

SA24491/SA24492/SA24493/SA24493E/SA24493L

High Efficiency, 36V Input, 1/2/3A Synchronous Step Down Regulators

General Description

The SA2449x is a high-efficiency synchronous step-down DC-DC converter capable of delivering a load current of 1A/2A/3A. It operates over a wide input voltage range of 4.5V to 36V and integrates main and synchronous MOSFET switches with very low $R_{DS(ON)}$ to minimize conduction loss.

The SA2449x uses a peak current control architecture. The switching frequency is adjustable from 300kHz to 2.2MHz using an external resistor. The SA24491/SA24492/SA24493/SA24493L features ultra-low quiescent current to achieve high efficiency under light load conditions. The SA24493E works at Force Continuous Conduction Mode (FCCM) under light load for small output voltage ripple. Additionally, the internal soft-start function limits inrush current during power-up.

The SA2449x is available in a QFN2×2-12 Package.

Part Number	Output Current	Light Load Mode	Output Discharge Function
SA24491TLQ	1A	PFM	Y
SA24492TLQ	2A	PFM	Y
SA24493TLQ	3A	PFM	Y
SA24493ETLQ	3A	FCCM	Y
SA24493LTLQ	3A	PFM	N

Key Features

- Low $R_{DS(ON)}$ for Internal Switches (Top/Bottom): 130/75mΩ
- 4.5-36V Input Voltage Range
- Low quiescent current: $I_Q = 18 \mu A$ (Typ.)
- Internal Compensation
- Internal 1ms Soft-start Limits the Inrush Current
- Adjustable Switching Frequency Range: 300kHz to 2.2MHz
- Light Load Operating Mode
 - SA24491/SA24492/SA24493/SA24493L: PFM
 - SA24493E: FCCM
- Output Current Capability
 - SA24491: 1A
 - SA24492: 2A
 - SA24493/SA24493E/SA24493L: 3A
- $\pm 1\%$ 0.6V Reference Over $-40^\circ C \sim 125^\circ C$
- Cycle-by-cycle Peak Current Limit
- Short-Circuit Protection
- Spread Spectrum Function
- Thermal Shutdown and Auto Recovery
- Compact Package: QFN2×2-12
- Automotive AEC- Q100 Grade 1 Qualified
- MSL Rating: MSL1

Applications

- Automotive
- Industrial
- High-Voltage DC/DC Converters

Typical Application

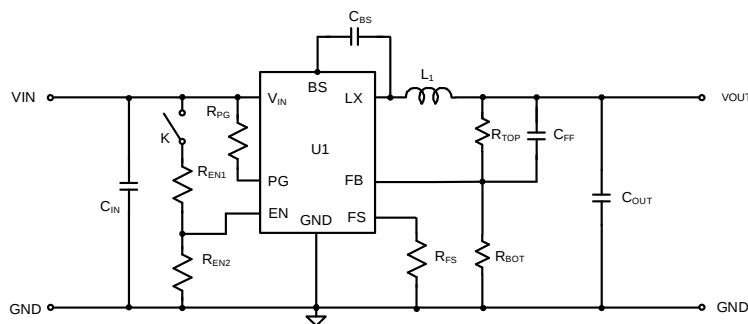


Figure 1. Typical Application Circuit

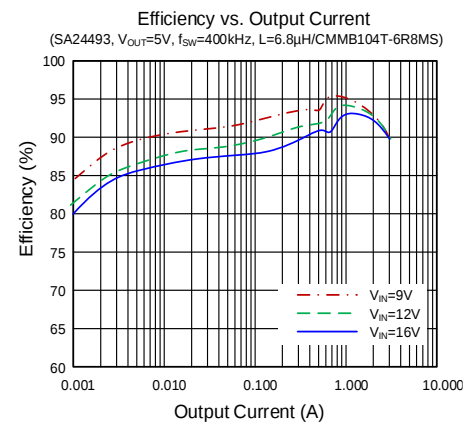
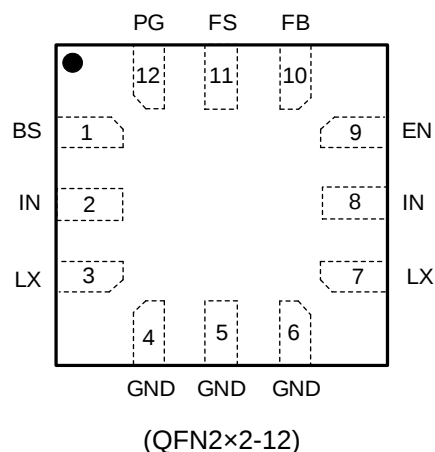


Figure 2. Efficiency vs. Load Current



Pinout (top view)

x = year code, y = week code, z = lot number code



Pin Number	Pin Name	Pin Description
1	BS	Boot-strap pin. Supply high side gate driver. Connect a 0.1μF ceramic capacitor between the BS and the LX pins.
2, 8	IN	Input pin. Decouple this pin to GND pin with at least 4.7uF ceramic cap.
3, 7	LX	Inductor pin. Connect this pin to the switching node of inductor.
4, 5, 6	GND	Ground.
9	EN	Enable control. Pull high to turn on. Do not leave floating.
10	FB	Output Feedback Pin. Connect this pin to the center point of the output resistor divider (as shown in Figure 1) to program the output voltage: $V_{OUT}=0.6 \times (1+R_{top}/R_{bot})$.
11	FS	Frequency setting pin. Connect a resistor from this pin to GND to program the switching frequency. The switching frequency equals to: $f_{sw}(kHz) = 10^6 / (9.3 \times R_{FS}(k\Omega) + 30)$.
12	PG	Power good indicator. Open drain output. High-impedance, externally pulled high when V_{OUT} is within the regulation range. Otherwise, internally pulled low.

Block Diagram

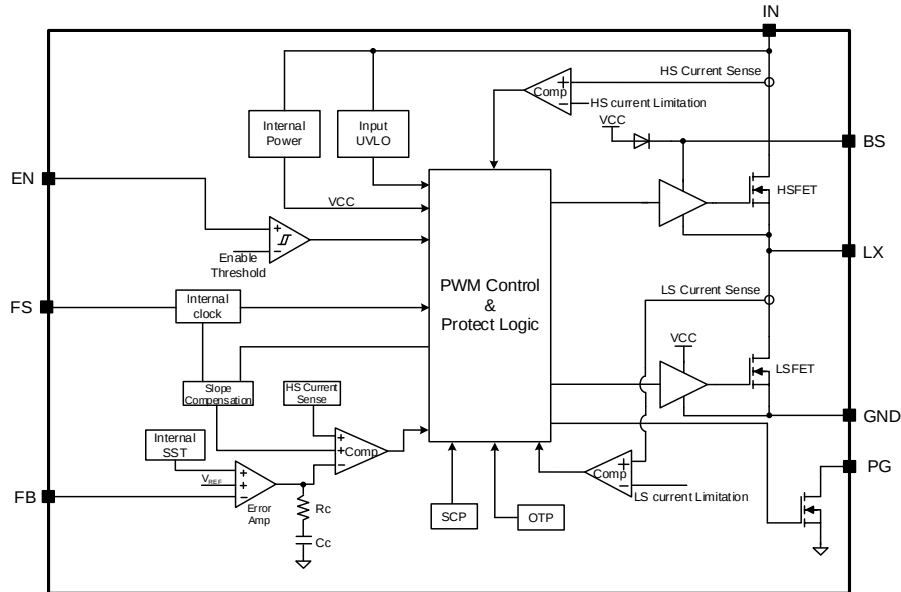


Figure 3. Block Diagram

Absolute Maximum Ratings

Parameter (Note 1)	Min	Max	Unit
IN	-0.3	40	V
LX, FB, EN, FS, PG	-0.3	40	
BS-LX	-0.3	6	
Dynamic LX Voltage in 20ns Duration	GND - 5	IN + 5	
Junction Temperature, Operating	-40	150	°C
Lead Temperature (Soldering,10s)		260	
Storage Temperature	-65	150	
ESD Susceptibility			
HBM (Human Body Model)		±2000	V
CDM (Charged Device Model)		±750	

Thermal Information

Parameter (Note 2)	Typ	Unit
θ_{JA} Junction-to-Ambient Thermal Resistance	40.5	°C/W
θ_{JB} Junction-to-Board Thermal Resistance	17.4	
θ_{JC_top} Junction-to-Case (top) Thermal Resistance	21.3	
Ψ_{JT} Junction-to-Top Characterization Parameter	0.6	
P_D Power Dissipation $T_A = 25^\circ\text{C}$	3.08	W

Recommended Operating Conditions

Parameter (Note 3)	Min	Max	Unit
IN	4.5	36	V
Junction Temperature	-40	150	°C
Ambient Temperature	-40	125	

Electrical Characteristics

($V_{IN} = 12V$, $T_J = -40^{\circ}C$ to $+125^{\circ}C$. Typical values are at $T_J = 25^{\circ}C$, unless otherwise specified. (Note 4))

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
Input	Input Voltage Range	V _{IN}		4.5		36	V
	Input UVLO Threshold	V _{UVLO}				4.5	V
	UVLO Hysteresis	V _{HYS}			0.3		V
	Quiescent Current	I _Q	SA24491/SA24492/SA24493, I _{OUT} =0, V _{FB} =V _{REF} ×105%		18	30	μA
	No Load Input Current	I _{NO_LOAD}	SA24493E		10	20	mA
	Shutdown Current	I _{SHDN}	EN=0		1	5	μA
Output	Feedback Reference Voltage	V _{REF}	T _J = -40°C~125°C, F _S =400kHz	0.594	0.6	0.606	V
			T _J = -40°C~125°C, F _S =2.2MHz	0.591	0.6	0.609	
	FB Input Current	I _{FB}	V _{FB} =0.65V	-50		50	nA
	Output Discharge Current	I _{DIS}	Except SA24493L		40		mA
	Soft-start Time	t _{SS}		0.5	1	2	ms
	Output Under Voltage Protection Threshold	V _{UVP}			33%		V _{REF}
	Hiccup Duty Cycle	D _{HICCUP}	(Note 5)		12.5		%
Power Good	Power Good Threshold	V _{PG}	V _{FB} falling, PG from high to low		87%		V _{REF}
			V _{FB} rising, PG from low to high		90%		V _{REF}
			V _{FB} rising, PG from high to low		115%		V _{REF}
			V _{FB} falling, PG from low to high		113%		V _{REF}
	Power Good Delay	T _{PG_F}	PG falling edge (Note 5)		20		μs
		T _{PG_R}	PG rising edge (Note 5)		150		μs
Power Good Output Low Voltage	V _{PG,LOW}	I _{PG_LOW} =5mA			0.7	V	
MOSFET	Top FET R _{ON}	R _{DS(ON)1}			130		mΩ
	Bottom FET R _{ON}	R _{DS(ON)2}			75		mΩ
	Top FET Current Limit	I _{LIM,TOP91}	SA24491	1.5	2	2.6	A
	Bottom FET Current Limit	I _{LIM, BOT91}		1	1.5	2	A
	Top FET Current Limit	I _{LIM,TOP92}	SA24492	2.6	3.5	4.5	A
	Bottom FET Current Limit	I _{LIM, BOT92}		2.1	2.9	3.8	A
	Top FET Current Limit	I _{LIM,TOP93}	SA24493/SA24493L	4	5	6	A
	Bottom FET Current Limit	I _{LIM, BOT93}		2.8	3.5	4.5	A
	Top FET Current Limit	I _{LIM,TOP93E}	SA24493E	4	5	6	A
	Bottom FET Current Limit	I _{LIM, BOT93E}		2.8	3.5	4.5	A
Enable (EN)	EN High Threshold	V _{ENH}		1.08	1.2	1.32	V
	EN Low Threshold	V _{ENL}		0.9	1.0	1.1	V
Frequency	Oscillator Frequency Program Range	f _{OSC,RNG}	R _{FS} =45.6kΩ~360kΩ	300		2200	kHz
	Oscillator Frequency Accuracy	f _{OSC,ACC}	F _{OSC} =2MHz, with R _{FS} resistor of 1% accuracy	-12%		12%	f _{OSC}
	Frequency Span Spread Spectrum Operation	f _{SS}	(Note 5)		±5		%
	Min ON Time	t _{ON,MIN}	(Note 5)		80		ns
	Min OFF Time	t _{OFF,MIN}	F _{OSC} =2MHz (Note 5)		90		ns
OTP	Thermal Shutdown Temperature	T _{SD}			165		°C



