4A 2.2MHz, COT Synchronous Step-Down Converter

Features

- **Efficiency Up to 97%**
- **26mΩ and 25mΩ Internal Power MOSFET**
- **V_{IN} Range 2.5V to 6V**
- **Adjustable Output Voltage from 0.6V to 4V**
- **Power Save Mode for Light Load Efficiency**
- **Constant-On-Time Control Scheme Design for Fast Transient Response, Stability with MLCC Output Capacitor**
- **100% Duty Cycle for Lowest Dropout**
- **6uA Operating Quiescent Current**
- **Output Discharge**
- **Power Good Output**
- **Cycle-by-Cycle Over Current Protection**
- **Input Under Voltage Lockout**
- **Output Under Voltage Protection (Hiccup)**
- **Thermal Shutdown Protection**

Applications

- **Portable and Mobile Devices**
- **Wireless and Networking Devices**
- **LCD TV Power Supply**
- **Solid State Drive**

General Description

The M2284 is a monolithic, step-down, switch mode converter with built-in internal power MOSFETs. It achieves 4A continuous output current from a 2.5V to 6.0V input voltage with excellent load and line regulation. The Output voltage can be regulated to as low as 0.6V. At medium to heavy loads, the switching frequency is 2.2MHz. At light load, the device automatically enters PSM to maintain high efficiency.

The Constant-On-Time control scheme in M2284 provides fast transient response to be optimized over a wide range of loads and output capacitors. Thermal shutdown and cycle-by-cycle current limiting are used for protection.

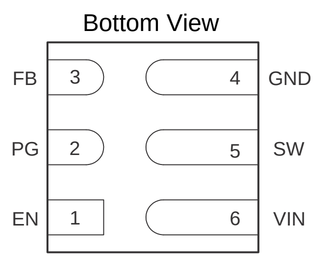
The M2284 is available in an ADFN1.5X1.5-6 package.

Ordering Information

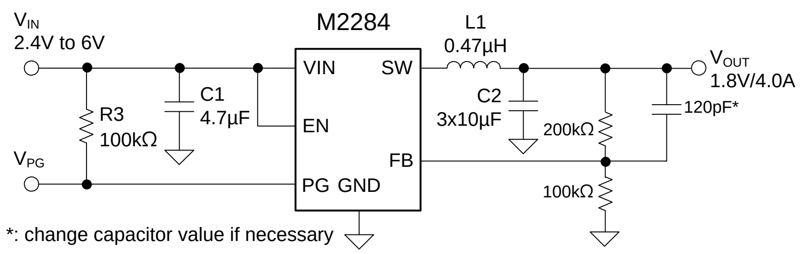
ORDER NUMBER	MARKING	TEMP. RANGE	PACKAGE (Green)
M2284A31D	22 4x	-40°C to +85°C	ADFN1.5X1.5-6

Note: A3: ADFN1.5X1.5-6
1: Bonding Code
D: Tape & Reel
Green: Lead Free / Halogen Free

Pin Configuration



Typical Application Circuit



Absolute Maximum Ratings

VIN, SW, FB, PG . . . .-0.3V to 6.5V
EN . . . . -0.3V to (V_{IN}+0.3v)
SW (AC, less than 10nS) . . . .-3V to 10V
Thermal Resistance of Junction to Ambient, (θ_{JA})*
ADFN1.5X1.5-6. . . . . 70°C/W
Continuous Power Dissipation (T_A = +25°C)*
ADFN1.5X1.5-6. . . . . 1.78W
Thermal Resistance of Junction to Case, (θ_{JC})
ADFN1.5X1.5-6. . . . . 18°C/W

Junction Temperature . . . . -40°C to150°C
Storage Temperature . . . . -65°C to 150°C
Reflow Temperature (soldering, 10sec) . . . . . . 260°C
ESD (HBM) 2KV

Recommended Operating Conditions

Supply Input Voltage. . . . . .2.5V to 6V
Ambient Temperature Range. . . . .-40°C to 85°C
Junction Temperature Range. . . . .-40°C to 125°C

* : Please refer to EV Board PCB Layout Section.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Electrical Characteristics

(V_{IN}=5V, T_A=25°C)

The device is not guaranteed to function outside its operating conditions. Parameters with MIN and/or MAX limits are 100% tested at +25°C, unless otherwise specified.

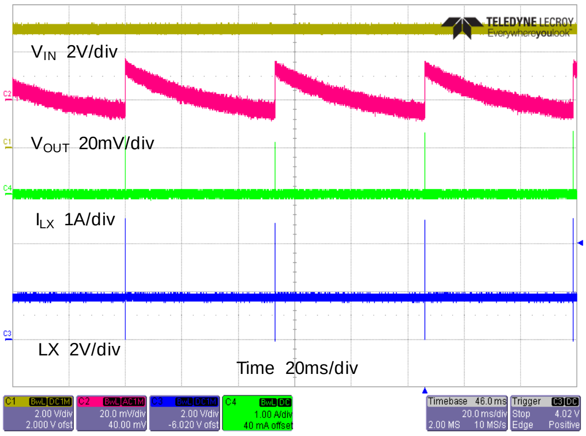
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
Input Voltage	V_{IN}		2.5	---	6	V
VIN Quiescent Current	I_Q	V_{EN}=V_{IN}, No load, device not switching	2	6	12	μA
VIN Shutdown Current	I_{SD}	V_{EN}=0V, Shutdown	0	0.05	0.5	μA
VIN Under Voltage Lockout Threshold	V_{UVLO}	V_{IN} falling	2.1	2.2	2.3	V
VIN Under Voltage Lockout Hysteresis	V_{UVLO_HYS}		---	150	---	mV
Thermal Shutdown Threshold	T_{JSD}	T_J rising	---	150	---	°C
Thermal Shutdown Hysteresis	T_{JSD_HYS}		---	30	---	°C
EN Input Logic High Voltage	V_{IH}	2.5V≦V_{IN}≦5.5V	1	---	---	V
EN Input Logic Low Voltage	V_{IL}	2.5V≦V_{IN}≦5.5V	---	---	0.4	V
EN Input Current	I_{EN}	V_{EN}= High	---	---	0.1	μA
Soft-Start Time	T_{SS}	Time from EN high to 95% of V_{OUT} nominal	350	500	700	μS
Enable Delay Time	T_{EN_DLY}	Time from EN high to SW switching	30	200	300	μS
Power Good Lower Threshold	V_{PGL_R}	V_{PG} rising, V_{FB} referenced to V_{FB} nominal	94	96	98	%
	V_{PGL_F}	V_{PG} falling, V_{FB} referenced to V_{FB} nominal	90	92	94	%
Power Good Upper Threshold	V_{PGU_R}	V_{PG} rising, V_{FB} referenced to V_{FB} nominal	103	105	107	%
	V_{PGU_F}	V_{PG} falling, V_{FB} referenced to V_{FB} nominal	108	110	112	%
PG Low-Level Output Voltage	$V_{PG(OL)}$	I_{SINK}=1mA	---	---	0.4	V
PG Input Leakage Current	$I_{PG(LK)}$	V_{PG}=5V	---	---	0.1	μA
Power Good Delay	t_{PG_RDLY}	V_{FB} rising	---	100	---	μS
	t_{PG_FDLY}	V_{FB} falling	---	20	---	μS
Feedback Reference Voltage	V_{REF}	2.5V≦VIN≦5.5V	0.594	0.6	0.606	V
Feedback Leakage Current	$I_{FB(LK)}$	V_{FB} = 0.6V	---	---	0.05	μA
Output Discharge Current	I_{SW_DIS}	V_{EN}=0V, V_{SW}=0.4V	75	400	---	mA
PWM Switching Frequency	f_{SW}	I_{OUT}=1A	---	2.2	---	MHz
PFET Switch On Resistance	$R_{DSON(P)}$		---	26	---	mΩ
NFET Switch On Resistance	$R_{DSON(N)}$		---	25	---	mΩ
PFET Switch Current Limit	$I_{LIM(P)}$		4.8	6	7.5	A
NFET Switch Current Limit	$I_{LIM(N)}$		4	5	6.3	A

Typical Performance Characteristics

(V_{IN}=5V, V_{OUT}=1.8V, C_{IN}=4.7µF , C_{OUT}=10µF*3, L=0.47µH, T_A=25°C)

