

# LM53600/01-Q1 0.65A/1A、36V 同步、2.1MHz、 汽车类降压 DC-DC 转换器

## 1 特性

- 适用于汽车电子 应用
- 具有符合 AEC-Q100 的下列结果：
  - 器件温度 1 级：-40°C 至 125°C 的环境运行温度范围
  - 器件人体放电模式 (HBM) 分类等级 2
  - 器件组件充电模式 (CDM) 分类等级 C5
- 结温范围：-40°C 至 150°C
- 宽运行输入电压范围：3.55V 至 36V（瞬态电压最高达 42V）
- 提供扩展频谱选项
- 2.1MHz 固定开关频率
- 低静态电流：23μA
- 关断电流：1.8μA
- 可调节、3.3V 或 5V 三种输出
- 最大电流负载：650mA (LM53600-Q1)，1000mA (LM53601-Q1)
- 可通过引脚选择的强制脉宽调制 (PWM) 模式
- 具有滤波和延迟释放功能的  $\overline{\text{RESET}}$  输出
- 外部频率同步
- 内部补偿、软启动、电流限制和欠压锁定 (UVLO)
- 具有可湿性侧面的 10 引脚 3mm x 3mm 小外形尺寸无引线 (SON) 封装

## 2 应用

- 汽车摄像机 应用
- 汽车驾驶员辅助系统
- 汽车车身 应用

## 3 说明

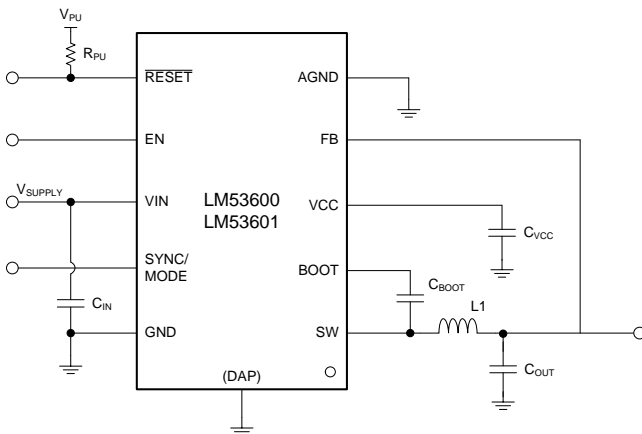
LM53600-Q1 和 LM53601-Q1 同步降压稳压器针对汽车应用进行了优化，可提供 5V、3.3V 或可调节输出三种输出电压。LM53600-Q1 支持高达 650mA 的负载电流，而 LM53601-Q1 支持高达 1000mA 的负载电流。LM53600-Q1 和 LM53601-Q1 器件可利用高级高速电路在 2.1MHz 的固定频率下实现从 18V 输入到 3.3V 输出的稳压。这两款器件采用创新型架构，在输入电压仅为 3.8V 时也可提供 3.3V 稳压输出。输入电压最高可达 36V，容许的最高瞬态电压达 42V，这简化了输入浪涌保护设计。开漏复位输出具有滤波和延迟释放功能，可提供正确的系统状态指示。凭借这一特性，器件无需使用附加监控组件，这节省了成本和电路板空间。这两款器件可在 PWM 和脉频调制 (PFM) 两种模式之间无缝切换，并且静态电流仅为 23μA，这确保了其在所有负载条件下均可展现高效率 and 出色的瞬态响应。外部组件需求的降低使得器件的印刷电路板 (PCB) 布局更加紧凑。尽管 LM53600-Q1 和 LM53601-Q1 器件属于 Q1 级，但均可在 -40°C 至 150°C 的结温范围内保证电气特性。

器件信息<sup>(1)</sup>

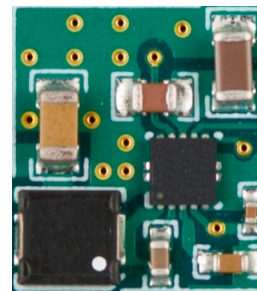
器件型号	封装	封装尺寸 (标称值)
LM53600-Q1	WSON (10)	3.00mm x 3.00mm
LM53601-Q1		

(1) 要了解所有可用封装，请见数据表末尾的可订购产品附录。

简化电路原理图 – 固定输出



汽车类 11.2mm x 12.7mm 布局



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## 4 修订历史记录

Changes from Revision A (December 2015) to Revision B	Page
• Updated tables in <a href="#">Device Comparison</a> .....	<b>3</b>
• Removed last sentence in SYNC/MODE description in Pin Functions table in <a href="#">Pin Configuration and Functions</a> .....	<b>4</b>
• Updated $I_B$ Parameter in <a href="#">Electrical Characteristics</a> table .....	<b>6</b>
• Changed $R_{RESET\ MAX}$ from "80" to "120" in <a href="#">Electrical Characteristics</a> table .....	<b>8</b>
• Changed $V_{out}$ to $V_{out\_3\_3V}$ , $V_{out\_5V}$ , and $V_{out\_ADJ}$ for 3.3-V, 5-V, and ADJ output voltage options in <a href="#">System Characteristics</a> table .....	<b>8</b>
• 已更正 <a href="#">相关文档</a> .....	<b>32</b>

Changes from Original (June 2015) to Revision A	Page
• 已将器件状态由“产品预览”更改为“量产数据” .....	<b>1</b>

## 5 Device Comparison

### LM53600-Q1 Devices<sup>(1)</sup>

Part Number	Output Voltage	Spread Spectrum	Package Qty <sup>(2)</sup>
LM53600AQDSXRQ1	Adjustable	No	3000
LM53600AQDSXTQ1	Adjustable	No	250
LM536003QDSXRQ1	3.3 V	No	3000
LM536003QDSXTQ1	3.3 V	No	250
LM536005QDSXRQ1	5.0 V	No	3000
LM536005QDSXTQ1	5.0 V	No	250
LM53600MQDSXRQ1	Adjustable	Yes	3000
LM53600MQDSXTQ1	Adjustable	Yes	250
LM53600NQDSXRQ1	3.3 V	Yes	3000
LM53600NQDSXTQ1	3.3 V	Yes	250
LM53600LQDSXRQ1	5.0 V	Yes	3000
LM53600LQDSXTQ1	5.0 V	Yes	250

(1) LM53600-Q1 devices have maximum recommended operating current of 650 mA.

(2) See Package Option Addendum for tape and reel details as well as links used to order parts.

### LM53601-Q1 Devices<sup>(1)</sup>

Part Number	Output Voltage	Spread Spectrum	Package Qty <sup>(2)</sup>
LM53601AQDSXRQ1	Adjustable	No	3000
LM53601AQDSXTQ1	Adjustable	No	250
LM536013QDSXRQ1	3.3 V	No	3000
LM536013QDSXTQ1	3.3 V	No	250
LM536015QDSXRQ1	5.0 V	No	3000
LM536015QDSXTQ1	5.0 V	No	250
LM53601MQDSXRQ1	Adjustable	Yes	3000
LM53601MQDSXTQ1	Adjustable	Yes	250
LM53601NQDSXRQ1	3.3 V	Yes	3000
LM53601NQDSXTQ1	3.3 V	Yes	250
LM53601LQDSXRQ1	5.0 V	Yes	3000
LM53601LQDSXTQ1	5.0 V	Yes	250

(1) LM53601-Q1 devices have maximum recommended operating current of 1000 mA.

(2) See Package Option Addendum for tape and reel details as well as links used to order parts.



## 7 Specifications

### 7.1 Absolute Maximum Ratings

over the recommended operating junction temperature range of  $-40^{\circ}\text{C}$  to  $150^{\circ}\text{C}$  (unless otherwise noted)

	MIN	MAX	UNIT
VIN to GND <sup>(1)</sup>	-0.3	42	V
SW to GND <sup>(2)</sup>	-0.3	VIN+0.3	
BOOT to SW	-0.3	3.6	
EN to GND <sup>(1)</sup>	-0.3	42	
BIAS to GND: LM53600-Q1/LM53601-Q1-ADJ	-0.3	16	
FB to GND : LM53600-Q1/LM53601-Q1 - 3.3 V, LM53600-Q1/LM53601-Q1 - 5.0 V	-0.3	16	
FB to GND : LM53600-Q1/LM53601-Q1-ADJ	-0.3	5.5	
$\overline{\text{RESET}}$ to GND	-0.3	8	
$\overline{\text{RESET}}$ sink current <sup>(3)</sup>		8	mA
SYNC/MODE to GND <sup>(1)</sup>	-0.3	42	V
VCC	-0.3	3.6	
GND <sup>(4)</sup> to AGND (Fixed version only)	-1	2	
Storage temperature, T <sub>stg</sub>	-40	150	$^{\circ}\text{C}$

- (1) A maximum of 42 V can be sustained at this pin for a duration of  $\leq 100$  ms at a duty cycle of  $\leq 1\%$ .
- (2) A voltage of 2-V below GND and 2-V above VIN can appear on this pin for  $\leq 200$  ns with a duty cycle of  $\leq 0.01\%$ .
- (3) Do not exceed pin's voltage rating.
- (4) This specification applies to voltage durations of 1  $\mu\text{s}$  or less. The maximum D.C. voltage should not exceed  $\pm 0.3$  V.

