

# LMR24210 SIMPLE SWITCHER<sup>®</sup> 42Vin, 1.0A Step-Down Voltage Regulator

Check for Samples: [LMR24210](#)

## FEATURES

- Input Voltage Range of 4.5V to 42V
- Output Voltage Range of 0.8V to 24V
- Output Current up to 1.0A
- Integrated low  $R_{DS(ON)}$  Synchronous MOSFETs for High Efficiency
- Up to 1 MHz Switching Frequency
- Low Shutdown  $I_q$ , 25  $\mu$ A Typical
- Programmable Soft-Start
- No Loop Compensation Required
- COT Architecture with ERM
- 28-Bump DSBGA (2.45 x 3.64 x 0.60 mm) Packaging
- Fully Enabled for WEBENCH<sup>®</sup> Power Designer

## PERFORMANCE BENEFITS

- Tiny Overall Solution Reduces System Cost
- Integrated Synchronous MOSFETs Provides High Efficiency at Low Output Voltages
- COT with ERM Architecture Requires No Loop Compensation, Reduces Component Count, and Provides Ultra Fast Transient Response
- Stable with Low ESR Capacitors

## APPLICATIONS

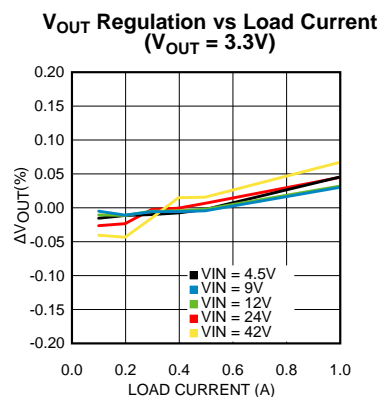
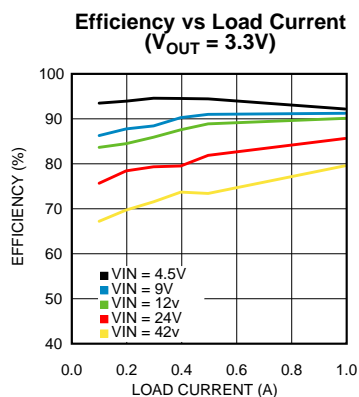
- Point-of-Load Conversions from 5V, 12V and 24V Rails
- Space Constrained Applications
- Industrial Distributed Power Applications
- Power Meters

## DESCRIPTION

The LMR24210 Synchronously Rectified Buck Converter features all required functions to implement a highly efficient and cost effective buck regulator. It is capable of supplying 1A to loads with an output voltage as low as 0.8V. Dual N-Channel synchronous MOSFET switches allow a low component count, thus reducing complexity and minimizing board size.

Different from most other COT regulators, the LMR24210 does not rely on output capacitor ESR for stability, and is designed to work exceptionally well with ceramic and other very low ESR output capacitors. It requires no loop compensation, results in a fast load transient response and simple circuit implementation. The operating frequency remains nearly constant with line variations due to the inverse relationship between the input voltage and the on-time. The operating frequency can be externally programmed up to 1 MHz. Protection features include  $V_{CC}$  under-voltage lock-out, output over-voltage protection, thermal shutdown, and gate drive under-voltage lock-out. The LMR24210 is available in the small DSBGA low profile chip-scale package.

## System Performance



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Typical Application

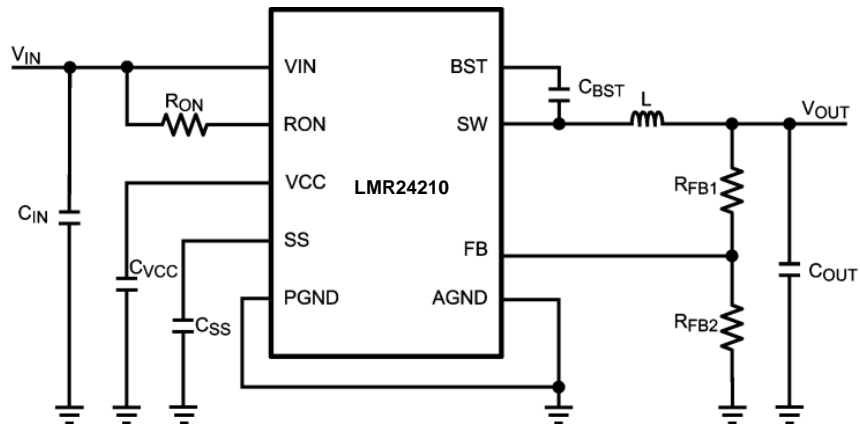


Figure 1. Connection Diagram

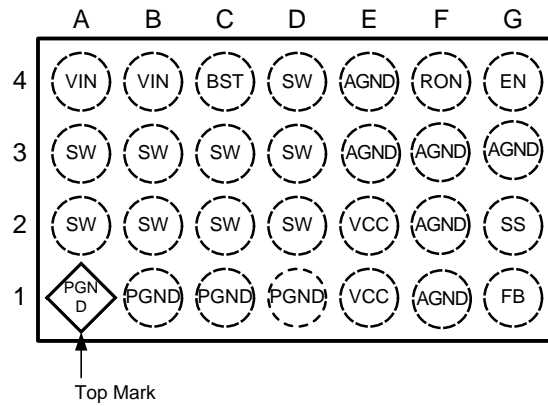


Figure 2. 28-Ball DSBGA (Balls Facing Down)  
See YPA0028 Package

**PIN DESCRIPTIONS**

Ball	Name	Description	Application Information
A2, A3, B2, B3, C2, C3, D2, D3, D4	SW	Switching Node	Internally connected to the source of the main MOSFET and the drain of the Synchronous MOSFET. Connect to the inductor.
A4, B4	VIN	Input supply voltage	Supply pin to the device. Nominal input range is 4.5V to 42V.
C4	BST	Connection for bootstrap capacitor	Connect a 33 nF capacitor from the SW pin to this pin. An internal diode charges the capacitor during the main MOSFET off-time.
E3, E4, F1, F2, F3, G3	AGND	Analog Ground	Ground for all internal circuitry other than the PGND pin.
G2	SS	Soft-start	An 8 $\mu$ A internal current source charges an external capacitor to provide the soft- start function.
G1	FB	Feedback	Internally connected to the regulation and over-voltage comparators. The regulation setting is 0.8V at this pin. Connect to feedback resistors.
G4	EN	Enable	Connect a voltage higher than 1.26V to enable the regulator. Leaving this input open circuit will enable the device at internal UVLO level.
F4	RON	On-time Control	An external resistor from the VIN pin to this pin sets the main MOSFET on-time.
E1, E2	VCC	Start-up regulator Output	Nominally regulated to 6V. Connect a capacitor of not less than 680 nF between the VCC and AGND pins for stable operation.
A1, B1, C1, D1	PGND	Power Ground	Synchronous MOSFET source connection. Tie to a ground plane.



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

### Absolute Maximum Ratings<sup>(1)(2)</sup>

VIN, RON to AGND		-0.3V to 43.5V
SW to AGND		-0.3V to 43.5V
SW to AGND (Transient)		-2V (< 100ns)
VIN to SW		-0.3V to 43.5V
BST to SW		-0.3V to 7V
All Other Inputs to AGND		-0.3V to 7V
ESD Rating	Human Body Model <sup>(3)</sup>	±2kV
Storage Temperature Range		-65°C to +150°C
Junction Temperature (T <sub>J</sub> )		150°C

- (1) Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Ratings are conditions under which operation of the device is intended to be functional. For ensured specifications and test conditions, see the Electrical Characteristics.
- (2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.
- (3) The human body model is a 100pF capacitor discharged through a 1.5kΩ resistor into each pin.

### Operating Ratings<sup>(1)</sup>

Supply Voltage Range (VIN)	4.5V to 42V
Junction Temperature Range (T <sub>J</sub> )	-40°C to +125°C
Thermal Resistance (θ <sub>JA</sub> ) 28-ball DSBGA <sup>(2)</sup>	50°C/W
For soldering specifications see <a href="#">SNOA549</a>	

- (1) Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Ratings are conditions under which operation of the device is intended to be functional. For ensured specifications and test conditions, see the Electrical Characteristics.
- (2) θ<sub>JA</sub> calculations were performed in general accordance with JEDEC standards JESD51–1 to JESD51–11.

