

Dual 2.0A, High Frequency Synchronous Step-Down DC-DC Regulator

General Description

The LM26420 regulator is a monolithic, high frequency, dual PWM step-down DC/DC converter in a 16 Pin LLP and a 20 Pin eTSSOP package. It provides all the active functions to provide local DC/DC conversion with fast transient response and accurate regulation in the smallest possible PCB area. With a minimum of external components, the LM26420 is easy to use. The ability to drive two 2.0A loads with an internal 75 mΩ PMOS top switch and an internal 50 mΩ NMOS bottom switch using state-of-the-art 0.5 µm BiCMOS technology results in the best power density available. The world-class control circuitry allows on-times as low as 30ns, thus supporting exceptionally high frequency conversion over the entire 3V to 5.5V input operating range down to the minimum output voltage of 0.8V. Switching frequency is internally set to 550 kHz or 2.2 MHz, allowing the use of extremely small surface mount inductors and chip capacitors. Even though the operating frequency is high, efficiencies up to 93% are easy to achieve. External shutdown is included, featuring an ultra-low stand-by current. The LM26420 utilizes current-mode control and internal compensation to provide high-performance regulation over a wide range of operating conditions. Additional features include internal soft-start circuitry to reduce inrush current, pulse-by-pulse current limit, thermal shutdown, power good indicators, precision enables, and output over-voltage protection.

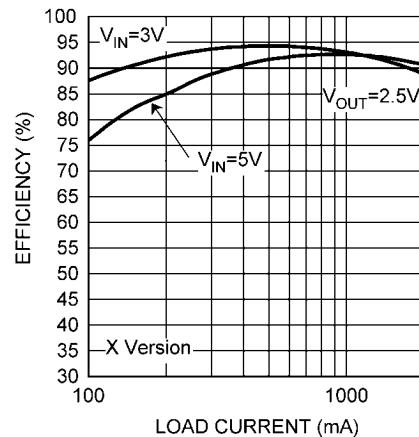
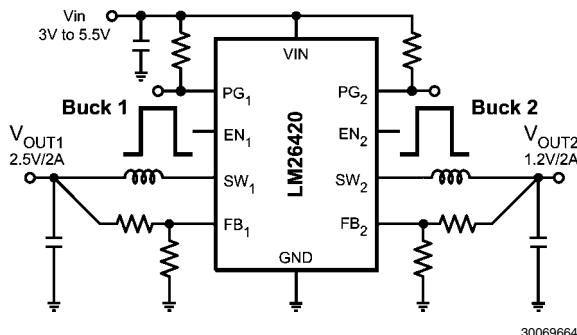
Features

- Input voltage range of 3.0V to 5.5V
- Output voltage range of 0.8V to 4.5V
- 2.0A output current per output
- High Switching Frequencies
2.2MHz (LM26420X)
0.55MHz (LM26420Y)
- 75mΩ PMOS switch
- 50mΩ NMOS switch
- 0.8V, 1.5% Internal Voltage Reference
- Internal soft-start
- Independent power good for each output
- Independent precision enable for each output
- Current mode, PWM operation
- Thermal Shutdown
- Over voltage protection
- Start-up into Pre-biased Output Loads
- Outputs are 180° out of phase

Applications

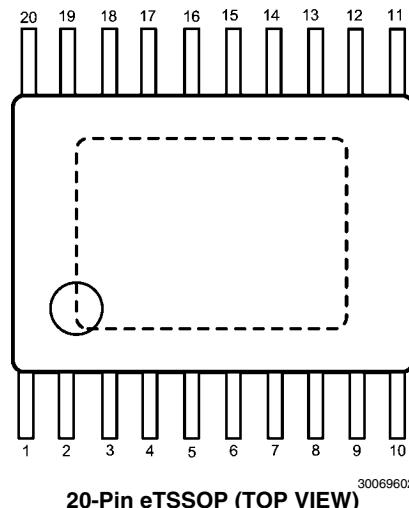
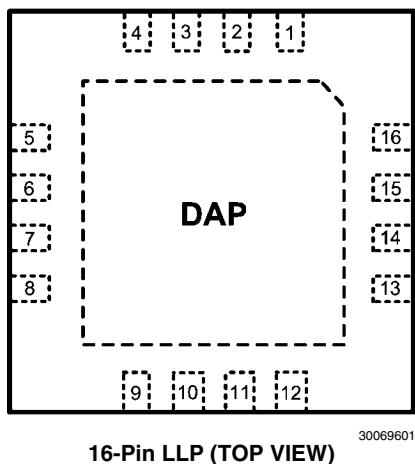
- Local 5V to Vcore Step-Down Converters
- Core Power in HDDs
- Set-Top Boxes
- USB Powered Devices
- DSL Modems
- Powering Core and I/O voltages for FPGAs, CPLDs, and ASICs

Typical Application Circuit



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Connection Diagrams



Ordering Information

Order Number	Frequency Option	Package Type	NSC Package Drawing	Top Mark	Supplied As
LM26420XMH	2.2MHz	eTSSOP-20	MXA20A	LM26420XMH	75 units Rail
LM26420XMHX					2500 units Tape and Reel
LM26420XSQ		LLP-16	SQB16A	L26420X	1000 units Tape and Reel
LM26420XSQX					4500 units Tape and Reel
LM26420YMH	0.55MHz	eTSSOP-20	MXA20A	LM26420YMH	75 units Rail
LM26420YMHX					2500 units Tape and Reel
LM26420YSQ		LLP-16	SQB16A	L26420Y	1000 units Tape and Reel
LM26420YSQX					4500 units Tape and Reel

NOPB versions available as well

Pin Descriptions 20-Pin eTSSOP

Pin	Name	Function
3, 4	VIND ₁	Power Input supply for Buck 1.
17, 18	VIND ₂	Power Input supply for Buck 2.
1	VINC	Input supply for control circuitry.
6,7	PGND ₁	Power ground pin for Buck 1.
14, 15	PGND ₂	Power ground pin for Buck 2.
20	AGND	Signal ground pin. Place the bottom resistor of the feedback network as close as possible to pin.
9	PG ₁	Power Good Indicator for Buck 1. Pin is connected through a resistor to an external supply (open drain output).
12	PG ₂	Power Good Indicator for Buck 2. Pin is connected through a resistor to an external supply (open drain output).
8	FB ₁	Feedback pin for Buck 1. Connect to external resistor divider to set output voltage.
13	FB ₂	Feedback pin for Buck 2. Connect to external resistor divider to set output voltage.
5	SW ₁	Output switch for Buck 1. Connect to the inductor.
16	SW ₂	Output switch for Buck 2. Connect to the inductor.
2	EN ₁	Enable control input. Logic high enable operation for Buck 1. Do not allow this pin to float or be greater than VIN + 0.3V.
19	EN ₂	Enable control input. Logic high enable operation for Buck 2. Do not allow this pin to float or be greater than VIN + 0.3V.
10, 11, DAP	Die Attach Pad	Connect to system ground for low thermal impedance, but it cannot be used as a primary GND connection.

Pin Descriptions 16-Pin LLP

Pin	Name	Function
1,2	VIND ₁	Power Input supply for Buck 1.
11, 12	VIND ₂	Power Input supply for Buck 2.
15	VINC	Input supply for control circuitry.
4	PGND ₁	Power ground pin for Buck 1.
9	PGND ₂	Power ground pin for Buck 2.
14	AGND	Signal ground pin. Place the bottom resistor of the feedback network as close as possible to pin.
6	PG ₁	Power Good Indicator for Buck 1. Pin is connected through a resistor to an external supply (open drain output).
7	PG ₂	Power Good Indicator for Buck 2. Pin is connected through a resistor to an external supply (open drain output).
5	FB ₁	Feedback pin for Buck 1. Connect to external resistor divider to set output voltage.
8	FB ₂	Feedback pin for Buck 2. Connect to external resistor divider to set output voltage.
3	SW ₁	Output switch for Buck 1. Connect to the inductor.
10	SW ₂	Output switch for Buck 2. Connect to the inductor.
16	EN ₁	Enable control input. Logic high enable operation for Buck 1. Do not allow this pin to float or be greater than VIN + 0.3V.
13	EN ₂	Enable control input. Logic high enable operation for Buck 2. Do not allow this pin to float or be greater than VIN + 0.3V.
DAP	Die Attach Pad	Connect to system ground for low thermal impedance and as a primary electrical GND connection.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

V_{IN}	-0.5V to 7V
FB Voltage	-0.5V to 3V
EN Voltage	-0.5V to 7V
SW Voltage	-0.5V to 7V
ESD Susceptibility	

Human Body Model (Note 3) 1.5kV

Junction Temperature (Note 2)

150°C

Storage Temperature

-65°C to +150°C

Soldering Information

Infrared or Convection Reflow
(15 sec)

220°C

Operating Ratings

V_{IN}	3V to 5.5V
Junction Temperature	-40°C to +125°C

Electrical Characteristics Per Buck

VIN = 5V unless otherwise indicated under the **Conditions** column. Limits in standard type are for $T_J = 25^\circ\text{C}$ only; limits in **boldface type** apply over the junction temperature (T_J) range of -40°C to +125°C. Minimum and Maximum limits are guaranteed 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.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{FB}	Feedback Voltage		0.788	0.800	0.812	V
$\Delta V_{FB}/V_{IN}$	Feedback Voltage Line Regulation	$V_{IN} = 3\text{V}$ to 5.5V		0.05		%/V
I_B	Feedback Input Bias Current			0.40	100	nA
UVLO	Under-voltage Lockout	V_{IN} Rising		2.628	2.90	V
		V_{IN} Falling	2.0	2.3		V
	UVLO Hysteresis			330		mV
F_{SW}	Switching Frequency	LM26420-X	1.85	2.2	2.65	MHz
		LM26420-Y	0.4	0.55	0.7	
F_{FB}	Frequency Fold-back	LM26420-X		300		kHz
		LM26420-Y		150		
D_{MAX}	Maximum Duty Cycle	LM26420-X	86	91.5		%
		LM26420-Y	90	98		
R_{DSON_TOP}	TOP Switch On Resistance	LLP-16 Package		75	135	mΩ
		eTSSOP-20 Package		70	135	
R_{DSON_BOT}	BOTTOM Switch On Resistance	LLP-16 Package		55	100	mΩ
		eTSSOP-20 Package		45	80	
I_{CL_TOP}	TOP Switch Current Limit	$V_{IN} = 3.3\text{V}$	2.4	3.3		A
I_{CL_BOT}	BOTTOM Switch Reverse Current Limit	$V_{IN} = 3.3\text{V}$	0.4	0.75		A
$\Delta\Phi$	Phase Shift Between SW ₁ and SW ₂		160	180	200	°
V_{EN_TH}	Enable Threshold Voltage		0.97	1.04	1.12	V
	Enable Threshold Hysteresis			0.15		
I_{SW_TOP}	Switch Leakage			-0.7		μA
I_{EN}	Enable Pin Current	Sink/Source		5.0		nA
V_{PG_TH-U}	Upper Power Good Threshold	FB Pin Voltage Rising	848	925	1,008	mV
	Upper Power Good Hysteresis			40		mV
V_{PG_TH-L}	Lower Power Good Threshold	FB Pin Voltage Rising	656	710	791	mV
	Lower Power Good Hysteresis			40		mV
I_{QVINC}	VINC Quiescent Current (non-switching) with both outputs on	LM26420X/Y $V_{FB} = 0.9$		3.3	5.0	mA
	VINC Quiescent Current (switching) with both outputs on	LM26420X/Y $V_{FB} = 0.7$		4.7	6.2	
	VINC Quiescent Current (shutdown)	All Options $V_{EN} = 0\text{V}$		0.05		
I_{QVIND}	VIND Quiescent Current (non-switching)	LM26420X/Y $V_{FB} = 0.9$		0.9	1.5	mA
	VIND Quiescent Current (switching)	LM26420X $V_{FB} = 0.7$		11.0	15.0	
		LM26420Y $V_{FB} = 0.7$		3.7	7.5	
	VIND Quiescent Current (shutdown)	All Options $V_{EN} = 0\text{V}$		0.1		μA

Symbol	Parameter	Conditions	Min	Typ	Max	Units
θ_{JA}	Junction to Ambient 0 LFPM Air Flow (<i>Note 4</i>)	LLP-16		40		°C/W
		eTSSOP-20		35		
θ_{JC}	Junction to Case (<i>Note 4</i>)	LLP-16		6.8		°C
		eTSSOP-20		3.9		
T_{SD}	Thermal Shutdown Temperature			165		°C

Note 1: Absolute maximum ratings indicate limits beyond which damage to the device may occur. Operating Range indicates conditions for which the device is intended to be functional, but does not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