### 7.2 ESD Ratings

			VALUE	UNIT
V <sub>(ESD)</sub> Electrostatic discharge	Human body model (HBM), per AEC Q100-002 <sup>(1)</sup>	VIN, SW, CBOOT	$\pm 2000$	V
		EN, BIAS, $\overline{\text{RESET}}$ , FB, SYNC, PWM, VCC	$\pm 2000$	
	Charged device model (CDM), per AEC Q100-011	Other pins	$\pm 750$	
		Corner pins (1, 5, 6, and 10)	$\pm 750$	

- (1) AEC Q100-002 indicates HBM stressing is done in accordance with the ANSI/ESDA/JEDEC JS-001 specification

### 7.3 Recommended Operating Conditions

over the recommended operating junction temperature range of  $-40^{\circ}\text{C}$  to  $150^{\circ}\text{C}$  (unless otherwise noted)

		MIN	NOM	MAX	UNIT
Input voltage range after startup <sup>(1)</sup>		3.8		36	V
Output voltage range	5 V <sup>(2)</sup>	0		5.5	V
	3.3 V <sup>(2)</sup>	0		3.63	
Output adjustment range <sup>(3)</sup> for LM53600-Q1-ADJ <sup>(2)</sup> , LM53601-Q1-ADJ <sup>(2)</sup>		3.3		6	V
Load current range	LM53600-Q1	0		650	mA
	LM53601-Q1	0		1000	
Junction temperature <sup>(4)</sup>		-40		150	$^{\circ}\text{C}$

- (1) An extended input voltage range to 3.55 V is possible; see [System Characteristics](#). See input UVLO in [Electrical Characteristics](#) for startup conditions.
- (2) Output voltage should not be allowed to fall below 0 V during normal operation.
- (3) The LM53600-Q1 and LM53601-Q1 devices can operate outside of the listed range output voltage range. For output voltage outside of the listed range, contact Texas Instruments concerning alternate application circuit BOM and additional operational limitations such as higher I<sub>Q</sub>.
- (4) High junction temperatures degrade operating lifetimes. Operating lifetime is de-rated for junction temperatures greater than  $125^{\circ}\text{C}$ .

## 7.4 Thermal Information

THERMAL METRIC <sup>(1)</sup>		LM53600-Q1, LM53601-Q1	UNIT
		DSX (WSON)	
		10 PINS	
R <sub>θJA</sub>	Junction -to-ambient thermal resistance	46.2	°C/W
R <sub>θJC</sub>	Junction -to-case (top) thermal resistance	31.5	°C/W
R <sub>θJB</sub>	Junction -to-board thermal resistance	20.9	°C/W
Φ <sub>JT</sub>	Junction- to-top characterization parameter	0.3	°C/W
Φ <sub>JB</sub>	Junction-to-board characterization parameter	21.0	°C/W
R <sub>θJC(bot)</sub>	Junction-to-case (bottom) thermal resistance	4.1	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report (SPRA953).

## 7.5 Electrical Characteristics

Limits apply over the recommended operating junction temperature range of –40°C to 150°C, unless otherwise noted. Minimum and maximum limits are ensured through test, design or statistical correlation. Typical values represent the most likely parametric norm at T<sub>J</sub> = 25°C, and are provided for reference purposes only. Unless otherwise stated the following conditions apply: V<sub>in</sub> = 13.5 V.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT	
V <sub>FB</sub>	Initial output voltage accuracy	V <sub>in</sub> = 3.8 V to 36 V T <sub>J</sub> = 25°C, Open Loop	–1%		1%	
		V <sub>in</sub> = 3.8 V to 36 V, Open Loop	–1.5%		1.5%	
I <sub>Q</sub>	Operating quiescent current; measured at V <sub>IN</sub> pin	V <sub>in</sub> = 13.5 V, Not switching V <sub>bias</sub> = 5 V	6.5			μA
		V <sub>in</sub> = 13.5 V, Not switching V <sub>bias</sub> = 5 V, T <sub>J</sub> = 85°C			16	
I <sub>B</sub>	Bias current into BIAS pin for adjustable versions and FB pin for fixed versions	V <sub>in</sub> = 13.5 V, Not switching V <sub>bias</sub> = 5 V, Mode = 0 V	46		80	
I <sub>SD</sub>	Shutdown quiescent current; measured at V <sub>IN</sub> pin	EN = 0, V <sub>IN</sub> = 13.5 V T <sub>J</sub> = 25°C	1.8			μA
		EN = 0, V <sub>IN</sub> = 13.5 V T <sub>J</sub> = 85°C			3	
V <sub>in_UVLO</sub>	Minimum input voltage to operate	Rising	3.2	3.6	3.75	V
V <sub>in_UVLO_hyst</sub>	Minimum input voltage hysteresis	Hysteresis	0.2	0.3	0.35	V
V <sub>reset_OV</sub>	$\overline{\text{RESET}}$ upper threshold voltage	Rising, % of V <sub>out</sub>	105%	106.5%	110%	
V <sub>reset_UV</sub>	$\overline{\text{RESET}}$ lower threshold voltage	Falling, % V <sub>out</sub>	92%	94%	97%	
V <sub>reset_guard</sub>	Magnitude of $\overline{\text{RESET}}$ lower threshold difference from steady state output voltage	Steady state output voltage and $\overline{\text{RESET}}$ threshold read at the same T <sub>J</sub> , and V <sub>IN</sub>	3.9%			
V <sub>reset_hyst</sub>	$\overline{\text{RESET}}$ hysteresis as a percent of output voltage set point		1%			
V <sub>reset_valid</sub>	Minimum input voltage for proper $\overline{\text{RESET}}$ function	50 μA pull-up to $\overline{\text{RESET}}$ pin, EN = 0 V, T <sub>J</sub> = 25°C			1.5	V
V <sub>OL</sub>	Low level $\overline{\text{RESET}}$ function output voltage	50 μA pull-up to $\overline{\text{RESET}}$ pin, V <sub>in</sub> = 1.5 V, EN = 0 V, T <sub>J</sub> = 25°C			0.4	V
		0.5mA pull-up to $\overline{\text{RESET}}$ pin, V <sub>in</sub> = 13.5 V, EN = 0 V			0.4	
		1mA pull-up to $\overline{\text{RESET}}$ pin, V <sub>in</sub> = 13.5 V, EN = 3.3 V			0.4	

## Electrical Characteristics (continued)

Limits apply over the recommended operating junction temperature range of  $-40^{\circ}\text{C}$  to  $150^{\circ}\text{C}$ , unless otherwise noted. 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:  $V_{in} = 13.5\text{ V}$ .

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT	
$F_{sw}$	Switching frequency	$V_{IN} = 13.5\text{ V}$ , Center frequency with spread spectrum, PWM operation	1.89	2.1	2.4	MHz
		$V_{IN} = 13.5\text{ V}$ , Without spread spectrum, PWM operation	1.89	2.1	2.4	
		$V_{IN} = 36\text{ V}$ , 3.3-V fixed output device and adjustable devices regardless of output voltage		1.0		
		$V_{IN} = 36\text{ V}$ , 5-V fixed output device		1.5		
$F_{SYNC}$	Sync frequency range	Output setting + 1 V < $V_{IN}$ < 18 V	1.9	2.1	2.3	MHz
$D_{SYNC}$	Sync input duty cycle range	High state input < 5.5 V and > 2.3 V	25%		75%	
$V_{SYNC/MODE}$	SYNC/MODE input threshold voltage	SYNC/MODE input high (MODE=FPWM)	1.5			V
		SYNC/MODE input low (MODE = AUTO with diode emulation)			0.4	
		SYNC/MODE input hysteresis	0.185		1	
$F_{SSS}$	Frequency span of spread spectrum operation <sup>(1)</sup>		$\pm 4\%$			
$F_{PSS}$	Spread spectrum pattern frequency <sup>(1)</sup>			30		Hz
$I_{SYNC/MODE}$	SYNC/MODE leakage current	$V_{in} = 13.5\text{ V}$ , $V_{SYNC/MODE} = 3.3\text{ V}$	1			$\mu\text{A}$
		$V_{IN} = V_{SYNC/MODE} = 13.5\text{ V}$	5			
$t_{MODE}$	Mode change transition time <sup>(1)</sup>	To FPWM Mode 20 mA load, $V_{IN} = 13.5\text{ V}$		100		$\mu\text{s}$
		To AUTO Mode 20-mA load, $V_{IN} = 13.5\text{ V}$		60		
$I_{L\_HS}$	High side switch current limit <sup>(2)</sup>	LM53600-Q1 Duty cycle approaches 0%	1.0	1.35	1.65	A
		LM53601-Q1 Duty cycle approaches 0%	1.5	1.83	2.1	
$I_{L\_LS}$	Low side switch current limit	LM53600-Q1	0.65	0.78	0.93	A
		LM53601-Q1	1.0	1.2	1.43	
$I_{L\_ZC}$	Zero-cross current limit MODE/SYNC = Low		-0.01			A
$I_{L\_NEG}$	Negative current limit MODE/SYNC = High	LM53600-Q1		-0.7		A
		LM53601-Q1		-0.7		
$R_{dson}$	Power switch on-resistance	High side MOSFET $R_{dson}$		220		m $\Omega$
		Low side MOSFET $R_{dson}$		200		
$V_{EN}$	Enable input threshold voltage - rising	Enable rising	1.7	-	2.0	V
$V_{EN\_HYST}$	Enable threshold hysteresis		0.40	-	0.55	V
$V_{EN\_WAKE}$	Enable Wake-up threshold		0.4			V
$I_{EN}$	Enable pin input current	$V_{IN} = V_{EN} = 13.5\text{ V}$		2.7		$\mu\text{A}$
$V_{CC}$	Internal Vcc voltage	$V_{IN} = 13.5\text{ V}$ , $V_{bias} = 0\text{ V}$		3.05		V
		$V_{IN} = 13.5\text{ V}$ , $V_{bias} = 3.3\text{ V}$		3.15		
$V_{CC\_UVLO}$	Internal Vcc input under voltage lock-out	VCC rising		2.7		V

(1) Ensured by design, statistical analysis and production testing of correlated parameters; not tested in production.

(2) High side current limit is a function of duty factor. Current limit value is highest at small duty factor and less at higher duty factors.