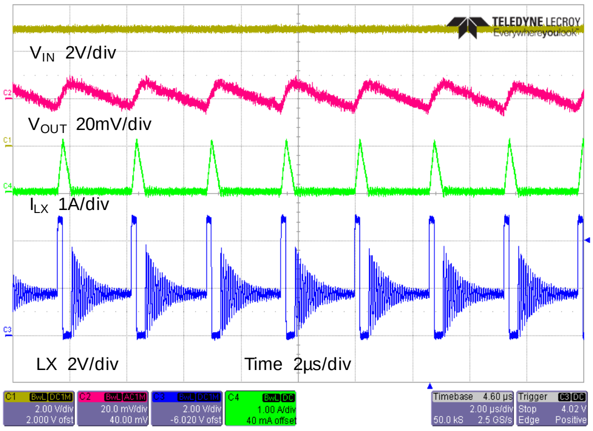
Steady State Operation

V_{OUT}=1.8V,No Load



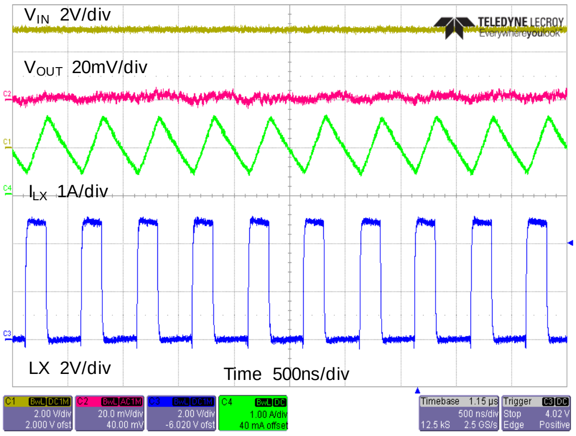
Steady State Operation

V_{OUT}=1.8V,I_{OUT}=100mA



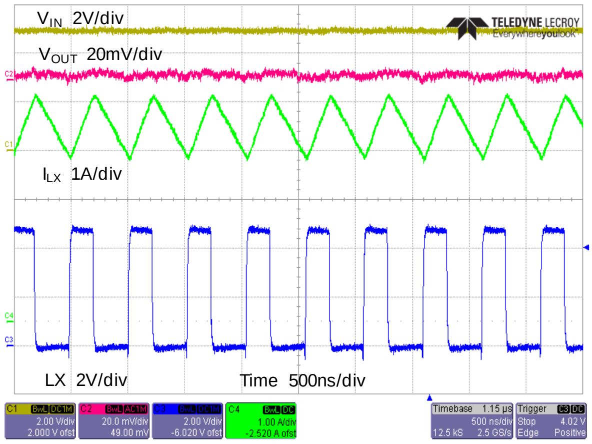
Steady State Operation

V_{OUT}=1.8V,I_{OUT}=1A



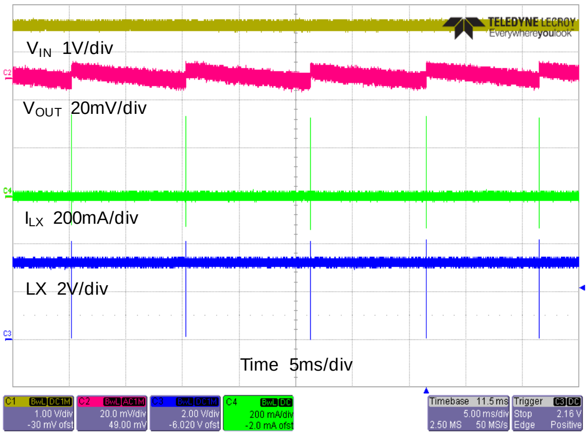
Steady State Operation

V_{OUT}=1.8V,I_{OUT}=4A



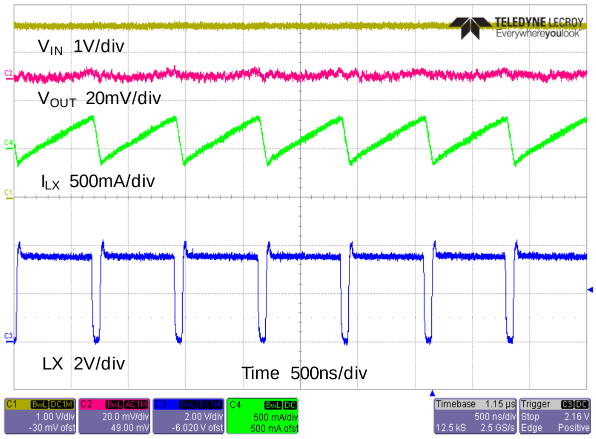
Steady State Operation

V_{IN}=3.6V,V_{OUT}=3.3V, No Load



Steady State Operation

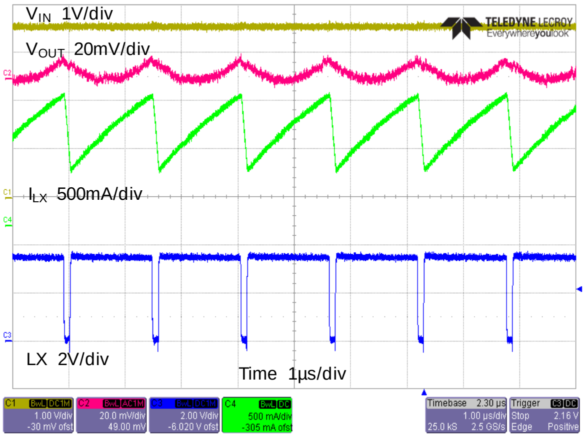
V_{IN}=3.6V,V_{OUT}=3.3V, I_{OUT}=100mA



Typical Performance Characteristics (continued)