SA24491/SA24492/SA24493/SA24493E/SA24493L

	Thermal Shutdown Hysteresis	$T_{SD,HYS}$			20		°C
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Note 1: Stresses beyond the “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Note 2: θ_{JA} is measured in the natural convection at $T_A = 25^\circ\text{C}$ on a four-layer Silergy demo board.

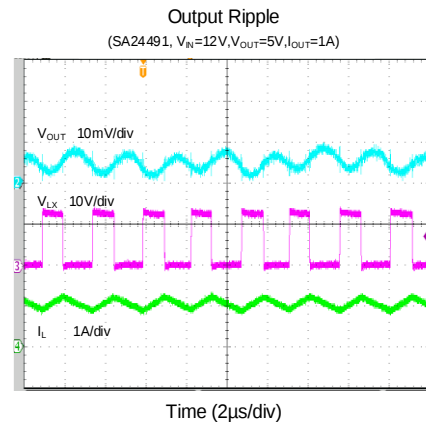
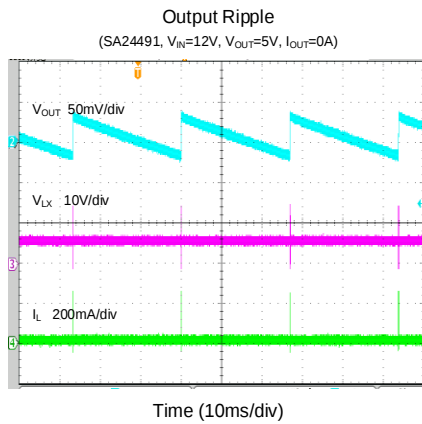
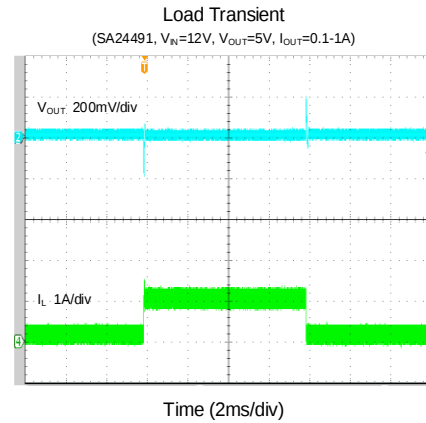
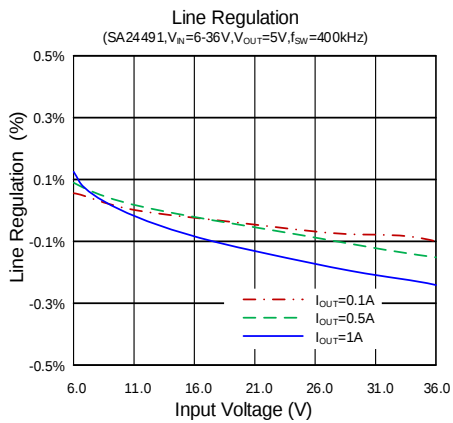
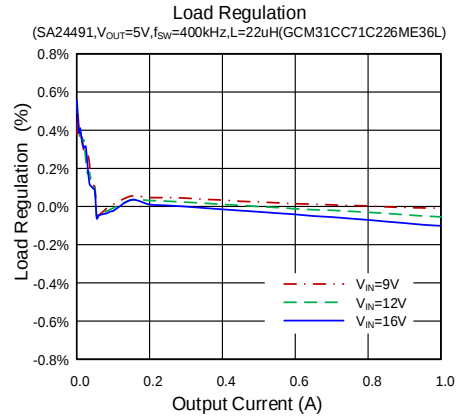
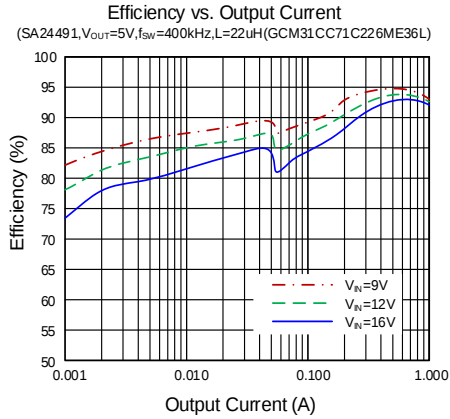
Note 3: The device is not guaranteed to function outside its operating conditions.

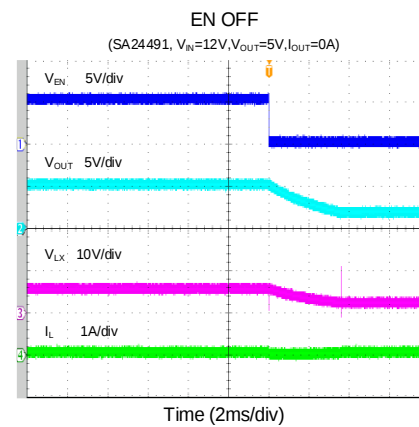
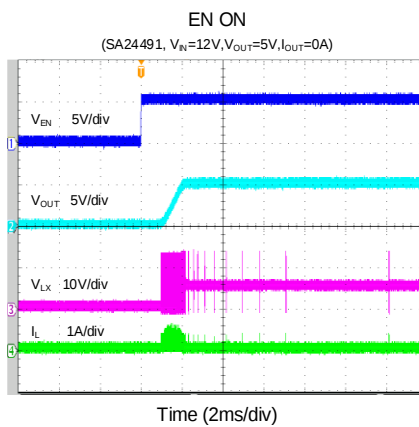
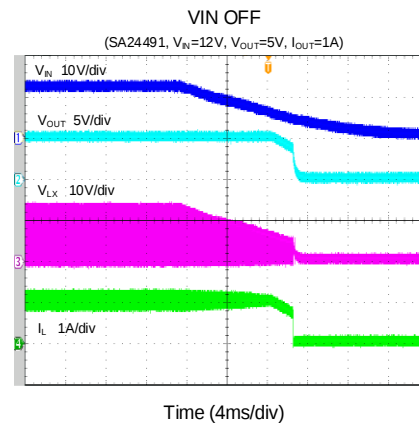
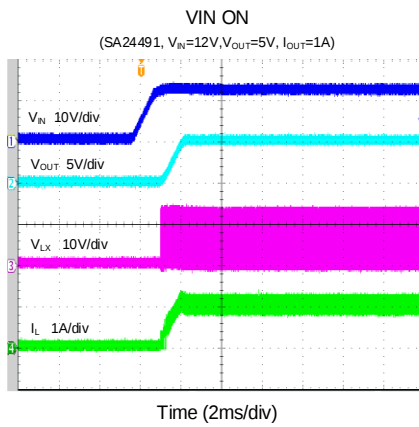
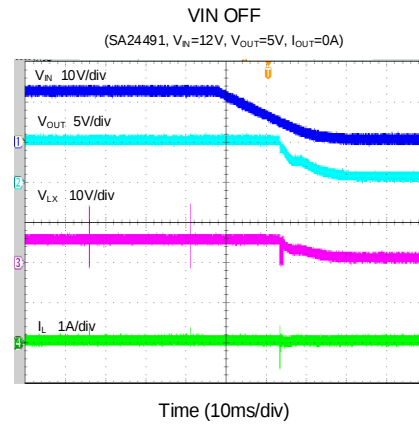
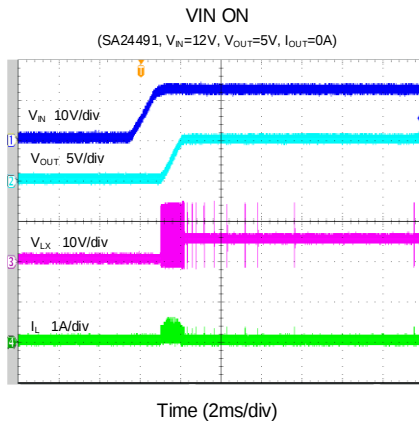
Note 4: Unless otherwise stated, limits are 100% production tested under pulsed load conditions such that $T_A \cong T_J = 25^\circ\text{C}$. Limits over the operating temperature range (See recommended operating conditions) and relevant voltage range(s) are guaranteed by design, test, or statistical correlation.

