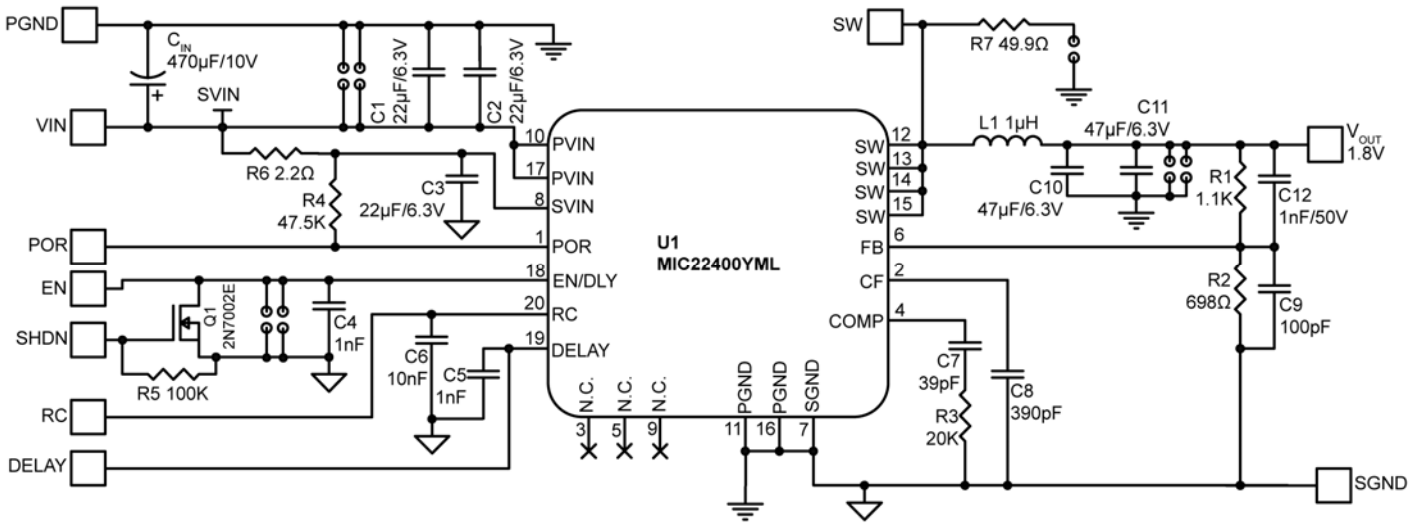


Figure 7. MIC22400YML Evaluation Board Schematic
(R9 is for testing purposes)

Bill of Materials

Item	Part Number	Manufacturer	Description	Qty.
C1, C2, C3	08056D226MAT	AVX(1)	Capacitor, 22µF, 6.3V, X5R, Size 0805	3
	C2012X5R0J226M	TDK(2)		
	GRM21BR60J226ME39L	Murata(3)		
C4, C5, C12	GRM188R71H102KA01D	Murata(3)	Capacitor, 1nF, 50V, X7R, Size 0603	2
	C1608C0G1H102J	TDK(2)	Capacitor, 1nF, 50V, COG, Size 0603	
	06035C102KAT2A	AVX(1)		
C6	GRM188R71H103KA01D	Murata(3)	Capacitor, 10nF, 50V, X7R, Size 0603	1
	C1608X7R1H103K	TDK(2)		
	06035C103KAT2A	AVX(1)		
C7	GRM188R71H390JA01	Murata(3)	Capacitor, 39pF, 50V, Size 0603	1
	C1608COG1H390J	TDK(2)		
	06035A390JAT2A	AVX(1)		
C8	GRM188R71H391JA01	Murata(3)	Capacitor, 390pF, 50V, Size 0603	1
	1608COG1H391J	TDK(2)		
	06035A391JAT2A	AVX(1)		
C9	GRM188R71H101JA01	Murata(3)	Capacitor, 100pF, 50V, Size 0603	1
	C1608COG1H101J	TDK(2)		
	06035A101JT2A	AVX(1)		
C10, C11	GRM31CR60J476ME19	Murata(3)	Capacitor, 47µF, 6.3V, X5R, Size 1206	2
	C3216X5R0J476M	TDK(2)		
	12066D476MAT2A	AVX(1)		
C_{IN}	B41125A3477M	Epcos	470µF, 10V, Electrolytic, 8x10-case	