## Electrical Characteristics

Specifications with standard type are for  $T_J = 25^\circ\text{C}$  only; limits in **boldface type** apply over the full Operating Junction Temperature ( $T_J$ ) range. Minimum and Maximum limits are ensured through test, design, or statistical correlation. Typical values represent the most likely parametric norm at  $T_J = 25^\circ\text{C}$ , and are provided for reference purposes only. Unless otherwise stated the following conditions apply:  $V_{IN} = 18\text{V}$ ,  $V_{OUT} = 3.3\text{V}$ .<sup>(1)</sup>

Symbol	Parameter	Conditions	Min	Typ	Max	Units
<b>Start-Up Regulator, <math>V_{CC}</math></b>						
$V_{CC}$	$V_{CC}$ output voltage	$C_{CC} = 680\text{nF}$ , no load	<b>5.0</b>	6.0	<b>7.2</b>	V
$V_{IN} - V_{CC}$	$V_{IN} - V_{CC}$ dropout voltage	$I_{CC} = 20\text{mA}$		350		mV
$I_{VCC}$	$V_{CC}$ current limit <sup>(2)</sup>	$V_{CC} = 0\text{V}$	<b>40</b>	65		mA
$V_{CC-UVLO}$	$V_{CC}$ under-voltage lockout threshold (UVLO)	$V_{IN}$ increasing	<b>3.55</b>	3.75	<b>3.95</b>	V
$V_{CC-UVLO-HYS}$	$V_{CC}$ UVLO hysteresis	$V_{IN}$ decreasing – DSBGA package		150		mV
$t_{VCC-UVLO-D}$	$V_{CC}$ UVLO filter delay			3		$\mu\text{s}$
$I_{IN}$	$I_{IN}$ operating current	No switching, $V_{FB} = 1\text{V}$		0.7	<b>1</b>	mA
$I_{IN-SD}$	$I_{IN}$ operating current, Device shutdown	$V_{EN} = 0\text{V}$		25	<b>40</b>	$\mu\text{A}$
<b>Switching Characteristics</b>						
$R_{DS-UP-ON}$	Main MOSFET $R_{DS(on)}$			0.18	<b>0.375</b>	$\Omega$
$R_{DS-DN-ON}$	Syn. MOSFET $R_{DS(on)}$			0.11	<b>0.225</b>	$\Omega$
$V_{G-UVLO}$	Gate drive voltage UVLO	$V_{BST} - V_{SW}$ increasing		3.3	<b>4</b>	V
<b>Soft-start</b>						
$I_{SS}$	SS pin source current	$V_{SS} = 0.5\text{V}$		11		$\mu\text{A}$
<b>Current Limit</b>						
$I_{CL}$	Syn. MOSFET current limit threshold	LMR24210	<b>1.2</b>	1.8	<b>2.6</b>	A
<b>ON/OFF Timer</b>						
$t_{on}$	ON timer pulse width	$V_{IN} = 10\text{V}$ , $R_{ON} = 100\text{k}\Omega$		1.38		$\mu\text{s}$
		$V_{IN} = 30\text{V}$ , $R_{ON} = 100\text{k}\Omega$		0.47		
$t_{on-MIN}$	ON timer minimum pulse width			150		ns
$t_{off}$	OFF timer pulse width			260		ns
<b>Enable Input</b>						
$V_{EN}$	EN Pin input threshold	$V_{EN}$ rising	<b>1.13</b>	1.18	<b>1.23</b>	V
$V_{EN-HYS}$	Enable threshold hysteresis	$V_{EN}$ falling		90		mV
<b>Regulation and Over-Voltage Comparator</b>						
$V_{FB}$	In-regulation feedback voltage	$V_{SS} \geq 0.8\text{V}$ $T_J = -40^\circ\text{C}$ to $+125^\circ\text{C}$	<b>0.784</b>	0.8	<b>0.816</b>	V
$V_{FB-OV}$	Feedback over-voltage threshold		<b>0.888</b>	0.920	<b>0.945</b>	V
$I_{FB}$	FB pin current			5		nA
<b>Thermal Shutdown</b>						
$T_{SD}$	Thermal shutdown temperature	$T_J$ rising		165		$^\circ\text{C}$
$T_{SD-HYS}$	Thermal shutdown temperature hysteresis	$T_J$ falling		20		$^\circ\text{C}$

- (1) Min and Max limits are 100% production tested at  $25^\circ\text{C}$ . Limits over the operating temperature range are ensured through correlation using Statistical Quality Control (SQC) methods. Limits are used to calculate Average Outgoing Quality Level (AOQL).
- (2)  $V_{CC}$  provides self bias for the internal gate drive and control circuits. Device thermal limitations limit external loading.

### Typical Performance Characteristics

Unless otherwise specified all curves are taken at  $V_{IN} = 18V$  with the configuration in the typical application circuit for  $V_{OUT} = 3.3V$  (Figure 27)  $T_A = 25^\circ C$ .

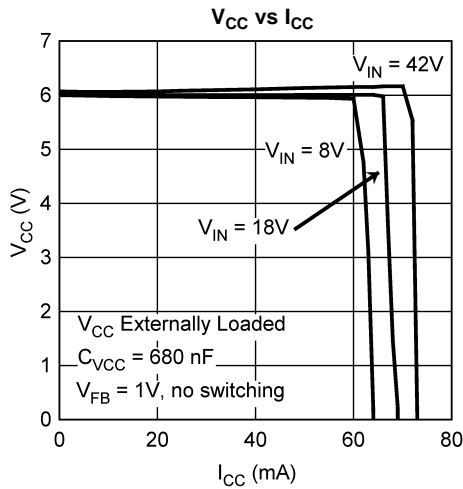


Figure 3.

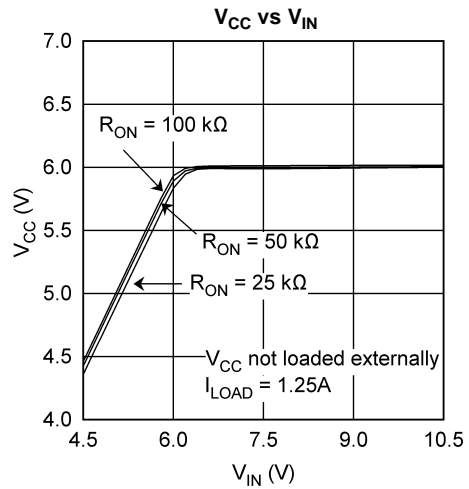


Figure 4.

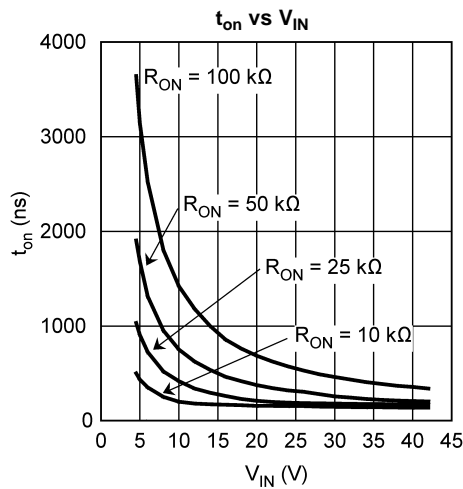


Figure 5.

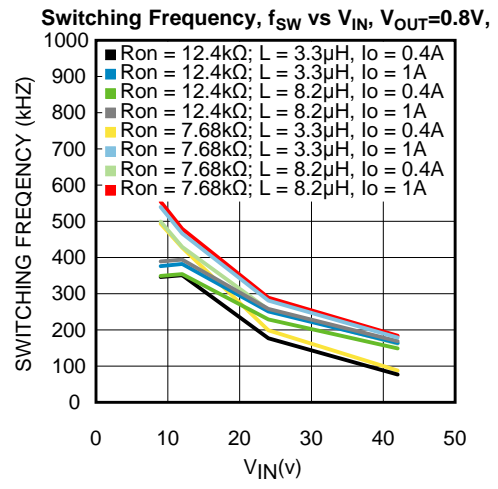


Figure 6.

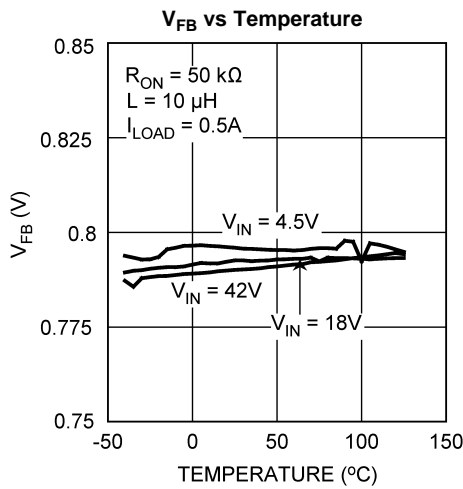


Figure 7.