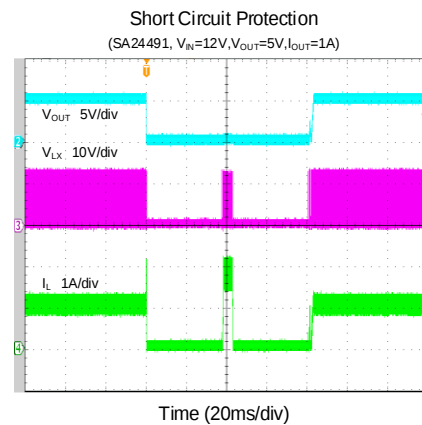
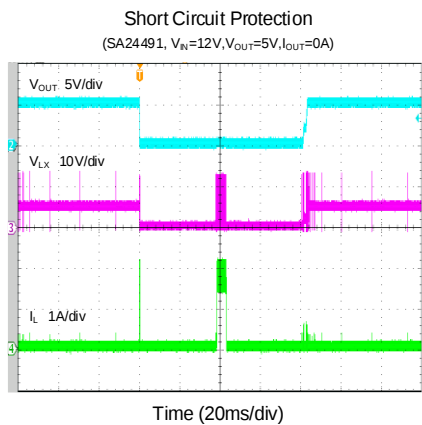
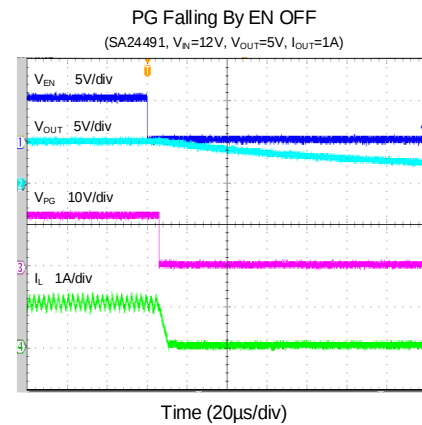
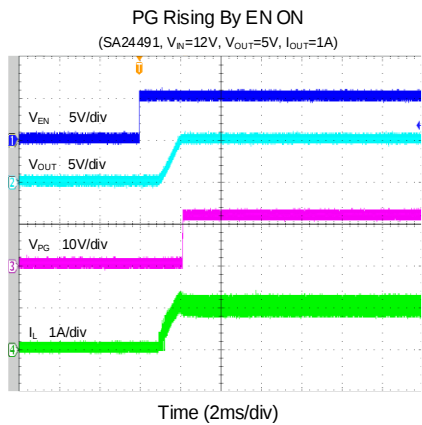
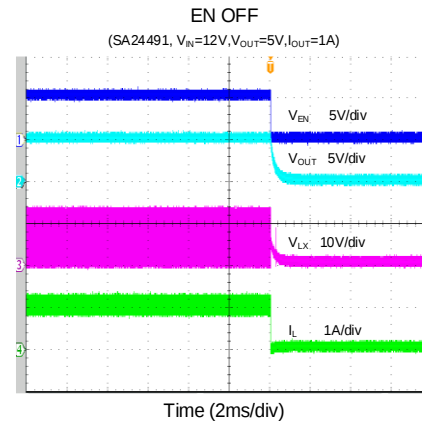
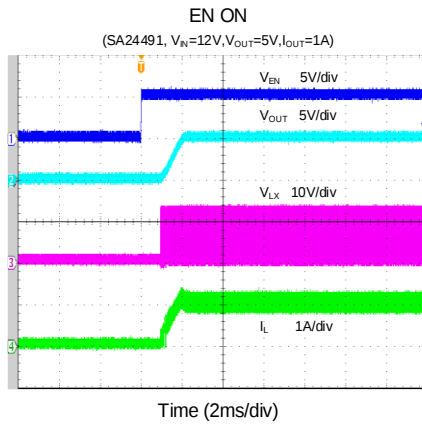
Note 5: Guaranteed by design or statistical correlation and not production tested.

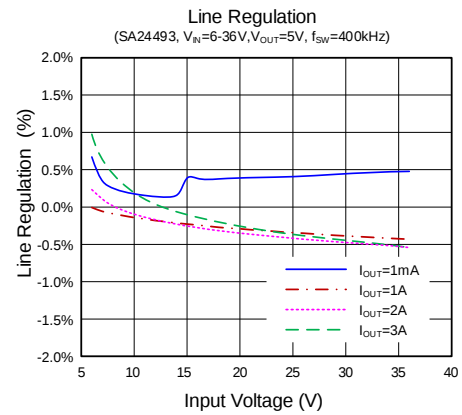
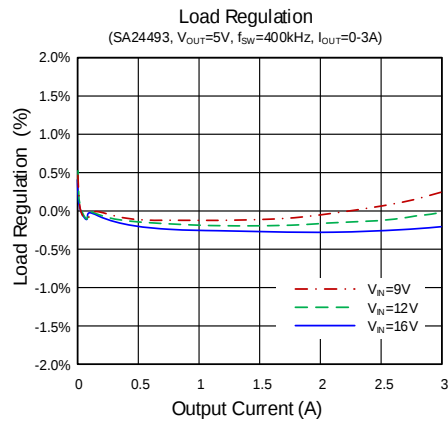
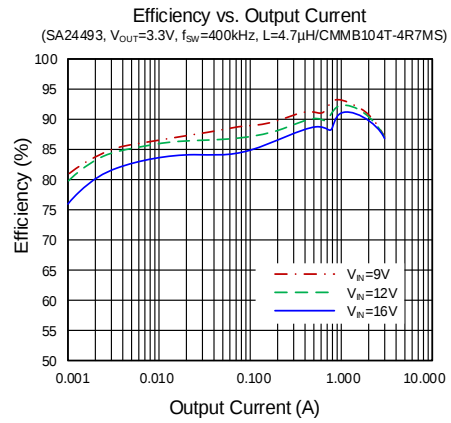
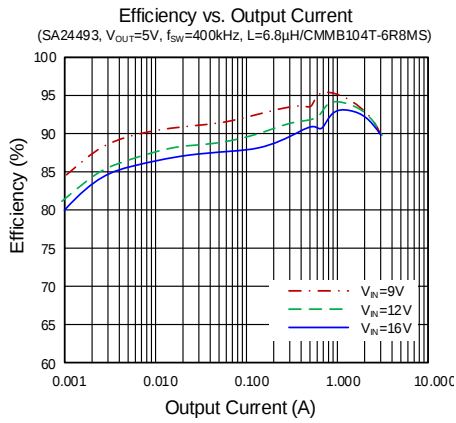
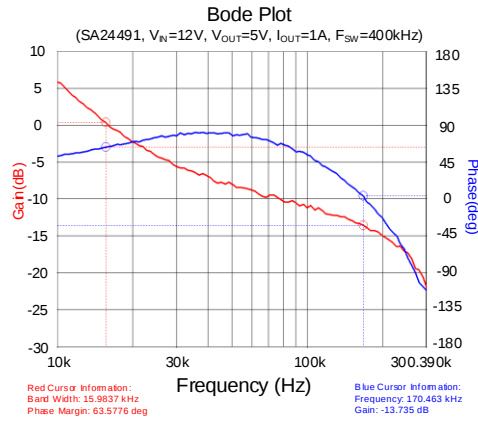
Typical Performance Characteristics

($V_{IN} = 12V$, $C_{OUT} = 44\mu F$, $f_{SW} = 400kHz$, $T_A = 25^\circ C$ unless otherwise specified)



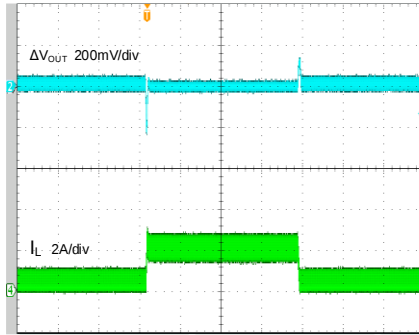






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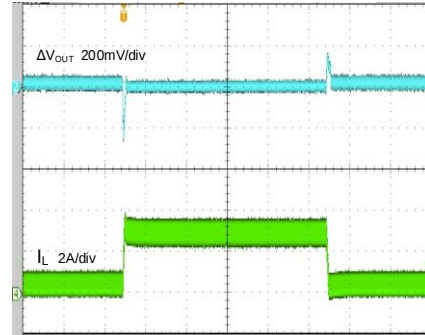
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Time (800µs/div)

Load Transient

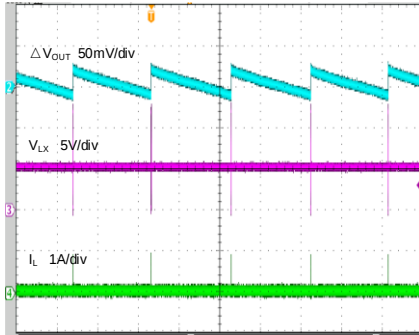
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Time (800µs/div)

Output Ripple

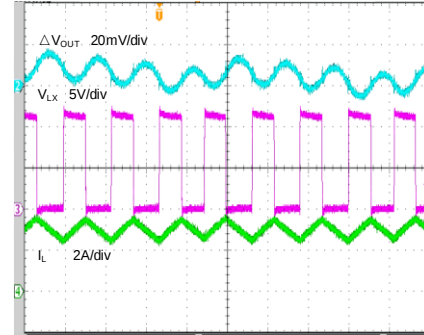
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Time (10ms/div)

Output Ripple

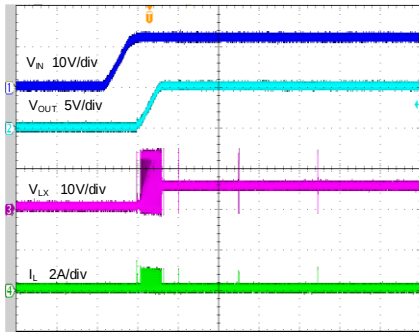
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Time (2µs/div)