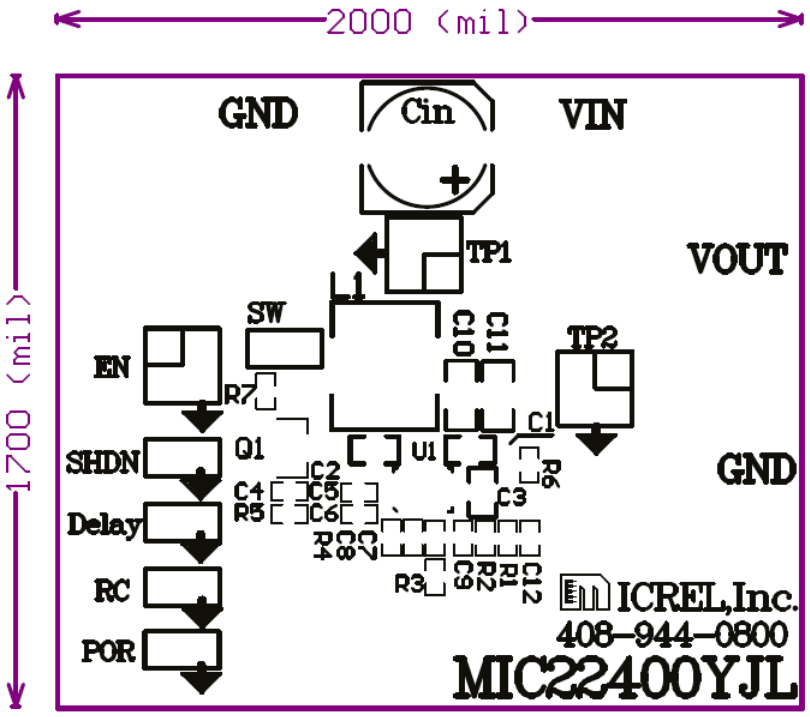
Bill of Materials (Continued)

Item	Part Number	Manufacturer	Description	Qty.
L1	FP3-1R0-R(7.2x6.7x3mm)	Cooper[5]	Inductor, 1µH, 6.26A	1
	CDRH8D28NP-1R0NC (8x6x3mm)	Sumida[6]	Inductor, 1µH, 8A	1
	SPM6530T-1R0M120 (7x6.5x3mm)	TDK[2]	Inductor, 1µH, 12A	1
R1	CRCW06031101FKEYE3	Vishay[4]	Resistor, 1.1k, 1%, Size 0603	1
R2	CRCW06036980FKEYE3	Vishay[4]	Resistor, 698, 1%, Size 0603	1
R3	CRCW06032002FKEYE3	Vishay[4]	Resistor, 20k, 1%, Size 0603	1
R4	CRCW06034752FKEYE3	Vishay[4]	Resistor, 47.5k, 1%, Size 0603	1
R5	CRCW06031003FKEYE3	Vishay[4]	Resistor, 100k, 1%, Size 0603	1
R6	CRCW06032R20FKEA	Vishay[4]	Resistor, 2.2Ω, 1%, Size 0603	1
R7	CRCW060349R9FKEA	Vishay[4]	Resistor, 49.9Ω, 1%, Size 0603	1
Q1	2N7002E	Vishay[4]	Open	1
U1	**MIC22400YML**	**Micrel[7]**	**Integrated 4A Synchronous Buck Regulator**	**1**