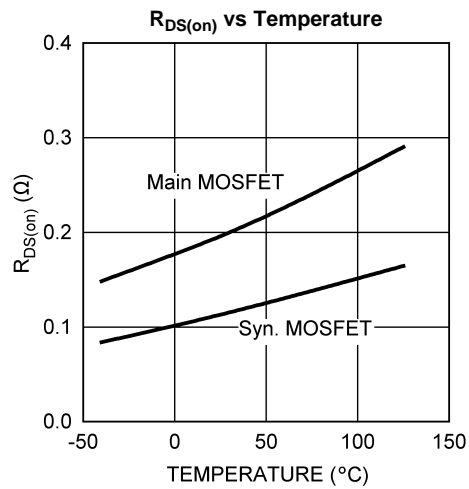


Figure 8.

### Typical Performance Characteristics (continued)

Unless otherwise specified all curves are taken at  $V_{IN} = 18V$  with the configuration in the typical application circuit for  $V_{OUT} = 3.3V$  (Figure 27)  $T_A = 25^\circ C$ .

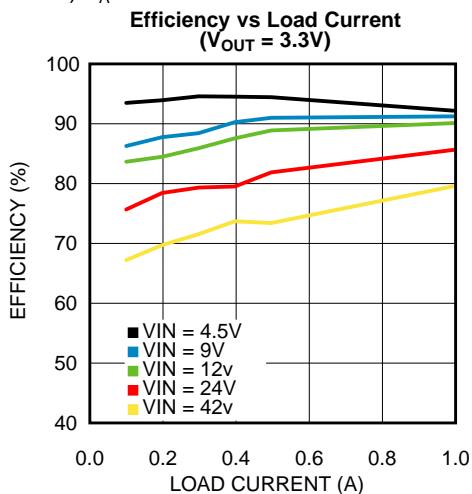


Figure 9.

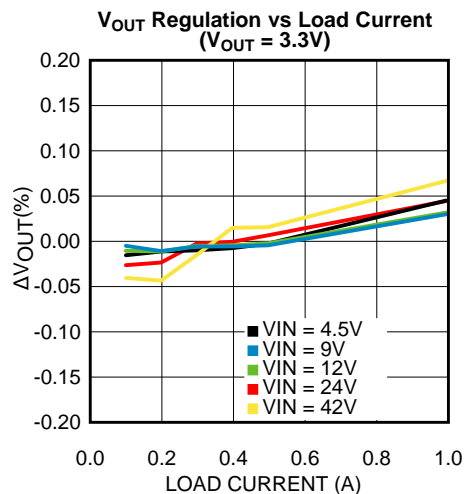


Figure 10.

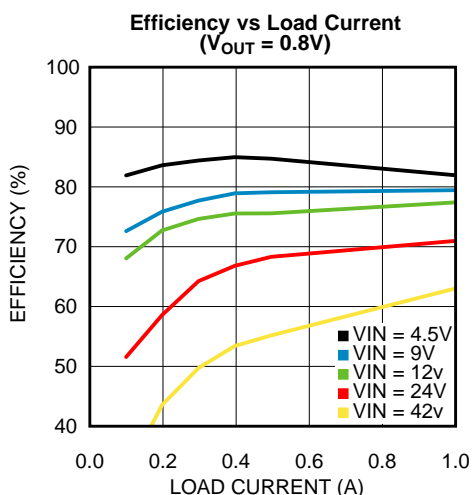


Figure 11.

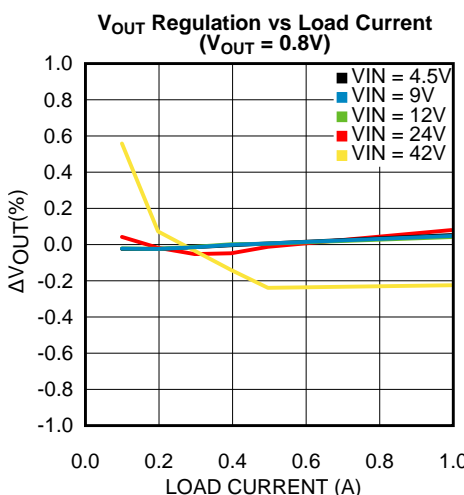


Figure 12.

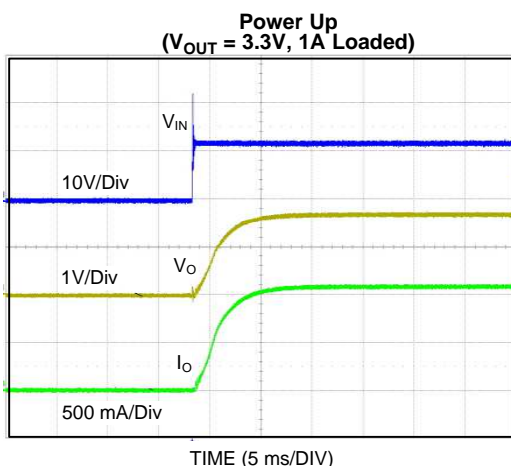


Figure 13.

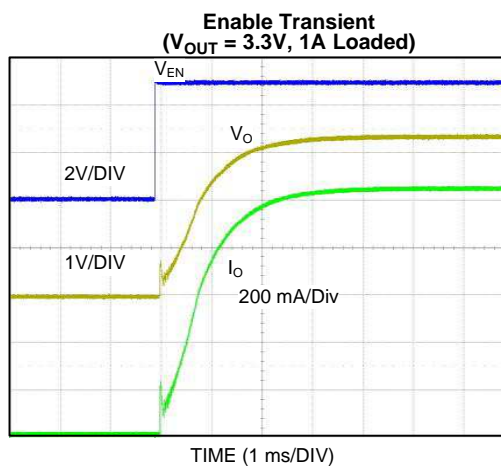


Figure 14.

**Typical Performance Characteristics (continued)**

Unless otherwise specified all curves are taken at  $V_{IN} = 18V$  with the configuration in the typical application circuit for  $V_{OUT} = 3.3V$  (Figure 27)  $T_A = 25^\circ C$ .

**Shutdown Transient**  
( $V_{OUT} = 3.3V, 1A$  Loaded)

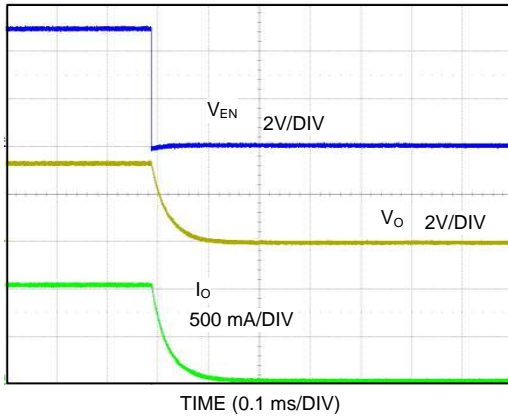


Figure 15.

**Continuous Mode Operation**  
( $V_{OUT} = 3.3V, 1A$  Loaded)

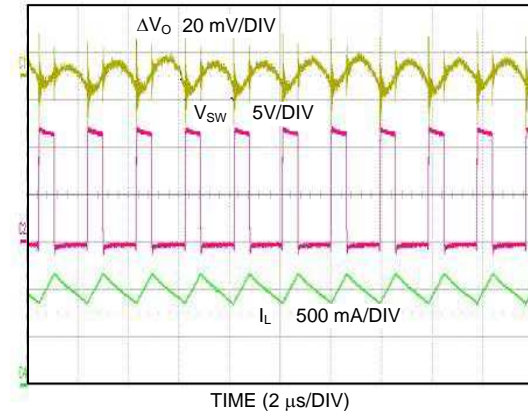


Figure 16.

**Discontinuous Mode Operation**  
( $V_{OUT} = 3.3V, 0.050A$  Loaded)

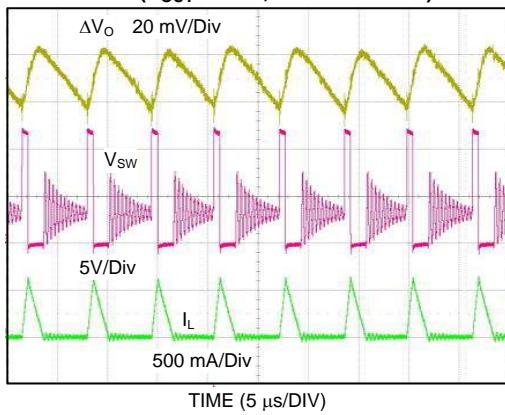


Figure 17.