VIN ON

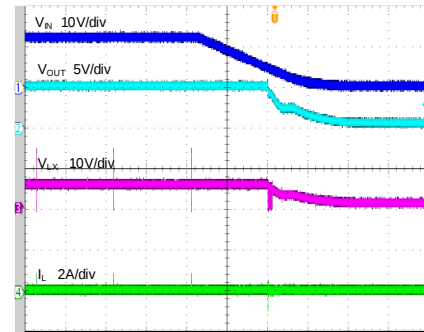
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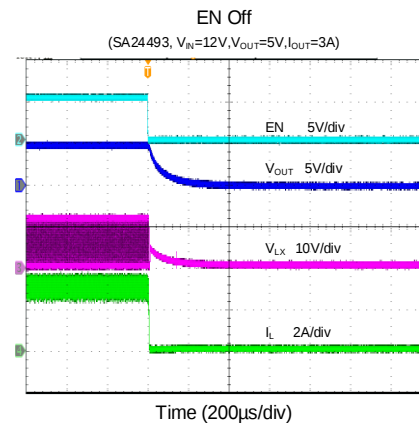
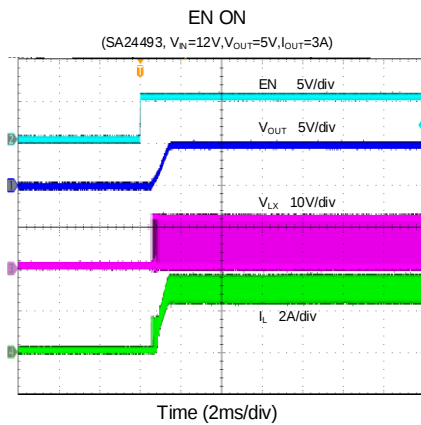
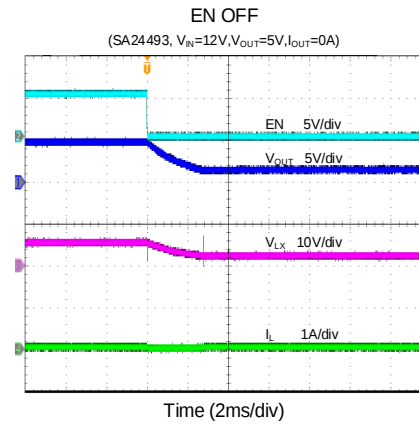
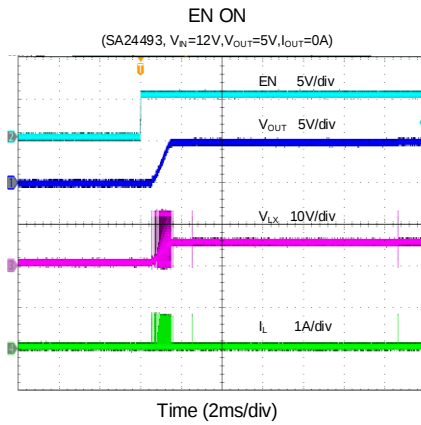
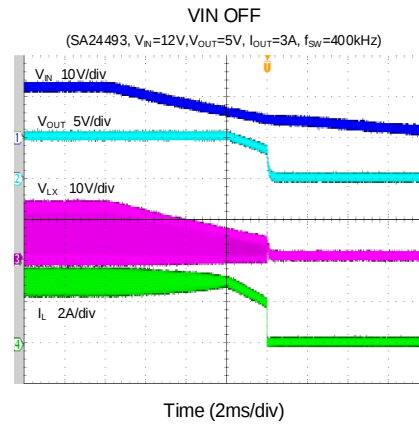
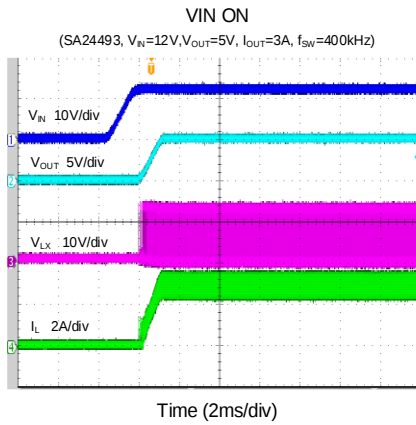
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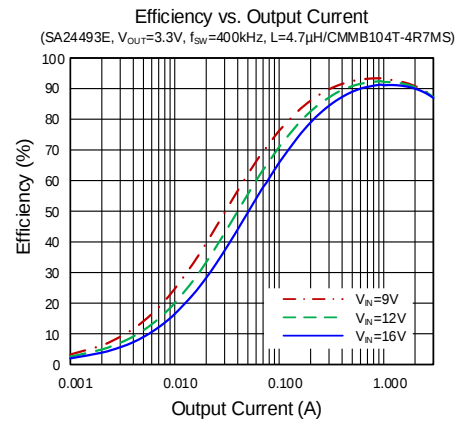
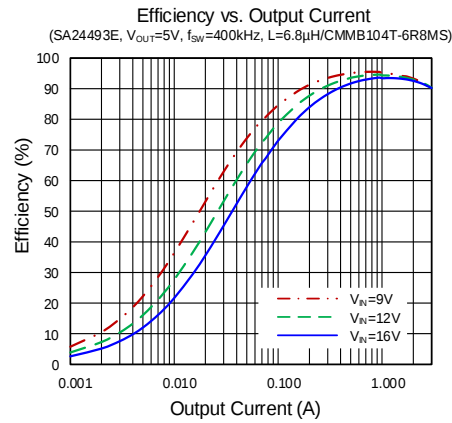
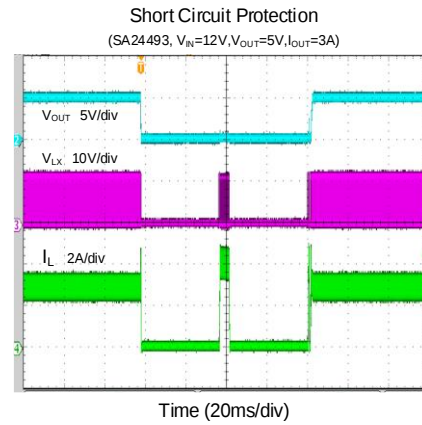
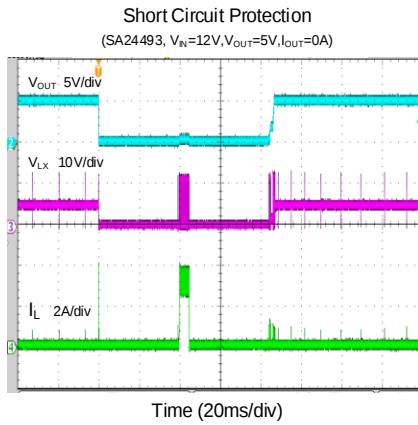
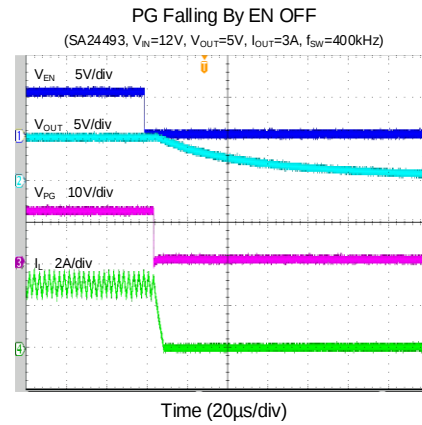
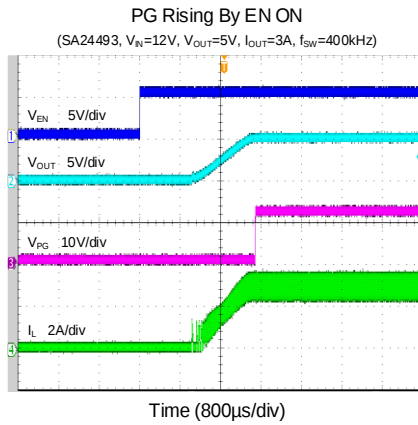
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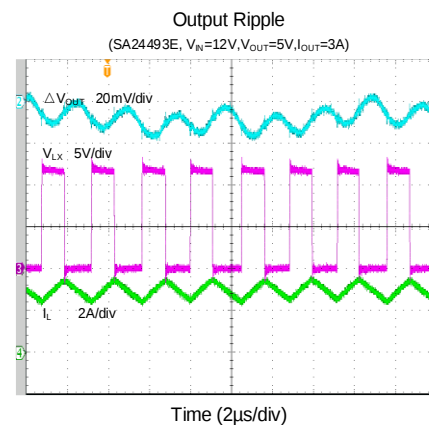
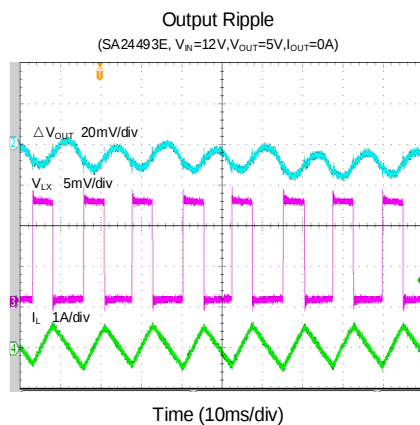
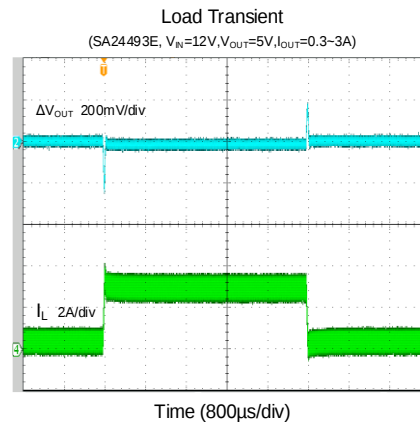
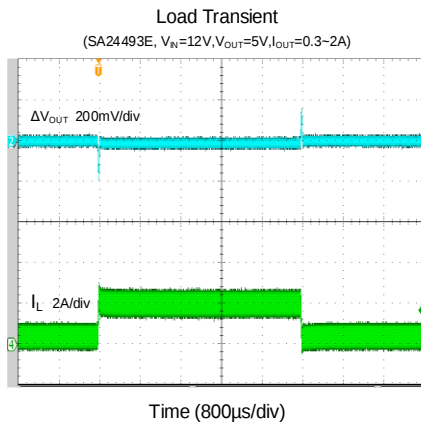
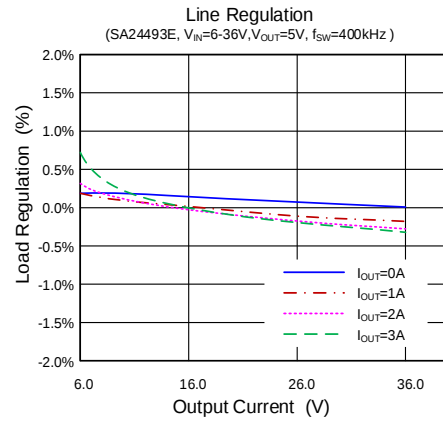
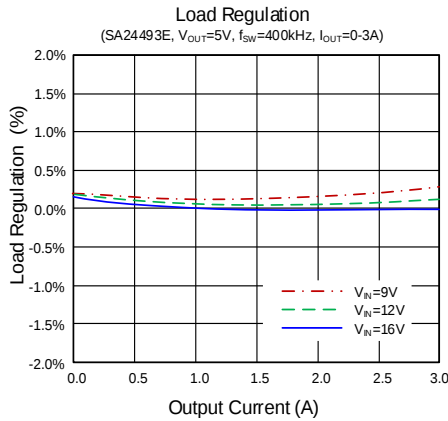
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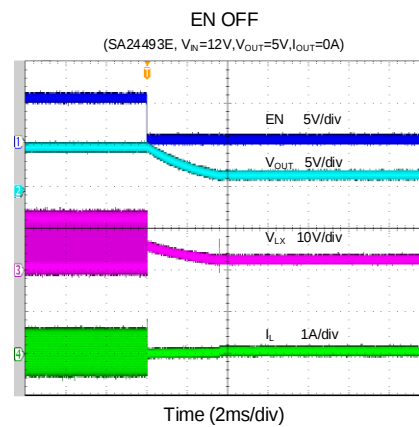
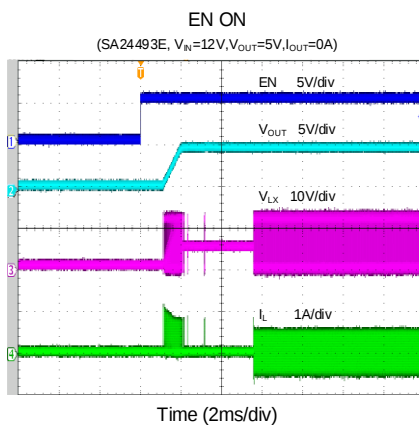
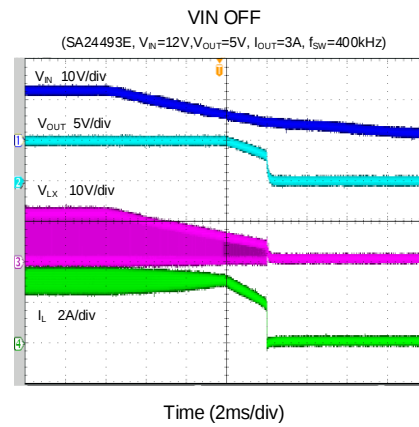
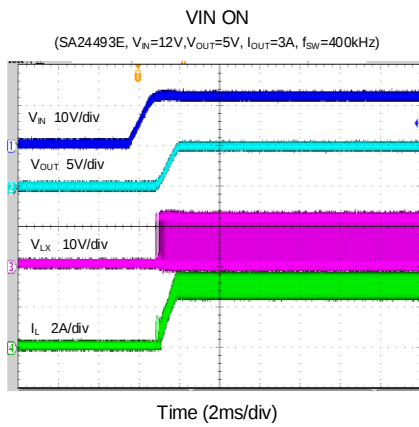
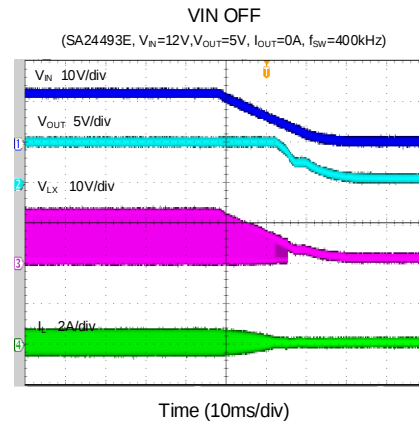
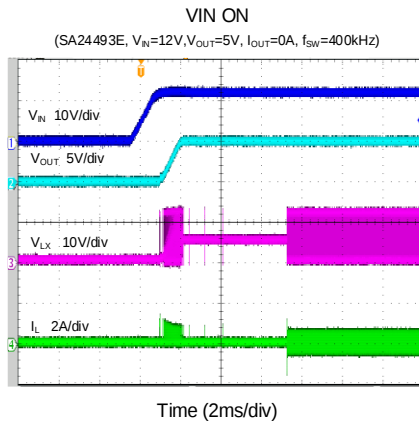