## Electrical Characteristics (continued)

Limits apply over the recommended operating junction temperature range of  $-40^{\circ}\text{C}$  to  $150^{\circ}\text{C}$ , unless otherwise noted. 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:  $V_{in} = 13.5\text{ V}$ .

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT		
$V_{cc\_UVLO\_hyst}$	Input under voltage lock-out hysteresis	Hysteresis below $V_{cc\_uvlo}$		190	mV		
$I_{FB}$	Input current from FB to AGND	LM53600-Q1-ADJ, FB = 1 V		20	nA		
$V_{ref}$	Reference voltage for ADJ option only	$T_j = 25^{\circ}\text{C}$		0.993	1	1.007	V
				0.985	1	1.015	
$R_{RESET}$	$R_{dson}$ of $\overline{RESET}$ output		50	120	$\Omega$		
$T_{SD}$	Thermal shutdown rising threshold <sup>(1)</sup>	151	167	185	$^{\circ}\text{C}$		
$T_{SDF}$	Thermal shutdown falling threshold <sup>(1)</sup>	140	157				
$T_{SD\_hyst}$	Thermal shutdown hysteresis <sup>(1)</sup>		10				
$D_{max}$	Maximum switch duty cycle <sup>(1)</sup>	Fsw = 2.1 MHz		76%			
		While in frequency fold back		96%			

## 7.6 System Characteristics

The following specifications are ensured by design provided that the component values in the typical application circuit are used. These parameters are not ensured by production testing. Limits apply over the recommended operating junction temperature range of  $-40^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ , unless otherwise noted. 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:  $V_{in} = 13.5\text{ V}$ .

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT		
$V_{in\_min}$	Minimum input voltage for full functionality at 500-mA load, after start-up	$V_{OUT} = 3.3\text{ V}$		3.55	V		
	Minimum input voltage for full functionality at 100% of max rated load, after start-up	$V_{OUT} = 3.3\text{ V}$		3.8	V		
$V_{out\_3.3V}$	Output voltage for 3.3-V option	$V_{IN} = 4.0\text{ V to }36\text{ V}$ , $I_{OUT} = \text{Maximum recommended load current}$		3.23	3.3	3.37	V
		$V_{IN} = 3.8\text{ V to }36\text{ V}$ , $I_{OUT} = 100\ \mu\text{A to }100\text{ mA}$ , typical value in Auto Mode		3.23	3.33	3.39	
$V_{out\_5V}$	Output voltage for 5-V option	$V_{IN} = 5.8\text{ V to }36\text{ V}$ , $I_{OUT} = \text{Maximum recommended load current}$		4.9	5	5.1	V
		$V_{IN} = 5.5\text{ V to }36\text{ V}$ , $I_{OUT} = 100\ \mu\text{A to }100\text{ mA}$ , typical value in Auto Mode		4.9	5.05	5.125	
$V_{out\_ADJ}$	Output voltage ADJ option	$V_{IN} = V_{OUT} + 0.6\text{ V to }36\text{ V}$ , $I_{OUT} = 100\text{ mA}$ , FPWM mode		-2%		+2%	
		$V_{IN} = V_{OUT} + 0.6\text{ V to }36\text{ V}$ , $I_{OUT} = 100\ \mu\text{A to }100\text{ mA}$ , Auto mode		-2%		+2.5%	
	Load regulation for ADJ option <sup>(1)</sup>	$V_{IN} = V_{OUT} + 1\text{ V to }36\text{ V}$ , $I_{OUT} = 0\text{ A to }1\text{ A}$ , $T_j = 125^{\circ}\text{C}$ , FPWM mode			-1%		
$I_{Q\_VIN}^{(2)}$	Input current to $V_{IN}$ node of DC/DC utilizing the LM53600-Q1/LM53601-Q1	$V_{IN} = 13.5\text{ V}$ , $V_{OUT} = 3.3\text{ V}$ , $I_{OUT} = 0\text{ A}$			23		$\mu\text{A}$
		$V_{IN} = 13.5\text{ V}$ , $V_{OUT} = 5\text{ V}$ , $I_{OUT} = 0\text{ A}$			30		
$V_{DROP1}$	Minimum input to output voltage differential to maintain regulation accuracy, without inductor DCR drop	$V_{OUT} = 3.3\text{ V}$ , $I_{OUT} = 1000\text{ mA}$ , +2/-3% output accuracy			0.6		V

(1)  $125^{\circ}\text{C}$  is worst case temperature for load regulation. Layout is critical since adjustable option does not have an AGND terminal.

(2) See [Auto Mode Operation and  \$I\_{Q\\_VIN}\$](#)  in [Detailed Description](#) for the meaning of this specification and how it can be calculated.



## System Characteristics (continued)

The following specifications are ensured by design provided that the component values in the typical application circuit are used. These parameters are not ensured by production testing. Limits apply over the recommended operating junction temperature range of  $-40^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ , unless otherwise noted. 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:  $V_{in} = 13.5\text{ V}$ .

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{\text{DROP}2}$	Minimum input to output voltage differential to maintain $F_{\text{SW}} \geq 1.85\text{ MHz}$ , without inductor DCR drop	$V_{\text{OUT}} = 3.3\text{ V}$ , $I_{\text{OUT}} = 1000\text{ mA}$ , $F_{\text{SW}} = 1.85\text{ MHz}$ , 2% regulation accuracy			2.0	V
Efficiency	Typical Efficiency without inductor loss	$V_{\text{IN}} = 13.5\text{ V}$ , $V_{\text{OUT}} = 5.0\text{ V}$ , $I_{\text{OUT}} = 1\text{ A}$		85%		
		$V_{\text{IN}} = 13.5\text{ V}$ , $V_{\text{OUT}} = 3.3\text{ V}$ , $I_{\text{OUT}} = 1\text{ A}$		80%		
		$V_{\text{IN}} = 13.5\text{ V}$ , $V_{\text{OUT}} = 5.0\text{ V}$ , $I_{\text{OUT}} = 0.65\text{ A}$		86%		
		$V_{\text{IN}} = 13.5\text{ V}$ , $V_{\text{OUT}} = 3.3\text{ V}$ , $I_{\text{OUT}} = 0.65\text{ A}$		83%		

## 7.7 Timing Requirements

Limits apply over the recommended operating junction temperature range of  $-40^{\circ}\text{C}$  to  $150^{\circ}\text{C}$ , unless otherwise noted. 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:  $V_{in} = 13.5\text{ V}$ .

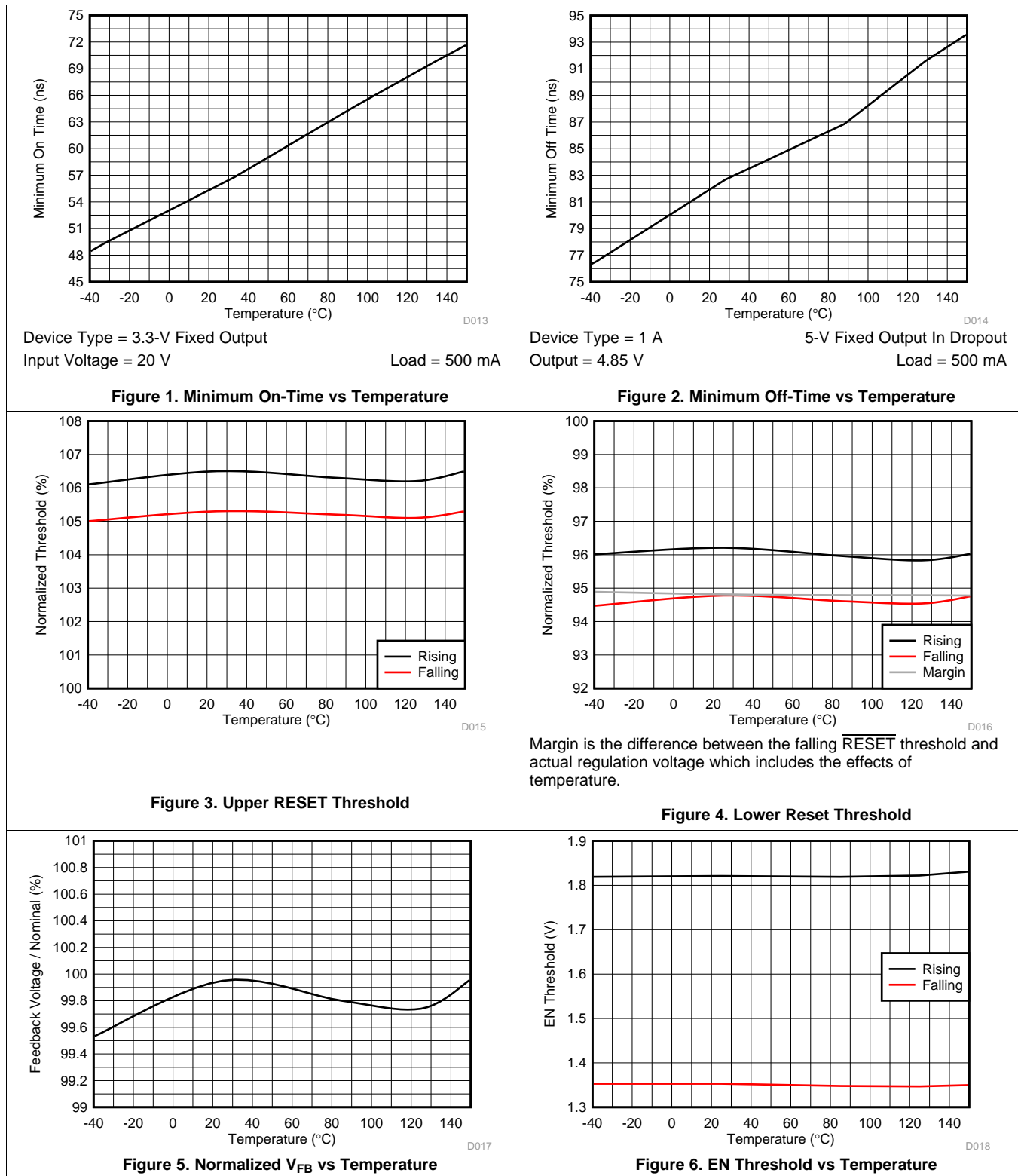
			MIN	NOM	MAX	UNIT
$t_{\text{on}}$	Minimum switch on time <sup>(1)</sup>	$V_{\text{IN}} = 18\text{ V}$ , $I_{\text{OUT}} = 500\text{ mA}$		50	80.5	ns
$t_{\text{off}}$	Minimum switch off time <sup>(1)</sup>	$I_{\text{OUT}} = 500\text{ mA}$		90	125	
$t_{\text{reset\_act}}$	Delay time to $\overline{\text{RESET}}$ high signal		4	6	8	ms
$t_{\text{reset\_filter}}$	Glitch filter time constant for $\overline{\text{RESET}}$ function			24		$\mu\text{s}$
$t_{\text{SS}}$	Soft-start time	Time from first SW node pulse to $V_{\text{ref}}$ at 90%, $V_{\text{IN}} \geq 4.2\text{ V}$	1.3	3	4.5	ms
$t_{\text{EN}}$	Turn-on delay <sup>(2)</sup>	Time from EN high until first SW node pulse. $V_{\text{IN}} = 13.5$ , $C_{\text{vcc}} = 1\text{ }\mu\text{F}$		0.7		ms
$t_{\text{W}}$	Short circuit wait time ( <i>Hiccup</i> time)			4.5		ms