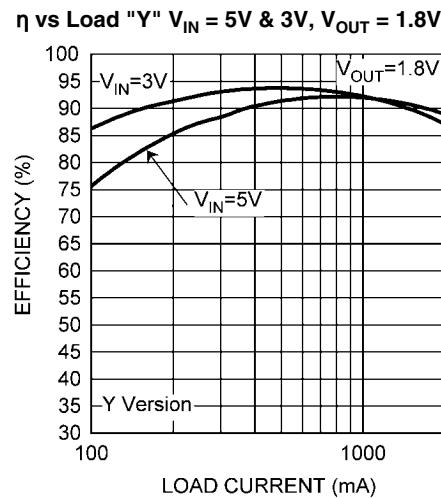
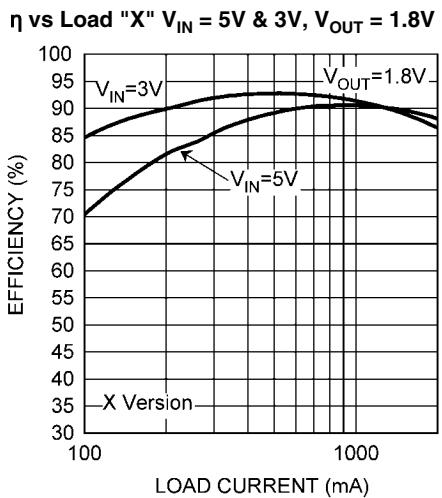
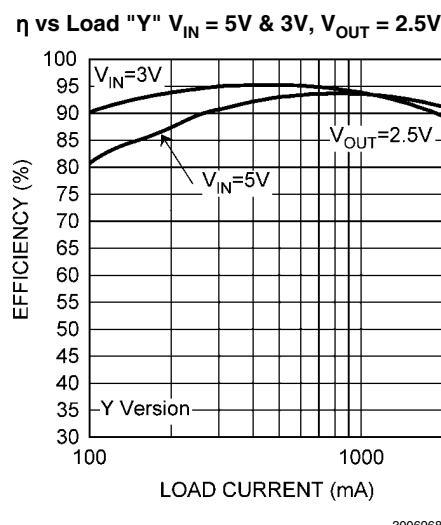
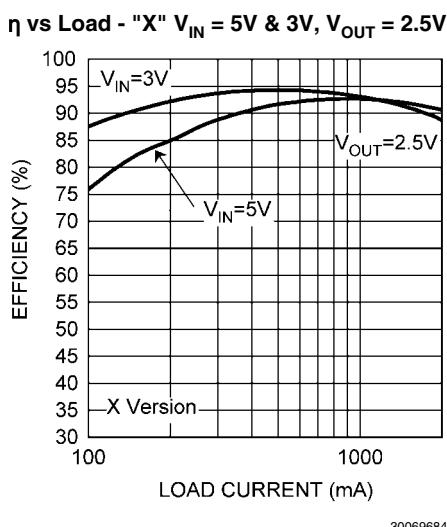
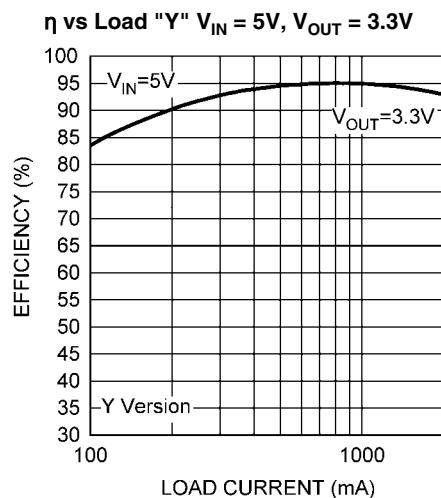
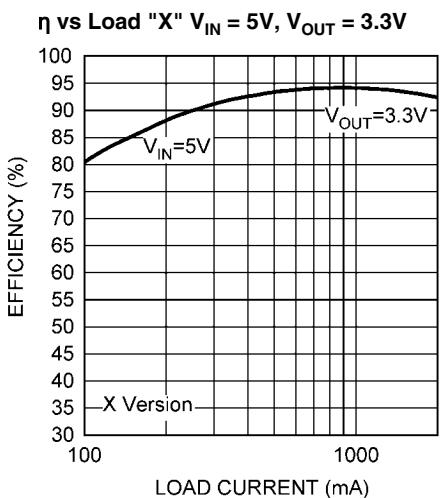
Note 2: Thermal shutdown will occur if the junction temperature exceeds the maximum junction temperature of the device.

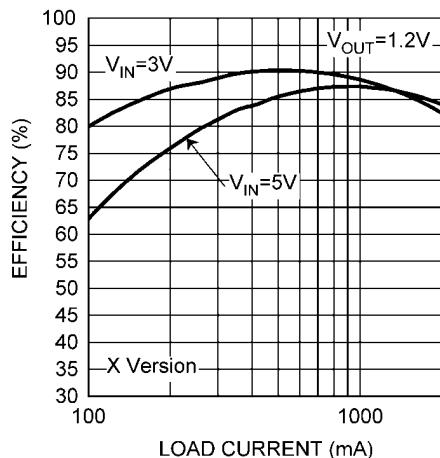
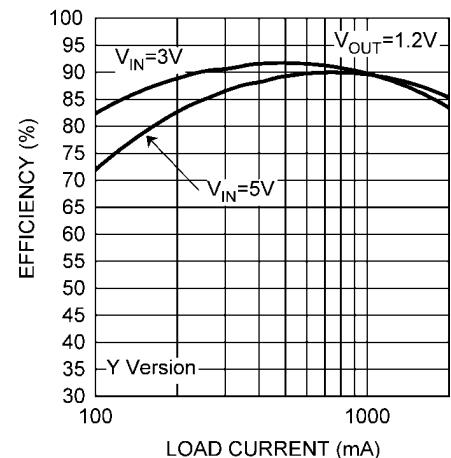
Note 3: The human body model is a 100pF capacitor discharged through a 1.5 k Ω resistor into each pin. Test method is per JESD-22-A114.

Note 4: Applies to a 4-layer standard JEDEC thermal test board or 4LJEDEC is 4"x3" in size. The board has 2 imbedded copper layers which cover roughly the same size as the board. The copper thickness for the four layers, starting from the top one, is 2 oz./1oz./1oz./2 oz. For LLP, thermal vias are placed between the die attach pad in the 1st. copper layer and 2nd. copper layer.

Typical Performance Characteristics

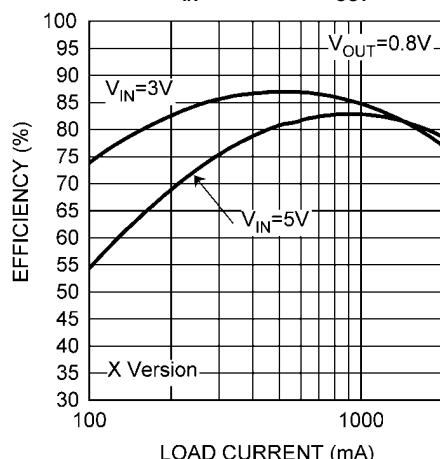
All curves taken at $V_{IN} = 5.0V$ with configuration in typical application circuit shown in Application Information section of this datasheet. $T_J = 25^\circ C$, unless otherwise specified.



η vs Load "X" $V_{IN} = 5V \& 3V$, $V_{OUT} = 1.2V$  η vs Load "Y" $V_{IN} = 5V \& 3V$, $V_{OUT} = 1.2V$ 

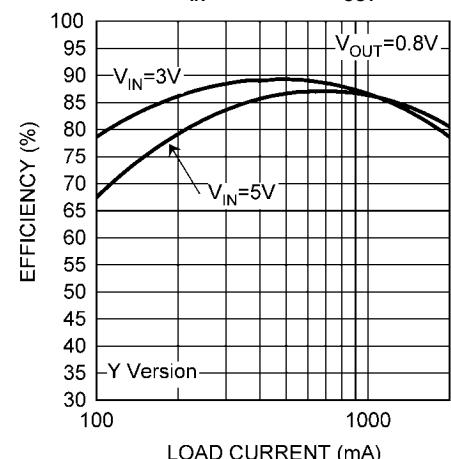
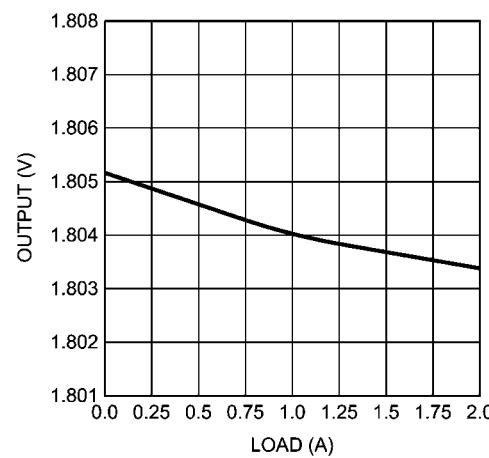
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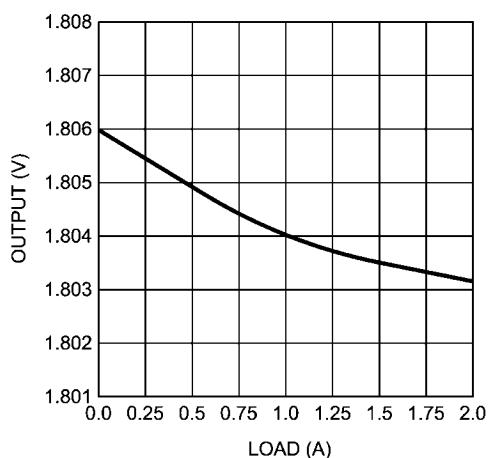
 η vs Load "X" $V_{IN} = 5V \& 3V$, $V_{OUT} = 0.8V$ 

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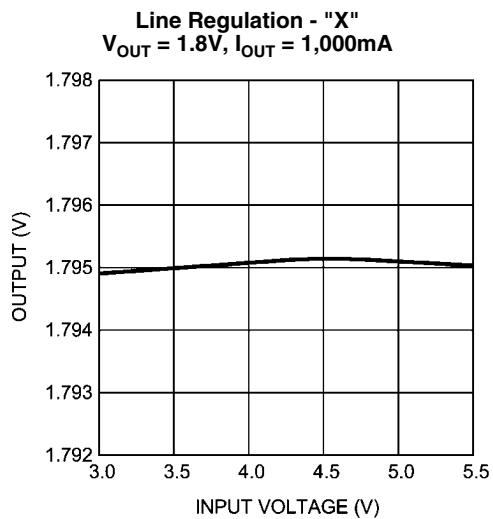
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 η vs Load "Y" $V_{IN} = 5V \& 3V$, $V_{OUT} = 0.8V$ Load Regulation
 $V_{IN} = 5V$, $V_{OUT} = 1.8V$ (All Options)

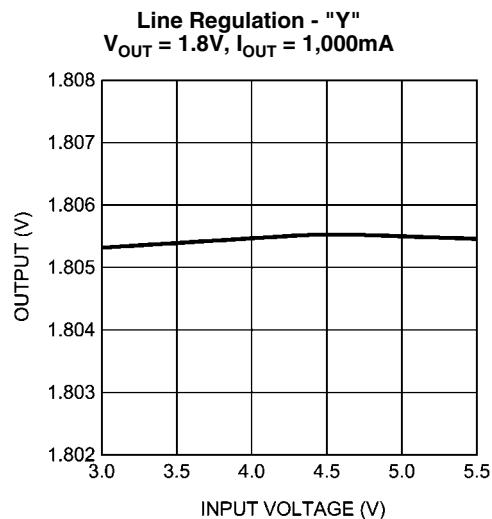
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Load Regulation
 $V_{IN} = 3V$, $V_{OUT} = 1.8V$ (All Options)