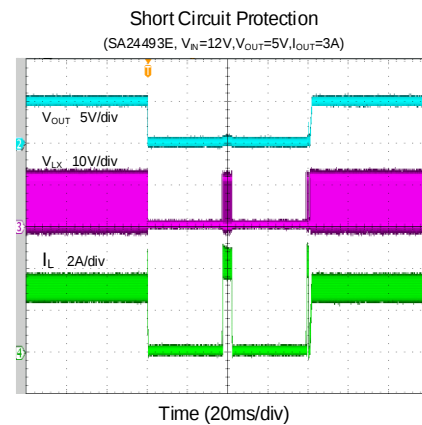
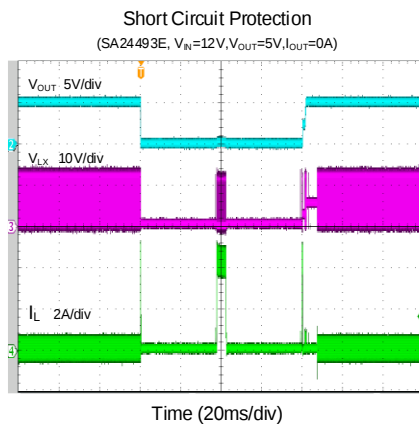
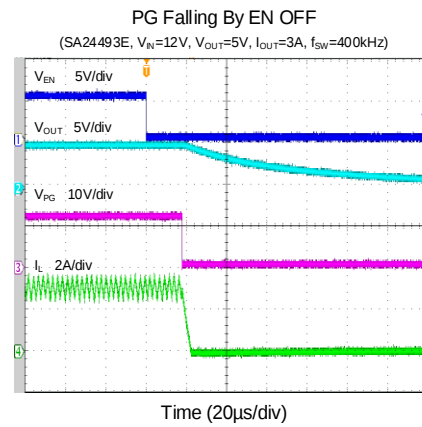
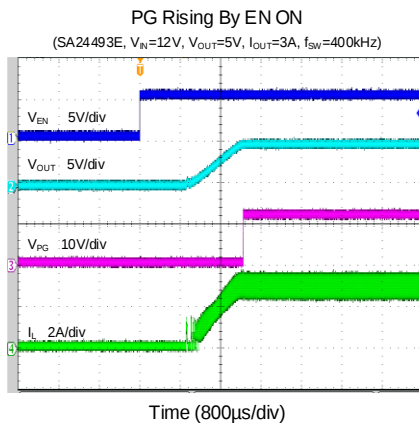
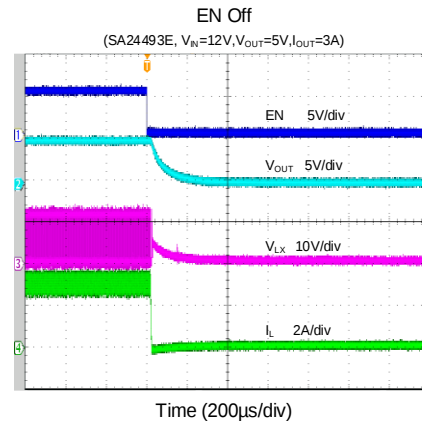
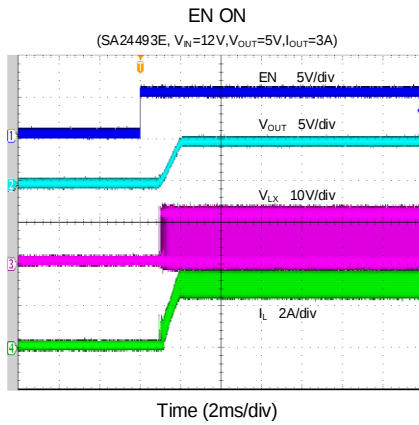
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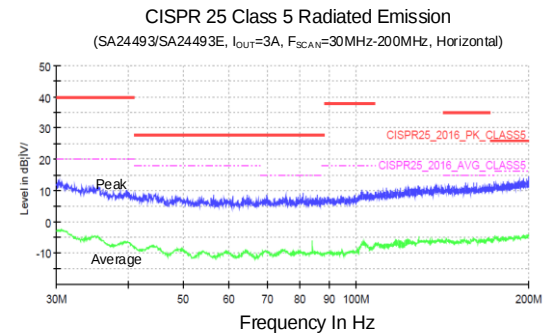
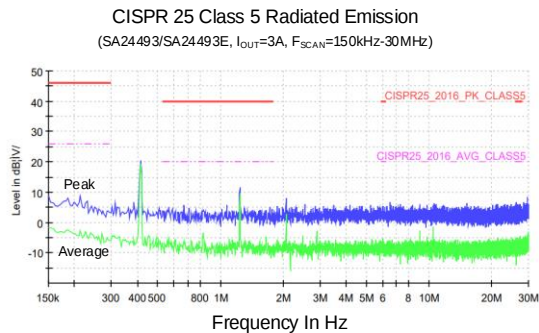
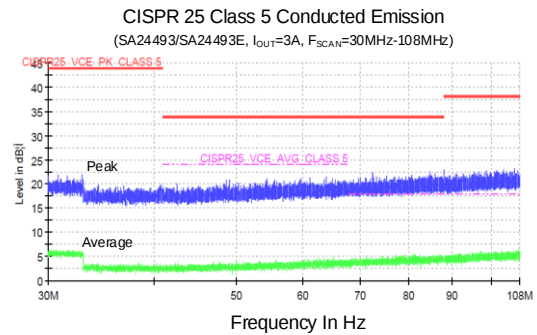
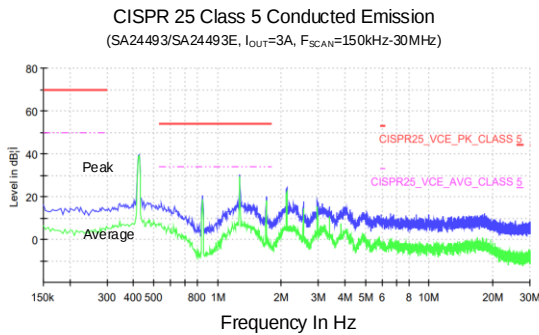
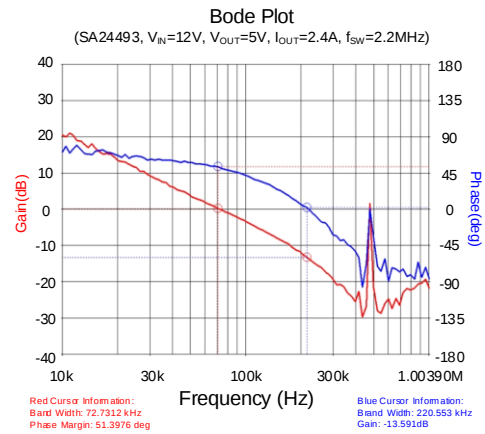
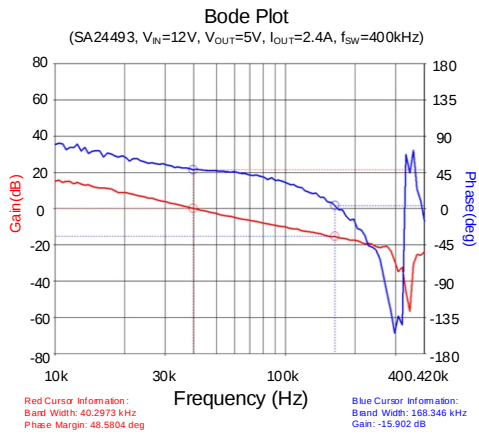


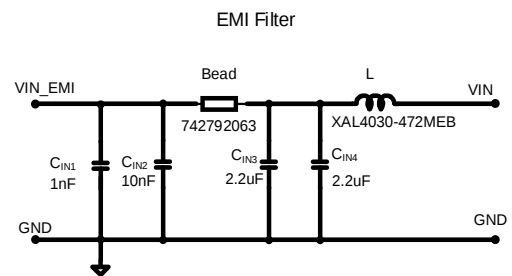
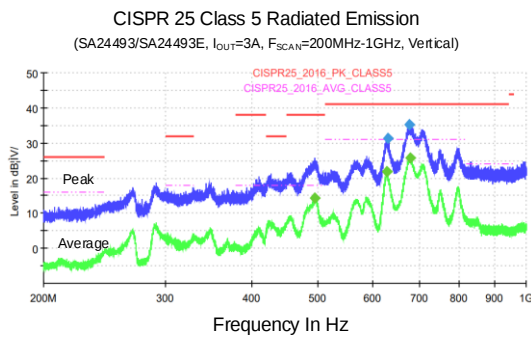
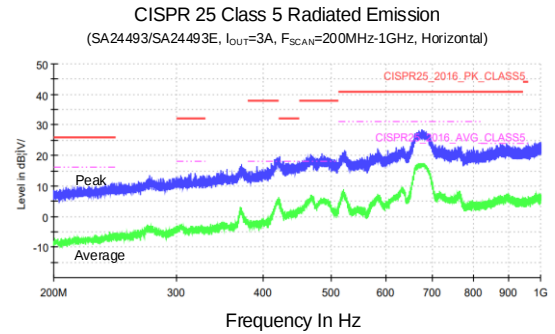
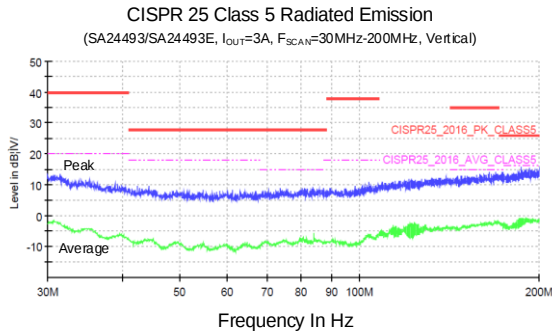












Functional Description

The SA2449x is a high-efficiency synchronous step-down DC-DC regulator featuring internal power and synchronous rectifier MOSFETs. It operates with fixed frequency and peak current control over a wide input voltage range of 4.5V to 36V and can deliver continuous output currents of 1A/2A/3A.