(1) See [Detailed Description](#)

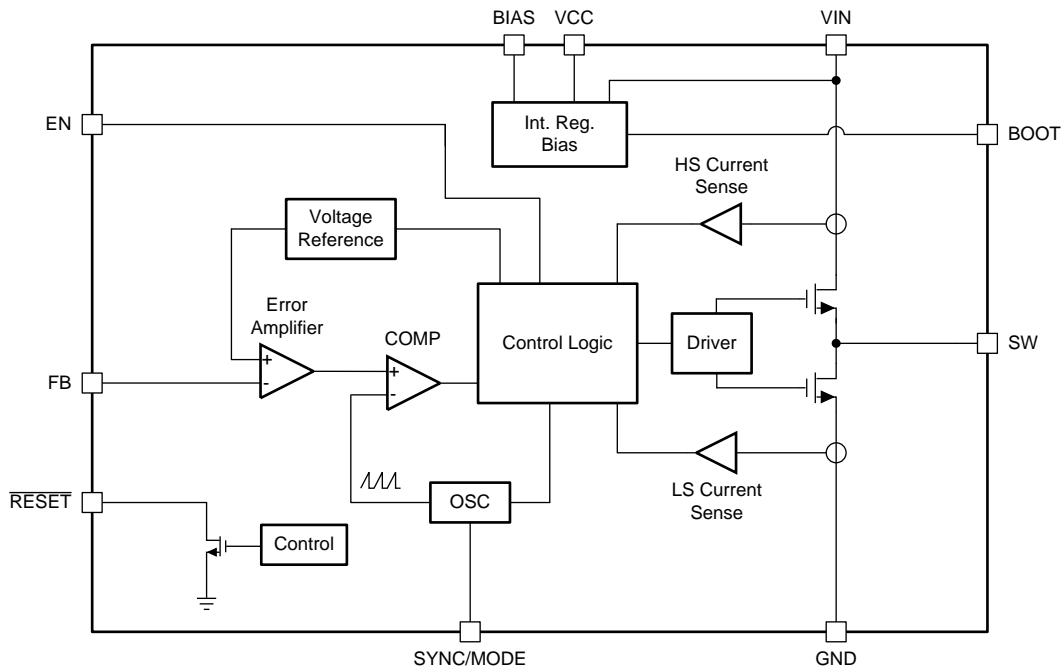
(2) Ensured by design, statistical analysis and production testing of correlated parameters; not tested in production.

## 7.8 Typical Characteristics

$V_{IN} = 13.5\text{ V}$ ,  $T_A = 25^\circ\text{C}$  (unless otherwise noted). Specified temperatures are ambient.





**Functional Block Diagram (continued)**

**Figure 8. Adjustable Versions**
**8.3 Feature Description**
**8.3.1 Control Scheme**

The control scheme of the LM53600-Q1 and LM53601-Q1 devices allows this part to operate under a wide range of conditions with a low number of external components. Peak current mode control allows a wide range of input voltages and output capacitance values, while maintaining a constant switching frequency. Stable operation is maintained while output capacitance is changed during operation as well. This allows use in systems that require high performance during load transients and which have load switches which remove loads as system operating state changes. Short minimum on- and off-times ensure constant frequency regulation over a wide range of conversion ratios. These on- and off- times allow for a duty factor window of 13% to 77% at 2.1-MHz switching frequency.

This architecture uses frequency foldback in order to achieve low dropout voltage maintaining output regulation as the input voltage falls close to output voltage. The frequency foldback is smooth and continuous, and activated as off-time approaches its minimum. Under these conditions, the LM53600-Q1 and LM53601-Q1 devices operate much like a constant off-time converter allowing maximum duty cycle to reach 97%, which allows output voltage regulation with 600-mV dropout.

If input voltage exceeds approximately 21 V, frequency is reduced smoothly as a function of input voltage. This frequency reduction allows output voltage regulation and current mode control to operate with duty factor below 13%. Since current mode control continues at high input voltage insensitivity to output capacitance is maintained. This form of fold back will not be active if input voltage is below 18 V, insuring constant frequency operation over normal automotive operating conditions.

High input voltage foldback has two settings; see  $F_{SW}$  under 36-V input conditions for detail. Since adjustable output voltage versions fold back under high input voltage conditions as though output voltage were 3.3 V, larger inductance and output capacitance is required if an adjustable device is used with output voltage above 4.2 V. If a 4.7- $\mu$ H inductor is used in system with greater 4.2-V output using an adjustable device, the converter remains stable but may not achieve full output current when operating at high input voltages, such as 36 V, due to excessive inductor current ripple.

## Feature Description (continued)

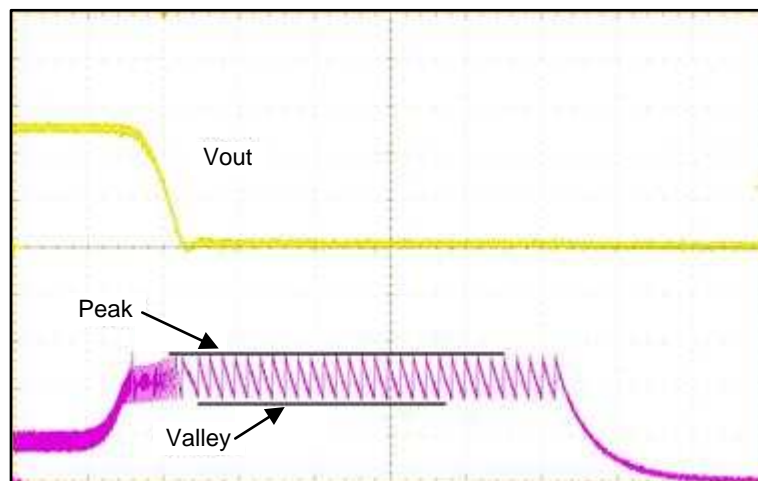
As load current is reduced, the LM53600-Q1 and LM53601-Q1 devices transition to light load mode if SYNC/MODE is low. In this mode, diode emulation is used to reduce RMS inductor current and switching frequency is reduced. Also, fixed voltage versions do not need a voltage divider connected to FB saving additional power. As a result, only 23  $\mu\text{A}$  (typical, while converting 13.5 V to 3.3 V) is consumed to regulate output voltage if output is unloaded. Average output voltage increases slightly while lightly loaded.

### 8.3.2 Soft-Start Function

Soft-start time is fixed internally at about 3.0 ms. Soft-start is achieved by ramping the internal reference. The LM53600-Q1 and LM53601-Q1 devices operate correctly even if there is a voltage present on output before activation of the LM53600-Q1 or LM53601-Q1.

### 8.3.3 Current Limit

The LM53600-Q1 and LM53601-Q1 devices use two current limits which allow the use of smaller inductors than systems utilizing a single current limit. A coarse high side or peak current limit is provided to protect against faults and saturated inductors. High side current limit limits the duration of high sides FET's on period during a given clock cycle. A precision valley current limit prevents excessive average output current from the Buck converter of the LM53600-Q1 and LM53601-Q1 devices. A new switching cycle is not initiated until inductor current drops below the valley current limit. This scheme allows use of inductors with saturation current rated less than twice the rated operating current of the LM53600-Q1 or LM53601-Q1.



**Figure 9. Current Limit Operation**

Figure 9 shows the response of the LM53600-Q1 or LM53601-Q1 device to a short circuit: Peak current limit prevents excessive peak current while valley current limit prevents excessive average inductor current. After a small number of cycles, hiccup mode is activated.

### 8.3.4 Hiccup Mode

In order to prevent excessive heating and power consumption under sustained short circuit conditions, a hiccup mode is included. If an over current condition is maintained, the LM53600-Q1 or LM53601-Q1 device shuts off its output and waits for  $t_{\text{W}}$  (approximately 4.5 ms), after which the LM53600-Q1 or LM53601-Q1 restarts operation beginning by activating soft start.