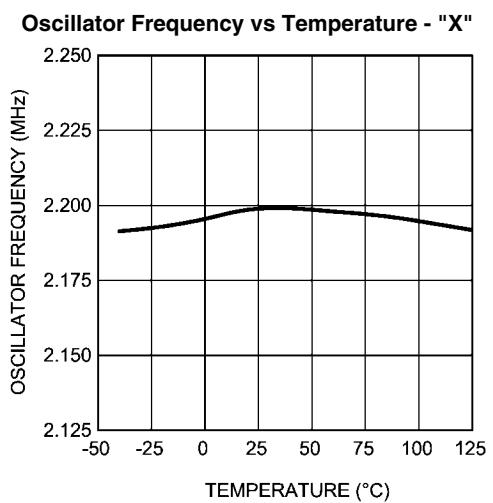
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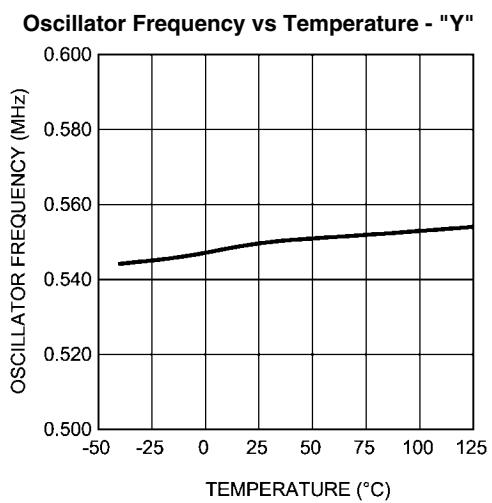
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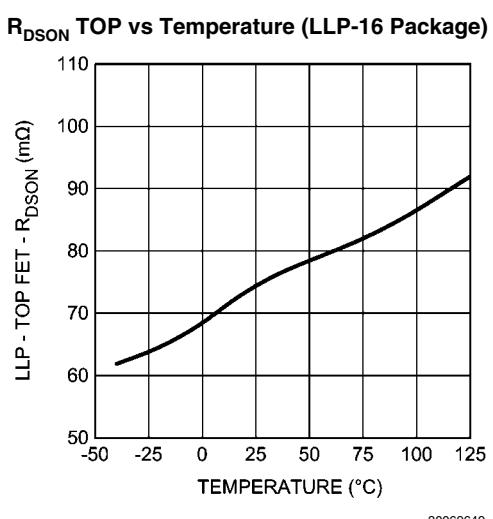
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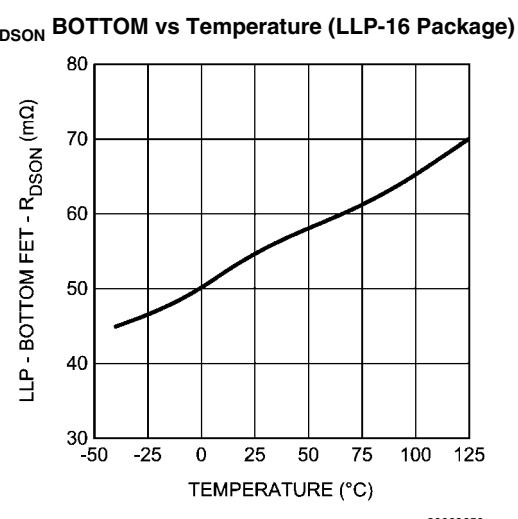
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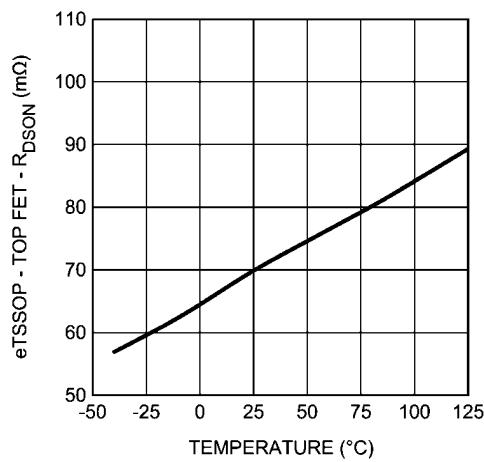
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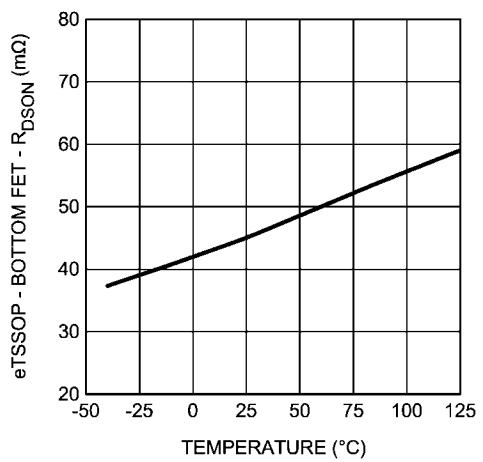
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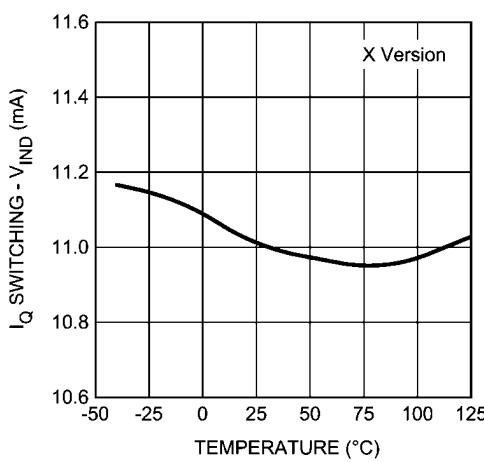
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R_{DSON} TOP vs Temperature (eTSSOP-20 Package)

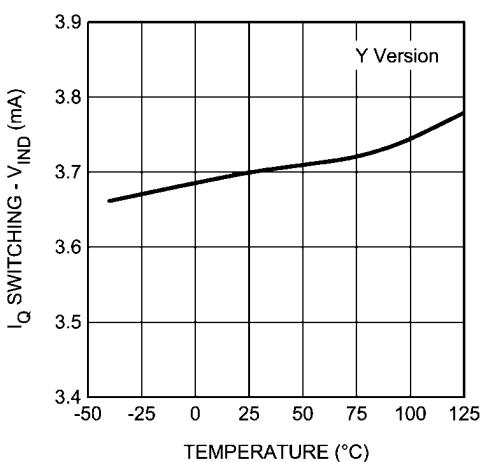
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 R_{DSON} BOTTOM vs Temperature (eTSSOP-20 Package)

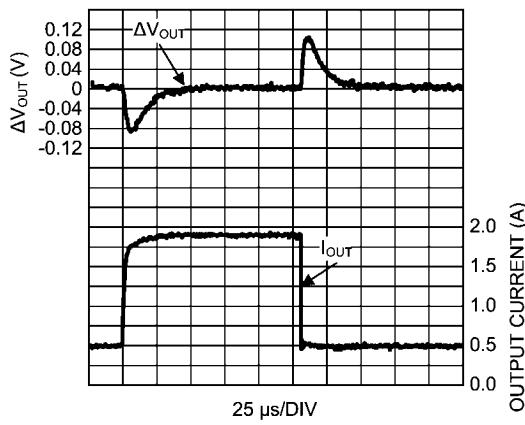
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 I_Q (Quiescent Current Switching) - "X"

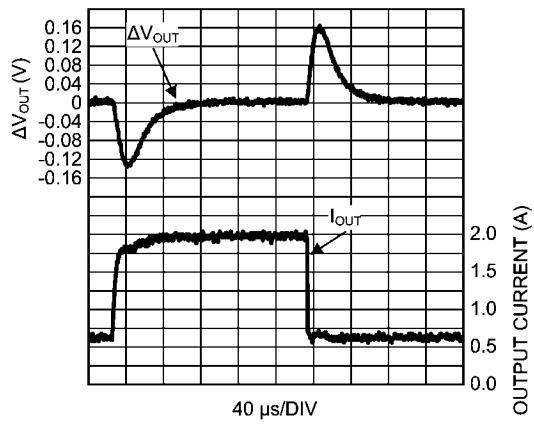
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 I_Q (Quiescent Current Switching) - "Y"

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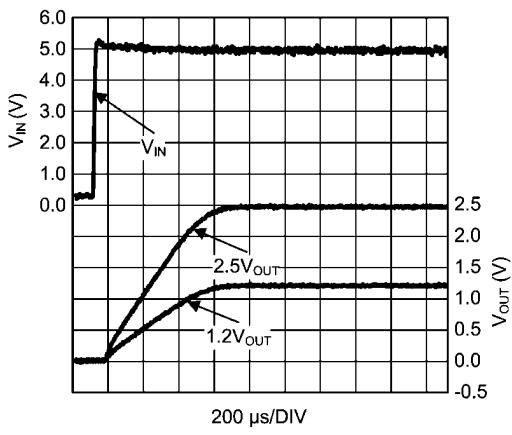
**Load Transient Response - X Version
(V_{OUT} = 1.2V, 25-100% Load Transient)**

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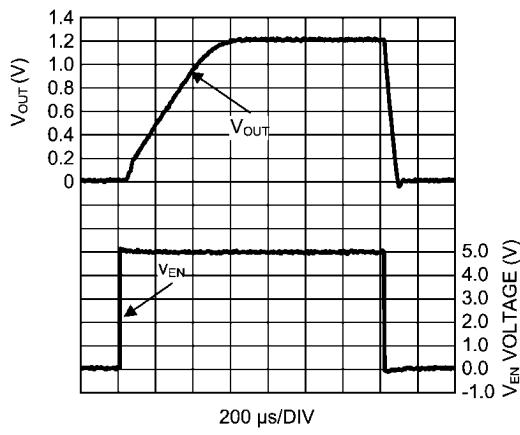
**Load Transient Response - Y Version
(V_{OUT} = 1.2V, 25-100% Load Transient)**

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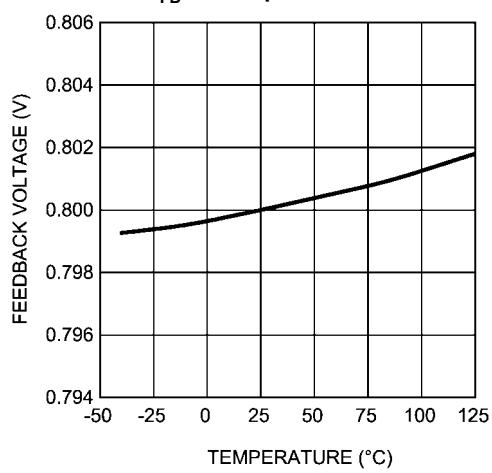
Start-Up (Soft-Start)
($V_{OUT} = 1.8V @ 1A$, $V_{IN} = 5V$)



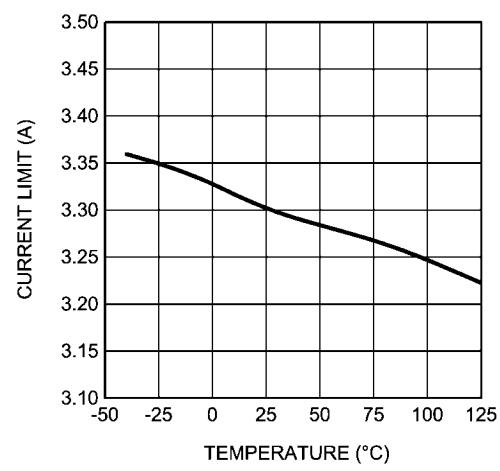
Enable - Disable
($V_{OUT} = 1.8V @ 1A$, $V_{IN} = 5V$)



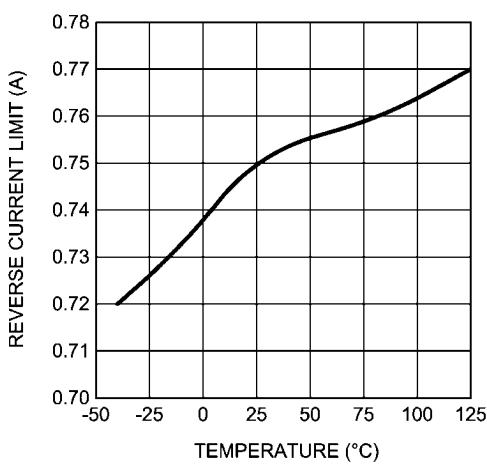
V_{FB} vs Temperature



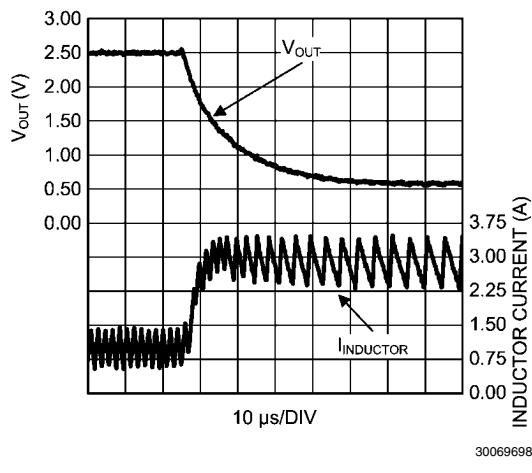
Current Limit vs Temperature
($V_{IN} = 5V$ and $3.3V$)