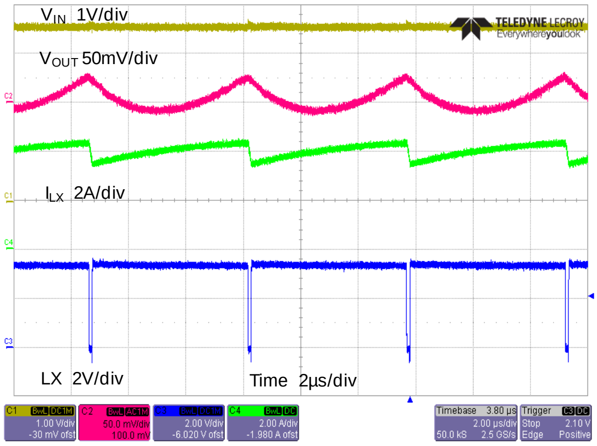
Steady State Operation

V_{IN}=3.6V,V_{OUT}=3.3V, I_{OUT}=1A



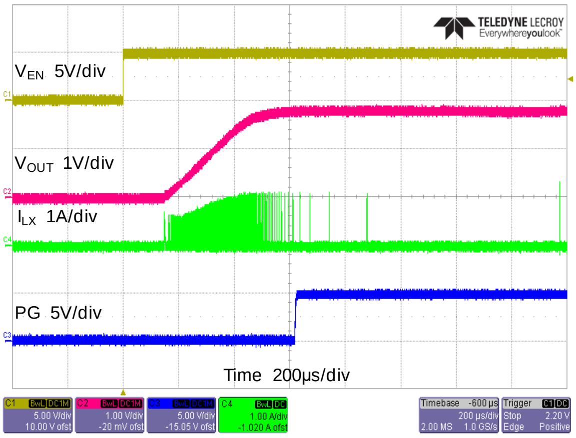
Steady State Operation

V_{IN}=3.6V,V_{OUT}=3.3V, I_{OUT}=4A



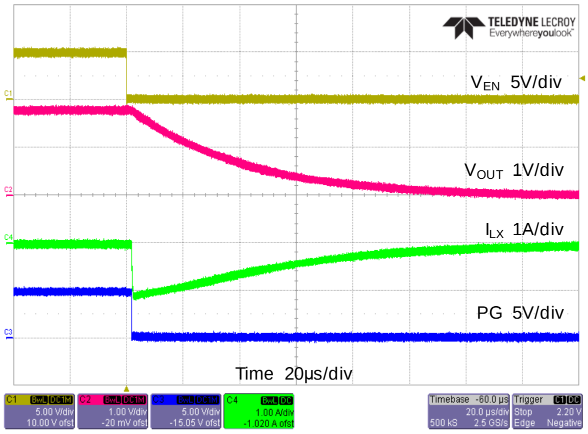
Start-up Through Enable

V_{OUT}=1.8V,No Load



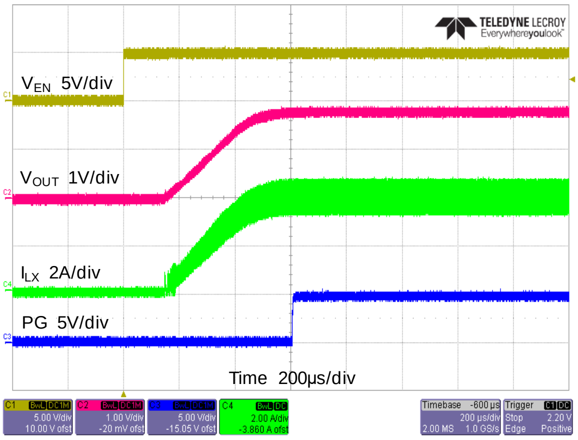
Start-down Through Enable

V_{OUT}=1.8V,No Load



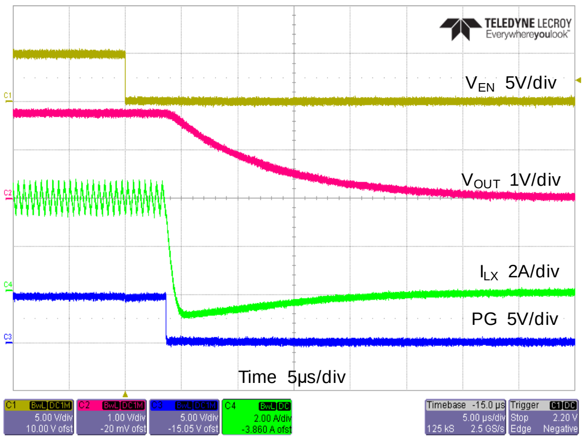
Start-up Through Enable

V_{OUT}=1.8V, I_{OUT}=4A



Start-down Through Enable

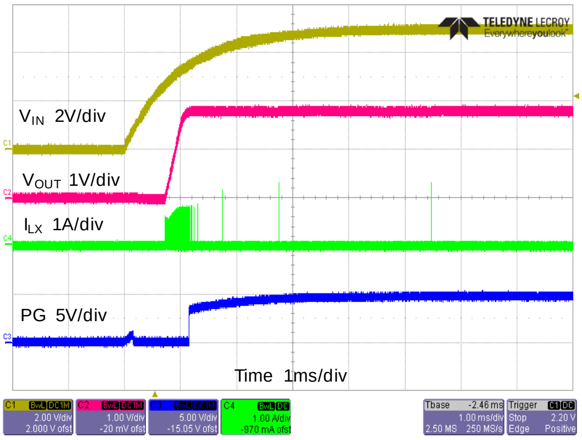
V_{OUT}=1.8V, I_{OUT}=4A



Typical Performance Characteristics (continued)

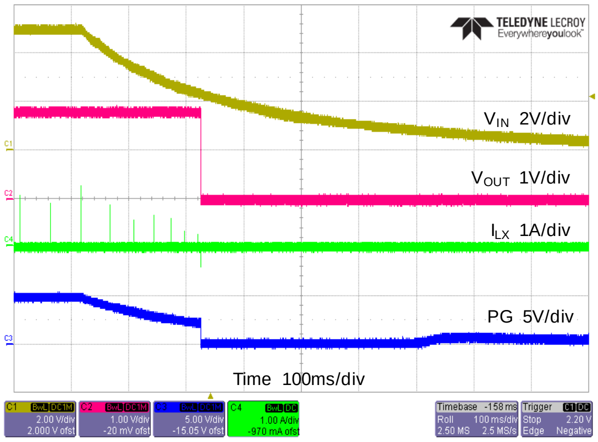
Start-up Through VIN

V_{OUT}=1.8V,No Load



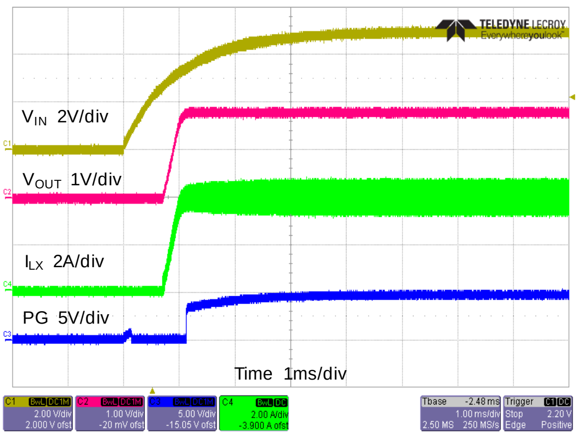
Start-down Through VIN

V_{OUT}=1.8V,No Load



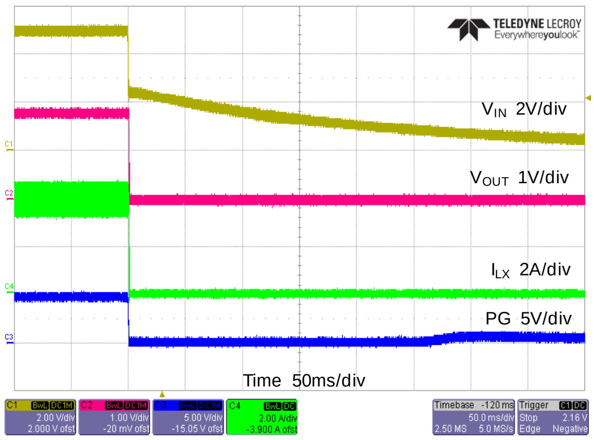
Start-up Through VIN

V_{OUT}=1.8V, I_{OUT}=4A



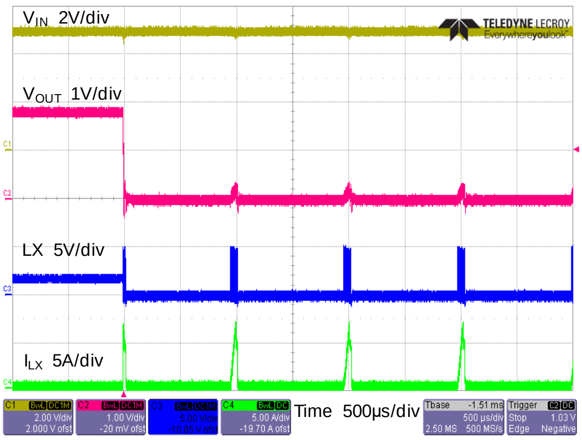
Start-down Through VIN

V_{OUT}=1.8V, I_{OUT}=4A



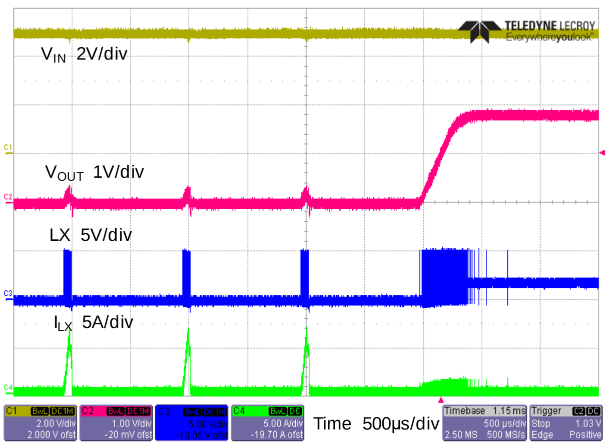
Short Circuit waveform

V_{OUT}=1.8V



Short Circuit Recovery

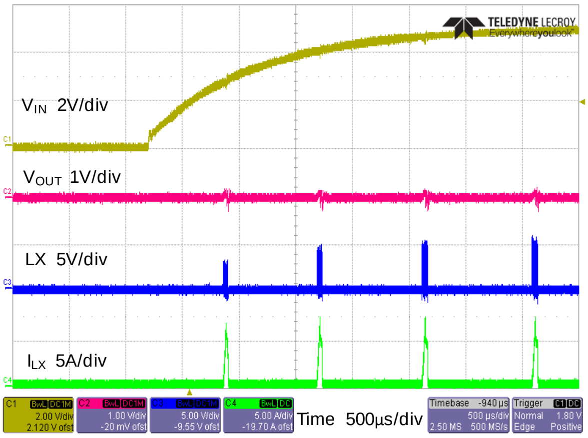
V_{OUT}=1.8V



Typical Performance Characteristics (continued)