The SA2449x is available in a QFN2x2 package. The switching frequency can be adjusted from 300kHz to 2.2MHz, allowing selection to meet application EMI limits and to minimize noise in critical frequency bands.

The SA2449x offers excellent efficiency over a wide range of applications by incorporating internal 130mΩ power and 75mΩ synchronous rectifier MOSFETs, along with frequency reduction at light load conditions to device with PFM mode. The 1μA shutdown supply current enables the device to be utilized in battery-powered applications. The SA2449x ensures safe operation under all conditions by providing cycle-by-cycle current limit, internal soft-start, short-circuit protection, and thermal shutdown.

General Features

Fixed Frequency PWM Control and Slope Compensation

The SA2449x uses fixed frequency and peak current mode control. The output voltage is fed back to the error amplifier through an external resistor divider connected to the FB pin and is compared with the internal reference voltage, V_{REF} . The output of the error amplifier (V_{COMP}) regulates both the peak current level and the output voltage.

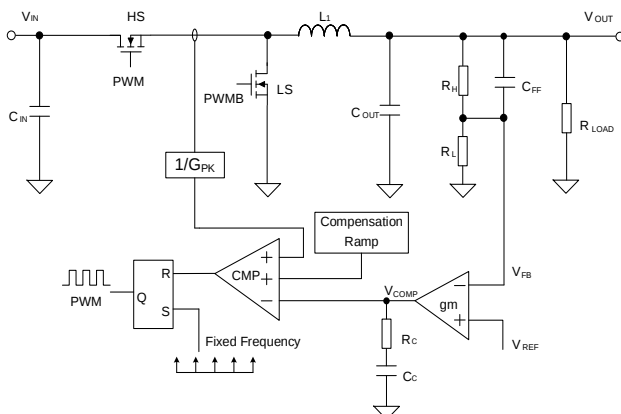


Figure 4. Fixed Frequency PWM Control and Slope Compensation Block Diagram

On the rising edge of the internally generated fixed-frequency clock, the internal high-side N-channel power MOSFET will turn on. The MOSFET current is converted into a ramp voltage signal using a $1/G_{PK}$ coefficient. When the sum of the ramp voltage and the compensation ramp reaches V_{COMP} , the high-side power MOSFET will turn off, and the synchronous rectifier MOSFET will turn on. Peak

current mode control also provides an inherent cycle-by-cycle peak current limit.

ON-OFF Sequence

The normal startup of the chip is determined by two factors. First, the EN pin level must exceed the logic high level threshold. Second, the voltage present at VIN pin must exceed the UVLO rising threshold. After the EN pin level is set high, whether the chip is turned on is determined by the voltage of the VIN pin. When both conditions are met, the internal reference voltage starts ramping and the device starts operating. After a 1ms delay, the soft-start circuit is enabled and the SW node begins switching. After a fixed soft-start time t_{SS} (1ms typ.), the output reaches the target value.

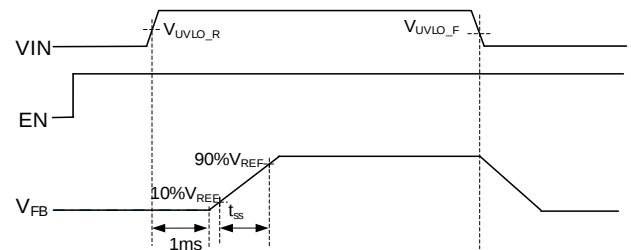


Figure 5. VIN ON/OFF Sequence

When the VIN pin voltage is higher than 4.5V, the EN pin voltage determines whether the chip begins operating. Once the EN pin voltage is above the logic high level, the internal reference voltage begins to build and the functional circuit begins operating. After a 1ms delay, the soft-start circuit begins operating and the SW node begins switching. After a fixed soft-start time, the output reaches the target value.

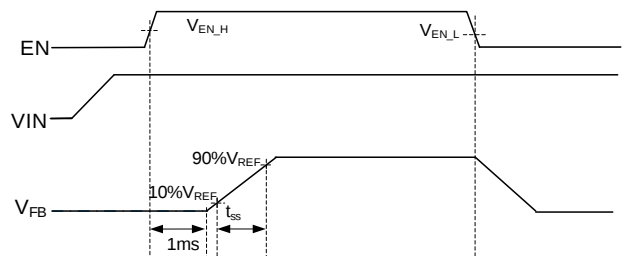


Figure 6. EN ON/OFF Sequence

Light Load Operation

The SA24491/SA24492/SA24493/SA24493L operate in pulse frequency modulation (PFM) mode under light load conditions. In PFM mode, the low-side synchronous rectifier is turned off when the current through the rectifier ramps down to zero, preventing recirculation current that can reduce efficiency during light loads. Additionally, the output of the error amplifier (V_{COMP}) naturally decreases, which in turn reduces the peak current under these conditions. When V_{COMP} decreases further with a reduced load and reaches the internal preset threshold, the device

stops switching to minimize switching power loss and quiescent current, thereby enhancing light load efficiency. Switching resumes when V_{COMP} rises above the threshold.

Power Good Indicator

The power good indicator (PG) is an open-drain output controlled by a window comparator connected to the feedback signal. This pin is pulled to ground if the output voltage is lower than 87% of the regulation voltage or higher than 115% of the regulation voltage. This pin enters a high-impedance state if the output voltage is between 90% and 113% of the regulation voltage.

PG should be connected to V_{IN} or another voltage source through a resistor (e.g., 10k Ω –100k Ω).

External Bootstrap Capacitor

The SA2449x integrates a floating power supply for the gate driver that operates the internal high-side N-channel power MOSFET. Connect a 0.1 μ F low ESR ceramic capacitor between BS and LX for proper operation.

Adjustable Switching Frequency

The switching frequency can be adjusted from 300kHz to 2.2MHz by connecting a resistor between FS and GND. The switching frequency can be calculated using the following formula:

$$f_{sw} (kHz) = \frac{10^6}{9.3 \times R_{FS} (k\Omega) + 30}$$

Note that the device stability will be affected if the on-time is close to the minimum on-time, $t_{ON,MIN}$. Table 1 presents the switching frequency and R_{FS} resistor values for typical applications.

Table 1. Adjustable Switching Frequency

$f_{sw}(kHz)$	$R_{FS}(k\Omega)$	$V_{IN}(V), V_{OUT} = 3.3V$	
		12	18
300	355	✓	✓
400	267	✓	✓
1000	104.3	✓	✓
2200	45.6	✓	×
400	OPEN	✓	✓

Minimum Duty Cycle and Maximum Duty Cycle

The switching frequency is influenced not only by component tolerances but also by the minimum on-time and off-time limits. Consequently, the minimum duty cycle is approximately 3.2% at a 400kHz switching frequency, accounting for an approximate minimum on-time of 80ns. Due to the device's on-time stretch function, the maximum duty cycle can reach up to 95%.

For SA24493E (FCCM version), special attention should be paid whether minimum on time ($t_{ON,MIN}$) will be continuously

triggered in the system application. This should be avoided for the sake of output voltage accuracy and ripple. Once the minimum on time is continuously triggered, the V_{OUT} voltage will increase with the switching until the OVP (typ. 115%* V_{REF}) is triggered and the IC stops switching to prevent output voltage runaway. Then the output voltage drops and after the output voltage is less than the set point, the IC enters FCCM again. This switching behavior will be repeated unless the condition disappears.

Frequency Spread Spectrum

A $\pm 5\%$ variation in the internal oscillator frequency is used to generate sidebands of the switching frequency and its harmonics. This variation broadens the emission power spectrum and reduces the peak electromagnetic interference (EMI) switching noise.

Fault Protection Modes

Peak Current Limit Protection

Because the converter operates using peak current mode control, the SA2449x provides inherent cycle-by-cycle peak current limiting (top MOSFET current limit). During t_{ON} , if the high-side power MOSFET current exceeds the current limit threshold, it is turned off, and the low-side synchronous rectifier is turned on. A blanking time period is used at the beginning of the on-time, during which current sampling is disabled to avoid false triggers caused by switching noise. The priority of peak current limit protection is lower than that of the minimum on-time.

Valley Current Limit Protection

The SA2449x provides valley current limit for the bottom MOSFET. If the peak current limit is triggered, the high-side MOSFET is turned off. The high-side switch cannot be turned on again until the low-side synchronous rectifier current falls below the bottom MOSFET current limit and the inductor current returns to safe levels.

Short-Circuit Protection

The SA2449x integrates hiccup mode short-circuit protection. If V_{FB} is less than 33% of V_{REF} and the peak current limit is triggered, the short-circuit protection mode will be initiated.

The SA2449x will shut down for approximately 40ms and then restart with a complete soft-start cycle lasting approximately 5.6ms. If the fault condition is resolved, the device will resume normal operation. Refer to Figure 5.

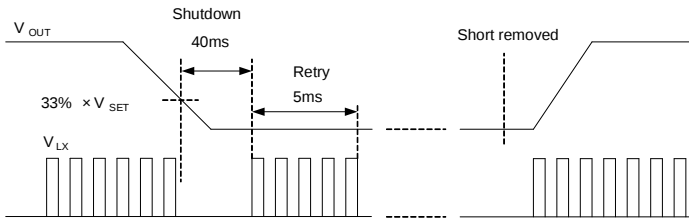


Figure 7. Short-Circuit Protection

Overtemperature Protection (OTP)

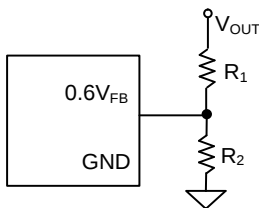
The SA2449x includes overtemperature protection (OTP) circuitry to prevent overheating caused by excessive power dissipation. This feature shuts down switching operations when the junction temperature exceeds 165°C. Once the junction temperature decreases by approximately 15°C, the IC will resume normal operation with a complete soft-start cycle. To ensure continuous operation, provide adequate cooling to prevent the junction temperature from exceeding the OTP threshold.