Reverse Current Limit vs Temperature

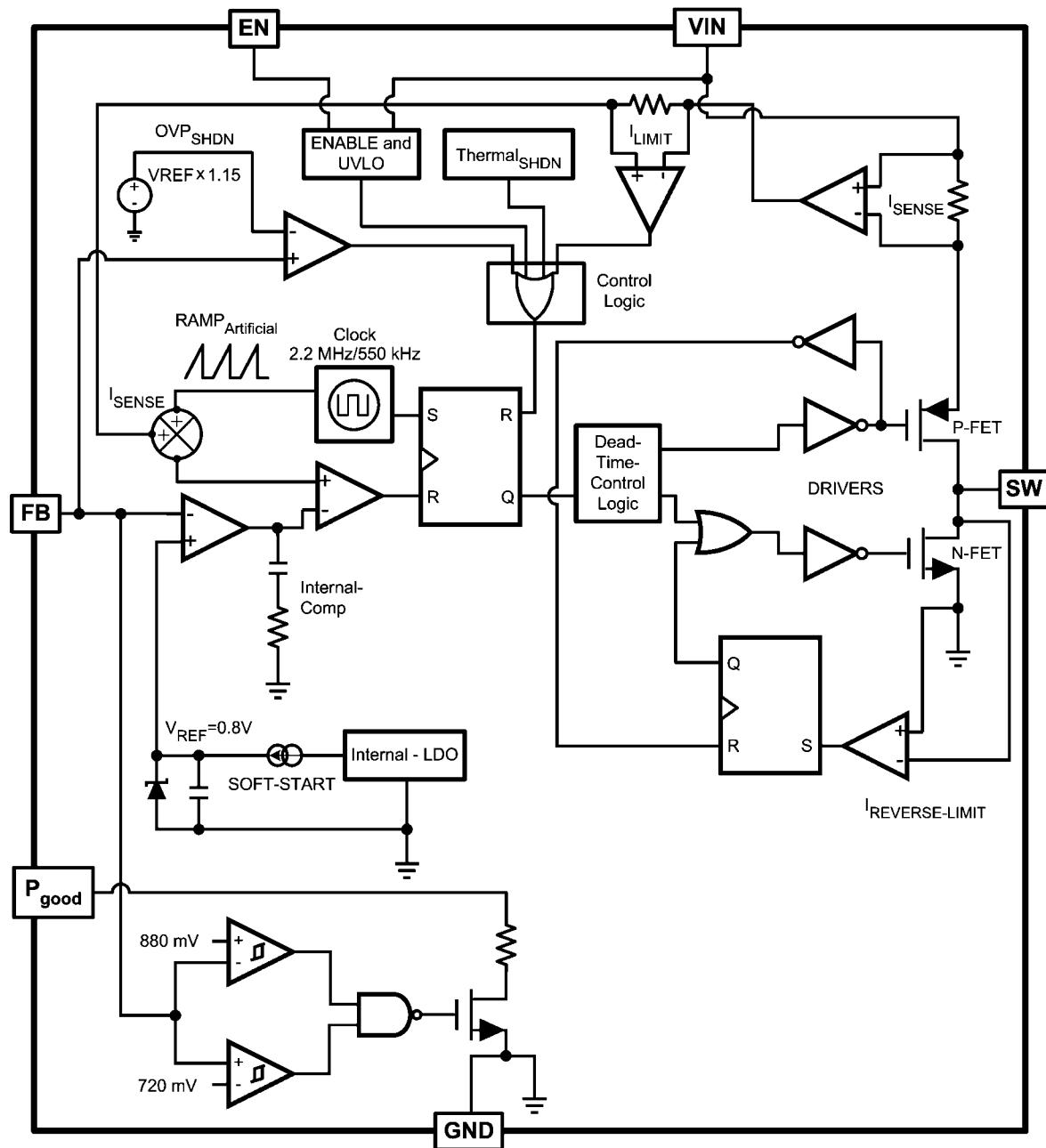


Short Circuit Waveforms



Simplified Block Diagram Per Buck

LM26420



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FIGURE 1.

Applications Information

THEORY OF OPERATION

The LM26420 is a constant frequency dual PWM buck synchronous regulator IC that delivers two 2.0A load currents. The regulator has a preset switching frequency of 2.2MHz or 550kHz. This high frequency allows the LM26420 to operate with small surface mount capacitors and inductors, resulting in a DC/DC converter that requires a minimum amount of board space. The LM26420 is internally compensated, so it is simple to use and requires few external components. The LM26420 uses current-mode control to regulate the output voltage. The following operating description of the LM26420 will refer to the Simplified Block Diagram (Figure 1), which depicts the functional blocks for one of the two channels, and to the waveforms in Figure 2. The LM26420 supplies a regulated output voltage by switching the internal PMOS and NMOS switches at constant frequency and variable duty cycle. A switching cycle begins at the falling edge of the reset pulse generated by the internal clock. When this pulse goes low, the output control logic turns on the internal PMOS control switch (TOP Switch). During this on-time, the SW pin voltage (V_{SW}) swings up to approximately V_{IN} , and the inductor current (I_L) increases with a linear slope. I_L is measured by the current sense amplifier, which generates an output proportional to the switch current. The sense signal is summed with the regulator's corrective ramp and compared to the error amplifier's output, which is proportional to the difference between the feedback voltage and V_{REF} . When the PWM comparator output goes high, the TOP Switch turns off and the NMOS switch (BOTTOM Switch) turns on after a short delay, which is controlled by the Dead-Time-Control Logic, until the next switching cycle begins. During the top switch off-time, inductor current discharges through the BOTTOM Switch, which forces the SW pin to swing to ground. The regulator loop adjusts the duty cycle (D) to maintain a constant output voltage.

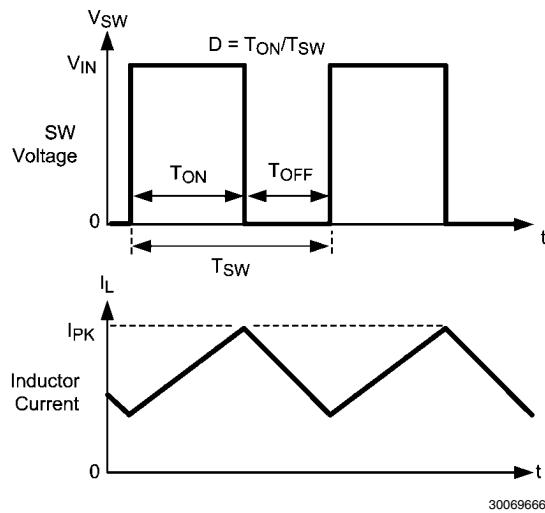
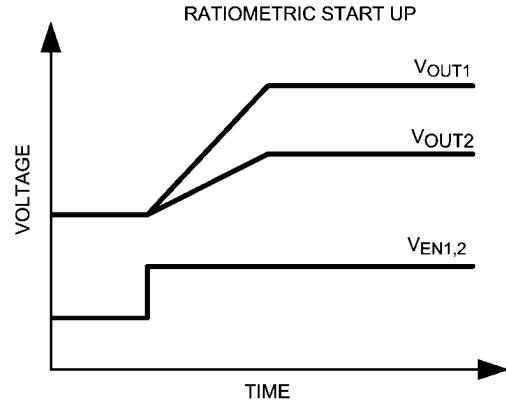


FIGURE 2. Typical Waveforms

SOFT-START

This function forces V_{OUT} to increase at a controlled rate during start up in a controlled fashion, which helps reduce inrush

current and eliminate overshoot on V_{OUT} . During soft-start, the error amplifier's reference voltage ramps from 0V to its nominal value of 0.8V in approximately 600 μ s. If the converter is turned on into a pre-biased condition then the feedback will begin ramping from the pre-bias voltage but at the same rate as if it had started from 0V. The two outputs startup ratiometrically if enabled at the same time, see figure below.



OUTPUT OVER-VOLTAGE PROTECTION

The over-voltage comparator compares the FB pin voltage to a voltage that is approximately 15% higher than the internal reference V_{REF} . Once the FB pin voltage goes 15% above the internal reference, the internal PMOS control switch is turned off, which allows the output voltage to decrease toward regulation.

UNDER-VOLTAGE LOCKOUT

Under-voltage lockout (UVLO) prevents the LM26420 from operating until the input voltage exceeds 2.628V (typ). The UVLO threshold has approximately 330 mV of hysteresis, so the part will operate until V_{IN} drops below 2.3V (typ). Hysteresis prevents the part from turning off during power up if V_{IN} is non-monotonic.

CURRENT LIMIT

The LM26420 uses cycle-by-cycle current limiting to protect the output switch. During each switching cycle, a current limit comparator detects if the output switch current exceeds 3.3A (typ), and turns off the switch until the next switching cycle begins.

THERMAL SHUTDOWN

Thermal shutdown limits total power dissipation by turning off the output switch when the IC junction temperature exceeds 165°C. After thermal shutdown occurs, the output switch does not turn on until the junction temperature drops to approximately 150°C.

POWER GOOD

The LM26420 features an open drain power good (PG) pin to sequence external supplies or loads and to provide fault detection. This pin requires an external resistor (R_{PG}) to pull PG high when the output is within the PG tolerance window. Typical values for this resistor range from 10 kΩ to 100 kΩ.

PRECISION ENABLE

The LM26420 features independent precision enables that allow the converter to be controlled by an external signal. This feature allows the device to be sequenced either by a external control signal or the output of another converter in conjunction

with a resistor divider network. It can also be set to turn on at a specific input voltage when used in conjunction with a resistor divider network connected to the input voltage. The device is enabled when the EN pin exceeds 1.04V and has a 150mV hysteresis.

Design Guide

INDUCTOR SELECTION

The Duty Cycle (D) can be approximated quickly using the ratio of output voltage (V_{OUT}) to input voltage (V_{IN}):

$$D = \frac{V_{OUT}}{V_{IN}}$$

The voltage drop across the internal NMOS (SW_BOT) and PMOS (SW_TOP) must be included to calculate a more accurate duty cycle. Calculate D by using the following formulas:

$$D = \frac{V_{OUT} + V_{SW_BOT}}{V_{IN} + V_{SW_BOT} - V_{SW_TOP}}$$

V_{SW_TOP} and V_{SW_BOT} can be approximated by:

$$V_{SW_TOP} = I_{OUT} \times R_{DSON_TOP}$$

$$V_{SW_BOT} = I_{OUT} \times R_{DSON_BOT}$$

The inductor value determines the output ripple current. Lower inductor values decrease the size of the inductor, but increase the output ripple current. An increase in the inductor value will decrease the output ripple current.

One must ensure that the minimum current limit (2.4A) is not exceeded, so the peak current in the inductor must be calculated. The peak current (I_{LPK}) in the inductor is calculated by:

$$I_{LPK} = I_{OUT} + \Delta I_L$$

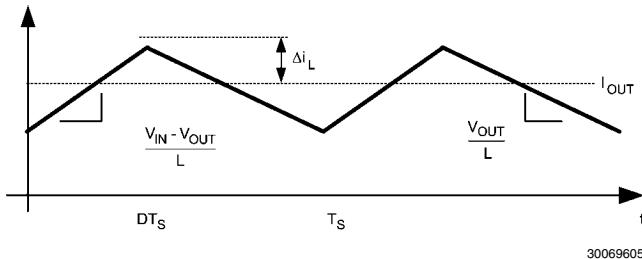


FIGURE 3. Inductor Current

$$\frac{V_{IN} - V_{OUT}}{L} = \frac{2\Delta I_L}{DT_S}$$

In general,

$$\Delta I_L = 0.1 \times (I_{OUT}) \rightarrow 0.2 \times (I_{OUT})$$

If $\Delta I_L = 20\%$ of 2A, the peak current in the inductor will be 2.4A. The minimum guaranteed current limit over all operating conditions is 2.4A. One can either reduce ΔI_L , or make the engineering judgment that zero margin will be safe enough. The typical current limit is 3.3A.

The LM26420 operates at frequencies allowing the use of ceramic output capacitors without compromising transient response. Ceramic capacitors allow higher inductor ripple without significantly increasing output ripple. See the output capacitor section for more details on calculating output voltage ripple. Now that the ripple current is determined, the inductance is calculated by:

$$L = \left(\frac{DT_S}{2\Delta I_L} \right) \times (V_{IN} - V_{OUT})$$

Where

$$T_S = \frac{1}{f_S}$$

When selecting an inductor, make sure that it is capable of supporting the peak output current without saturating. Inductor saturation will result in a sudden reduction in inductance and prevent the regulator from operating correctly. The peak current of the inductor is used to specify the maximum output current of the inductor and saturation is not a concern due to the exceptionally small delay of the internal current limit signal. For example, if the designed maximum output current is 2.0A and the peak current is 2.3A, then the inductor should be specified with a saturation current limit of > 2.3A. There is no need to specify the saturation or peak current of the inductor at the 3.25A typical switch current limit. The difference in inductor size is a factor of 5. Ferrite based inductors are preferred to minimize core losses when operating with the frequencies used by the LM26420. This presents little restriction since the variety of ferrite-based inductors is huge. Lastly, inductors with lower series resistance (R_{DCR}) will provide better operating efficiency. For recommended inductors see Example Circuits.

INPUT CAPACITOR SELECTION

The input capacitors provide the AC current needed by the nearby power switch so that current provided by the upstream power supply does not carry a lot of AC content, generating less EMI. To the buck regulator in question, the input capacitor also prevents the drain voltage of the FET switch from dipping when the FET is turned on, therefore providing a healthy line rail for the LM26420 to work with. Since typically most of the AC current is provided by the local input capacitors, the power loss in those capacitors can be a concern. In the case of the LM26420 regulator, since the two channels operate 180° out of phase, the AC stress in the input capacitors is less than if they operated in phase. The measure for the AC stress is called input ripple RMS current. It is strongly recommended that at least one 10µF ceramic capacitor be placed next to each of the VIND pins. Bulk capacitors such as electrolytic capacitors or OSCON capacitors can be added to help stabilize the local line voltage, especially during large load transient events. As for the ceramic capacitors, use X7R or X5R types. They maintain most of their capacitance over a wide temperature range. Try to avoid sizes smaller than 0805. Otherwise significant drop in capacitance may be caused by the DC bias voltage. See OUTPUT CAPACITOR SELECTION section for more information. The DC voltage rating of the ceramic capacitor should be higher than the highest input voltage.