Feature Description (continued)

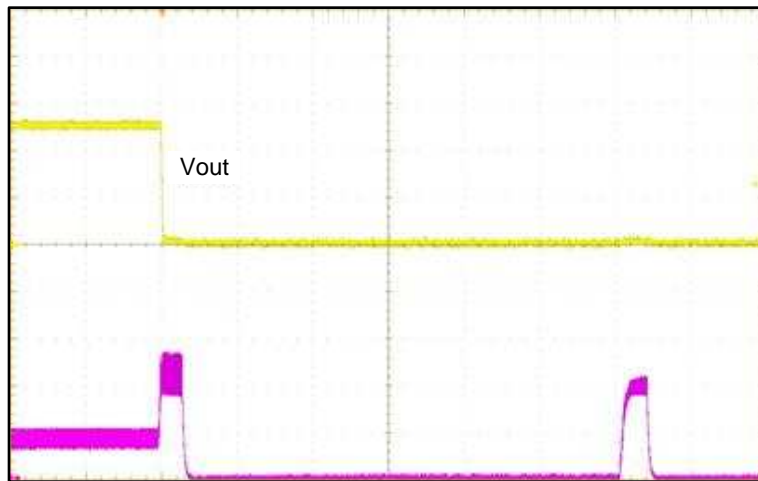


Figure 10. Hiccup Operation

Figure 10 shows hiccup mode operation: The switch node of the LM53600-Q1 LM53601-Q1 is high impedance after a short circuit or over current persists for a short duration. Periodically, the LM53600-Q1 or LM53601-Q1 attempts to restart. If the short has been removed before one of these restart attempts, the LM53600-Q1 or LM53601-Q1 operates normally.

8.3.5 RESET Function

While the reset function of the LM53600-Q1 and LM53601-Q1 devices resembles a standard power good function, its functionality is designed to replace a discrete reset IC, reducing BOM cost. There are three major differences between the reset function and the normal power good function seen in most regulators:

- A delay has been added for release of reset. See waveforms below.
- RESET output signals a fault (pulls its output to ground) while the part is disabled.
- RESET continues to operate with input voltage as low as 1.5 V. Below this input voltage, RESET output may be high impedance.

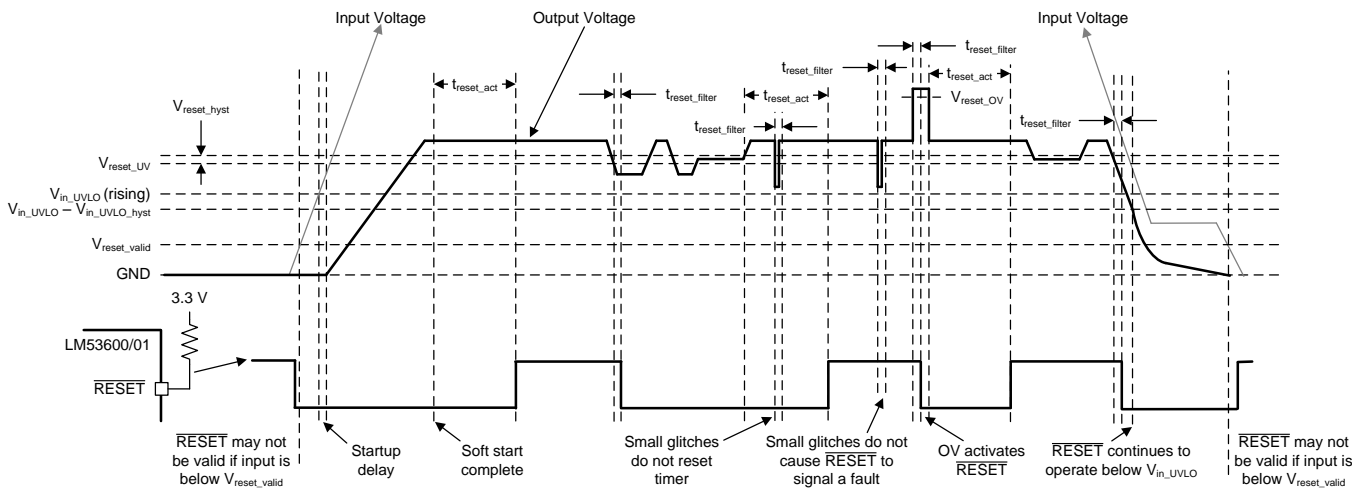


Figure 11. Reset Output Function Operation

The following table summarizes conditions that cause a fault to be flagged by RESET. Once a fault is flagged, RESET will not be released (become high impedance) until either there is no fault for  $t_{reset\_act}$  or VIN drops below  $V_{reset\_valid}$ .

## Feature Description (continued)

Table showing conditions that cause  $\overline{\text{RESET}}$  to signal a fault (pull low).

FAULT CONDITION INITIATED	FAULT CONDITION ENDS (AFTER WHICH $T_{\text{reset\_act}}$ MUST PASS BEFORE $\overline{\text{RESET}}$ OUTPUT IS RELEASED)
FB below $V_{\text{reset\_UV}}$ for longer than $t_{\text{reset\_filt}}$	FB above $V_{\text{reset\_UV}} + V_{\text{reset\_hyst}}$ for longer than $t_{\text{reset\_filt}}$
FB above $V_{\text{reset\_OV}}$ for longer than $t_{\text{reset\_filt}}$	FB below $V_{\text{reset\_OV}} - V_{\text{reset\_hyst}}$ for longer than $t_{\text{reset\_filt}}$
Junction temperature exceeds $T_{\text{SD}}$	Junction temperature falls below $T_{\text{SD}} - T_{\text{SD\_hyst}}$
EN low	$t_{\text{EN}}$ passes after EN becomes high <sup>(1)</sup>
VIN falls below $V_{\text{in\_UVLO}} - V_{\text{in\_UVLO\_hyst}}$ or VCC pin falls below $V_{\text{cc\_UVLO}} - V_{\text{cc\_UVLO\_hyst}}$	Voltage on $V_{\text{IN}}$ exceeds $V_{\text{in\_UVLO}}$ and VCC exceed $V_{\text{cc\_UVLO}}$

(1) As an additional safety feature,  $\overline{\text{RESET}}$  remains low until approximately 1ms after soft start ends even if all other conditions in this table are met and  $t_{\text{reset\_act}}$  has passed. Lockout during soft start does not require  $t_{\text{reset\_act}}$  to pass before  $\overline{\text{RESET}}$  is released.

The threshold voltage for the  $\overline{\text{RESET}}$  function is specified taking advantage of the availability of the LM53600-Q1 internal feedback threshold to the  $\overline{\text{RESET}}$  circuit. This allows a maximum threshold of 97% of selected output voltage to be specified at the same time as 95.7% of actual operating point. The net result is a more accurate reset function while expanding the system allowance for transient response without the need for extremely accurate internal circuitry. See output voltage error stack up comparison, below.

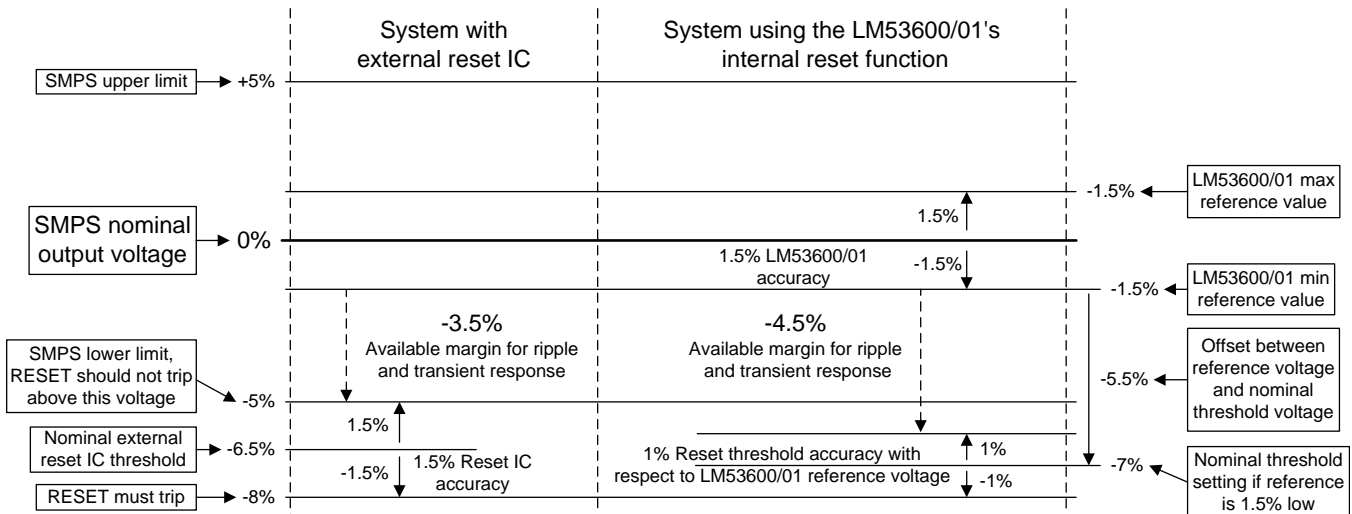


Figure 12. Reset Threshold Voltage Stack Up

### 8.3.6 Forced PWM Operation

When constant frequency operation is more important than light load efficiency, the SYNC/MODE input of the LM53600-Q1 and LM53601-Q1 devices should be pulled high, or a valid synchronization input be provided. Once activated, this feature ensures that the switching frequency will stay above the AM frequency band, while operating between the minimum and maximum duty cycle limits. Essentially, the diode emulation feature is turned off in this mode. This means that the device will remain in CCM under light loads. Under conditions where the device must reduce the on-time or off-time below the ensured minimum to maintain regulation, the frequency will reduce to maintain the effective duty cycle required for regulation. This occurs for very high and very low input/output voltage ratios.

This feature may be activated and deactivated while the part is regulating without removing the load. This feature activates and deactivates gradually, over approximately 40  $\mu\text{s}$ , preventing perturbation of output voltage. When in FPWM mode, a limited reverse current is allowed through the inductor allowing power to pass from the regulators output to its input.