**DCM to CCM Transition**  
( $V_{OUT} = 3.3V, 0.50A - 1A$  Load)

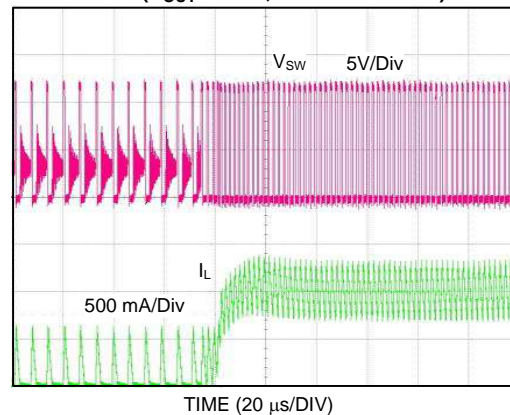


Figure 18.

**Load Transient**  
( $V_{OUT} = 3.3V, 0.20A - 1A$  Load,)

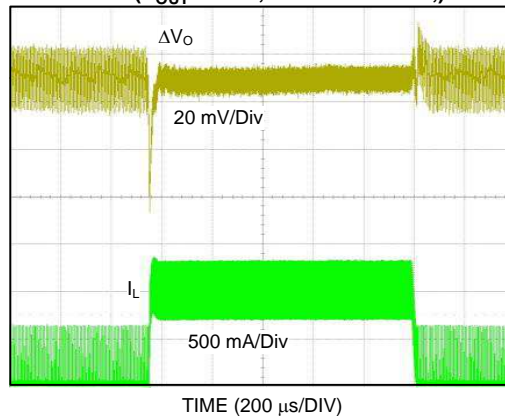
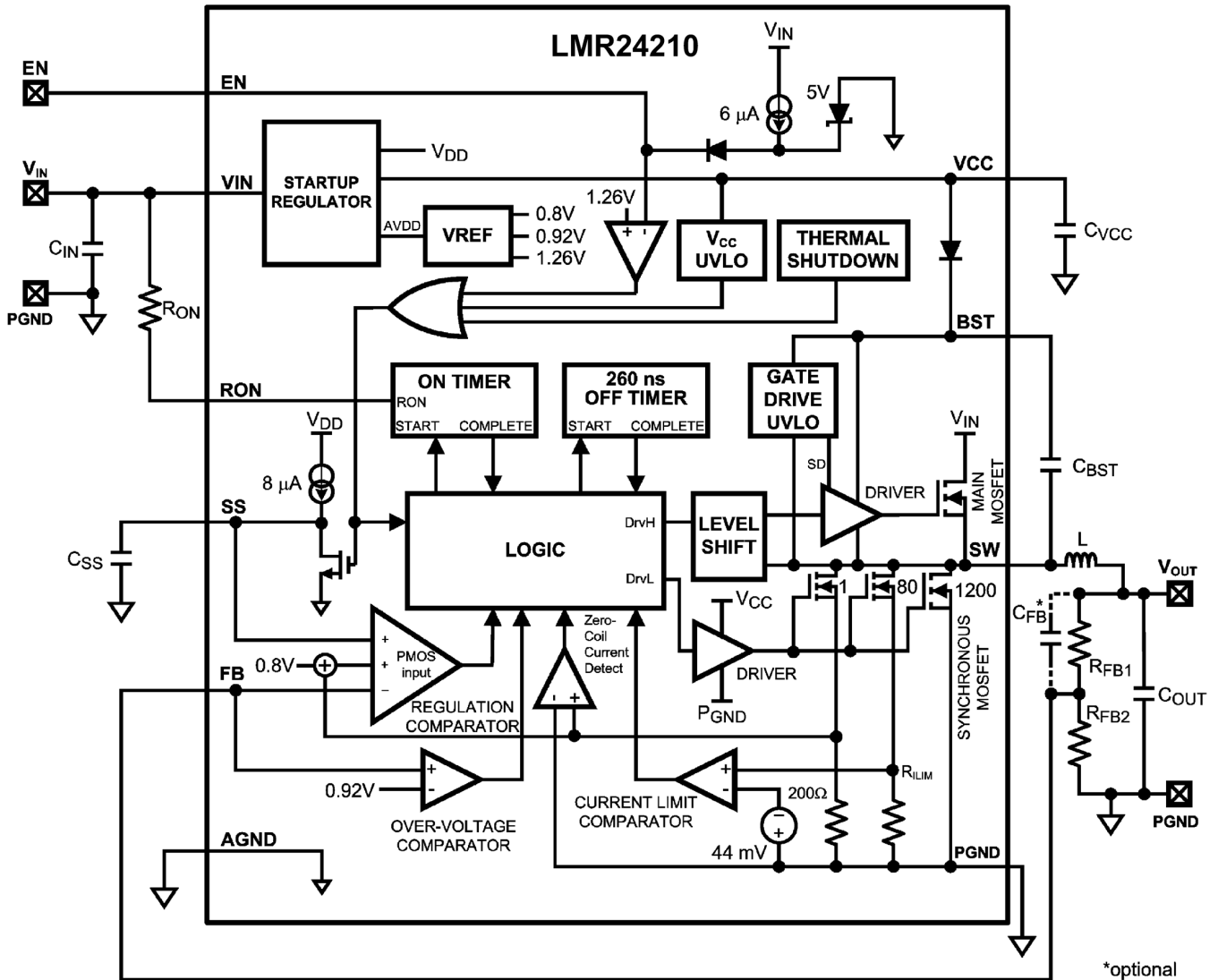


Figure 19.



Simplified Functional Block Diagram



## FUNCTIONAL DESCRIPTION

The LMR24210 Step Down Switching Regulator features all required functions to implement a cost effective, efficient buck power converter capable of supplying 1A to a load. It contains Dual N-Channel main and synchronous MOSFETs. The Constant ON-Time (COT) regulation scheme requires no loop compensation, results in fast load transient response and simple circuit implementation. The regulator can function properly even with an all ceramic output capacitor network, and does not rely on the output capacitor's ESR for stability. The operating frequency remains constant with line variations due to the inverse relationship between the input voltage and the on-time. The valley current limit detection circuit, with the limit set internally at 1.8A, inhibits the main MOSFET until the inductor current level subsides.

The LMR24210 can be applied in numerous applications and can operate efficiently for inputs as high as 42V. Protection features include output over-voltage protection, thermal shutdown,  $V_{CC}$  under-voltage lock-out and gate drive under-voltage lock-out. The LMR24210 is available in a small DSBGA chip scale package.

### COT Control Circuit Overview

COT control is based on a comparator and a one-shot on-timer, with the output voltage feedback (feeding to the FB pin) compared with an internal reference of 0.8V. If the voltage of the FB pin is below the reference, the main MOSFET is turned on for a fixed on-time determined by a programming resistor  $R_{ON}$  and the input voltage  $V_{IN}$ , upon which the on-time varies inversely. Following the on-time, the main MOSFET remains off for a minimum of 260 ns. Then, if the voltage of the FB pin is below the reference, the main MOSFET is turned on again for another on-time period. The switching will continue to achieve regulation.

The regulator will operate in the discontinuous conduction mode (DCM) at a light load, and the continuous conduction mode (CCM) with a heavy load. In the DCM, the current through the inductor starts at zero and ramps up to a peak during the on-time, and then ramps back to zero before the end of the off-time. It remains zero and the load current is supplied entirely by the output capacitor. The next on-time period starts when the voltage at the FB pin falls below the internal reference. The operating frequency in the DCM is lower and varies larger with the load current as compared with the CCM. Conversion efficiency is maintained since conduction loss and switching loss are reduced with the reduction in the load and the switching frequency respectively. The operating frequency in the DCM can be calculated approximately as follows:

$$f_{SW} = \frac{V_{OUT} (V_{IN} - 1) \times L \times 1.18 \times 10^{20} \times I_{OUT}}{(V_{IN} - V_{OUT}) \times R_{ON}^2} \quad (1)$$

In the continuous conduction mode (CCM), the current flows through the inductor in the entire switching cycle, and never reaches zero during the off-time. The operating frequency remains relatively constant with load and line variations. The CCM operating frequency can be calculated approximately as follows:

$$f_{SW} = \frac{V_{OUT}}{1.3 \times 10^{-10} \times R_{ON}} \quad (2)$$

Please consider [Equation 4](#) and [Equation 5](#) when choosing the switching frequency.