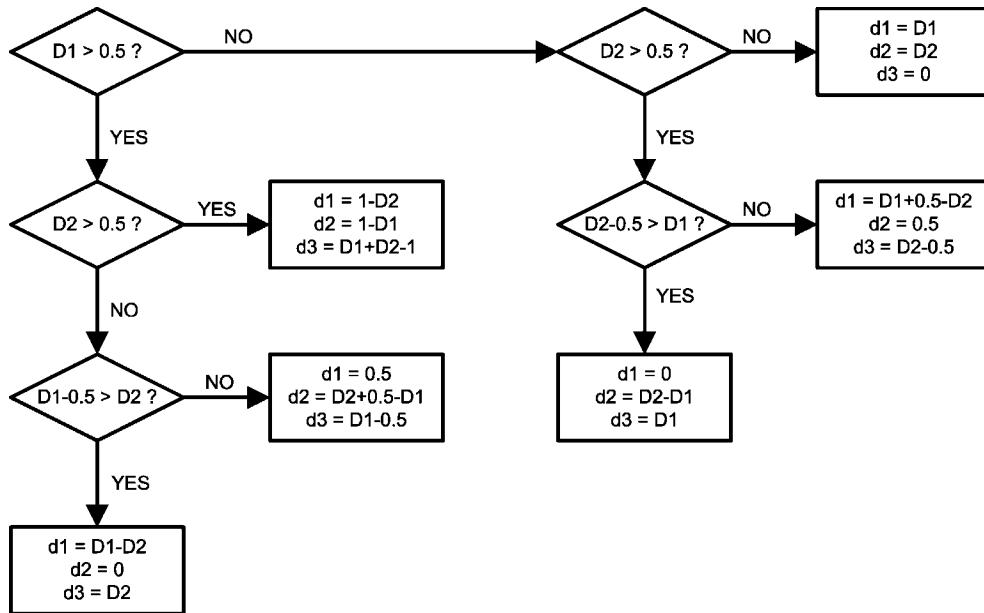
Capacitor temperature is a major concern in board designs. While using a 10µF or higher MLCC as the input capacitor is a good starting point, it is a good idea to check the temperature in the real thermal environment to make sure the capacitors are not over heated. Capacitor vendors may provide curves of ripple RMS current vs. temperature rise, based on a designated thermal impedance. In reality, the thermal impedance may be very different. So it is always a good idea to check the capacitor temperature on the board.

Since the duty cycles of the two channels may overlap, calculation of the input ripple RMS current is a little tedious. Use the following equation.

$$I_{irrms} = \sqrt{(I_1 - I_{av})^2 d1 + (I_2 - I_{av})^2 d2 + (I_1 + I_2 - I_{av})^2 d3}$$

I_1 is Channel 1's maximum output current. I_2 is Channel 2's maximum output current. $d1$ is the non-overlapping portion of Channel 1's duty cycle D_1 . $d2$ is the non-overlapping portion of Channel 2's duty cycle D_2 . $d3$ is the overlapping portion of the two duty cycles. I_{av} is the average input current. $I_{av} = I_1 \cdot D_1 + I_2 \cdot D_2$. To quickly determine the values of $d1$, $d2$ and $d3$, refer to the decision tree in . To determine the duty cycle of each channel, use $D = V_{OUT}/V_{IN}$ for a quick result or use the following equation for a more accurate result.

$$D = \frac{V_{OUT} + V_{SW_BOT} + I_{OUT} \times R_{DC}}{V_{IN} + V_{SW_BOT} - V_{SW_TOP}}$$



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FIGURE 4. Determining $d1$, $d2$ and $d3$

OUTPUT CAPACITOR

The output capacitor is selected based upon the desired output ripple and transient response. The initial current of a load transient is provided mainly by the output capacitor. The output ripple of the converter is:

$$\Delta V_{OUT} = \Delta I_L \left(R_{ESR} + \frac{1}{8 \times F_{SW} \times C_{OUT}} \right)$$

When using MLCCs, the ESR is typically so low that the capacitive ripple may dominate. When this occurs, the output ripple will be approximately sinusoidal and 90° phase shifted from the switching action. Given the availability and quality of MLCCs and the expected output voltage of designs using the LM26420, there is really no need to review any other capacitor technologies. Another benefit of ceramic capacitors is their ability to bypass high frequency noise. A certain amount of

R_{DC} is the winding resistance of the inductor. R_{DS} is the ON resistance of the MOSFET switch.

Example:

$V_{IN} = 5V$, $V_{OUT1} = 3.3V$, $I_{OUT1} = 2A$, $V_{OUT2} = 1.2V$, $I_{OUT2} = 1.5A$, $R_{DS} = 170m\Omega$, $R_{DC} = 30m\Omega$. (I_{OUT1} is the same as I_1 in the input ripple RMS current equation, I_{OUT2} is the same as I_2).

First, find out the duty cycles. Plug the numbers into the duty cycle equation and we get $D_1 = 0.75$, and $D_2 = 0.33$. Next, follow the decision tree in to find out the values of $d1$, $d2$ and $d3$. In this case, $d1 = 0.5$, $d2 = D_2 + 0.5 - D_1 = 0.08$, and $d3 = D_1 - 0.5 = 0.25$. $I_{av} = I_{OUT1} \cdot D_1 + I_{OUT2} \cdot D_2 = 1.995A$. Plug all the numbers into the input ripple RMS current equation and the result is $I_{irrms} = 0.77A$.

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

$$V_{REF} = 0.80V$$

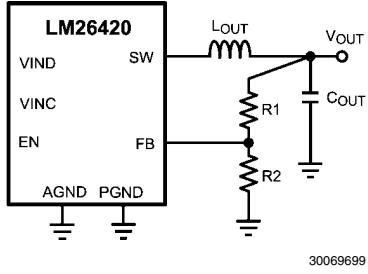


FIGURE 5. Programming V_{OUT}

To determine the maximum allowed resistor tolerance, use the following equation:

$$\sigma = \left(\frac{1}{1 + 2x} \frac{1 - \frac{V_{FB}}{V_{OUT}}}{\frac{TOL - \phi}{3.5\% - 1.5\%}} \right)$$

where TOL is the set point accuracy of the regulator, Φ is the tolerance of V_{FB} .

Example:

$V_{OUT} = 2.5V$, with a set point accuracy of $\pm 3.5\%$.

$$\sigma = \left(\frac{1}{1 + 2x} \frac{1 - \frac{0.8V}{2.5V}}{3.5\% - 1.5\%} \right) = 1.4\%$$

Choose 1% resistors. If $R2 = 10k\Omega$, then $R1$ is $21.25k\Omega$.

VINC FILTERING COMPONENTS

Additional filtering is required between VINC and AGND in order to prevent high frequency noise on VIN from disturbing the sensitive circuitry connected to VINC. A small RC filter can be used on the VINC pin as shown below.

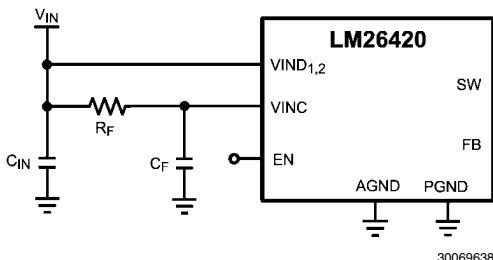


FIGURE 6. RC filter on V_{INC}

In general, R_F is typically between 1Ω and 10Ω so that the steady state voltage drop across the resistor due to the VINC bias current does not affect the UVLO level. C_F can range from $0.22\mu F$ to $1.0\mu F$ in X7R or X5R dielectric, where the RC

time constant should be at least $2\mu s$. C_F should be placed as close as possible to IC with a direct connection from VINC and AGND.

USING PRECISION ENABLE AND POWER GOOD

The LM26420's precision enable and power good pins address many of the sequencing requirements required today's challenging applications. Each output can be controlled independently and have independent power goods. This allows for a multitude of ways to control each output. Typically, the enables to each output are tied together to the input voltage and the outputs will ratiometrically ramp up when the input voltage reaches above UVLO rising threshold. There may be instances where it is desired that the second output (V_{OUT2}) does not turn on until the first output (V_{OUT1}) has reached 90% of the desired set-point. This is achieved easily with an external resistor divider attached from V_{OUT1} to EN_2 , see figure .

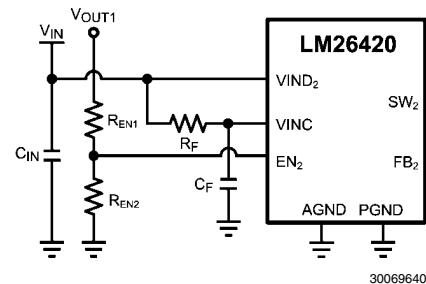


FIGURE 7. V_{OUT1} controlling V_{OUT2} with resistor divider.

If it is not desired to have a resistor divider to control V_{OUT2} with V_{OUT1} , then the PG1 can be connected to the EN2 pin to control V_{OUT2} , see figure below. R_{PG1} is a pull up resistor on the range of $10k\Omega$ to $100k\Omega$, $50k\Omega$ is the suggested value. This will turn on V_{OUT2} when V_{OUT1} is approximately 90% of the programmed output. NOTE, this will also turn off V_{OUT2} when V_{OUT1} is outside the $\pm 10\%$ of the programmed output.

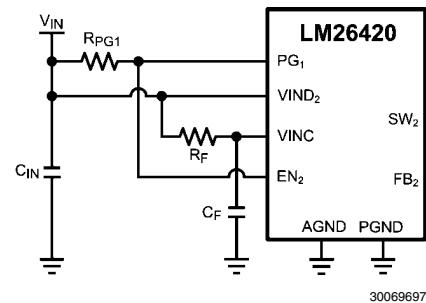


FIGURE 8. PG_1 controlling V_{OUT2} .

Another example might be that the output is not to be turned on until the input voltage reaches 90% of desired voltage set-point. This verifies that the input supply is stable before turning on the output. Select R_{EN1} and R_{EN2} such that the the voltage at the EN pin is greater than $1.12V$ when reaching the 90% desired set-point.

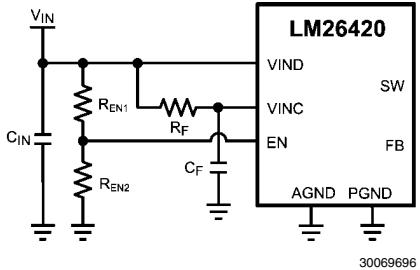


FIGURE 9. V_{IN} controlling V_{OUT}

The LM26420's power good feature is design with hysteresis in order to insure no false power good flags are asserted during large transient. Once power good is asserted high, it will not be pulled low until the output voltage exceeds $\pm 14\%$ of the setpoint for a duraing $\sim 7.5\mu\text{s}$ (typ.), see figure below.

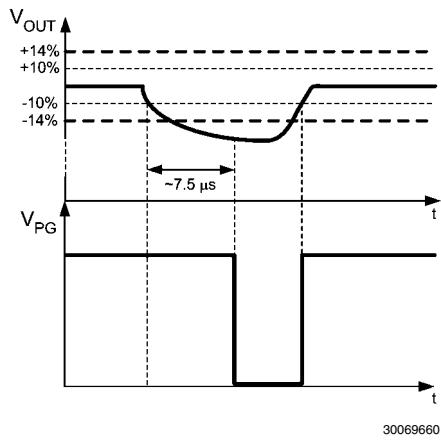


FIGURE 10. Power Good Hysteresis Operation

OVER-CURRENT PROTECTION

When the switch current reaches the current limit value, it immediately is turned off. This effectively reduces the duty cycle and therefore the output voltage dips and continues to droop until the output load matches the peak current limit inductor current. As the FB voltage drops below 480mV the operating frequency begins to decrease until it hits full on frequency

fold-back which is set to approximately 150kHz for the Y version and 300kHz for the X version. Frequency fold back helps reduce the thermal stress in the IC by reducing the switching losses and to prevent runaway of the inductor current when the output is shorted to ground.

It is important to note that when recovering from a over-current condition the converter does not go through the soft-start process. There may be an over shoot due to the sudden removal of the over-current fault. The reference voltage at the non-inverting input of the error amplifier always sits at 0.8V during the over-current condition, therefore when the fault is removed the converter bring the FB voltage back to 0.8V as quickly as possible. The over-shoot depend on whether there is a load on the output after the removal of the over-current fault, the size of the inductor, and the amount of capacitance on the output. The small the inductor and the larger the capacitance on the output the small the overshoot. Note, over-current protection for each output is independent.