Note that while FPWM is activated, larger currents pass through the inductor, if lightly loaded, than in *auto* mode. This may result in more EMI, though at a predictable frequency. Once loads are heavy enough to necessitate CCM operation, FPWM mode has no measurable effect on regulator operation.



### 8.3.7 Auto Mode Operation and $I_{Q\_VIN}$

If SYNC/MODE is held low for a period greater than a few microseconds, the LM53600-Q1 and LM53601-Q1 devices will enable automatic power saving light load operation and diode emulation. In this mode, if peak current needed to regulate output voltage drops below a selected value, the clock of the LM53600-Q1 or LM53601-Q1 device slows to maintain regulation. The gain of this clock slowing circuit is low to maintain stability. Output voltage with no load is approximately 1% higher than with a load high enough to allow full frequency operation.

$I_{Q\_VIN}$  is the current consumed by a converter utilizing a LM53600-Q1 or LM53601-Q1 device while regulating without a load. While operating without a load, the LM53600-Q1 or LM53601-Q1 is only powering itself. The LM53600-Q1 and LM53601-Q1 device draws power from two sources, its VIN pin,  $I_Q$ , and either its FB pin for fixed versions or BIAS pin for adjustable versions,  $I_B$ . Since BIAS or FB is connected to the circuit's output, the power consumed is converted from input power with an effective efficiency,  $\eta_{eff}$ , of ~80%. Here, effective efficiency is the added input power needed when lightly loading the converter of the LM53600-Q1 and LM53601-Q1 devices is divided by the corresponding additional load. This allows unloaded current to be calculated as follows:

$$I_{Q\_VIN} = I_Q + I_{EN} + (I_B + I_{div}) \frac{\text{Output Voltage}}{\eta_{eff} \times \text{Input Voltage}}$$

where

- $I_{Q\_VIN}$  is the current consumed by the Buck converter utilizing the LM53600-Q1 or LM53601-Q1 while unloaded.
- $I_Q$  is the current drawn by the LM53600-Q1 or LM53601-Q1 from its VIN terminal. See  $I_Q$  in section 7.6.
- $I_{EN}$  is current drawn by the LM53600-Q1 or LM53601-Q1 from its EN terminal. Include this current if EN is connected to VIN. See  $I_{EN}$  in section 7.6. Note that this current drops to a very low value if connected to a voltage less than 5 V.
- $I_B$  is bias/feedback current drawn by the LM53600-Q1 or LM53601-Q1 while the Buck converter utilizing it is unloaded. See  $I_B$  in section 7.6.
- $I_{div}$  is the current drawn by the feedback voltage divider used to set output voltage for adjustable devices. This current is zero for fixed output voltage devices.
- $\eta_{eff}$  is the light load efficiency of the Buck converter with  $I_{Q\_VIN}$  removed from the Buck converter's input current. 0.8 is a conservative value that can be used under normal operating conditions (1)

Note that the EN pin consumes a few microamperes when tied to high; see  $I_{EN}$ . Add  $I_{EN}$  to  $I_Q$  as shown in the above equation if EN is tied to  $V_{IN}$ . If EN is tied to a voltage less than 5 V, virtually no current is consumed allowing EN to be used as a UVL once a voltage divider is added.

### 8.3.8 SYNC Operation

Often it is desirable to synchronize the operation of multiple regulators in a single system. This technique results in better defined EMI and can reduce the need for capacitance on some power rails. The LM53600-Q1 and LM53601-Q1 devices provide a SYNC/MODE input, which allows synchronization with an external clock. The LM53600-Q1/LM53601-Q1 implements an in-phase locking scheme – the rising edge of the clock signal provided to the input of the LM53600-Q1 or LM53601-Q1 device corresponds to turning on the high side device within the LM53600-Q1 or LM53601-Q1. This function is implemented using phase locking over a limited frequency range eliminating large glitches upon initial application of an external clock. The clock fed into the LM53600-Q1 or LM53601-Q1 device replaces the internal free running clock but does not affect frequency fold-back operation. Output voltage will continue to be well regulated with duty factors outside of the normal 15% through 77% range though at reduced frequency.

The device remains in FPWM mode and operates in CCM for light loads when synchronization input is provided.

### 8.3.9 Spread Spectrum

The spread spectrum is a factory option. In order to find which parts have spread spectrum enabled, see [Device Comparison](#).

The purpose of the spread spectrum is to eliminate peak emissions at specific frequencies by spreading emissions across a wider range of frequencies than a part with fixed frequency operation. In most systems containing the LM53600-Q1 and LM53601-Q1 devices, low frequency conducted emissions from the first few harmonics of the switching frequency can be easily filtered. A more difficult design criterion is reduction of emissions at higher harmonics which fall in the FM band. These harmonics often couple to the environment through electric fields around the switch node. The LM53600-Q1 and LM53601-Q1 devices use a  $\pm 4\%$  spread of frequencies which spread energy smoothly across the FM band but is small enough to limit sub-harmonic emissions below its switching frequency. Peak emissions at the part's switching frequency are only reduced by slightly less than 1 dB, while peaks in the FM band are typically reduced by more than 6dB.

The LM53600-Q1 and LM53601-Q1 devices use a cycle to cycle frequency hopping method based on a linear feedback shift register (LFSR). Intelligent pseudo random generator limits cycle to cycle frequency changes to limit output ripple. Pseudo random pattern repeats by approximately 7 Hz which is below the audio band.

The spread spectrum is only available while the clock of the LM53600-Q1 and LM53601-Q1 devices is free running at its natural frequency. Any of the following conditions overrides spread spectrum, turning it off:

1. An external clock is applied to the SYNC/MODE terminal.
2. The clock is slowed due to operation low input voltage – this is operation in dropout.
3. The clock is slowed due to high input voltage – input voltage above approximately 21 V disables spread spectrum.
4. The clock is slowed under light load in Auto mode – this is normally not seen above 200 mA of load. In FPWM mode, spread spectrum is active even if there is no load.

## 8.4 Device Functional Modes

### 8.4.1 Shutdown

The LM53600-Q1 and LM53601-Q1 devices shut down most internal circuitry and both high side and low side power switches connected to its switch node under any of the following conditions:

1. EN is below  $V_{EN}$
2. VIN is below  $V_{in\_UVLO}$
3. Junction temperature exceeds  $T_{SD}$

Note that the above conditions have hysteresis. Also,  $\overline{RESET}$  remains active to a very low input voltage,  $V_{reset\_valid}$ .

### 8.4.2 FPWM Operation

If SYNC/MODE is above  $V_{SYNC/MODE}$  high or a valid synchronizing is applied to SYNC/MODE, constant frequency operation is maintained across load. This requires negative current be allowed in the inductor if load is light. If a large negative load is present, operation is halted by a reverse current limit,  $I_{L-NEG}$ .

### 8.4.3 Auto Mode Operation

If SYNC/MODE is below  $V_{SYNC/MODE}$  low, reverse current in the inductor is not allowed – this feature is called diode emulation. While load is heavy, operation is the same as in FPWM operation. If load is light, switching frequency is reduced saving energy and allowing regulation to be maintained. Note that while under loads which require moderate reduction of frequency, pulses often are seen if small groups, often called burst mode operation, which can increase output ripple. Under this condition, output ripple can be reduced by increasing output capacitance.

## 9 Applications and Implementation

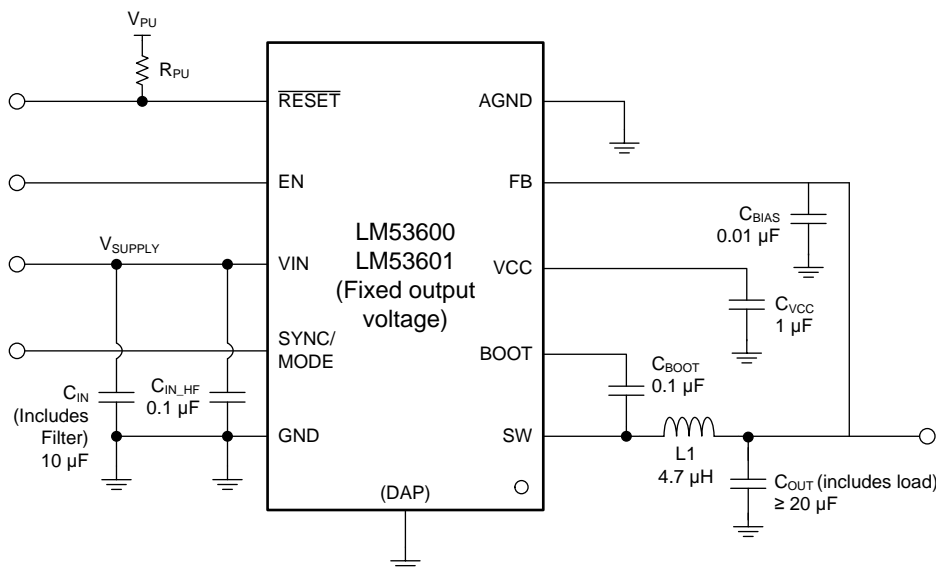
### NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 9.1 Application Information

The LM53600-Q1 and LM53601-Q1 are step-down DC–DC converters, typically used to convert a higher DC voltage to a lower DC voltage with a maximum output current of either 1 A or 650 mA. The following design procedure can be used to select components for the LM53600-Q1 or LM53601-Q1. Alternately, the WEBENCH® Design Tool may be used to generate a complete design. This tool utilizes an iterative design procedure and has access to a comprehensive database of components. This allows the tool to create an optimized design and allows the user to experiment with various design options.

Figure 13 shows the minimum required application circuit for the fixed output voltage versions, while Figure 14 shows the connections for complete processor control of the LM53601-Q1. Please refer to these figures while following the design procedures. Table 2 provides an example of typical design requirements.