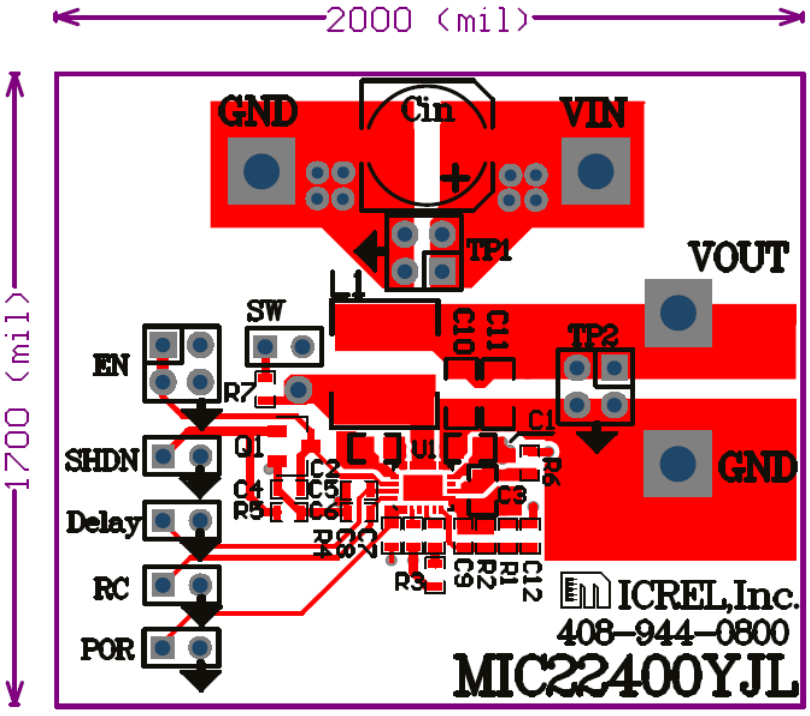
Notes:

1. AVX: www.avx.com.
2. TDK: www.tdk.com.
3. Murata: www.murata.com.
4. Vishay: www.vishay.com.
5. Cooper Bussmann: www.cooperet.com.
6. Sumida: www.sumida.com.
7. **Micrel, Inc.: www.micrel.com.**

PCB Layout Recommendations



Top Silk



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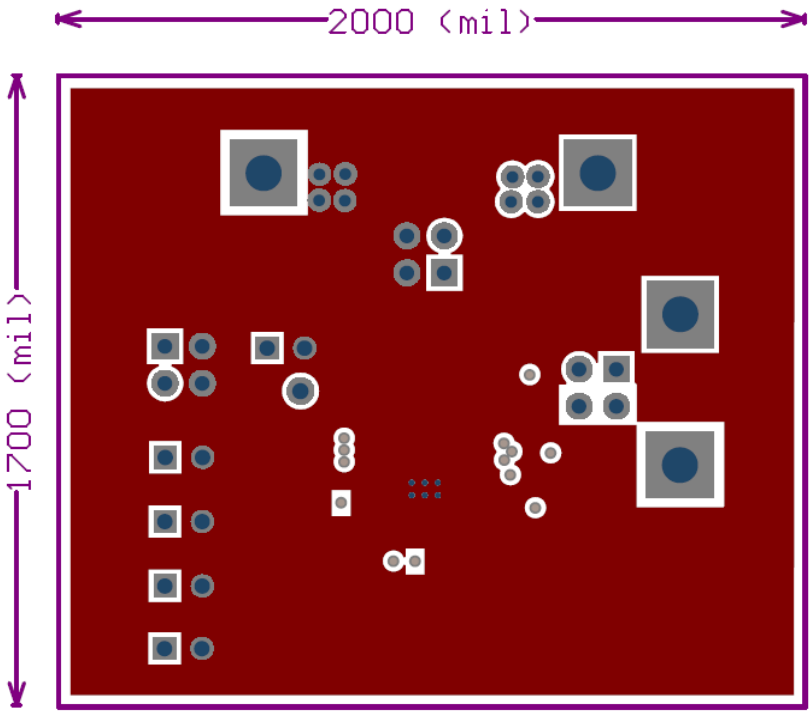