Application Information

The following paragraphs describe the selection process for the feedback resistors (R_1 and R_2), the input capacitor (C_{IN}), the output capacitor (C_{OUT}), and the output inductor (L).

Feedback Resistor-Divider R_1 and R_2

Choose R_1 and R_2 to program the proper output voltage. Select large resistance values between 10kΩ and 1MΩ for both R_1 and R_2 to minimize power consumption under light loads. Given $V_{OUT} = 3.3V$ and $R_1 = 100k\Omega$, then R_2 can be calculated as 22.2kΩ using the following equation:

$$R_2 = \frac{0.6V}{V_{OUT} - 0.6V} \times R_1$$


With a calculated value of 22.2kΩ for R_2 , a standard 1% 22.1kΩ resistor is selected.

Input Capacitor Selection

Input filter capacitors are essential for reducing the ripple voltage on the input, filtering the switched current drawn from the input supply, and minimizing EMI. When selecting an input capacitor, choose a voltage rating at least 20% greater than the maximum voltage of the input supply and a temperature rating that exceeds the system requirements. The X7R series ceramic capacitors are often preferred due to their small size, low cost, surge current capability, and high RMS current ratings over wide temperature and voltage ranges. Systems powered by wall adapters or long,

inductive wires may experience significant inductive ringing at the input of the device. In these cases, consider adding bulk capacitance, such as electrolytic, tantalum, or polymer capacitors. Utilizing a combination of bulk capacitors (to reduce overshoot or ringing) in parallel with ceramic capacitors (to meet RMS current requirements) is beneficial in these scenarios.

Consider the RMS current rating of the input capacitor and, if necessary, parallel additional capacitors to meet the calculated RMS ripple current.

$$I_{CIN_RMS} = I_{OUT} \times \sqrt{D \times (1 - D)}$$

The worst-case condition occurs at $D = 0.5$, then

$$I_{CIN_RMS,MAX} = \frac{I_{OUT}}{2}$$

For simplicity, choose an input capacitor with an RMS current rating greater than half of the maximum load current.

The input capacitor value determines the input voltage ripple of the converter. If there is a requirement for input voltage ripple in the system, select an appropriate input capacitor that meets the specifications. Due to the very low ESR and ESL of ceramic capacitors, the input voltage ripple can be estimated as follows:

$$V_{CIN_RIPPLE,CAP} = \frac{I_{OUT}}{f_{SW} \times C_{IN}} \times D \times (1 - D)$$

The worst-case condition occurs at $D = 0.5$, then

$$V_{CIN_RIPPLE,CAP,MAX} = \frac{I_{OUT}}{4 \times f_{SW} \times C_{IN}}$$

The capacitance value is less important than the RMS current rating. In most applications, using two 10μF X7R capacitors connected in parallel is sufficient. Place the ceramic input capacitors as close to the IN and GND pins as possible.

Inductor Selection

The inductor is essential for supplying a constant current to the output load while being driven by the switched input voltage. Selecting a low inductor value can help reduce size and cost and enhance transient response; however, it will also increase peak inductor ripple current, which can reduce efficiency and increase output voltage ripple. The low DC resistance (DCR) of these low-value inductors may help minimize DC losses and improve efficiency. Conversely, higher inductor values generally exhibit higher DCR and slower transient response.

A reasonable compromise between size, efficiency, and transient response can be achieved by selecting a ripple current (ΔI_L) that is approximately 20%–50% of the maximum output current. To calculate the approximate inductor value, begin by selecting the input and output

voltages, the operating frequency (f_{SW}), the maximum output current ($I_{OUT,MAX}$) is a fixed value (SA24492 and SA24493x are 3A, The SA24491 is 1A, and estimating ΔI_L as a percentage of that current.

$$L_1 = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{V_{IN} \times f_{SW} \times \Delta I_L}$$

Use this inductance value to determine the actual inductor ripple current (ΔI_L) and the required peak inductor current ($I_{L,PEAK}$) according to the following equations:

$$\Delta I_L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{V_{IN} \times f_{SW} \times L_1}$$

$$I_{L,PEAK} = I_{OUT,MAX} + \frac{\Delta I_L}{2}$$

Select an inductor with a saturation current in excess of $I_{L,PEAK}$.

For maximum efficiency, select an inductor with a low DCR that meets the requirements for inductance, size, and cost. Consider using low-loss ferrite materials.

Output Capacitor C_{OUT} Selection

Select the output capacitor C_{OUT} to meet the output ripple requirements, considering both steady-state ripple and transient conditions. Ceramic and POS types are typically chosen for their small size and low cost.

Output voltage ripple at the switching frequency is caused by the inductor current ripple (ΔI_L) on the output capacitors' equivalent series resistance (ESR) as well as the stored charge (capacitive ripple). When estimating the total ripple, both factors should be considered.

$$V_{RIPPLE,ESR} = \Delta I_L \times ESR$$

$$V_{RIPPLE,CAP} = \frac{\Delta I_L}{8 \times C_{OUT} \times f_{SW}}$$

It is recommended to use two X7R or better grade ceramic capacitors in parallel, each with a minimum capacitance of 22 μ F for typical applications.

Load Transient Considerations

The device integrates compensation components to achieve stability and fast transient responses. Adding a small ceramic capacitor, C_{FF} , in parallel with R_H may further enhance the load transient responses and is therefore highly recommended for applications with significant load transient step requirements.

Thermal Design Considerations

Maximum power dissipation depends on the thermal resistance of the IC package, the PCB layout, the

surrounding airflow, and the difference between the junction and ambient temperatures. The maximum power dissipation can be calculated as follows:

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

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.

To comply with the recommended operating conditions, the maximum junction temperature is 125°C. The junction-to-ambient thermal resistance (θ_{JA}) is layout-dependent. For the QFN2 $\times$ 2-12 package, the thermal resistance (θ_{JA}) is 40.5°C/W when measured on a standard Silergy four-layer thermal test board. These standard thermal test layouts feature a large area with long 2-oz. copper traces connected to each pin and substantial, unbroken 1-oz. internal power and ground planes.

Meeting the performance of the standard thermal test board in a typical board design requires the following:

- Wide copper traces that are well connected to the IC's backside pads leading to exposed copper areas on the component side of the board
- Good thermal vias from the exposed pad connecting to a wide middle-layer ground plane and to an exposed copper area on the board's solder side.

The maximum power dissipation at $T_A = 25^\circ\text{C}$ may be calculated using the following formula:

$$P_{D,MAX} = (150^\circ\text{C} - 25^\circ\text{C}) / (40.5^\circ/\text{W}) = 3.08\text{W}$$

Maximum power dissipation is dependent on the operating ambient temperature for a fixed $T_{J,MAX}$ and thermal resistance θ_{JA} . Use the derating curve in Figure 8 to determine the impact of increasing ambient temperature on maximum power dissipation.

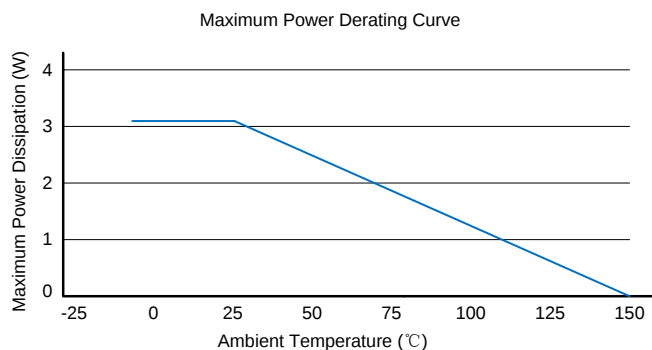
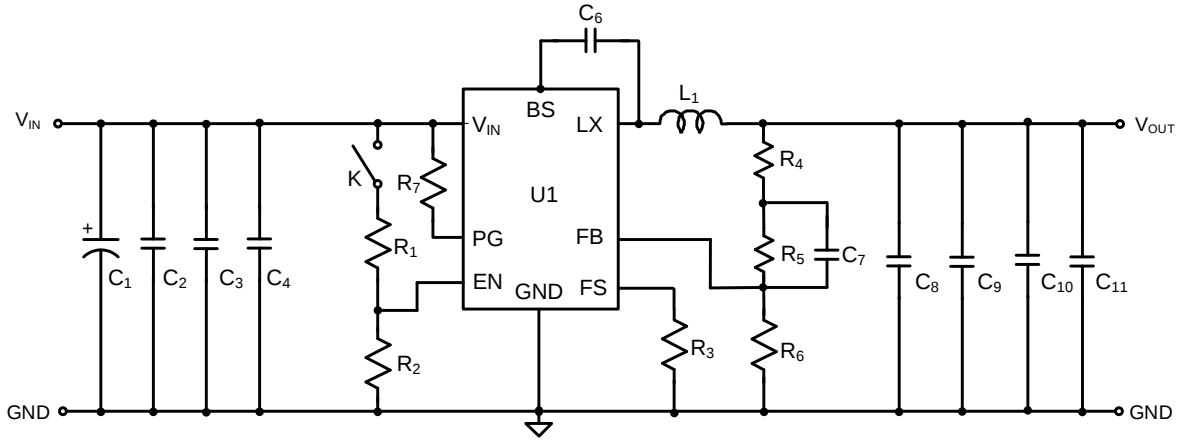


Figure 8. Derating Curve

Application Schematic



BOM List

Designator	Description	Part Number	Manufacturer
U ₁	1A/2A/3A, Buck	SA2449xTLQ	Silergy
L ₁	6.8μH	CMMB104T-6R8MS	Cyntec
C ₁	47μF/100V Electrolytic Cap		
C ₂ , C ₄	10μF/50V/X7T,1206	GCM31CD71H106KE36L	Murata
C ₃ , C ₆	100nF/50V/X7R,0603	GCJ188R71H104KA12D	Murata
C ₅ , C ₉ , C ₁₁	Null		
R ₁	10k, 1%, 0603		
R ₂	1M, 1%, 0603		
R ₄	0Ω, 1%, 0603		
R ₇	100k, 1%, 0603		

Recommend Component Values for Typical Applications

(SA24491TLQ)

V _{OUT} (V)	f _{sw} (kHz)	R ₃ (kΩ)	R ₅ (kΩ)	R ₆ (kΩ)	C ₇ (pF)	L ₁ /Part Number	C _{OUT} /Part Number
3.3	400	267	100	22.2	47	15μH VCMT063T-150MN5TM	22μF*2 GCM31CC71C226ME36L
5	400	267	100	13.7	47	22μH VCMT063T-220MN5TM	22μF*2 GCM31CC71C226ME36L
3.3	2200	45.3	100	22.2	33	3.3μH VCMT053T-3R3MN5TM	22μF*2 GCM31CC71C226ME36L
5	2200	45.3	100	13.7	33	4.7μH VCMT053T-4R7MN5TM	22μF*2 GCM31CC71C226ME36L