**Figure 13. Off Battery, Automotive, Fixed Output Voltage, Buck, 2.1 MHz, Spread Spectrum**

Application Information (continued)

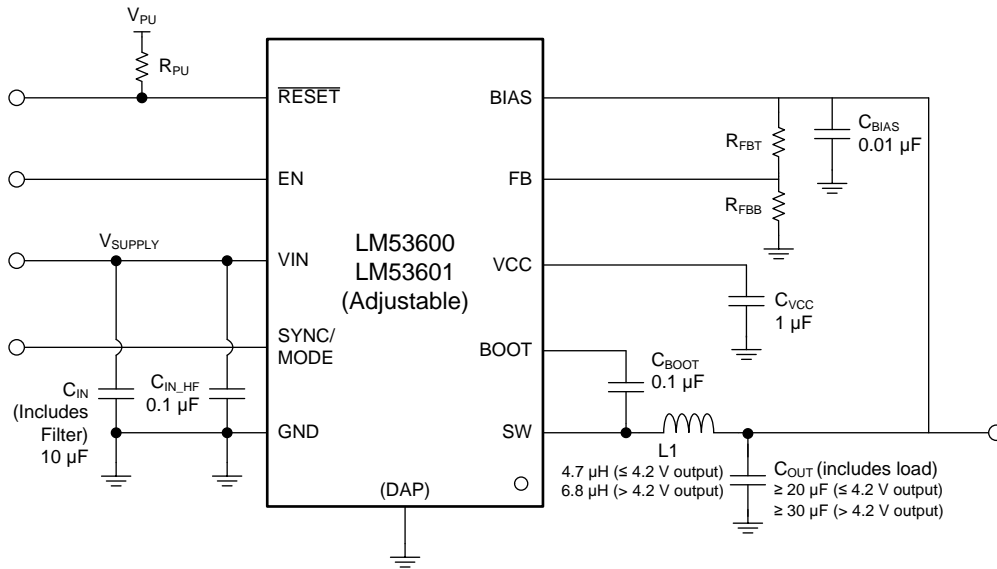


Figure 14. Off Battery, Automotive, Adjustable Output Voltage, Buck, 2.1 MHz, Spread Spectrum

9.2 Typical Applications

9.2.1 Off-Battery 5-V, 1-A Output Automotive Converter with Spread Spectrum

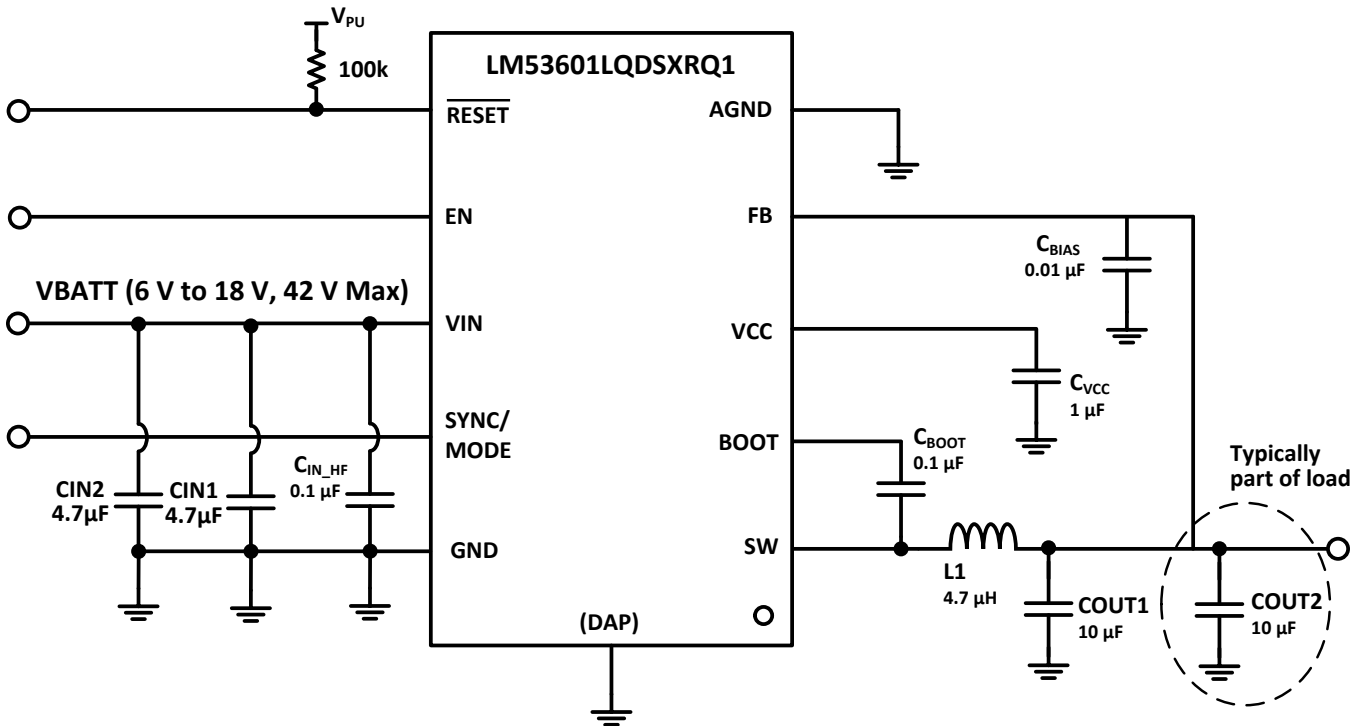


Figure 15. Typical LM53601LQDSXRQ1 Application Schematic

## Typical Applications (continued)

### 9.2.1.1 Design Requirements

For this design example, use the parameters listed in [Table 1](#) as the input parameters.

**Table 1. Design Parameters**

DESIGN PARAMETER	VALUE	COMMENT
Input voltage range	6 V to 18 V with excursions to 42 V	This converter will run continuously up to 36 V
Output voltage	5 V	Fixed option used
Output current range	No Load to 1 A	
Light load mode	Switchable	
Spread spectrum	Enabled	Factory option

### 9.2.1.2 Detailed Design Procedure

#### 9.2.1.2.1 Inductor Selection

The LM53600-Q1 and LM53601-Q1 devices run in current mode and has internal compensation. This compensation is stable with inductance between 4  $\mu\text{H}$  and 10  $\mu\text{H}$ . For most applications, 4.7  $\mu\text{H}$  should be used with fixed 5-V and 3.3-V versions of the LM53600-Q1 and LM53601-Q1 devices. The output inductor is limited by current ripple while operating at high input voltage to a minimum rating of 4.7  $\mu\text{H}$  for 3.3 V and 5-V fixed output devices. Since adjustable devices operate at the same frequency under high input voltage conditions as devices set to deliver 3.3 V, inductor current ripple at high input voltages can become excessive while using a 4.7  $\mu\text{H}$  while using an adjustable device that is delivering output voltage above 4.2 V. 6.8  $\mu\text{H}$  is recommended if an adjustable device is used to produce output voltage above 4.2 V. Not exceeding 6.8  $\mu\text{H}$  is recommended since use of large inductance causes poor transient load response. For the LM53601-Q1 (1-A output), a saturation rating of about 2 A is recommended since this is the maximum current limit rating. Likewise, a saturation current rating of about 1.5 A is recommended for the LM53600-Q1. See  $I_{L\_HS}$  in the data sheet.

**Table 2. Output Inductor**

PART TYPE	RECOMMENDED INDUCTANCE RATING <sup>(1)</sup>	RECOMMENDED MINIMUM SATURATION CURRENT <sup>(2)</sup>	COMMENT
LM53601-Q1 3.3 V and 5 V	4.7 $\mu\text{H}$	about 2 A	6.8 $\mu\text{H}$ works in systems with less demanding transient load requirements
LM53601-Q1 ADJ set to $\leq$ 4.2-V output	4.7 $\mu\text{H}$	about 2 A	
LM53601-Q1 ADJ set to $>$ 4.2-V output	6.8 $\mu\text{H}$	about 2 A	
LM53600-Q1 3.3 V and 5 V	4.7 $\mu\text{H}$	about 1.5 A	Up to 10 $\mu\text{H}$ works in systems with less demanding transient load requirements
LM53600-Q1 ADJ set to $\leq$ 4.2-V output	4.7 $\mu\text{H}$	about 1.5 A	
LM53600-Q1 ADJ set to $>$ 4.2-V output	6.8 $\mu\text{H}$	about 1.5 A	

(1) The values shown in this table are standard inductance ratings. The LM53600-Q1/LM53601-Q1 tolerates reduced inductance due to DC current and temperature.

(2) The LM53600-Q1/LM53601-Q1 tolerates partial saturation of inductors (reduction of ~40% reduction of inductance of the current value listed due to saturation. Partial saturation may reduce maximum current available at maximum voltage).

### 9.2.1.2.2 Output Capacitor Selection

The current mode control scheme of the LM53600-Q1 and LM53601-Q1 devices allows operation over a wide range of output capacitance. A minimum of 10  $\mu\text{F}$  is needed to ensure stability. Capacitance above 20  $\mu\text{F}$  is recommended to ensure load transient response typically desired in systems. 40  $\mu\text{F}$  is recommended for applications with demanding load transient requirements and for which Auto mode ripple is important. 40  $\mu\text{F}$  also aids devices with output voltage below 4-V transition into high voltage mode. Capacitance above 400  $\mu\text{F}$  can cause excessive current to be drawn during start up so is not recommended. These capacitance values include load capacitance – only 10  $\mu\text{F}$  is needed near to the LM53600-Q1 and LM53601-Q1 devices. Output capacitors should have low ESR to reduce output ripple. These capacitors should have at least X7R rating and should be of automotive grade if used in automotive applications.