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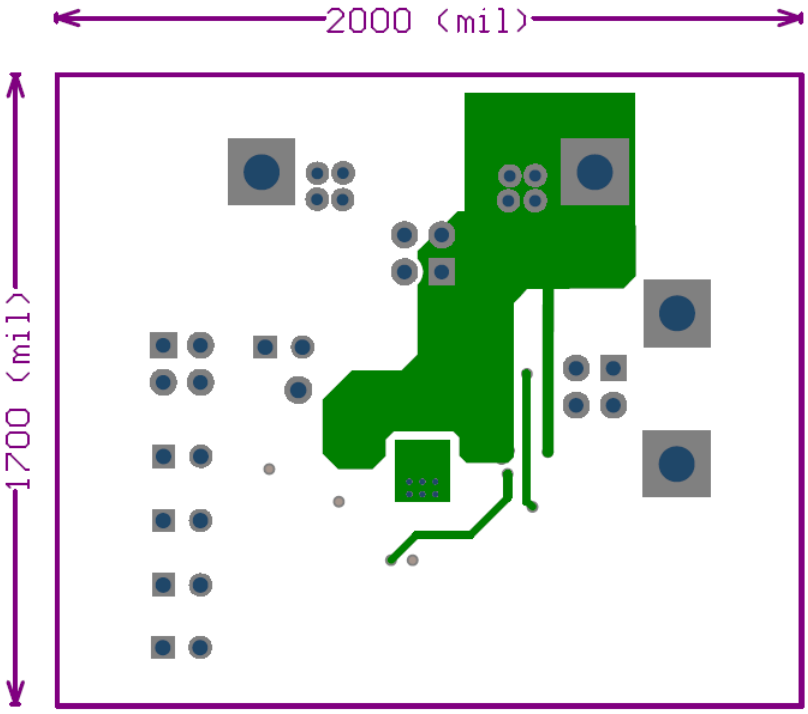
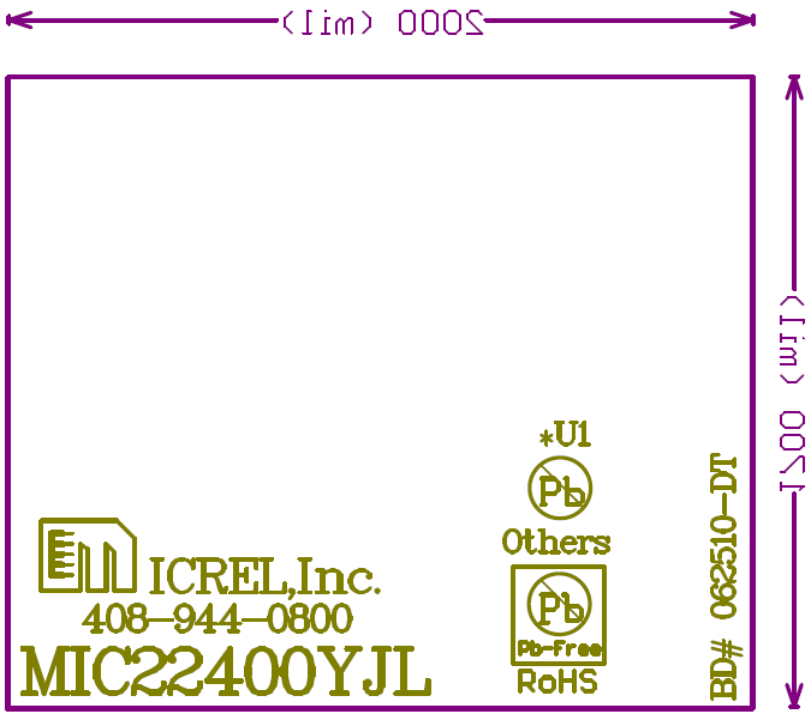