(SA24492TLQ, SA24493TLQ, SA24493ETLQ, SA24493LTLQ)

$V_{OUT}(V)$	$f_{SW}(kHz)$	$R_3(k\Omega)$	$R_5(k\Omega)$	$R_6(k\Omega)$	$C_7(pF)$	$L_1/Part\ Number$	C_{OUT}
1.2	400	267	100	100	68	2.2 μH CMMB104T-2R2MS	22 $\mu F \times 2$ GCM31CC71C226ME36L
3.3	400	267	100	22.2	68	4.7 μH CMMB104T-4R7MS	22 $\mu F \times 2$ GCM31CC71C226ME36L
5	400	267	100	13.7	68	6.8 μH CMMB104T-6R8MS	22 $\mu F \times 2$ GCM31CC71C226ME36L
12	400	267	100	5.23	68	10 μH CMMB104T-100MS	22 $\mu F \times 2$ GCM31CC71C226ME36L
3.3	2200	45.3	100	22.2	68	1.5 μH CMMB104T-1R5MS	22 $\mu F \times 2$ GCM31CC71C226ME36L
5	2200	45.3	100	13.7	68	2.2 μH CMMB104T-2R2MS	22 $\mu F \times 2$ GCM31CC71C226ME36L

Layout Design

Follow these PCB layout guidelines for optimal performance:

- Place C_{IN} , C_{BS} , R_{TOP} , R_{BOT} , and R_{FS} as close as possible to the converter.
- To achieve the best thermal and noise performance, maximize the PCB copper area connected to the GND pin. A ground plane is highly recommended if board space allows.
- Place C_{IN} close to pins IN and GND. Minimize the loop area formed by C_{IN} and GND.
- Separate the ground of the sensitive signal(R_{BOT} , and R_{FS}) from the ground of the power circuit as

much as possible

- Minimize the PCB copper area associated with the LX pin.
- To reduce noise, ensure that R_{TOP} , R_{BOT} and the trace connecting to the FB pin are not adjacent to the LX net on the PCB layout.
- If the system chip driving the EN pin has a high impedance state during shutdown and the IN pin is connected directly to a power source such as a Li-Ion battery, add a 1M Ω pull-down resistor between the EN and GND pins to prevent the noise from falsely turning on the regulator during shutdown.

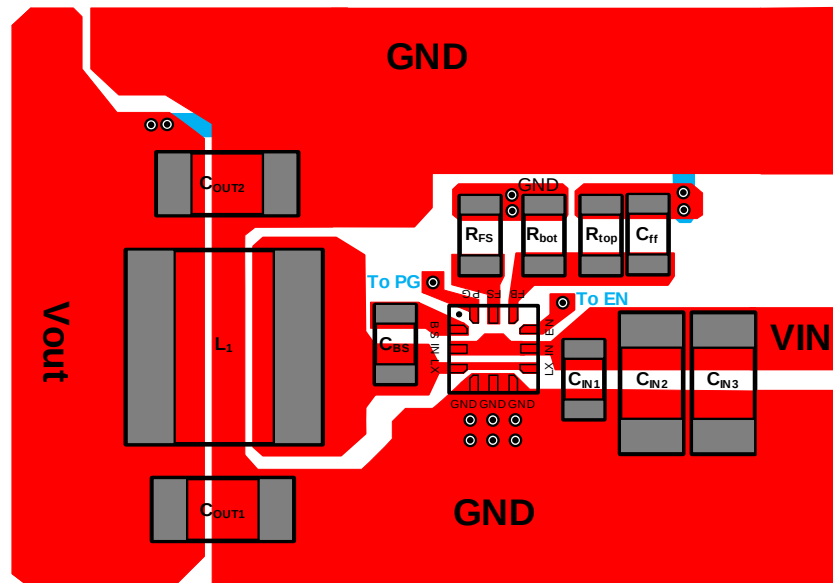
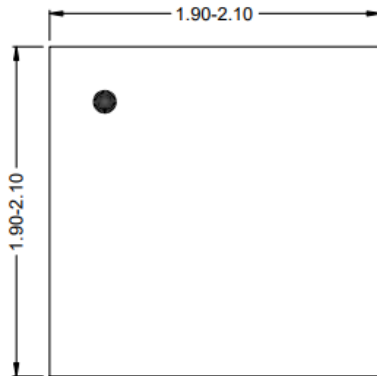
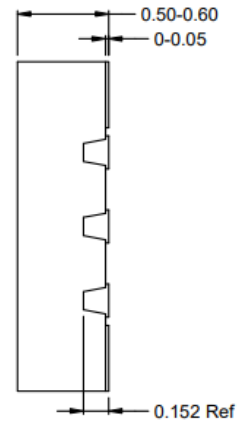


Figure 7. Suggested PCB Layout

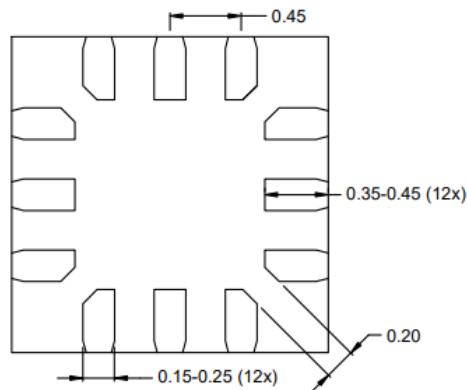
QFN2×2-12 Package Outline Drawing



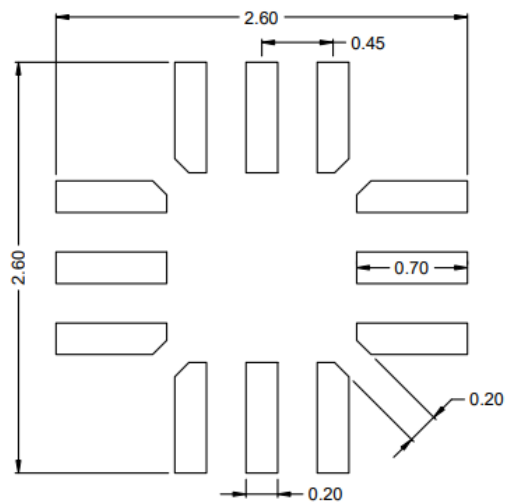
Top View



Side View



Bottom View

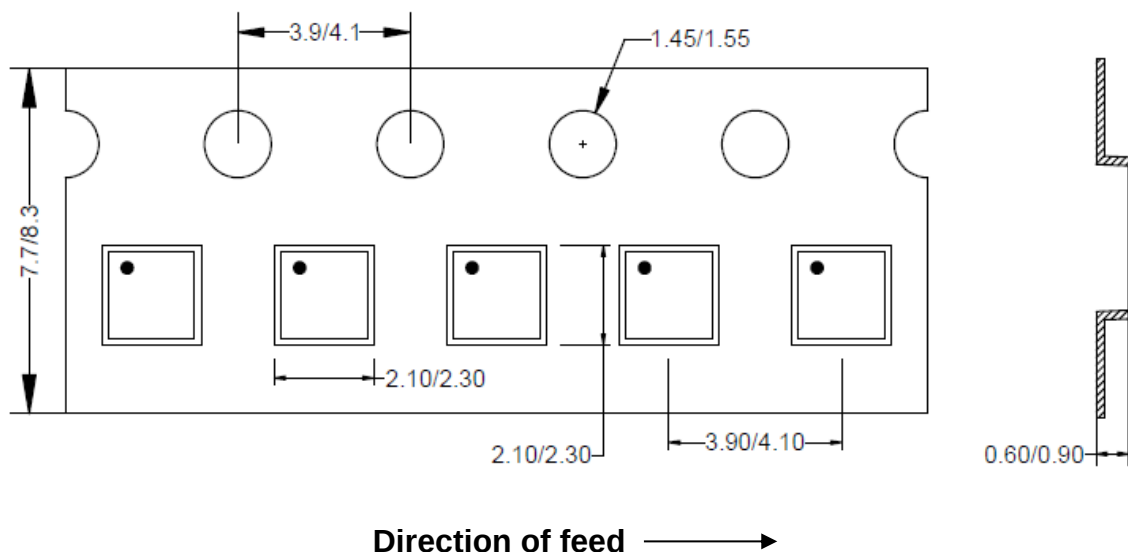


Recommended PCB Layout

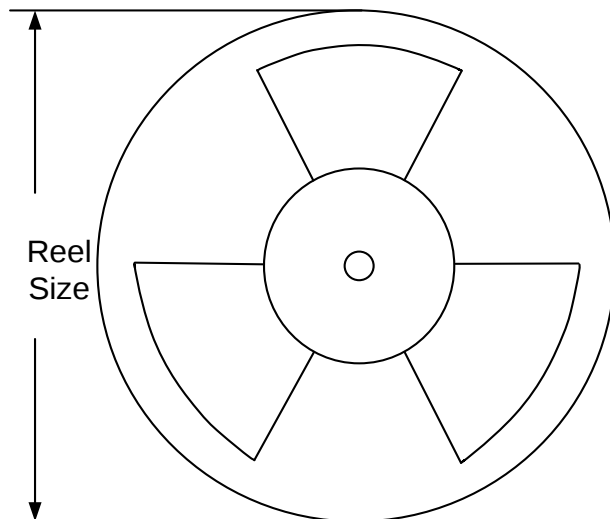
Notes: 1. All dimensions in millimeter and exclude mold flash & metal burr.
2. Recommended PCB layout only for reference.

Tape and Reel Specification

Tape Dimensions and Pin 1 Orientation



Reel Dimensions



Package types	Tape width (mm)	Pocket pitch(mm)	Reel size (Inch)	Trailer length(mm)	Leader length (mm)	Qty per reel
QFN2x2	8	4	7"	400	160	3000

All Dimension are nominal



SA24491/SA24492/SA24493/SA24493E/SA24493L

Revision History

The revision history provided is for informational purposes only and is believed to be accurate, however, not warranted. Please make sure that you have the latest revision.

Date	Revision	Change	Pages changed
Dec.18, 2024	Revision 1.0	SA24493TLQ initial release.	-
Apr.27, 2025	Revision 1.0A	1. Change recommended operating max junction temperature from 125°C to 150°C.	P3
		2. Update PD parameters simultaneously from 2.47W to 3.08W.	P3, P21
		3. Correct description mistake of BOM list and Recommend Component Values (Value unchanged).	P22
Apr.28, 2025	Revision 1.0A	SA24492TLQ initial release.	-
Oct.14, 2025	Revision 1.0A1	1. SA24493ETLQ initial release. 2. Change recommend BOM of SA24491TLQ C7 47pF to 33pF on 2.2MHz application.	P22
Nov.12, 2025	Revision 1.0A2	1. SA24491TLQ initial release. 2. Add "Typical Performance Characteristics" of SA24491TLQ.	P6-9
Nov.25, 2025	Revision 1.0A3	SA24493LTLQ initial release.	-



SA24491/SA24492/SA24493/SA24493E/SA24493L

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