PCB LAYOUT CONSIDERATIONS

When planning layout there are a few things to consider when trying to achieve a clean, regulated output. The most important consideration is the close coupling of the GND connections of the input capacitor and the PGND pin. These ground ends should be close to one another and be connected to the GND plane with at least two through-holes. Place these components as close to the IC as possible. Next in importance is the location of the GND connection of the output capacitor, which should be near the GND connections of VIND and PGND. There should be a continuous ground plane on the bottom layer of a two-layer board except under the switching node island. The FB pin is a high impedance node and care should be taken to make the FB trace short to avoid noise pickup and inaccurate regulation. The feedback resistors should be placed as close as possible to the IC, with the GND of R1 placed as close as possible to the GND of the IC. The V_{OUT} trace to R2 should be routed away from the inductor and any other traces that are switching. High AC currents flow through the V_{IN} , SW and V_{OUT} traces, so they should be as short and wide as possible. However, making the traces wide increases radiated noise, so the designer must make this trade-off. Radiated noise can be decreased by choosing a shielded inductor. The remaining components should also be placed as close as possible to the IC. Please see Application Note AN-1229 for further considerations and the LM26420 demo board as an example of a four-layer layout.

Calculating Efficiency, and Junction Temperature

The complete LM26420 DC/DC converter efficiency can be calculated in the following manner.

$$\eta = \frac{P_{OUT}}{P_{IN}}$$

Or

$$\eta = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

Calculations for determining the most significant power losses are shown below. Other losses totaling less than 2% are not discussed.

Power loss (P_{LOSS}) is the sum of two basic types of losses in the converter: switching and conduction. Conduction losses usually dominate at higher output loads, whereas switching losses remain relatively fixed and dominate at lower output loads. The first step in determining the losses is to calculate the duty cycle (D):

$$D = \frac{V_{OUT} + V_{SW_BOT}}{V_{IN} + V_{SW_BOT} - V_{SW_TOP}}$$

V_{SW_TOP} is the voltage drop across the internal PFET when it is on, and is equal to:

$$V_{SW_TOP} = I_{OUT} \times R_{DSON_TOP}$$

V_{SW_BOT} is the voltage drop across the internal NFET when it is on, and is equal to:

$$V_{SW_BOT} = I_{OUT} \times R_{DSON_BOT}$$

If the voltage drop across the inductor (V_{DCR}) is accounted for, the equation becomes:

$$D = \frac{V_{OUT} + V_{SW_BOT} + V_{DCR}}{V_{IN} + V_{SW_BOT} + V_{DCR} - V_{SW_TOP}}$$

Another significant external power loss is the conduction loss in the output inductor. The equation can be simplified to:

$$P_{IND} = I_{OUT}^2 \times R_{DCR}$$

The LM26420 conduction loss is mainly associated with the two internal FETs:

$$P_{COND_TOP} = (I_{OUT}^2 \times D) \left(1 + \frac{1}{3} \times \left(\frac{\Delta i_L}{I_{OUT}} \right)^2 \right) R_{DSON_TOP}$$

$$P_{COND_BOT} = (I_{OUT}^2 \times (1-D)) \left(1 + \frac{1}{3} \times \left(\frac{\Delta i_L}{I_{OUT}} \right)^2 \right) R_{DSON_BOT}$$

If the inductor ripple current is fairly small, the conduction losses can be simplified to:

$$P_{COND_TOP} = (I_{OUT}^2 \times R_{DSON_TOP} \times D)$$

$$P_{COND_BOT} = (I_{OUT}^2 \times R_{DSON_BOT} \times (1-D))$$

$$P_{COND} = P_{COND_TOP} + P_{COND_BOT}$$

Switching losses are also associated with the internal FETs. They occur during the switch on and off transition periods, where voltages and currents overlap resulting in power loss. The simplest means to determine this loss is to empirically measuring the rise and fall times (10% to 90%) of the switch at the switch node.

Switching Power Loss is calculated as follows:

$$P_{SWR} = 1/2(V_{IN} \times I_{OUT} \times F_{SW} \times T_{RISE})$$

$$P_{SWF} = 1/2(V_{IN} \times I_{OUT} \times F_{SW} \times T_{FALL})$$

$$P_{SW} = P_{SWR} + P_{SWF}$$

Another loss is the power required for operation of the internal circuitry:

$$P_Q = I_Q \times V_{IN}$$

I_Q is the quiescent operating current, and is typically around 8.4mA ($I_{QVINC} = 4.7\text{mA}$ + $I_{QVIND}=3.7\text{mA}$) for the 550 kHz frequency option.

Due to Dead-Time-Control Logic in the converter, there is a small delay (~4nS) between the turn ON and OFF of the TOP and BOTTOM FET. During this time, the body diode of the BOTTOM FET is conducting with a voltage drop of V_{BDIODE} (~.65V). This allows the inductor current to circulate to the output, until the BOTTOM FET is turned ON and the inductor current passes through the FET. There is a small amount of power loss due to this body diode conducting and it can be calculated as follows:

$$P_{BDIODE} = 2x(V_{BDIODE} \times I_{OUT} \times F_{SW} \times T_{BDIODE})$$

Typical Application power losses are:

$$P_{LOSS} = \sum P_{COND} + P_{SW} + P_{BDIODE} + P_{IND} + P_Q$$

$$P_{INTERNAL} = \sum P_{COND} + P_{SW} + P_{BDIODE} + P_Q$$

Power Loss Tabulation

V_{IN}	5.0V	V_{OUT}	1.2V
I_{OUT}	2.0A	P_{OUT}	2.4W
F_{SW}	550kHz		
V_{BDIODE}	0.65V	P_{BDIODE}	5.7mW
I_Q	8.4mA	P_Q	42mW
T_{RISE}	1.5nS	P_{SWR}	4.1mW
T_{FALL}	1.5nS	P_{SWF}	4.1mW
R_{DSON_TOP}	75m Ω	P_{COND_TOP}	81mW
R_{DSON_BOT}	55m Ω	P_{COND_BOT}	167mW
IND_{DCR}	20m Ω	P_{IND}	80mW
D	0.262	P_{LOSS}	384mW
η	86.2%	$P_{INTERNAL}$	304mW

These calculations assume a junction temperature of 25°C. The R_{DSON} values will be larger due to internal heating and therefore the internal power loss ($P_{INTERNAL}$) must be first calculated to estimate the rise in junction temperature.

Thermal Definitions

T_J = Chip junction temperature

T_A = Ambient temperature

$R_{\theta JC}$ = Thermal resistance from chip junction to device case

$R_{\theta JA}$ = Thermal resistance from chip junction to ambient air

Heat in the LM26420 due to internal power dissipation is removed through conduction and/or convection.

Conduction: Heat transfer occurs through cross sectional areas of material. Depending on the material, the transfer of heat can be considered to have poor to good thermal conductivity properties (insulator vs. conductor).

Heat Transfer goes as:

Silicon → package → lead frame → PCB

Convection: Heat transfer is by means of airflow. This could be from a fan or natural convection. Natural convection occurs when air currents rise from the hot device to cooler air.

Thermal impedance is defined as:

$$R_{\theta} = \frac{\Delta T}{\text{Power}}$$

Thermal impedance from the silicon junction to the ambient air is defined as:

$$R_{\theta JA} = \frac{T_J - T_A}{P_{\text{INTERNAL}}}$$

The PCB size, weight of copper used to route traces and ground plane, and number of layers within the PCB can greatly effect $R_{\theta JA}$. The type and number of thermal vias can also make a large difference in the thermal impedance. Thermal vias are necessary in most applications. They conduct heat from the surface of the PCB to the ground plane. Five to eight thermal vias should be placed under the exposed pad to the ground plane if the LLP package is used. Up to 12 thermal vias should be used in the eTSSOP-20 package for optimum heat transfer from the device to the ground plane.

Thermal impedance also depends on the thermal properties of the application's operating conditions (V_{IN} , V_{OUT} , I_{OUT} etc), and the surrounding circuitry.

Method 1: Silicon Junction Temperature Determination

To accurately measure the silicon temperature for a given application, two methods can be used. The first method requires the user to know the thermal impedance of the silicon junction to top case temperature.

Some clarification needs to be made before we go any further. $R_{\theta JC}$ is the thermal impedance from all six sides of an IC package to silicon junction.

$R_{\Phi JC}$ is the thermal impedance from top case to the silicon junction.

In this data sheet we will use $R_{\Phi JC}$ so that it allows the user to measure top case temperature with a small thermocouple attached to the top case.

$R_{\Phi JC}$ is approximately $20^{\circ}\text{C}/\text{Watt}$ for the 16-pin LLP package with the exposed pad. Knowing the internal dissipation from the efficiency calculation given previously, and the case temperature, which can be empirically measured on the bench we have:

$$R_{\Phi JC} = \frac{T_J - T_C}{P_{\text{INTERNAL}}}$$

Therefore:

$$T_j = (R_{\Phi JC} \times P_{\text{INTERNAL}}) + T_C$$

From the previous example:

$$T_j = 20^{\circ}\text{C}/\text{W} \times 0.304\text{W} + T_C$$

Method 2: Thermal Shutdown Temperature Determination

The second method, although more complicated, can give a very accurate silicon junction temperature.

The first step is to determine $R_{\theta JA}$ of the application. The LM26420 has over-temperature protection circuitry. When the silicon temperature reaches 165°C , the device stops switching. The protection circuitry has a hysteresis of about 15°C . Once the silicon temperature has decreased to approximately 150°C , the device will start to switch again. Knowing this, the $R_{\theta JA}$ for any application can be characterized during the early stages of the design one may calculate the $R_{\theta JA}$ by placing the PCB circuit into a thermal chamber. Raise the ambient temperature in the given working application until the circuit enters thermal shutdown. If the SW-pin is monitored, it will be obvious when the internal FETs stop switching, indicating a junction temperature of 165°C . Knowing the internal power dissipation from the above methods, the junction temperature, and the ambient temperature $R_{\theta JA}$ can be determined.

$$R_{\theta JA} = \frac{165^{\circ} - T_A}{P_{\text{INTERNAL}}}$$

Once this is determined, the maximum ambient temperature allowed for a desired junction temperature can be found.

An example of calculating $R_{\theta JA}$ for an application using the National Semiconductor LM26420 LLP demonstration board is shown below.

The four layer PCB is constructed using FR4 with 1 oz copper traces. The copper ground plane is on the bottom layer. The ground plane is accessed by eight vias. The board measures $3.0\text{cm} \times 3.0\text{cm}$. It was placed in an oven with no forced airflow. The ambient temperature was raised to 152°C , and at that temperature, the device went into thermal shutdown.

From the previous example:

$$P_{\text{INTERNAL}} = 304\text{mW}$$

$$R_{\theta JA} = \frac{165^{\circ}\text{C} - 152^{\circ}\text{C}}{304 \text{ mW}} = 42.8^{\circ} \text{C/W}$$

If the junction temperature was to be kept below 125°C , then the ambient temperature could not go above 112°C .

$$T_j - (R_{\theta JA} \times P_{\text{INTERNAL}}) = T_A$$

$$125^{\circ}\text{C} - (42.8^{\circ}\text{C/W} \times 304\text{mW}) = 112.0^{\circ}\text{C}$$

LLP Package

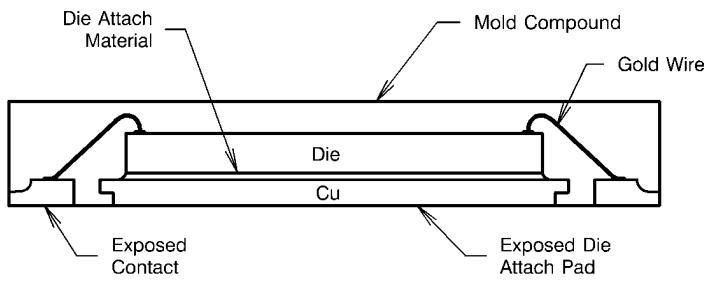


FIGURE 11. Internal LLP Connection

For certain high power applications, the PCB land may be modified to a "dog bone" shape (see Figure 6). By increasing the size of ground plane, and adding thermal vias, the R_{GA} for the application can be reduced.