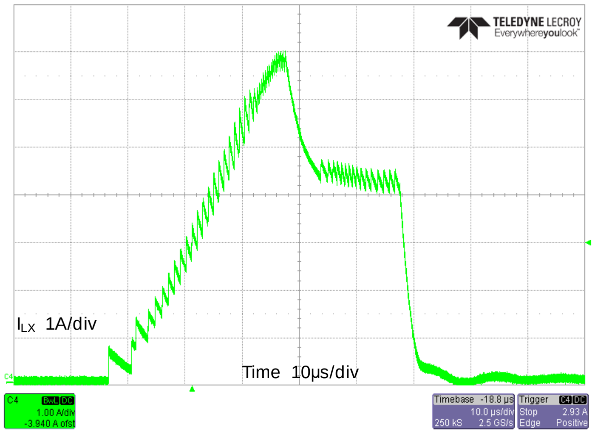
Short Circuit waveform

V_{OUT}=1.8V



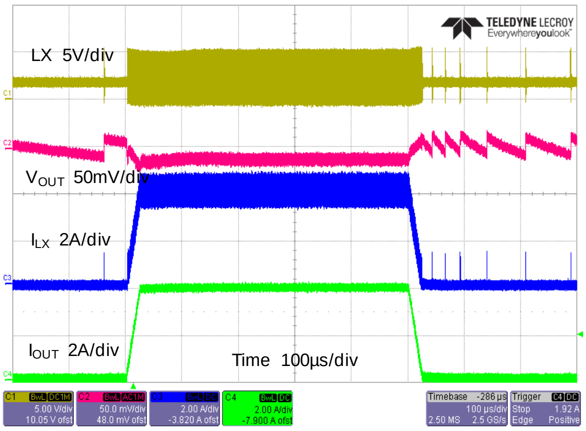
Current Limit

V_{OUT}=1.8V



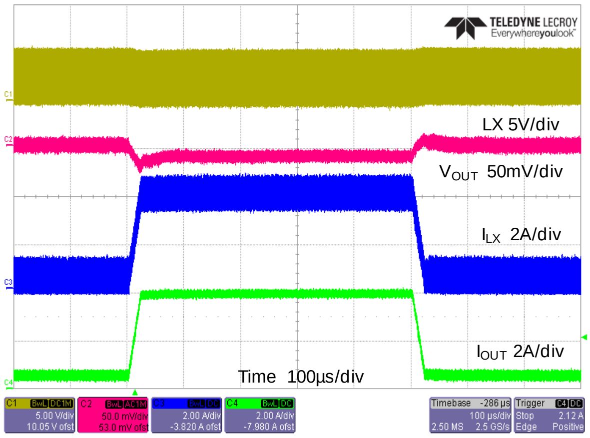
Load Transient Response

V_{OUT}=1.8V, I_{OUT}=0mA~4A



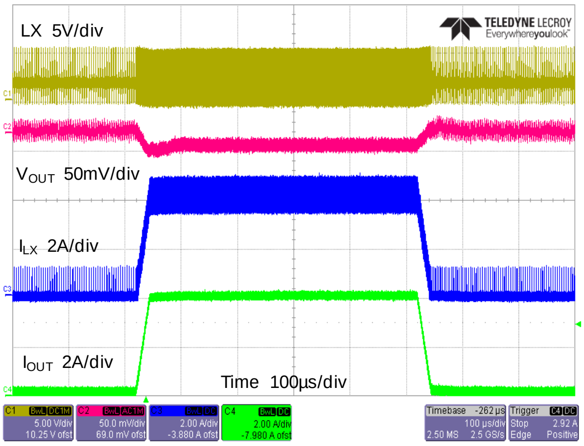
Load Transient Response

V_{OUT}=1.8V, I_{OUT}=500mA~4A



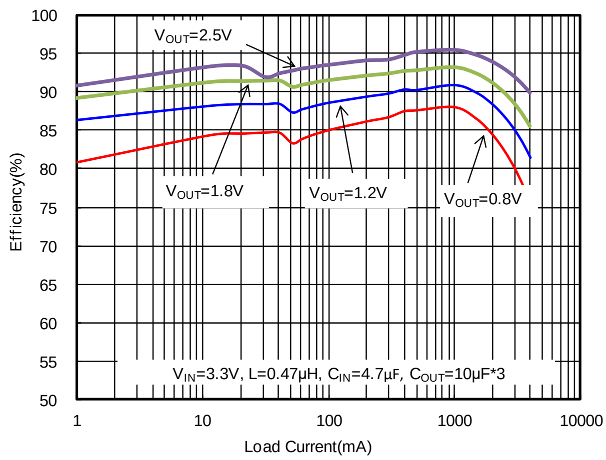
Load Transient Response

V_{OUT}=1.8V, I_{OUT}=100mA~4A

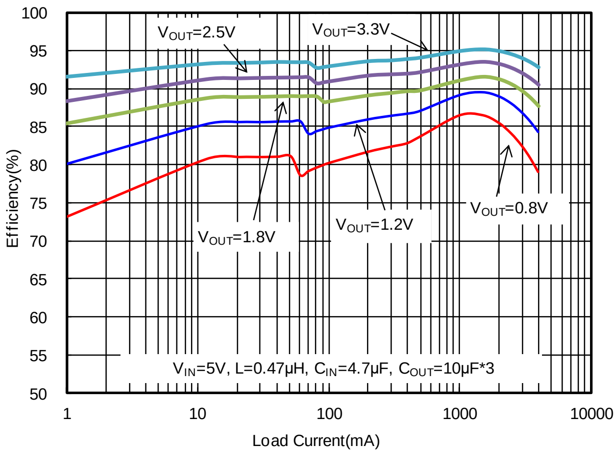


Typical Performance Characteristics (continued)