The output voltage is set by two external resistors  $R_{FB1}$  and  $R_{FB2}$ . The regulated output voltage is

$$V_{OUT} = 0.8V \times (R_{FB1} + R_{FB2})/R_{FB2} \quad (3)$$

## Startup Regulator ( $V_{CC}$ )

A startup regulator is integrated within the LMR24210. The input pin  $V_{IN}$  can be connected directly to a line voltage up to 42V. The  $V_{CC}$  output regulates at 6V, and is current limited to 65 mA. Upon power up, the regulator sources current into an external capacitor  $C_{VCC}$ , which is connected to the VCC pin. For stability,  $C_{VCC}$  must be at least 680 nF. When the voltage on the VCC pin is higher than the under-voltage lock-out (UVLO) threshold of 3.75V, the main MOSFET is enabled and the SS pin is released to allow the soft-start capacitor  $C_{SS}$  to charge.

The minimum input voltage is determined by the dropout voltage of the regulator and the  $V_{CC}$  UVLO falling threshold ( $\approx 3.7V$ ). If  $V_{IN}$  is less than  $\approx 4.0V$ , the regulator shuts off and  $V_{CC}$  goes to zero.

## Regulation Comparator

The feedback voltage at the FB pin is compared to a 0.8V internal reference. In normal operation (the output voltage is regulated), an on-time period is initiated when the voltage at the FB pin falls below 0.8V. The main MOSFET stays on for the on-time, causing the output voltage and consequently the voltage of the FB pin to rise above 0.8V. After the on-time period, the main MOSFET stays off until the voltage of the FB pin falls below 0.8V again. Bias current at the FB pin is nominally 5 nA.

## Zero Coil Current Detect

The current of the synchronous MOSFET is monitored by a zero coil current detection circuit which inhibits the synchronous MOSFET when its current reaches zero until the next on-time. This circuit enables the DCM operation, which improves the efficiency at a light load.

## Over-Voltage Comparator

The voltage at the FB pin is compared to a 0.92V internal reference. If it rises above 0.92V, the on-time is immediately terminated. This condition is known as over-voltage protection (OVP). It can occur if the input voltage or the output load changes suddenly. Once the OVP is activated, the main MOSFET remains off until the voltage at the FB pin falls below 0.92V. The synchronous MOSFET will stay on to discharge the inductor until the inductor current reduces to zero, and then switches off.

## ON-Time Timer, Shutdown

The on-time of the LMR24210 main MOSFET is determined by the resistor  $R_{ON}$  and the input voltage  $V_{IN}$ . It is calculated as follows:

$$t_{on} = \frac{1.3 \times 10^{-10} \times R_{ON}}{V_{IN}} \quad (4)$$

The inverse relationship of  $t_{on}$  and  $V_{IN}$  gives a nearly constant frequency as  $V_{IN}$  is varied.  $R_{ON}$  should be selected such that the on-time at maximum  $V_{IN}$  is greater than 150 ns. The on-timer has a limiter to ensure a minimum of 150 ns for  $t_{on}$ . This limits the maximum operating frequency, which is governed by the following equation:

$$f_{SW(MAX)} = \frac{V_{OUT}}{V_{IN(MAX)} \times 150 \text{ ns}} \quad (5)$$

The LMR24210 can be remotely shutdown by pulling the voltage of the EN pin below 1V. In this shutdown mode, the SS pin is internally grounded, the on-timer is disabled, and bias currents are reduced. Releasing the EN pin allows normal operation to resume because the EN pin is internally pulled up.

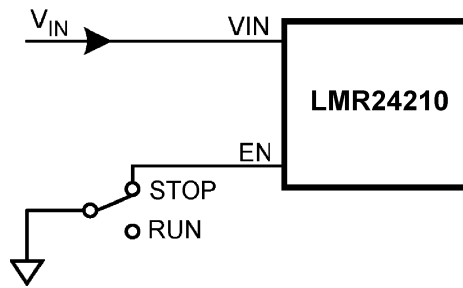


Figure 20. Shutdown Implementation

**Current Limit**

Current limit detection is carried out during the off-time by monitoring the re-circulating current through the synchronous MOSFET. Referring to [Simplified Functional Block Diagram](#), when the main MOSFET is turned off, the inductor current flows through the load, the PGND pin and the internal synchronous MOSFET. If this current exceeds 1.8A, the current limit comparator toggles, and as a result disabling the start of the next on-time period. The next switching cycle starts when the re-circulating current falls back below 1.8A (and the voltage at the FB pin is below 0.8V). The inductor current is monitored during the on-time of the synchronous MOSFET. As long as the inductor current exceeds 1.8A, the main MOSFET will remain inhibited to achieve current limit. The operating frequency is lower during current limit due to a longer off-time.

Figure 21 illustrates an inductor current waveform. On average, the output current  $I_{OUT}$  is the same as the inductor current  $I_L$ , which is the average of the rippled inductor current. In case of current limit (the current limit portion of Figure 21), the next on-time will not initiate until the current drops below 1.8A (assume the voltage at the FB pin is lower than 0.8V). During each on-time the current ramps up an amount equal to:

$$I_{LR} = \frac{(V_{IN} - V_{OUT}) \times t_{on}}{L} \tag{6}$$

During current limit, the LMR24210 operates in a constant current mode with an average output current  $I_{OUT(CL)}$  equal to  $1.8A + I_{LR} / 2$ .

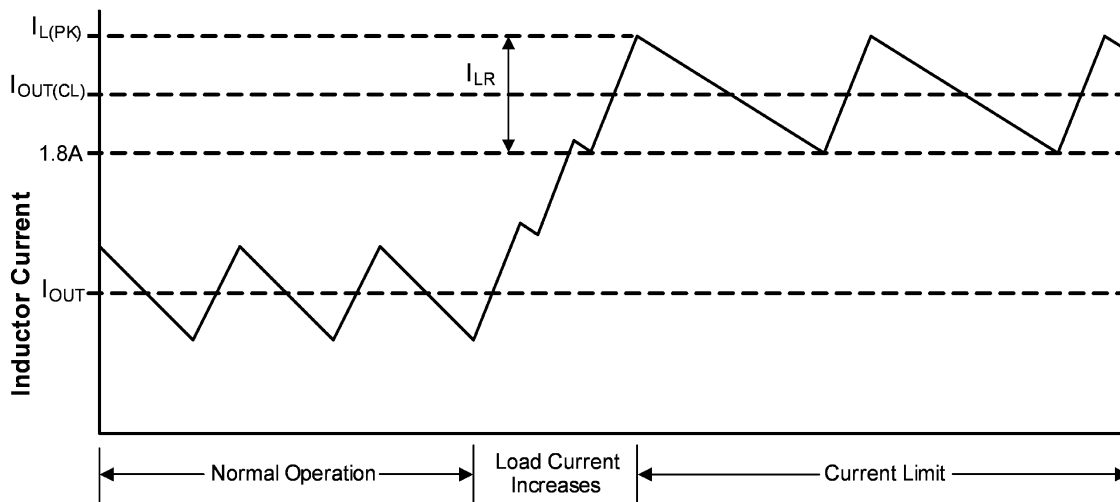


Figure 21. Inductor Current - Current Limit Operation

## N-Channel MOSFET and Driver

The LMR24210 integrates an N-Channel main MOSFET and an associated floating high voltage main MOSFET gate driver. The gate drive circuit works in conjunction with an external bootstrap capacitor  $C_{BST}$  and an internal high voltage diode.  $C_{BST}$  connecting between the BST and SW pins powers the main MOSFET gate driver during the main MOSFET on-time. During each off-time, the voltage of the SW pin falls to approximately -1V, and  $C_{BST}$  charges from  $V_{CC}$  through the internal diode. The minimum off-time of 260 ns provides enough time for charging  $C_{BST}$  in each cycle.

## Soft-Start

The soft-start feature allows the converter to gradually reach a steady state operating point, thereby reducing startup stresses and current surges. Upon turn-on, after  $V_{CC}$  reaches the under-voltage threshold, an 8  $\mu$ A internal current source charges up an external capacitor  $C_{SS}$  connecting to the SS pin. The ramping voltage at the SS pin (and the non-inverting input of the regulation comparator as well) ramps up the output voltage  $V_{OUT}$  in a controlled manner.

The soft start time duration to reach steady state operation is given by the formula:

$$t_{SS} = V_{REF} \times C_{SS} / 8\mu A = 0.8V \times C_{SS} / 8\mu A \quad (7)$$

This equation can be rearranged as follows:

$$C_{SS} = t_{SS} \times 8\mu A / 0.8V \quad (8)$$

Use of a 4.7nF capacitor results in a 0.5ms soft-start duration. This is a recommended value. Note that high values of  $C_{SS}$  capacitance will cause more output voltage drop when a load transient goes across the DCM-CCM boundary. If a fast load transient response is desired for steps between DCM and CCM mode the softstart capacitor value should be less than 18nF (which corresponds to a soft-start time of 1.8ms).