Mid Layer 2

PCB Layout Recommendations (Continued)



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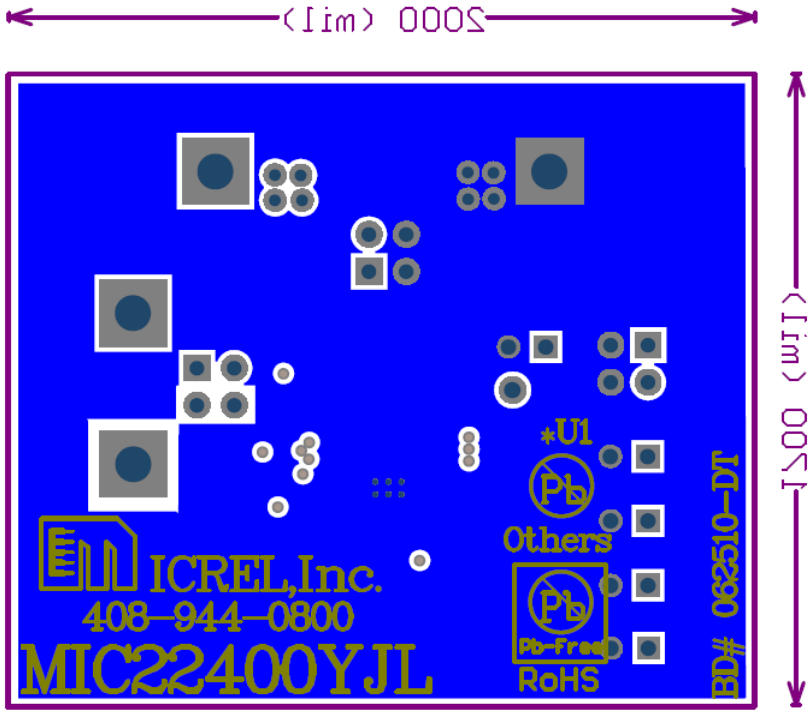
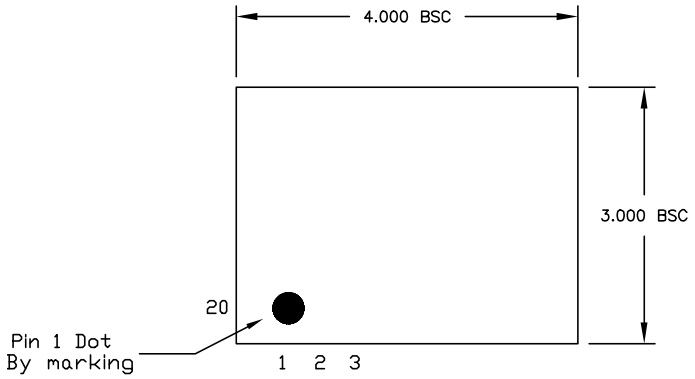
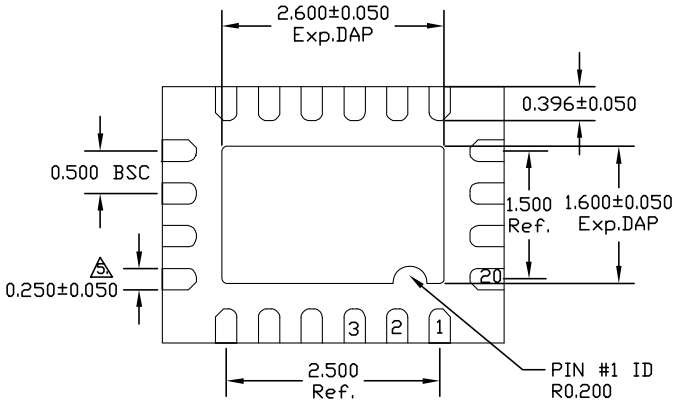