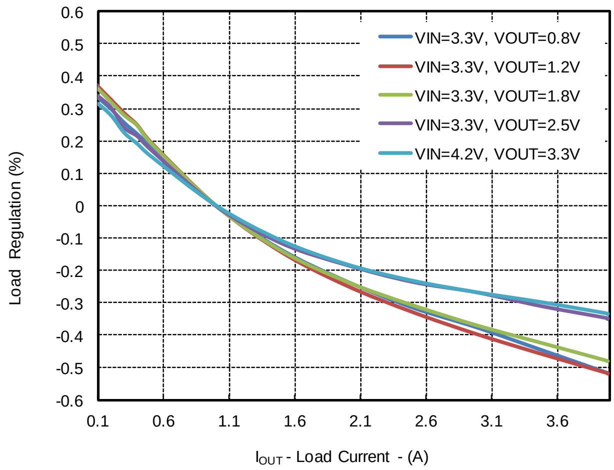
Efficiency VS. Load Current



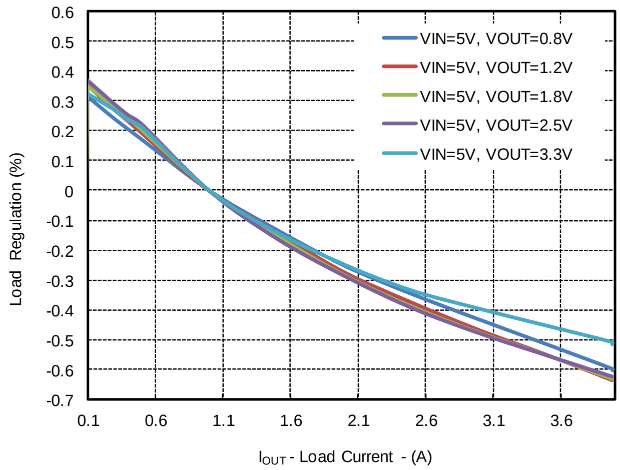
Efficiency VS. Load Current



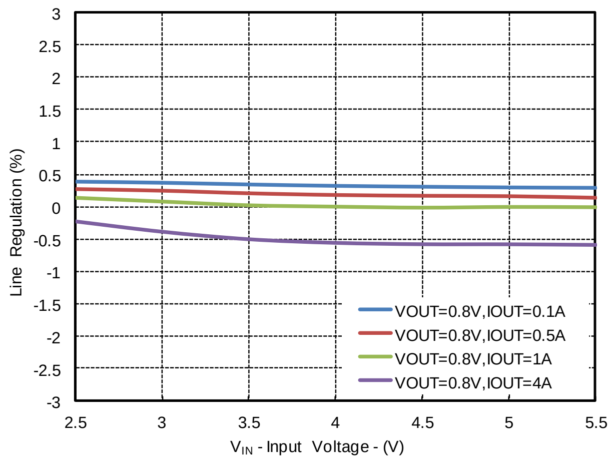
Load Regulation



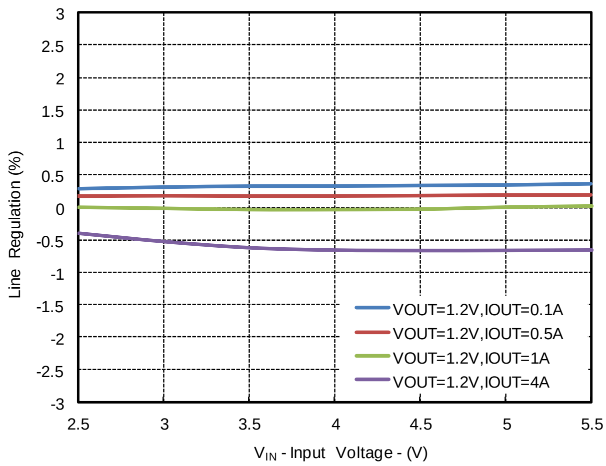
Load Regulation



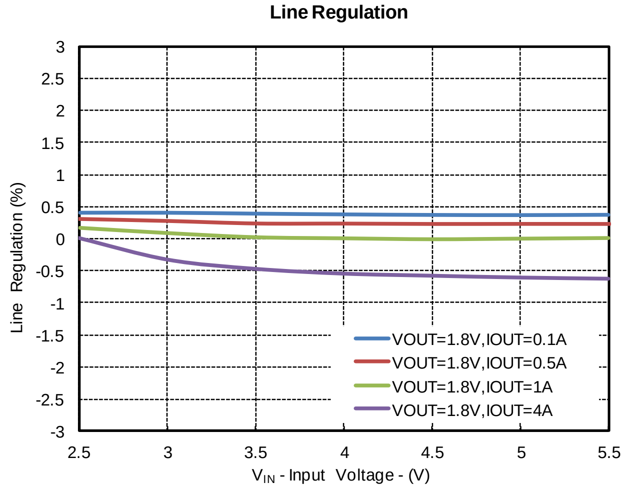
Line Regulation

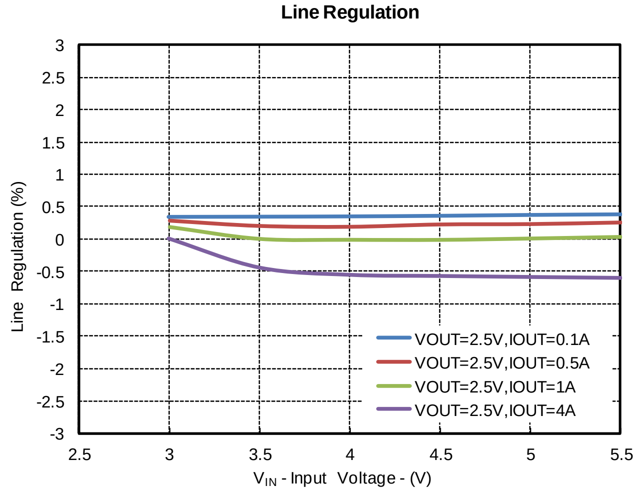


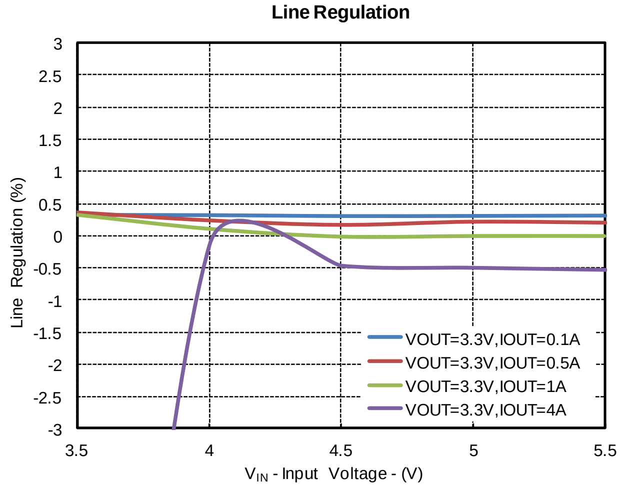
Line Regulation

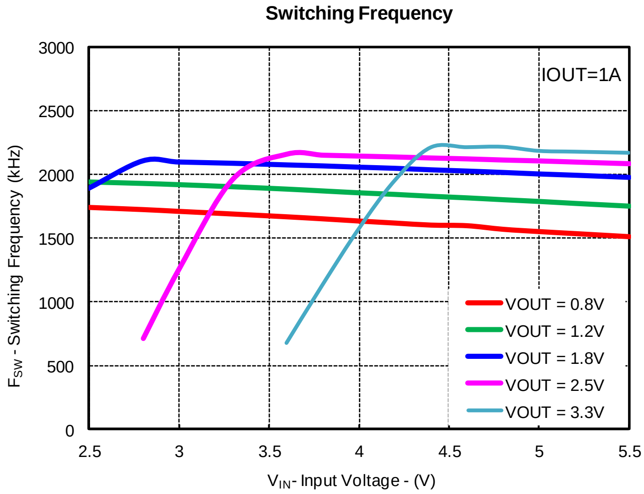


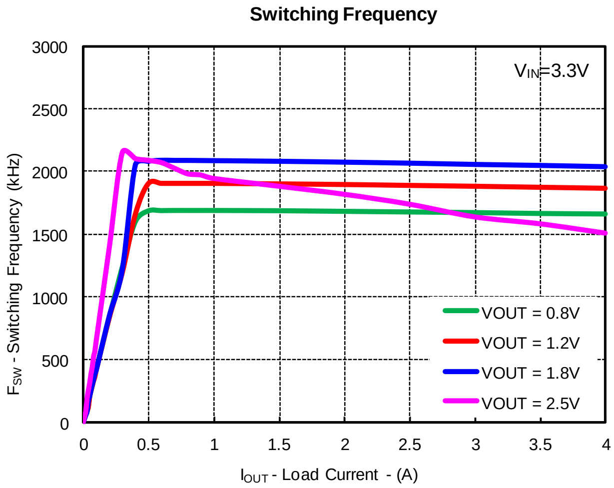
Typical Performance Characteristics (continued)