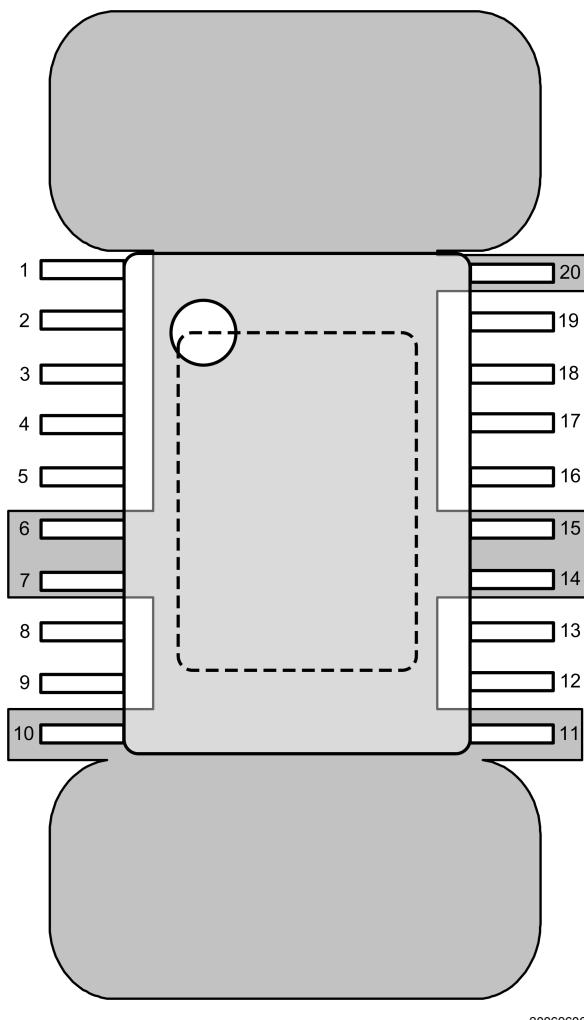


FIGURE 12. 20-Lead eTSSOP PCB Dog Bone Layout

LM26420X Design Example 1

LM26420

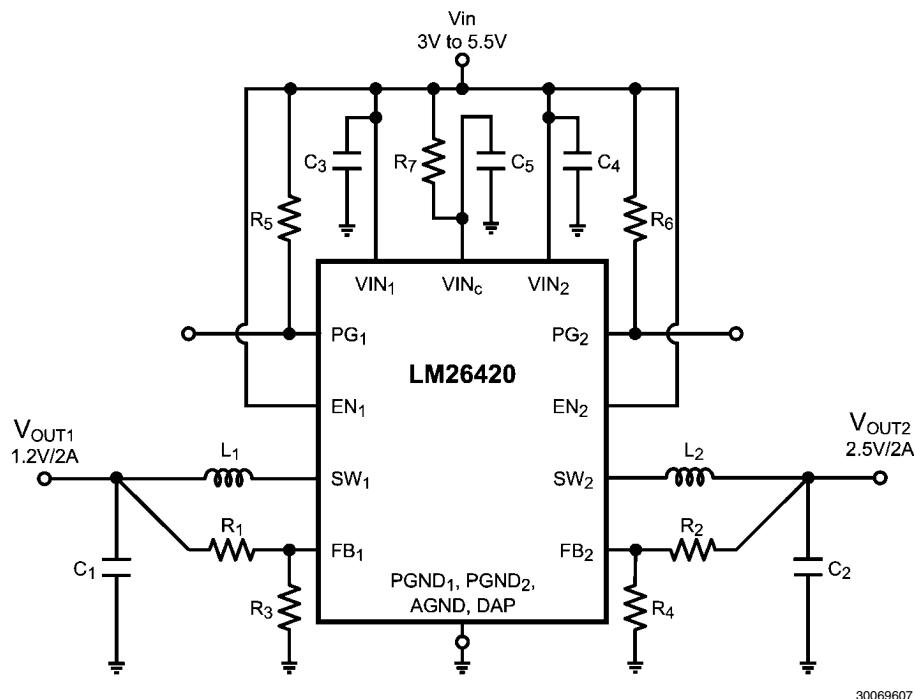


FIGURE 13. LM26420X (2.2MHz): $V_{IN} = 5V$, $V_{OUT1} = 1.2V$ @ 2.0A and $V_{OUT2} = 2.5V$ @ 2.0A

Bill of Materials

Part ID	Part Value	Manufacturer	Part Number
U1	2A Buck Regulator	NSC	LM26420X
C3, C4	15 μ F, 6.3V, 1206, X5R	TDK	C3216X5R0J156M
C1	33 μ F, 6.3V, 1206, X5R	TDK	C3216X5R0J336M
C2	22 μ F, 6.3V, 1206, X5R	TDK	C3216X5R0J226M
C5	0.47 μ F, 10V, 0805, X7R	Vishay	VJ0805Y474KXQCW1BC
L1	1.0 μ H, 7.9A	TDK	RLF7030T-1R0M6R4
L2	1.5 μ H, 6.5A	TDK	RLF7030T-1R5M6R1
R3, R4	10.0k Ω , 0603, 1%	Vishay	CRCW060310K0F
R1	4.99k Ω , 0603, 1%	Vishay	CRCW06034K99F
R5, R6	49.9k Ω , 0603, 1%	Vishay	CRCW060649K9F
R2	21.5k Ω , 0603, 1%	Vishay	CRCW060321K5F
R7	4.99 Ω , 0603, 1%	Vishay	CRCW06034R99F

LM26420X Design Example 2

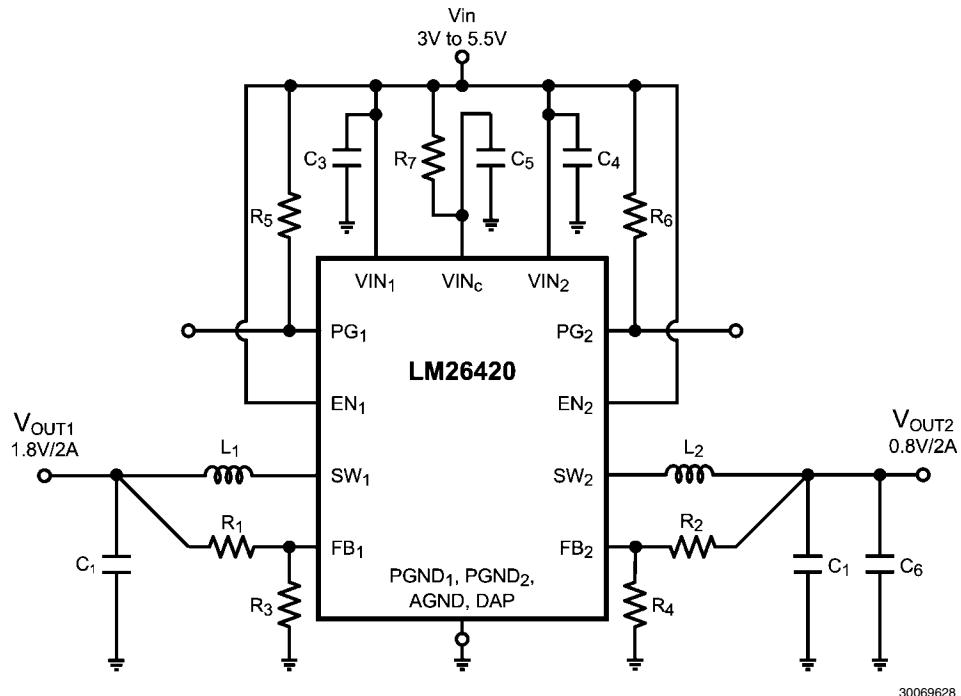


FIGURE 14. LM26420X (2.2MHz): $V_{IN} = 5V$, $V_{OUT1} = 1.8V$ @ 2.0A and $V_{OUT2} = 0.8V$ @ 2.0A

Bill of Materials

Part ID	Part Value	Manufacturer	Part Number
U1	2A Buck Regulator	NSC	LM26420X
C3, C4	15µF, 6.3V, 1206, X5R	TDK	C3216X5R0J156M
C1	33µF, 6.3V, 1206, X5R	TDK	C3216X5R0J336M
C2, C6	22µF, 6.3V, 1206, X5R	TDK	C3216X5R0J226M
C5	0.47µF, 10V, 0805, X7R	Vishay	VJ0805Y474KXQCW1BC
L1	1.0µH, 7.9A	TDK	RLF7030T-1R0M6R4
L2	0.7µH, 3.7A	Coilcraft	LPS4414-701ML
R3, R4	10.0kΩ, 0603, 1%	Vishay	CRCW060310K0F
R5, R6	49.9kΩ, 0603, 1%	Vishay	CRCW060649K9F
R1	12.7kΩ, 0603, 1%	Vishay	CRCW060312K7F
R7, R2	4.99Ω, 0603, 1%	Vishay	CRCW06034R99F

LM26420X Design Example 3

LM26420

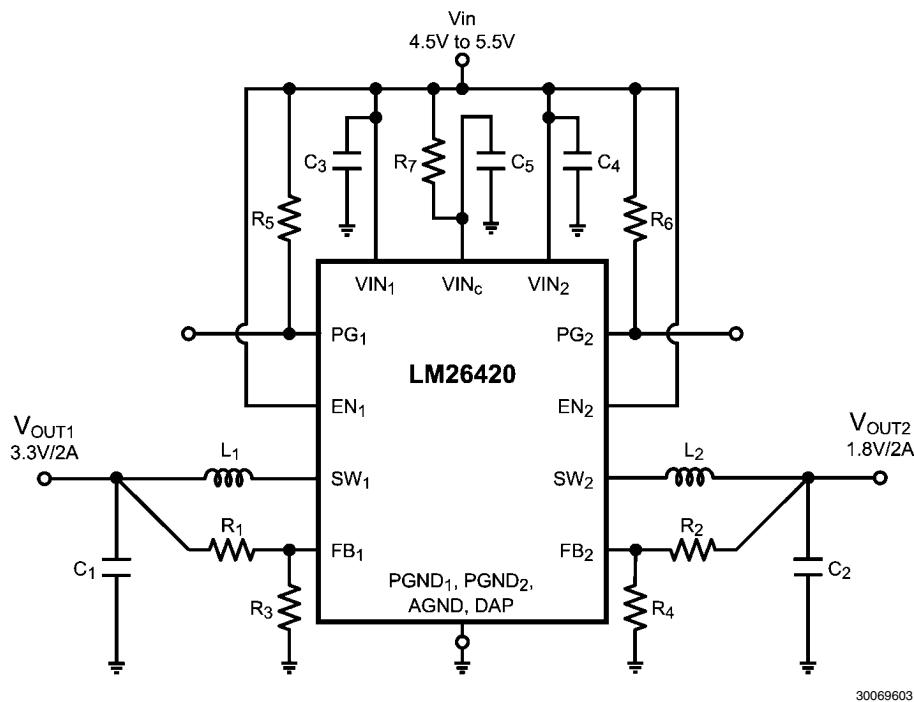
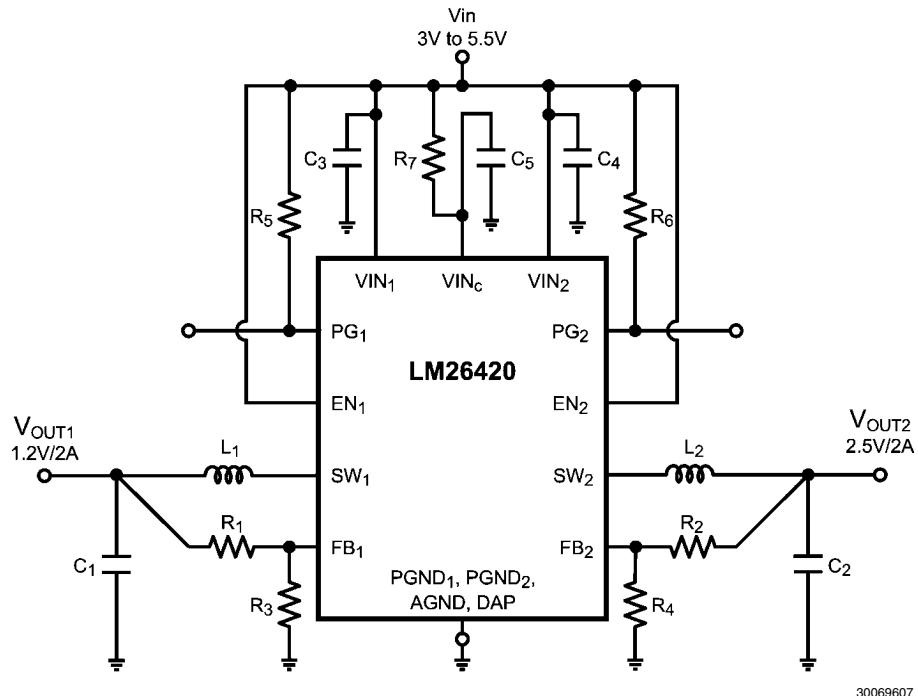


FIGURE 15. LM26420X (2.2MHz): $V_{IN} = 5V$, $V_{OUT1} = 3.3V$ @ 2.0A and $V_{OUT2} = 1.8V$ @ 2.0A

Bill of Materials

Part ID	Part Value	Manufacturer	Part Number
U1	2A Buck Regulator	NSC	LM26420X
C3, C4	15µF, 6.3V, 1206, X5R	TDK	C3216X5R0J156M
C1	22µF, 6.3V, 1206, X5R	TDK	C3216X5R0J226M
C2	33µF, 6.3V, 1206, X5R	TDK	C3216X5R0J336M
C5	0.47µF, 10V, 0805, X7R	Vishay	VJ0805Y474KXQCW1BC
L1, L2	1.0µH, 7.9A	TDK	RLF7030T-1R0M6R4
R3, R4	10.0kΩ, 0603, 1%	Vishay	CRCW060310K0F
R2	12.7kΩ, 0603, 1%	Vishay	CRCW060312K7F
R5, R6	49.9kΩ, 0603, 1%	Vishay	CRCW060649K9F
R1	31.6kΩ, 0603, 1%	Vishay	CRCW060331K6F
R7	4.99Ω, 0603, 1%	Vishay	CRCW06034R99F