Bottom Layer

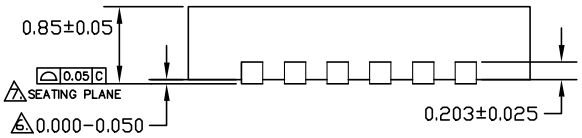
Package Information



TOP VIEW



BOTTOM VIEW

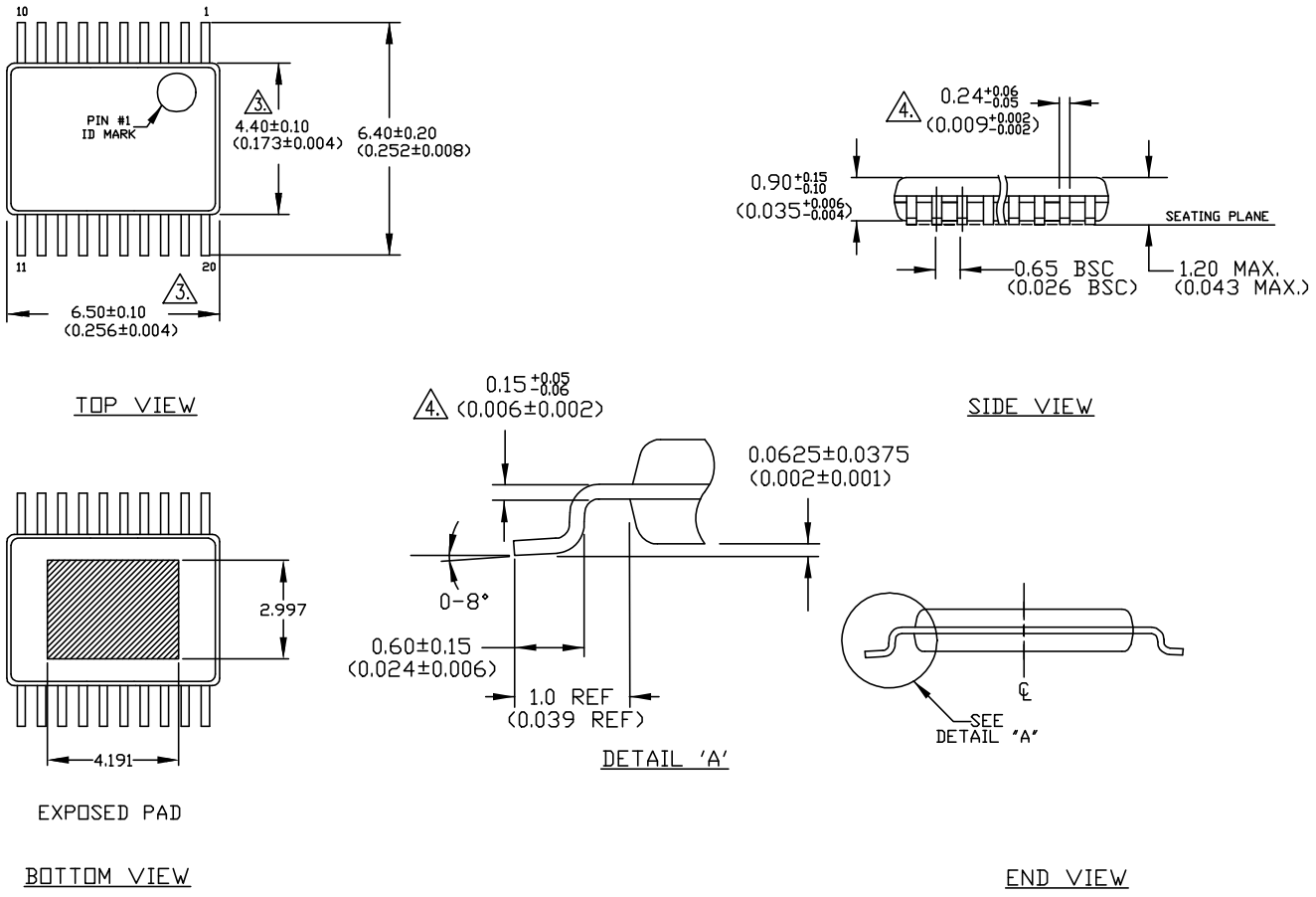


SIDE VIEW

NOTE:
1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. MAX. PACKAGE WARPAGE IS 0.05 mm.
3. MAXIMUM ALLOWABE BURRS IS 0.076 mm IN ALL DIRECTIONS.