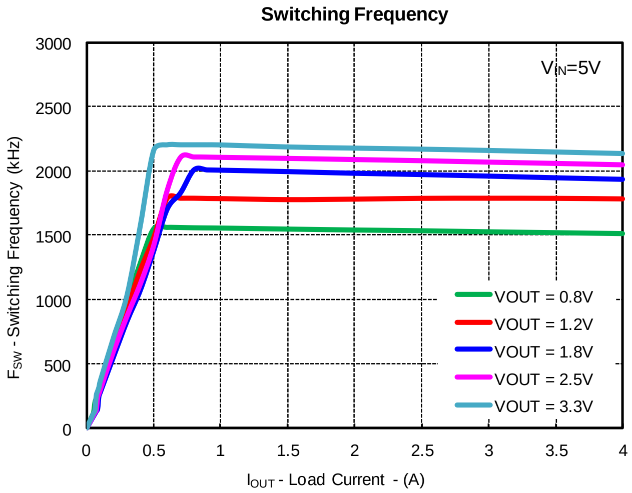




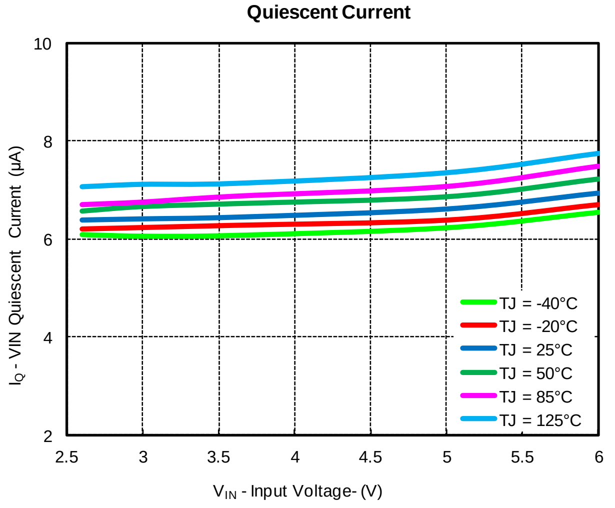


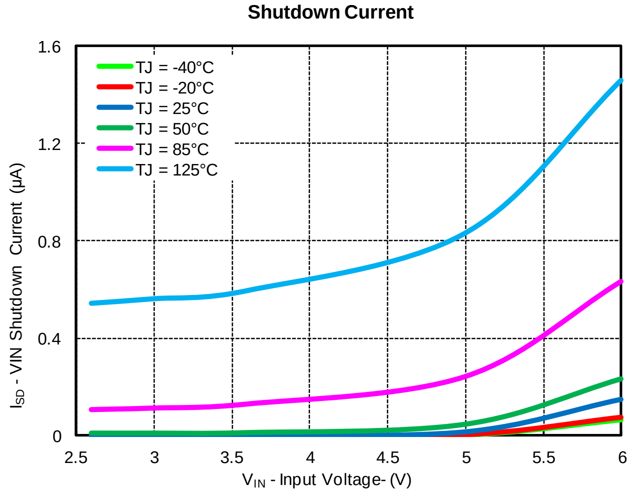


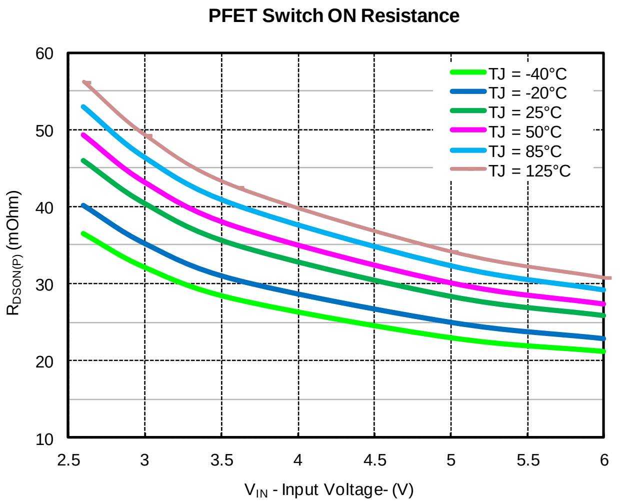


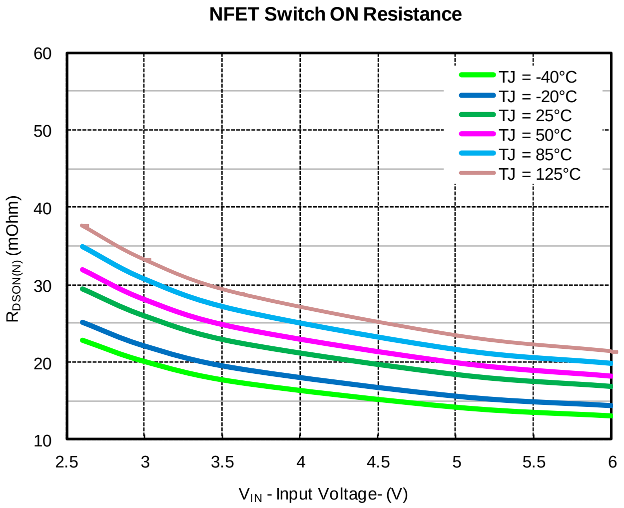


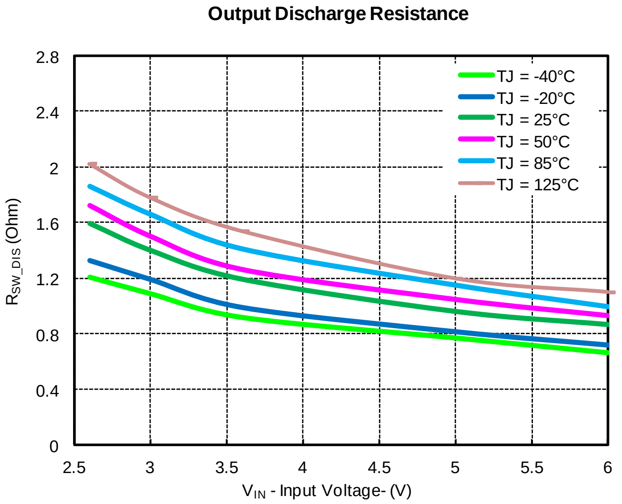
Typical Performance Characteristics (continued)







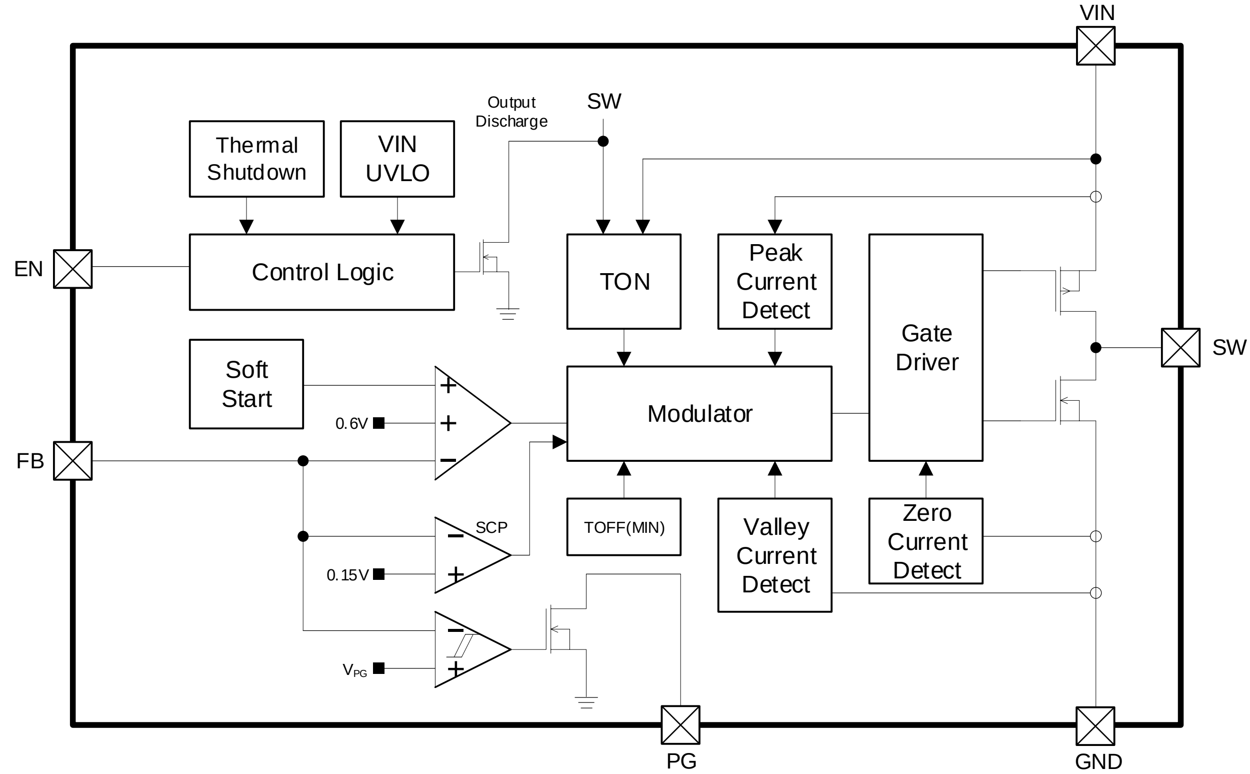




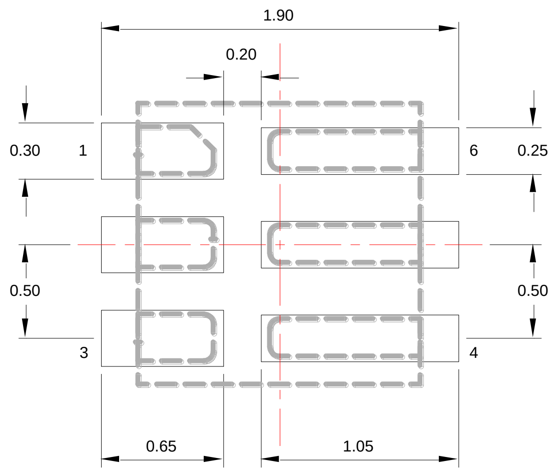
Pin Description

Pin	NAME	FUNCTION
1	EN	Enable control input. Do not leave floating.
2	PG	Power good open drain output pin. The pull-up resistor cannot be connected to any voltage higher than 6V. If unused, leave it floating.
3	FB	An external resistor divider from the output to GND, tapped to the FB pin, sets the output voltage.
4	GND	Ground.
5	SW	Switch node.
6	VIN	Supply voltage input.

Block Diagram



Minimum Footprint PCB Layout Section



Operation

The M2284 is a high efficiency synchronous step-down DC/DC converter. M2284 provides an adjustable regulated output voltage from 0.6V to 4V while delivering up to 4A of output current with input voltage from 2.5V to 6V.

The M2284 uses the constant on-time control scheme. In normal operation, the high side P-MOSFET is turned on when the switch controller is set by the comparator and is turned off when the Ton comparator resets the switch controller.

Low side MOSFET current is measured. The error amplifier adjusts COMP voltage by comparing the feedback signal (VFB) from the output voltage with the internal 0.6V reference. When the load current increases, it causes a drop in the feedback voltage relative to the reference, then the COMP voltage rises to allow higher inductor current to match the load current.

Enable

When the input voltage is greater than the under voltage lockout threshold, a logic-high (>1V) enables the converter; a logic-low (<0.4V). Do not leave EN floating. When the device is disabled, there is a resistive discharge path from SW pin and VIN must remain present for the discharge function.

Soft-Start (SS)

After EN goes high, there is an internal built-in soft-start to ramp the output voltage at a fixed slew rate to avoid in-rush current.

Over Current Protection (OCP)

The M2284 provides the over current protection by detecting the high side MOSFET peak inductor current (6A typ.) and the low-side MOSFET valley inductor current (5A typ.). If the inductor current is over the peak current limit threshold, the high-side MOSFET is turned off and the low-side MOSFET is turned on. Once the inductor current is larger than the valley current limit, the next switching cycle is not allowed. This avoids increasing the inductor current and protects the components.

HICCUP Protection

When the inductor current limit is triggered 8 times, the inductor current limit is reduced to half for the next 8 cycles, and then the device stops switching to protect the components. After a delay of 1ms, M2284 automatically starts a new start-up procedure. Therefore, Hiccup protection is achieved and repeated until the high load condition is removed.

Thermal Shutdown (OTP)

The device implements an internal thermal shutdown function when the junction temperature exceeds 150°C. The thermal shutdown forces the device to stop switching when the junction temperature exceeds the thermal shutdown threshold. Once the die temperature decreases below the hysteresis of 30°C, the device reinstates the power up sequence.