An internal switch grounds the SS pin if any of the following three cases happens: (i)  $V_{CC}$  is below the under-voltage lock-out threshold; (ii) a thermal shutdown occurs; or (iii) the EN pin is grounded. Alternatively, the output voltage can be shut off by connecting the SS pin to ground using an external switch. Releasing the switch allows the SS pin to ramp up and the output voltage to return to normal. The shutdown configuration is shown in [Figure 22](#).

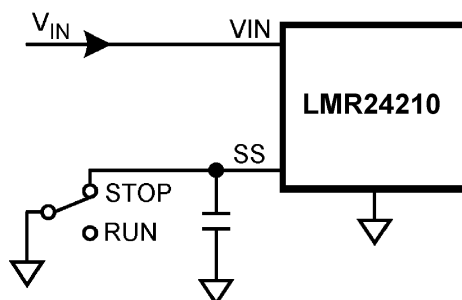


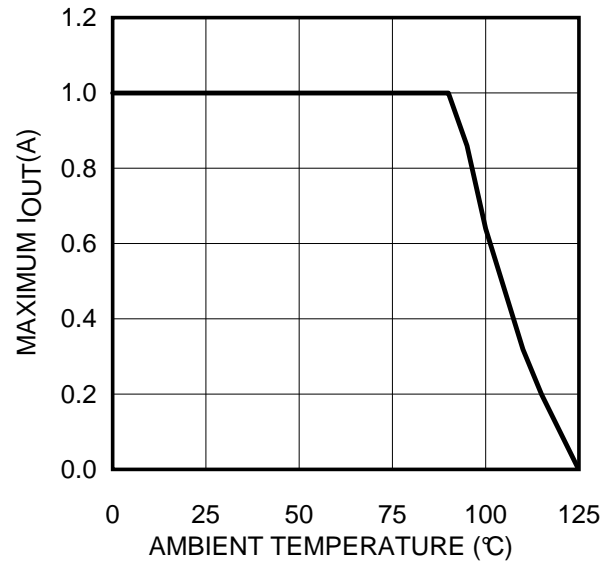
Figure 22. Alternate Shutdown Implementation

## Thermal Protection

The junction temperature of the LMR24210 should not exceed the maximum limit. Thermal protection is implemented by an internal Thermal Shutdown circuit, which activates (typically) at 165°C to make the controller enter a low power reset state by disabling the main MOSFET, disabling the on-timer, and grounding the SS pin. Thermal protection helps prevent catastrophic failures from accidental device overheating. When the junction temperature falls back below 145°C (typical hysteresis = 20°C), the SS pin is released and normal operation resumes.

## Thermal Derating

Temperature rise increases with frequency, load current, input voltage and smaller board dimensions. On a typical board, the LMR24210 is capable of supplying 1A below an ambient temperature of 90°C under worst case operation with input voltage of 42V. [Figure 23](#) shows a thermal derating curve for the output current without thermal shutdown against ambient temperature up to 125°C. Obtaining 1A output current is possible at higher temperature by increasing the PCB ground plane area, adding airflow or reducing the input voltage or operating frequency.



$\theta_{JA}=40^{\circ}\text{C}/\text{W}$ ,  $V_o = 3.3\text{V}$ ,  $f_s = 500\text{kHz}$   
(tested on the evaluation board)

**Figure 23. Thermal Derating Curve**

## APPLICATIONS INFORMATION

### EXTERNAL COMPONENTS

The following guidelines can be used to select external components.

**R<sub>FB1</sub>** and **R<sub>FB2</sub>** : These resistors should be chosen from standard values in the range of 1.0 kΩ to 10 kΩ, satisfying the following ratio:

$$R_{FB1}/R_{FB2} = (V_{OUT}/0.8V) - 1 \quad (9)$$

For  $V_{OUT} = 0.8V$ , the FB pin can be connected to the output directly with a pre-load resistor drawing more than 20 μA. This is needed because the converter operation needs a minimum inductor current ripple to maintain good regulation when no load is connected.

**R<sub>ON</sub>**: Equation 2 can be used to select R<sub>ON</sub> if a desired operating frequency is selected. But the minimum value of R<sub>ON</sub> is determined by the minimum on-time. It can be calculated as follows:

$$R_{ON} \geq \frac{V_{IN(MAX)} \times 150 \text{ ns}}{1.3 \times 10^{-10}} \quad (10)$$

If R<sub>ON</sub> calculated from Equation 2 is smaller than the minimum value determined in Equation 10, a lower frequency should be selected to re-calculate R<sub>ON</sub> by Equation 2. Alternatively, V<sub>IN(MAX)</sub> can also be limited in order to keep the frequency unchanged. The relationship of V<sub>IN(MAX)</sub> and R<sub>ON</sub> is shown in Figure 24.

On the other hand, the minimum off-time of 260 ns can limit the maximum duty ratio.

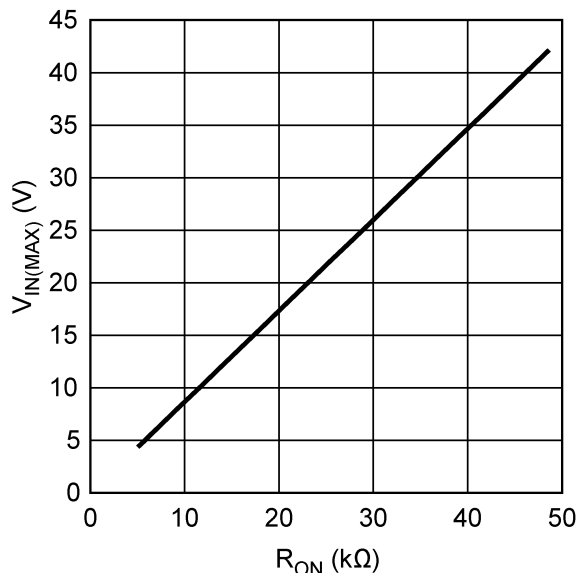


Figure 24. Maximum V<sub>IN</sub> for selected R<sub>ON</sub>

**L**: The main parameter affected by the inductor is the amplitude of inductor current ripple (I<sub>LR</sub>). Once I<sub>LR</sub> is selected, L can be determined by:

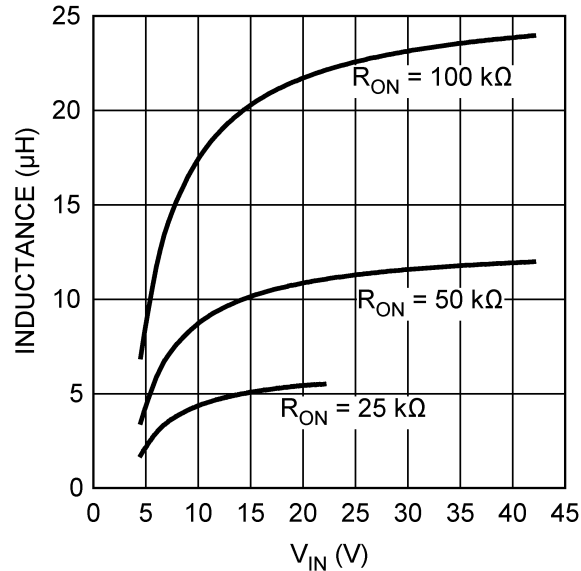
$$L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{I_{LR} \times f_{SW} \times V_{IN}}$$

where

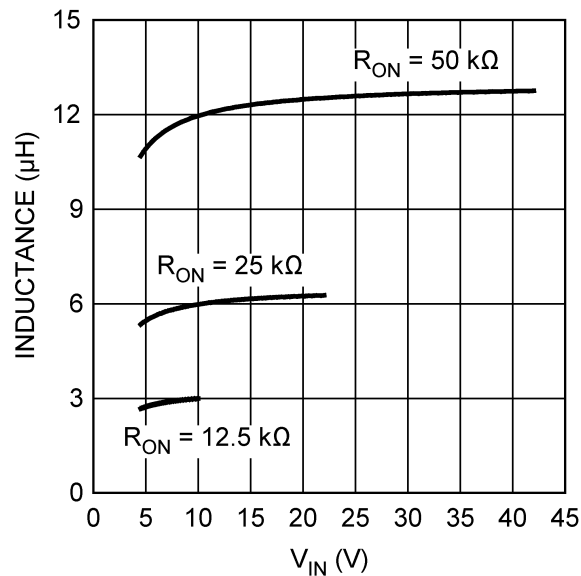
- V<sub>IN</sub> is the maximum input voltage and
- f<sub>SW</sub> is determined from Equation 2.