4. PIN #1 ID ON TOP WILL BE LASER/INK MARKED.
5. DIMENSION APPLIES TO METALIZED TERMINAL AND IS MEASURED BETWEEN 0.20 AND 0.25 mm FROM TERMINAL TIP.
6. APPLIED ONLY FOR TERMINALS.
7. APPLIED FOR EXPOSED PAD AND TERMINALS.

20-Pin 3mm x 4mm MLF® (ML)

Package Information (Continued)

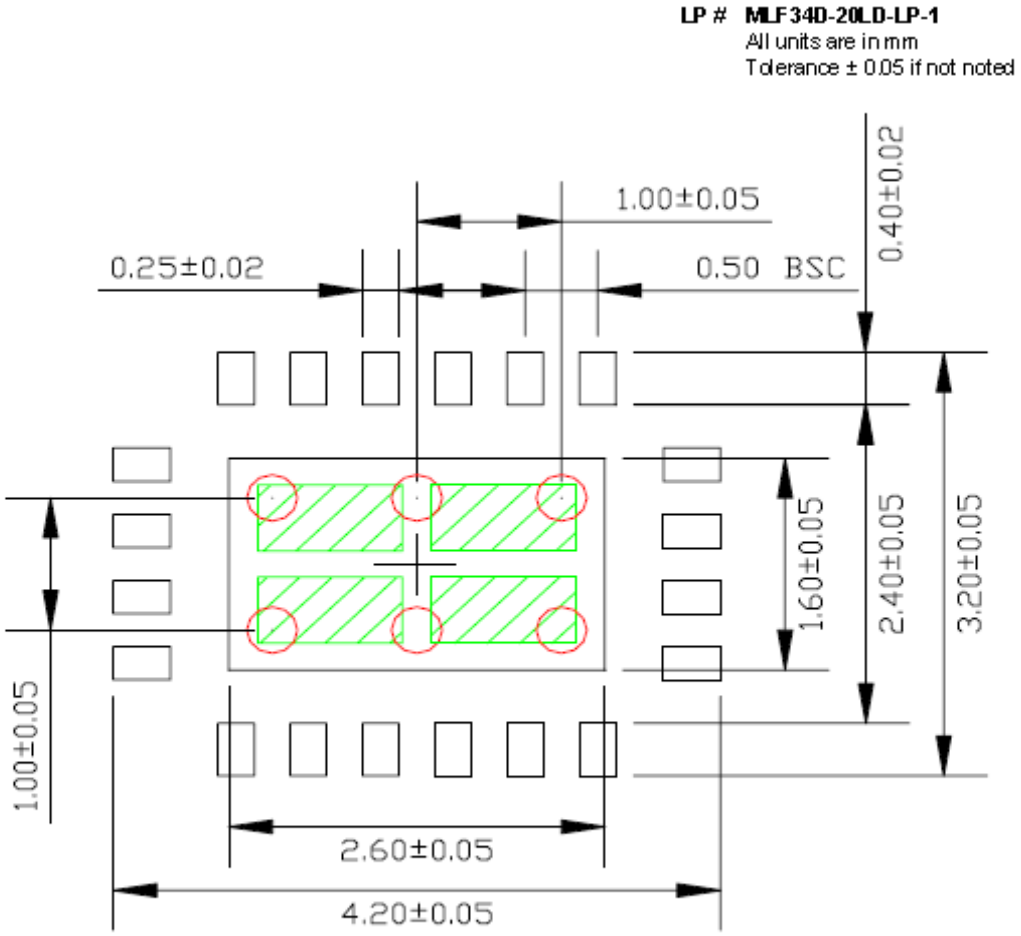


NOTES:

1. DIMENSIONS ARE IN MM[INCHES].
2. CONTROLLING DIMENSION: MM.
3. DIMENSION DOES NOT INCLUDE MOLD FLASH OF 0.254[0.010] MAX.
4. THIS DIMENSION INCLUDES LEAD FINISH.
5. EXPOSED PAD WILL BE DEPEND ON THE PAD SIZE OF THE L/F.

20-Pin e-TSSOP (TS)

Recommended Landing Pattern

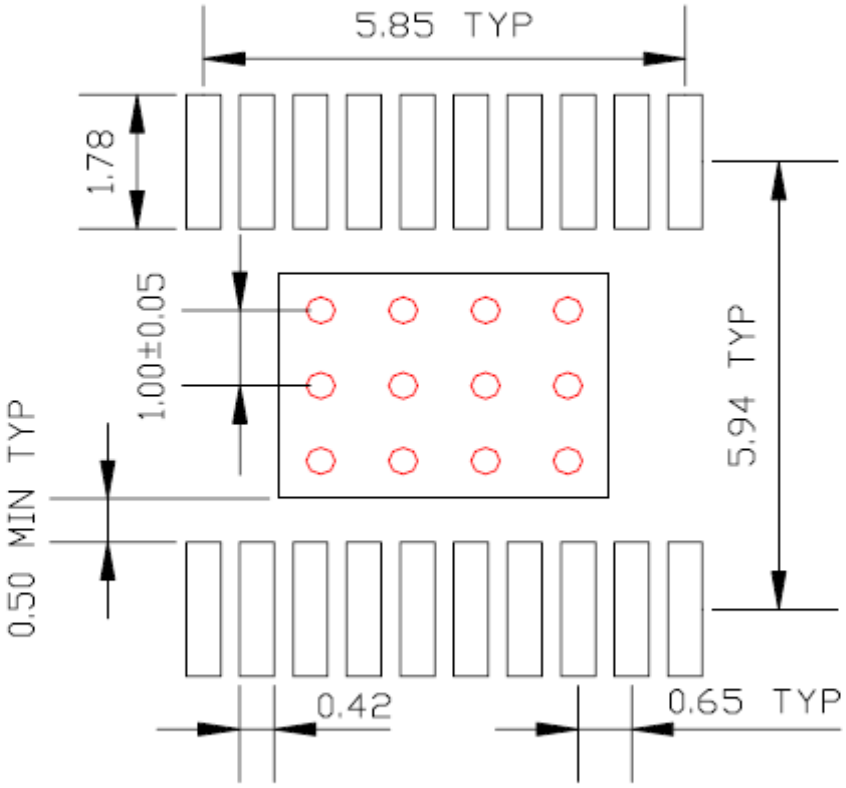


Red circle indicates Thermal Via. Size should be .300-.350 mm in diameter, 1.00 mm pitch and should be connected to GND plane for maximum thermal performance.
Green rectangle (with shaded area) indicates Solder Stencil Opening on exposed pad area. Size should be 1.00x0.50 mm in size, 0.70 mm pitch.

20-Pin 3mm x 4mm MLF® (ML)

Recommended Landing Pattern (Continued)

LP # TSSOPEP-20LD-LP-1
All units are in mm
Tolerance ± 0.05 if not noted



Red circle indicates Thermal Via. Size should be .300-.350 mm in diameter and it should be connected to GND plane for maximum thermal performance.

20-Pin e-TSSOP (TS)

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