Power Good (PG)

M2284 has an open drain and needs an external pull up resistor for the power good indicator. This function is performed by comparing V_{FB} with the internal voltages. When V_{FB} is high than 96% of nominal voltage, PG is pulled high by the external pull up resistor. If V_{FB} drops lower than 92% of nominal voltage, PG is pulled low by the internal NMOS. When V_{FB} is high than 110% of nominal voltage, PG is pulled high by the external pull up resistor. If V_{FB} drops lower than 105% of nominal voltage, PG is pulled low by the internal NMOS.

The PG rising and falling delay times are 100us and 20us, respectively. Please keep PG pull up voltage is lower than V_{IN}. Leave the PG pin unconnected when not used. Table 1 shows the PG logic status.

Table 1. PG logic status

Conditions		PG
Enable	EN=High , $V_{FB} \geqq V_{PGL\_R}$	High Z
	EN=High , $V_{FB} < V_{PGL\_F}$	Low
	EN=High , $V_{FB} \leqq V_{PGU\_R}$	High Z
	EN=High , $V_{FB} > V_{PGU\_F}$	Low
	EN=Low	Low
OTP	T_J>150°C	Low
UVLO	$0.5V < V_{IN} < V_{UVLO}$	Low
VIN Removal	$V_{IN} \leqq 0.5V$	High Z

Discharge Function

During EN or VIN shutdown, the inner control circuitry and power MOSFET are completely turned off, and the output voltage is discharged via SW pin. Besides, VIN must remain high enough to maintain well discharge function. The output discharge function is shown below.

Table 2. Discharge function logic table.

VIN	EN	OTP	Output Discharge
VIN > UVLO	High	T_J<150°C	No
		T_J>150°C	No
	Low	X	Yes
UVLO>VIN>1.2V*	X	X	Yes
VIN<1.2V*	X	X	Undefined**

*Typical value only and can vary due to temperature and process variation.

**Actually, the discharge circuitry partially enable once VIN> Vth.

Application Information

The M2284 is a single-phase step-down converter. It provides single feedback loop, constant on-time control with fast transient response. An internal 0.6V reference allows the output voltage to be precisely regulated for low output voltage applications and internal compensation are integrated to minimize external component count. Protection features include over current protection, under voltage protection and over temperature protection.

Output Voltage Setting

Connect a resistive voltage divider at the FB between V_{OUT} and GND to adjust the output voltage. The output voltage is set according to the following equation:

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

where V_{REF} is the feedback reference voltage 0.6V (typ.).

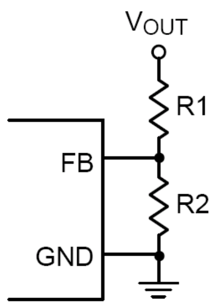


Figure 1. Setting V_{OUT} with a Voltage Divider

Chip Enable and Disable

The EN pin allows for power sequencing between the controller bias voltage and another voltage rail. The M2284 remains in shutdown if the EN pin is lower than 400mV. When the EN pin rises above the VEN trip point, the M2284 begins a new initialization and soft-start cycle.

Internal Soft-Start

The M2284 provides an internal soft-start function to prevent large inrush current and output voltage overshoot when the converter starts up. The soft-start (SS) automatically begins once the chip is enabled. During soft-start, the internal soft-start capacitor becomes charged and generates a linear ramping up voltage across the capacitor. This voltage clamps the voltage at the FB pin, causing PWM pulse width to increase slowly and in turn reduce the input surge current. The internal 0.6V reference takes over the loop control once the internal ramping-up voltage becomes higher than 0.6V.

UVLO Protection

The M2284 has input Under Voltage Lockout protection (UVLO). If the input voltage exceeds the UVLO rising threshold voltage (2.2V typ.), the converter resets and prepares the PWM for operation. If the input voltage falls below the UVLO falling threshold voltage during normal operation, the device will stop switching. The UVLO rising and falling threshold voltage has a hysteresis to prevent noise-caused reset.

Inductor Selection The switching frequency (on-time) and operating point (% ripple or LIR) determine the inductor value as shown below:

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

where LIR is the ratio of the peak-to-peak ripple current to the average inductor current. Find a low loss inductor having the lowest possible DC resistance that fits in the allotted dimensions. The core must be large enough not to saturate at the peak inductor current (I_{PEAK}) :

$$I_{PEAK} = I_{LOAD(MAX)} + \left(\frac{LIR}{2} \times I_{LOAD(MAX)}\right)$$

The calculation above serves as a general reference. To further improve transient response, the output inductor can be further reduced. This relation should be considered along with the selection of the output capacitor. Inductor saturation current should be chosen over IC's current limit.

Input Capacitor Selection

High quality ceramic input decoupling capacitor, such as X5R or X7R, with values greater than 10uF are recommended for the input capacitor. The X5R and X7R ceramic capacitors are usually selected for power regulator capacitors because the dielectric material has less capacitance variation and more temperature stability.

Voltage rating and current rating are the key parameters when selecting an input capacitor. Generally, selecting an input capacitor with voltage rating 1.5 times greater than the maximum input voltage is a conservatively safe design.

The input capacitor is used to supply the input RMS current, which can be approximately calculated using the following equation:

$$I_{IN\_RMS} = I_{LOAD} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)}$$

The next step is selecting a proper capacitor for RMS current rating. One good design uses more than one capacitor with low equivalent series resistance (ESR) in parallel to form a capacitor bank.

The input capacitance value determines the input ripple voltage of the regulator. The input voltage ripple can be approximately calculated using the following equation:

$$\Delta V_{IN} = \frac{I_{OUT(MAX)}}{C_{IN} \times f_{SW}} \times \frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Output Capacitor Selection

The output capacitor and the inductor form a low pass filter in the Buck topology. In steady state condition, the ripple current flowing into/out of the capacitor results in ripple voltage. The output voltage ripple (VP-P) can be calculated by the following equation:

$$V_{P\_P} = LIR \times I_{LOAD(MAX)} \times \left(ESR + \frac{1}{8 \times C_{OUT} \times f_{SW}}\right)$$

When load transient occurs, the output capacitor supplies the load current before the controller can respond. Therefore, the ESR will dominate the output voltage sag during load transient. The output voltage undershoot (VSAG) can be calculated by the following equation:

$$V_{SAG} = \Delta I_{LOAD} \times ESR$$

For a given output voltage sag specification, the ESR value can be determined.

Another parameter that has influence on the output voltage sag is the equivalent series inductance (ESL). The rapid change in load current results in di/dt during transient. Therefore, the ESL contributes to part of the voltage sag. Using a capacitor with low ESL can obtain better transient performance. Generally, using several capacitors connected in parallel can have better transient performance than using a single capacitor for the same total ESR.

Thermal Considerations

For continuous operation, do not exceed absolute maximum junction temperature. The maximum power dissipation depends on the thermal resistance of the IC package, PCB layout, rate of surrounding airflow, and difference between junction and ambient temperature. The maximum power dissipation can be calculated by the following formula:

$$P_{D(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$$

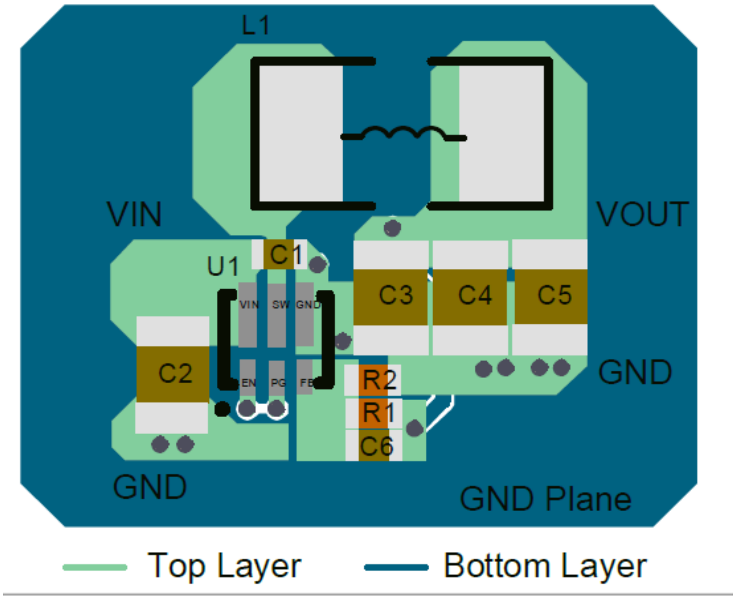
where $T_{J(MAX)}$ is the maximum junction temperature, T_A is the ambient temperature, and θ_{JA} is the junction to ambient thermal resistance.

For recommended operating condition specifications, the maximum junction temperature is 125°C. The junction to ambient thermal resistance, θ_{JA}, is layout dependent. The maximum power dissipation depends on the operating ambient temperature for fixed $T_{J(MAX)}$ and thermal resistance, θ_{JA}..