(11)

If the output current  $I_{OUT}$  is determined, by assuming that  $I_{OUT} = I_L$ , the higher and lower peak of  $I_{LR}$  can be determined. Beware that the higher peak of  $I_{LR}$  should not be larger than the saturation current of the inductor and current limits of the main and synchronous MOSFETs. Also, the lower peak of  $I_{LR}$  must be positive if CCM operation is required.



**Figure 25. Inductor selection for  $V_{OUT} = 3.3V$**



**Figure 26. Inductor selection for  $V_{OUT} = 0.8V$**

Figure 25 and Figure 26 show curves on inductor selection for various  $V_{OUT}$  and  $R_{ON}$ . For small  $R_{ON}$ , according to Equation 10,  $V_{IN}$  is limited. Some curves are therefore limited as shown in the figures.

**$C_{VCC}$ :** The capacitor on the  $V_{CC}$  output provides not only noise filtering and stability, but also prevents false triggering of the  $V_{CC}$  UVLO at the main MOSFET on/off transitions.  $C_{VCC}$  should be no smaller than 680 nF for stability, and should be a good quality, low ESR, ceramic capacitor.



**C<sub>OUT</sub> and C<sub>OUT3</sub>:** C<sub>OUT</sub> should generally be no smaller than 10 μF. Experimentation is usually necessary to determine the minimum value for C<sub>OUT</sub>, as the nature of the load may require a larger value. A load which creates significant transients requires a larger C<sub>OUT</sub> than a fixed load.

C<sub>OUT3</sub> is a small value ceramic capacitor located close to the LMR24210 to further suppress high frequency noise at V<sub>OUT</sub>. A 100 nF capacitor is recommended.

**C<sub>IN</sub> and C<sub>IN3</sub>:** The function of C<sub>IN</sub> is to supply most of the main MOSFET current during the on-time, and limit the voltage ripple at the VIN pin, assuming that the voltage source connecting to the VIN pin has finite output impedance. If the voltage source's dynamic impedance is high (effectively a current source), C<sub>IN</sub> supplies the average input current, but not the ripple current.

At the maximum load current, when the main MOSFET turns on, the current to the VIN pin suddenly increases from zero to the lower peak of the inductor's ripple current and ramps up to the higher peak value. It then drops to zero at turn-off. The average current during the on-time is the load current. For a worst case calculation, C<sub>IN</sub> must be capable of supplying this average load current during the maximum on-time. C<sub>IN</sub> is calculated from:

$$C_{IN} = \frac{I_{OUT} \times t_{on}}{\Delta V_{IN}}$$

where

- I<sub>OUT</sub> is the load current
  - t<sub>on</sub> is the maximum on-time
  - ΔV<sub>IN</sub> is the allowable ripple voltage at V<sub>IN</sub>
- (12)

C<sub>IN3</sub>'s purpose is to help avoid transients and ringing due to long lead inductance at the VIN pin. A low ESR 0.1 μF ceramic chip capacitor located close to the LMR24210 is recommended.

**C<sub>BST</sub>:** A 33 nF high quality ceramic capacitor with low ESR is recommended for C<sub>BST</sub> since it supplies a surge current to charge the main MOSFET gate driver at turn-on. Low ESR also helps ensure a complete recharge during each off-time.

**C<sub>SS</sub>:** The capacitor at the SS pin determines the soft-start time, i.e. the time for the reference voltage at the regulation comparator and the output voltage to reach their final value. The time is determined from the following equation:

$$t_{SS} = \frac{C_{SS} \times 0.8V}{8 \mu A}$$
(13)

**C<sub>FB</sub>:** If the output voltage is higher than 1.6V, C<sub>FB</sub> is needed in the Discontinuous Conduction Mode to reduce the output ripple. The recommended value for C<sub>FB</sub> is 10 nF.

## PC BOARD LAYOUT

The LMR24210 regulation, over-voltage, and current limit comparators are very fast and may respond to short duration noise pulses. Layout is therefore critical for optimum performance. It must be as neat and compact as possible, and all external components must be as close to their associated pins of the LMR24210 as possible. Refer to the [Simplified Functional Block Diagram](#), the loop formed by C<sub>IN</sub>, the main and synchronous MOSFET internal to the LMR24210, and the PGND pin should be as small as possible. The connection from the PGND pin to C<sub>IN</sub> should be as short and direct as possible. Vias should be added to connect the ground of C<sub>IN</sub> to a ground plane, located as close to the capacitor as possible. The bootstrap capacitor C<sub>BST</sub> should be connected as close to the SW and BST pins as possible, and the connecting traces should be thick. The feedback resistors and capacitor R<sub>FB1</sub>, R<sub>FB2</sub>, and C<sub>FB</sub> should be close to the FB pin. A long trace running from V<sub>OUT</sub> to R<sub>FB1</sub> is generally acceptable since this is a low impedance node. Ground R<sub>FB2</sub> directly to the AGND pin. The output capacitor C<sub>OUT</sub> should be connected close to the load and tied directly to the ground plane. The inductor L should be connected close to the SW pin with as short a trace as possible to reduce the potential for EMI (electromagnetic

interference) generation. If it is expected that the internal dissipation of the LMR24210 will produce excessive junction temperature during normal operation, making good use of the PC board's ground plane can help considerably to dissipate heat. Additionally the use of thick traces, where possible, can help conduct heat away from the LMR24210. Judicious positioning of the PC board within the end product, along with the use of any available air flow (forced or natural convection) can help reduce the junction temperature.

**Package Considerations**

The die has exposed edges and can be sensitive to ambient light. For applications with direct high intensity ambient red, infrared, LED or natural light it is recommended to have the device shielded from the light source to avoid abnormal behavior.