LM26420Y Design Example 4

FIGURE 16. LM26420Y (550kHz): $V_{IN} = 5V$, $V_{OUT1} = 1.2V$ @ 2.0A and $V_{OUT2} = 2.5V$ @ 2.0A

Bill of Materials

Part ID	Part Value	Manufacturer	Part Number
U1	2A Buck Regulator	NSC	LM26420Y
C3, C4	22µF, 6.3V, 1206, X5R	TDK	C3216X5R0J226M
C1, C6, C7	33µF, 6.3V, 1206, X5R	TDK	C3216X5R0J336M
C2	47µF, 6.3V, 1206, X5R	TDK	C3216X5R0J476M
C5	0.47µF, 10V, 0805, X7R	Vishay	VJ0805Y474KXQCW1BC
L1	3.3µH, 3.28A	Coilcraft	MSS7341-332NL
L2	5.0µH, 2.82A	Coilcraft	MSS7341-502NL
R3, R4	10.0kΩ, 0603, 1%	Vishay	CRCW060310K0F
R1	4.99kΩ, 0603, 1%	Vishay	CRCW06034K99F
R5, R6	49.9kΩ, 0603, 1%	Vishay	CRCW060649K9F
R2	21.5kΩ, 0603, 1%	Vishay	CRCW060321K5F
R7	4.99Ω, 0603, 1%	Vishay	CRCW06034R99F

LM26420Y Design Example 5

LM26420

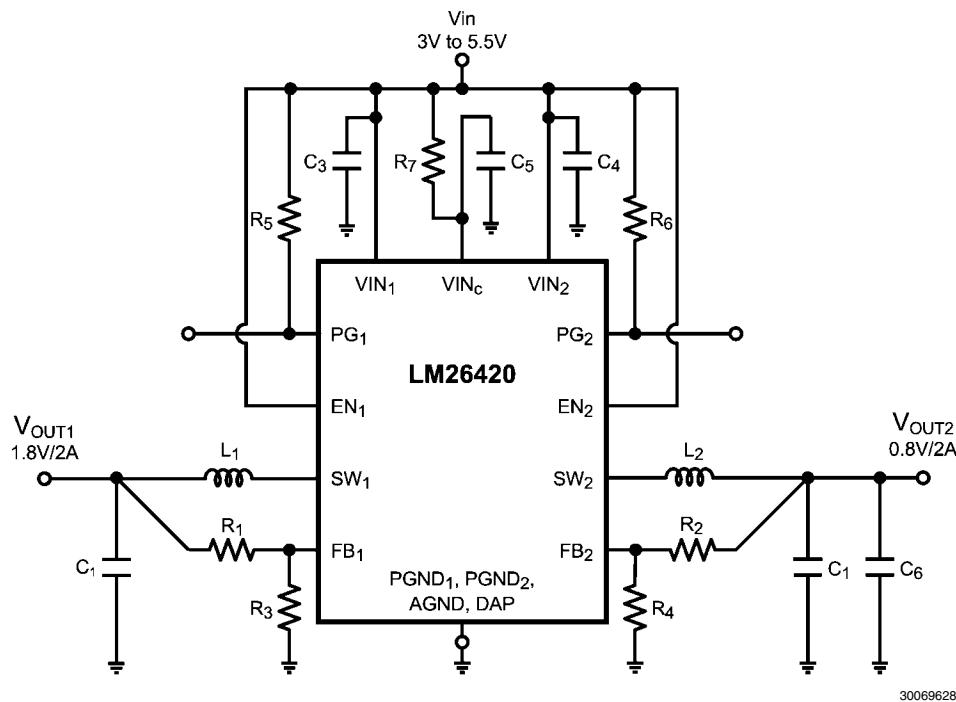
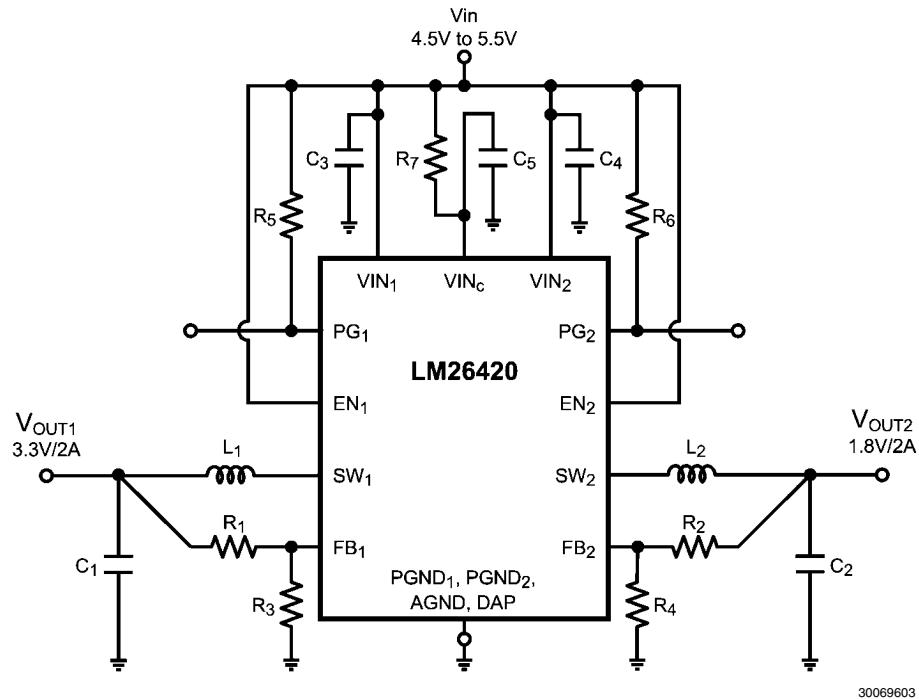


FIGURE 17. LM26420Y (550kHz): $V_{IN} = 5V$, $V_{OUT1} = 1.8V$ @ 2.0A and $V_{OUT2} = 0.8V$ @ 2.0A

Bill of Materials

Part ID	Part Value	Manufacturer	Part Number
U1	2A Buck Regulator	NSC	LM26420Y
C3, C4	22µF, 6.3V, 1206, X5R	TDK	C3216X5R0J226M
C1, C2, C6, C7, C8	47µF, 6.3V, 1206, X5R	TDK	C3216X5R0J476M
C5	0.47µF, 10V, 0805, X7R	Vishay	VJ0805Y474KXQCW1BC
L1	5.0µH, 2.82A	Coilcraft	MSS7341-502NL
L2	3.3µH, 3.28A	Coilcraft	MSS7341-332NL
R3, R4	10.0kΩ, 0603, 1%	Vishay	CRCW060310K0F
R5, R6	49.9kΩ, 0603, 1%	Vishay	CRCW060649K9F
R1	12.7kΩ, 0603, 1%	Vishay	CRCW060312K7F
R7, R2	4.99Ω, 0603, 1%	Vishay	CRCW06034R99F

LM26420Y Design Example 6



30069603

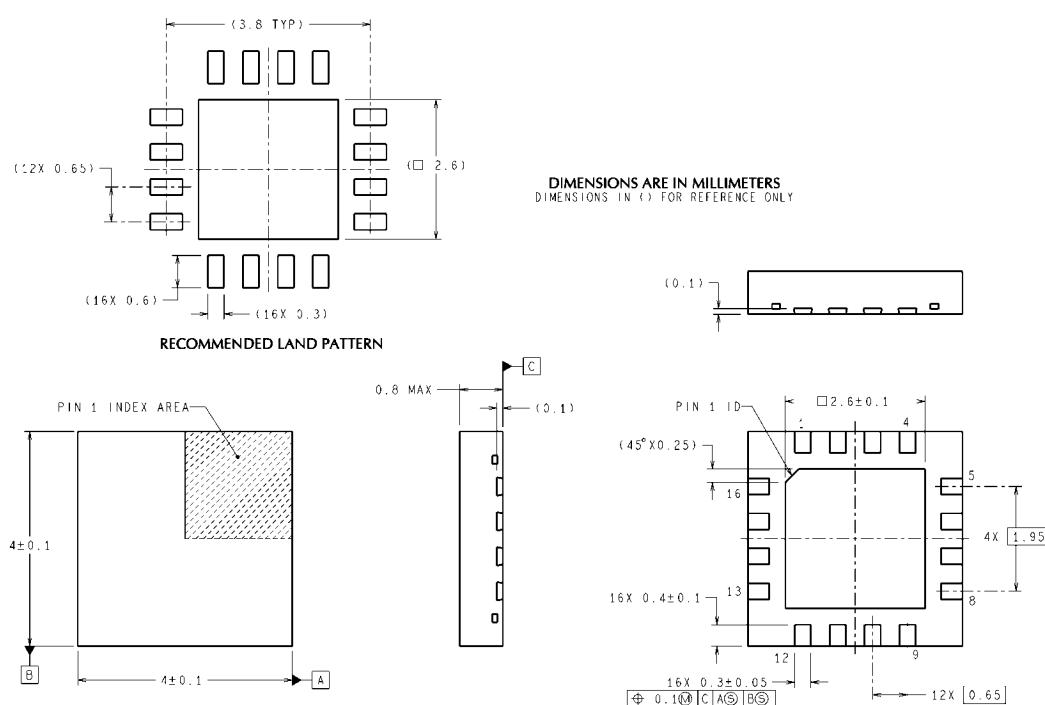
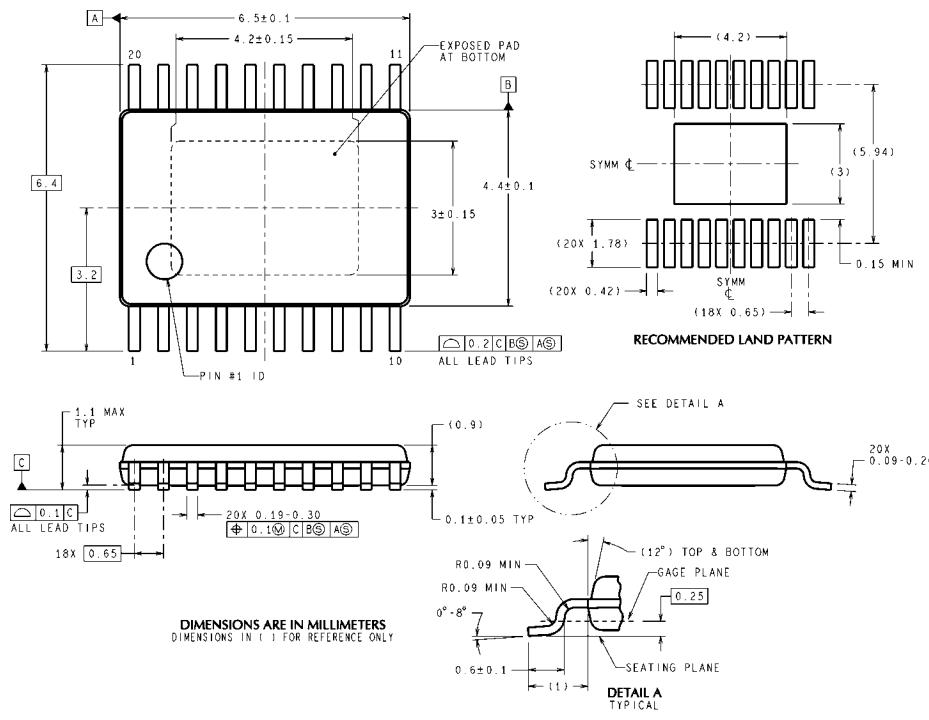
FIGURE 18. LM26420Y (550kHz): $V_{IN} = 5V$, $V_{OUT1} = 3.3V$ @ 2.0A and $V_{OUT2} = 1.8V$ @ 2.0A

Bill of Materials

Part ID	Part Value	Manufacturer	Part Number
U1	2A Buck Regulator	NSC	LM26420Y
C3, C4	22µF, 6.3V, 1206, X5R	TDK	C3216X5R0J226M
C1, C2, C6	47µF, 6.3V, 1206, X5R	TDK	C3216X5R0J476M
C5	0.47µF, 10V, 0805, X7R	Vishay	VJ0805Y474KXQCW1BC
L1, L2	5.0µH, 2.82A	Coilcraft	MSS7341-502NL
R3, R4	10.0kΩ, 0603, 1%	Vishay	CRCW060310K0F
R2	12.7kΩ, 0603, 1%	Vishay	CRCW060312K7F
R5, R6	49.9kΩ, 0603, 1%	Vishay	CRCW060649K9F
R1	31.6kΩ, 0603, 1%	Vishay	CRCW060331K6F
R7	4.99Ω, 0603, 1%	Vishay	CRCW06034R99F

Physical Dimensions

inches (millimeters) unless otherwise noted



Notes

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