Layout Consideration

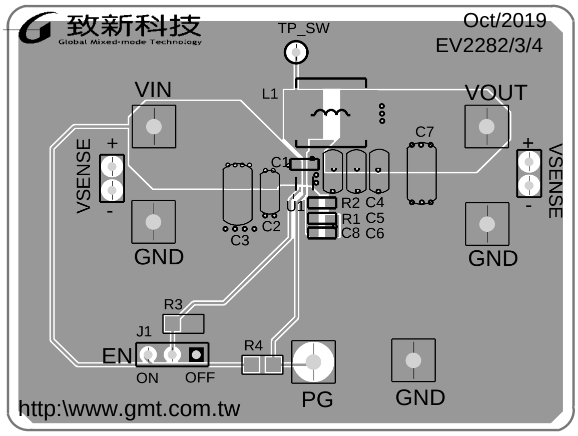
1. Component Placement:
   - Place input capacitors as close as possible to VIN.
   - Place the feedback resistors and compensation components as close as possible to the IC.

2. Layout Recommendation
   - To prevent electromagnetic interference (EMI) problems and reduce voltage ripple of the device, any high current copper trace which see high frequency switching should be optimized.
   - Therefore, use short and wide traces for power current paths and for power ground tracks, power plane and ground plane are recommended if possible.
   - It is important to minimize the area of the switching nodes and use the ground plane under them to minimize crosstalk to sensitive signals and ICs.
   - It's suggested to keep as complete of a ground plane under M2284 if possible.
   - It is always good practice to keep the sensitive tracks such as feedback connection (FB) away from switching signal connections (SW)

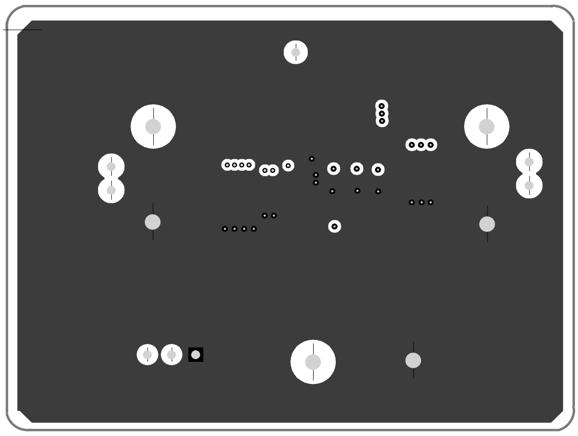


EV Board PCB Layout Section

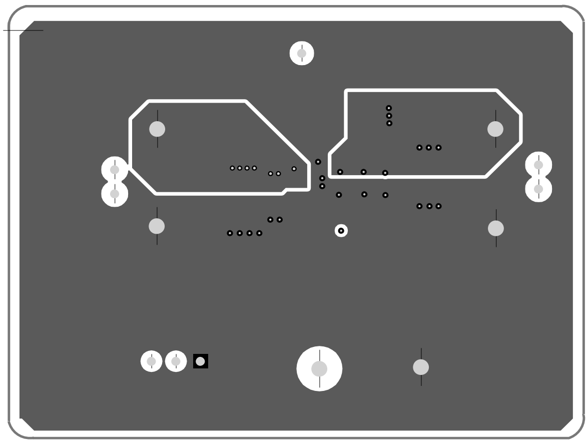
Top Layer



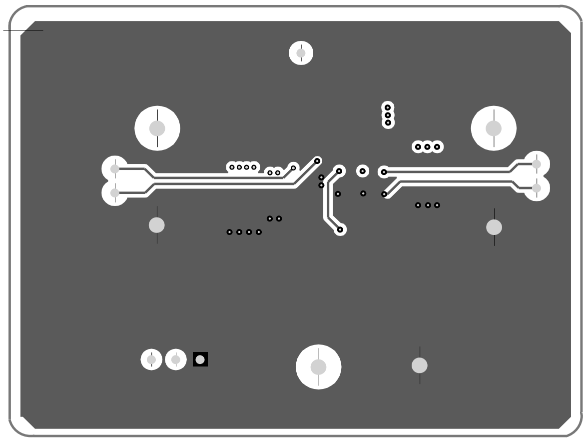
Mid Layer 1



Mid Layer 2

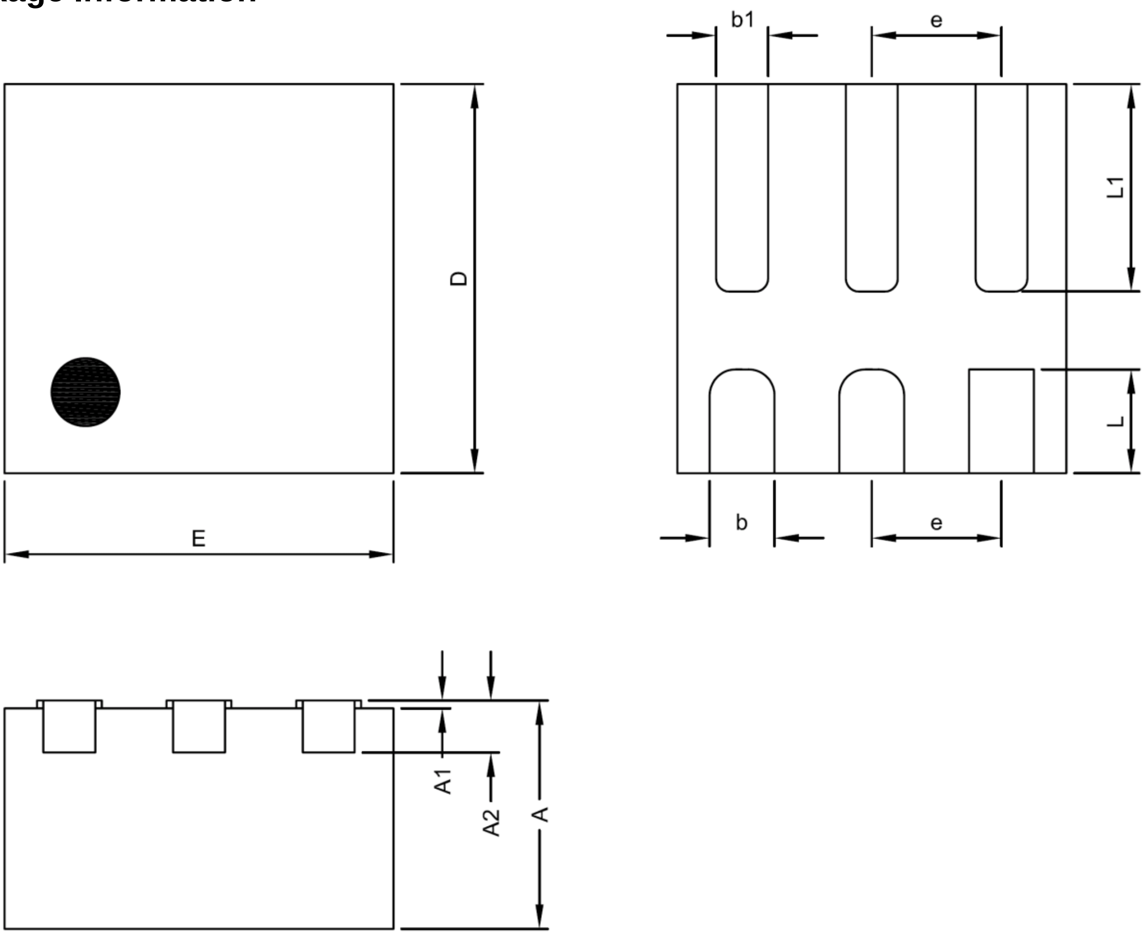


Bottom Layer



EV2282/3/4 PCB	Information
Board Material	FR4
Size	60mm×45mm
Board Thickness	1.6mm
Layers	4
Copper Thickness	2 oz.

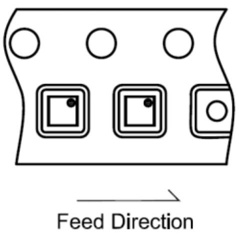
Package Information



ADFN1.5X1.5-6 Package

Symbol	DIMENSION IN MM			DIMENSION IN INCH		
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.
A	0.80	0.85	0.90	0.0315	0.0335	0.0354
A1	0.00	- - -	0.05	0.0000	- - -	0.0020
A2	0.20 REF			0.0079 REF		
D	1.45	1.50	1.55	0.0570	0.0590	0.0610
E	1.45	1.50	1.55	0.0570	0.0590	0.0610
b	0.20	0.25	0.30	0.0079	0.0098	0.0118
b1	0.15	0.20	0.25	0.0059	0.0079	0.0098
e	0.50 BSC			0.0197 BSC		
L	0.35	0.40	0.45	0.0138	0.0157	0.0177
L1	0.75	0.80	0.85	0.0295	0.0315	0.0335

Taping Specification



PACKAGE	Q'TY/REEL
ADFN1.5X1.5-6	3,000 ea