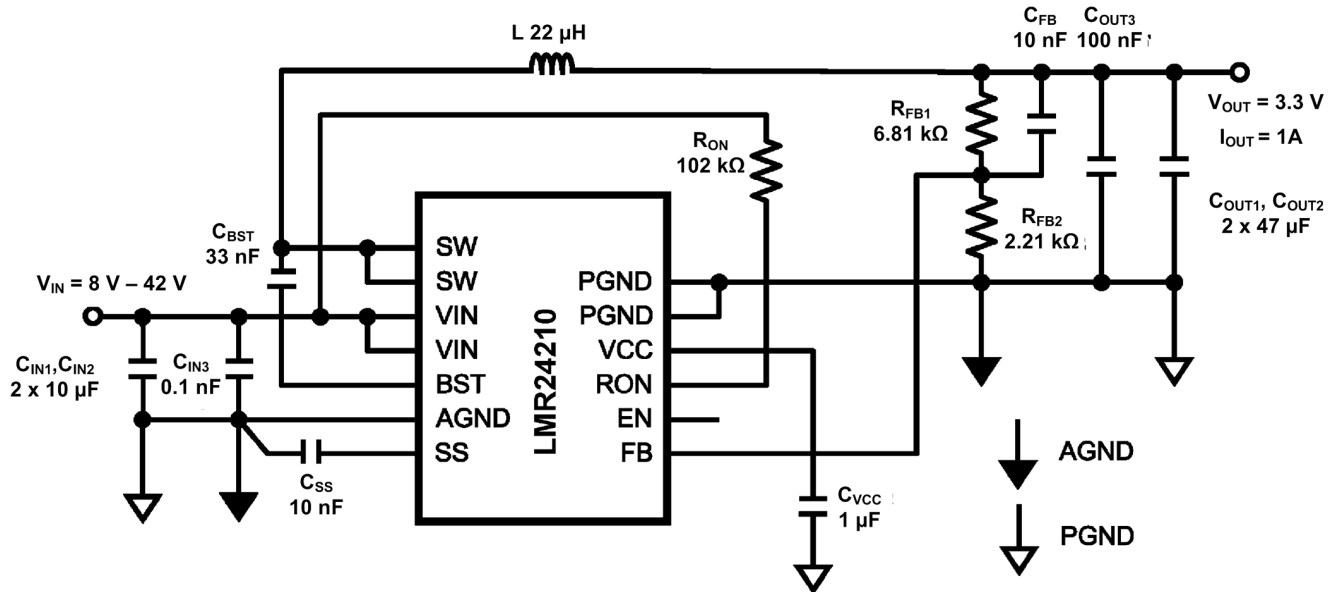


Figure 27. Typical Application Schematic for  $V_{OUT} = 3.3V$

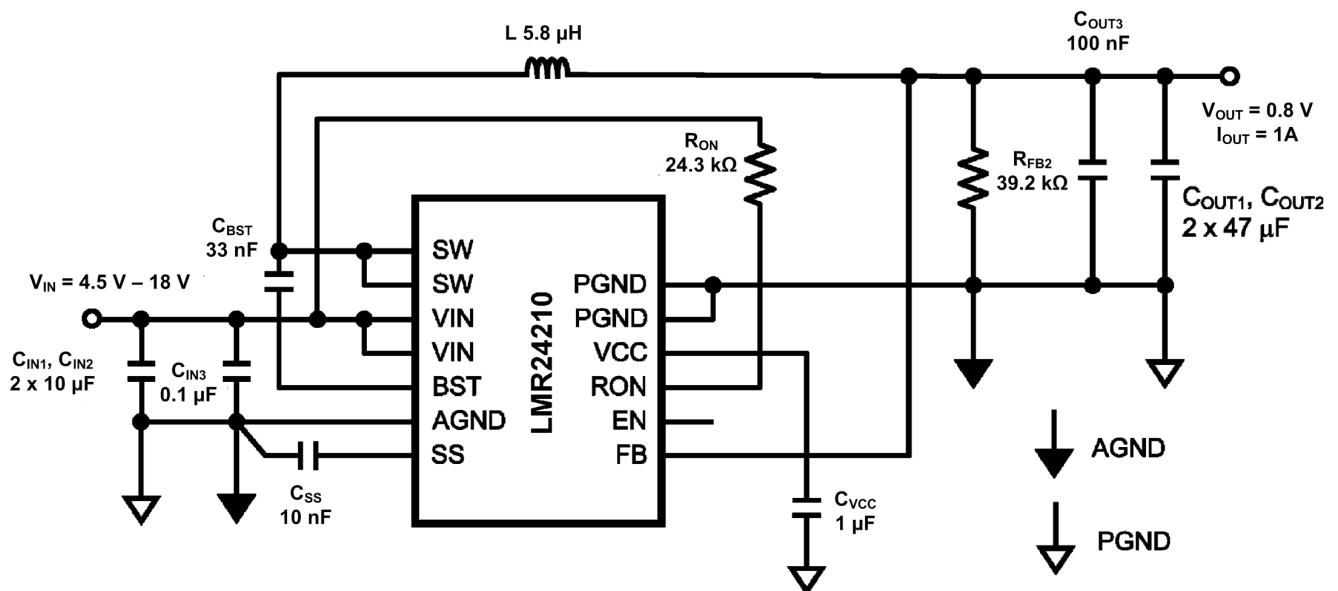


Figure 28. Typical Application Schematic for  $V_{OUT} = 0.8V$

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**REVISION HISTORY**

<b>Changes from Revision E (April 2013) to Revision F</b>	<b>Page</b>
<ul style="list-style-type: none"><li>• Changed layout of National Data Sheet to TI format .....</li></ul>	<a href="#">18</a>

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**PACKAGING INFORMATION**

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)	Samples
LMR24210TL/NOPB	ACTIVE	DSBGA	YPA	28	250	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-20 to 125	SJ5B	<a href="#">Samples</a>
LMR24210TLX/NOPB	ACTIVE	DSBGA	YPA	28	1000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-20 to 125	SJ5B	<a href="#">Samples</a>

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

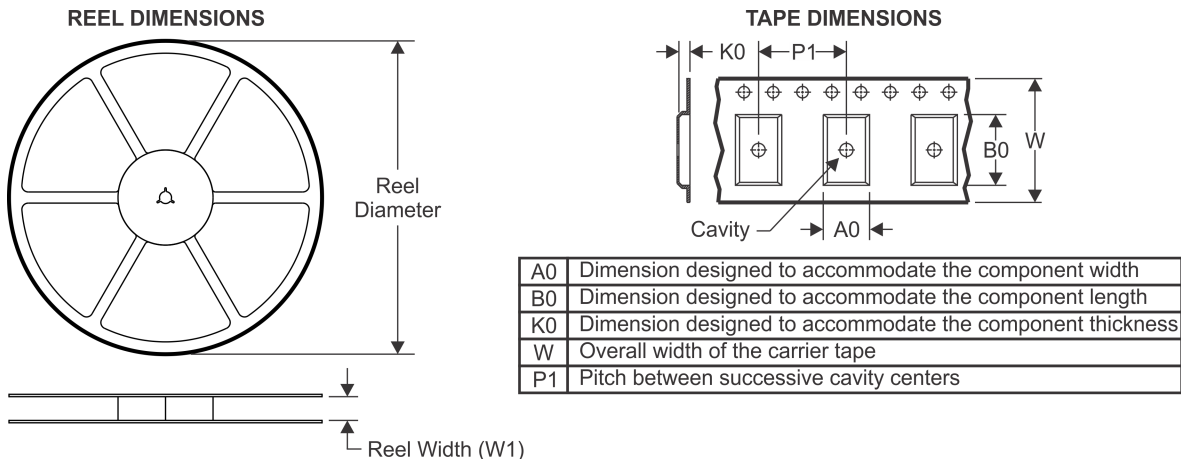
**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) Multiple Top-Side Markings will be inside parentheses. Only one Top-Side Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Top-Side Marking for that device.

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**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**


\*All dimensions are nominal

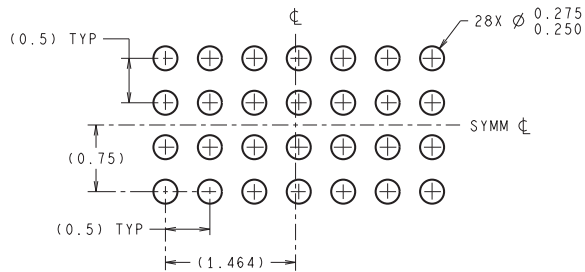
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LMR24210TL/NOPB	DSBGA	YPA	28	250	178.0	12.4	2.64	3.84	0.76	8.0	12.0	Q1
LMR24210TLX/NOPB	DSBGA	YPA	28	1000	178.0	12.4	2.64	3.84	0.76	8.0	12.0	Q1

**TAPE AND REEL BOX DIMENSIONS**


\*All dimensions are nominal

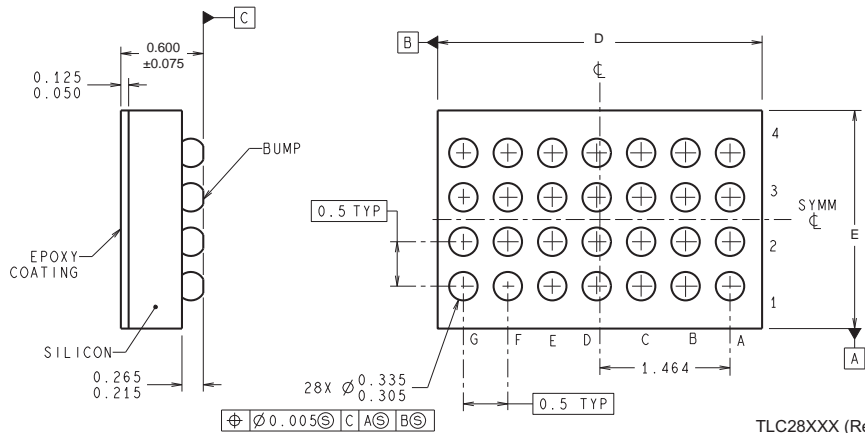
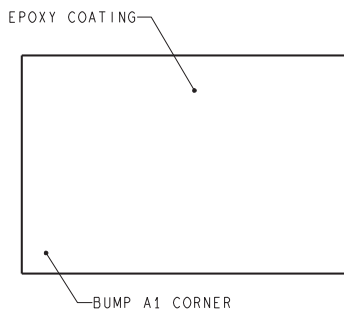
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LMR24210TL/NOPB	DSBGA	YPA	28	250	210.0	185.0	35.0
LMR24210TLX/NOPB	DSBGA	YPA	28	1000	210.0	185.0	35.0

YPA0028



LAND PATTERN RECOMMENDATION

DIMENSIONS ARE IN MILLIMETERS  
DIMENSIONS IN ( ) FOR REFERENCE ONLY



TLC28XXX (Rev A)

D: Max = 3.676 mm, Min = 3.615 mm  
E: Max = 2.48 mm, Min = 2.419 mm

4215064/A 12/12

NOTES: A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.  
B. This drawing is subject to change without notice.

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