**Table 3. Output Capacitor**

LM53600-Q1 AND LM53601-Q1 TYPE AND SYSTEM NEED	RECOMMENDED MINIMUM TOTAL OUTPUT CAPACITANCE	COMMENTS
LM53600-Q1 5 V	20 $\mu\text{F}$	Approximately 200-mV/A step load response with 1- $\mu\text{s}$ rise/fall time.
LM53601-Q1 5 V with typical system requirements	20 $\mu\text{F}$	Approximately 200-mV/A step load response with 1- $\mu\text{s}$ rise/fall time.
LM53601-Q1 5V in high performance systems	40 $\mu\text{F}$	Approximately 150-mV/A step load, approximately 20-mV maximum Auto mode ripple
LM53600-Q1/LM53601-Q1 3.3 V and adjustable parts with less than 4.2-V output setting with typical system requirements	20 $\mu\text{F}$	Approximately 200-mV/A step load response with 1 $\mu\text{s}$ rise/fall time, up to 60 mV of ripple during transition into high voltage mode and in Auto mode.
LM53600-Q1/LM53601-Q1 3.3 V and adjustable parts with less than 4.2 V in high performance systems	40 $\mu\text{F}$	Approximately 150-mV/A step load, approximately 30-mV maximum Auto mode ripple, and 15-mV maximum HV mode transition ripple.
LM53600-Q1 ADJ set to greater than 4.2-V output	40 $\mu\text{F}$	Larger capacitance is necessitated by higher inductance needed.

### 9.2.1.2.3 Input Capacitor Selection

Input capacitors serve two important functions: The first is to reduce input voltage ripple into the LM53601-Q1 and the input filter of the system. The second is to reduce high frequency noise. These two functions are implemented most effectively with separate capacitors, see [Table 4](#).

**Table 4. Input Capacitor**

CAPACITOR	RECOMMENDED VALUE	COMMENT
$C_{\text{IN\_HF}}$	0.1 $\mu\text{F}$	This capacitor is used to suppress high frequency noise originating during switching events. It is important to place capacitor as close to the LM53600-Q1 and LM53601-Q1 devices as design rules allow. Position is more important than exact capacity. Once high frequency propagates into a system, it can be hard to suppress or filter. Since this capacitor will be exposed to battery voltage in systems that operate directly off of battery, 50 V or greater rating is recommended.
$C_{\text{IN}}$	10 $\mu\text{F}$	This capacitance is used to suppress input ripple and transients due to output load transients. If CIN is too small, input voltage may dip during load transients resetting the system if the system is operated under low voltage conditions. 10 $\mu\text{F}$ is intended to include all capacitance in the LM53600-Q1/LM53601-Q1's input node. 4.7 $\mu\text{F}$ adjacent to the LM53600-Q1 and LM53601-Q1 devices is recommended. Since this capacitor will be exposed to battery voltage in systems that operate directly off of battery, 50 V or greater rating is recommended.

Table 5 shows recommended capacitor values other than input and output capacitors.

**Table 5. Other Capacitors**

CAPACITOR	MINIMUM VALUE	COMMENT
C <sub>BOOT</sub>	0.1 μF	While a voltage rating of only 5 V is necessary, using a higher voltage rating is recommended.
C <sub>VCC</sub>	1 μF	While a voltage rating of only 5 V is necessary, 16-V capacitors have a low voltage coefficient.
C <sub>BIAS</sub>	0.01 μF	This capacitor should be rated to survive output voltage.

Note that performance of converters utilizing an adjustable version of the LM53600-Q1 and LM53601-Q1 devices may be enhanced by adding C<sub>FF</sub>, a capacitor in parallel with R<sub>FBT</sub>. 100 pF is recommended.

#### 9.2.1.2.4 FB Voltage Divider for Adjustable Versions

The adjustable version of the LM53600-Q1 and LM53601-Q1 devices regulates output voltage to a level that results in the FB node being V<sub>ref</sub> which is approximately 1.0 V; see [Electrical Characteristics](#) Output voltage given a specific feedback divider can be calculated using the following equation:-

$$\text{Output Voltage} = V_{\text{ref}} \times \frac{R_{\text{FBB}} + R_{\text{FBT}}}{R_{\text{FBB}}} \quad (2)$$

See typical applications schematic for adjustable versions of the LM53600-Q1 and LM53601-Q1 devices. Since the value of R<sub>FBT</sub> is typically set by board leakage considerations, the above equation can be solved for R<sub>FBB</sub>, the remaining unknown:

$$R_{\text{FBB}} = \frac{V_{\text{ref}} \times R_{\text{FBT}}}{\text{Output Voltage} - V_{\text{ref}}} \quad (3)$$

Note that typically, 100 kΩ is used for R<sub>FBT</sub>.

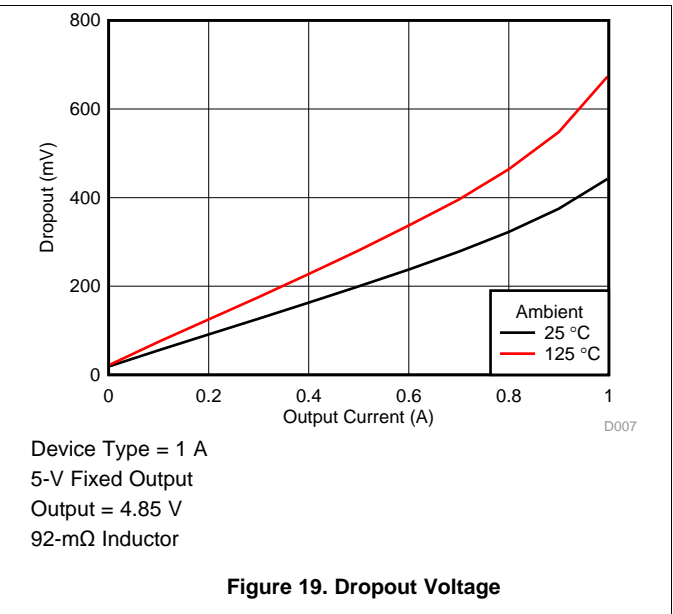
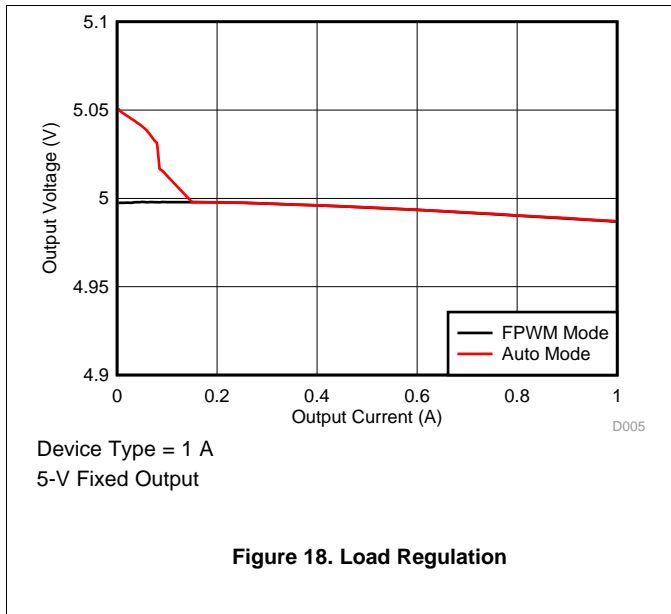
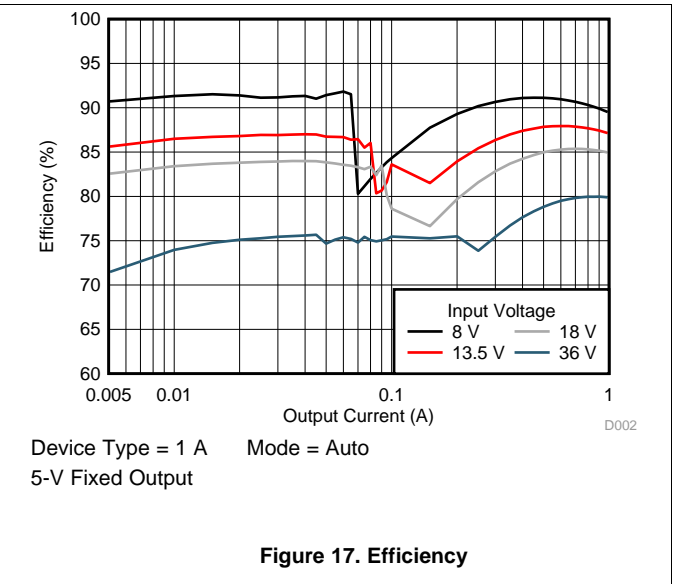
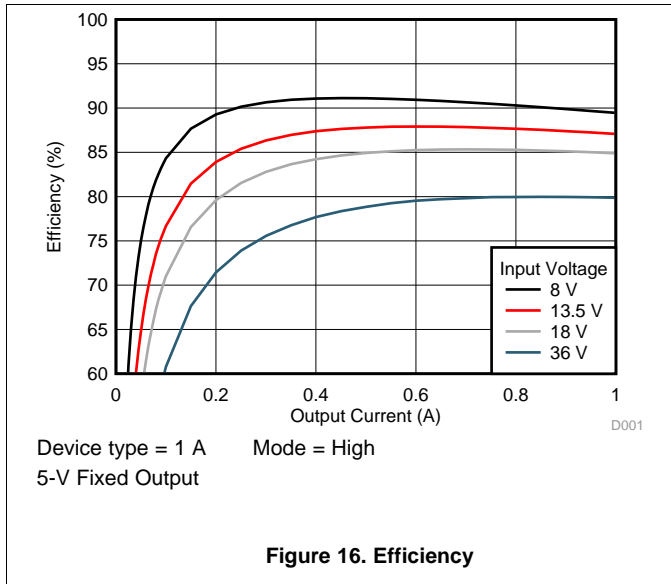
#### 9.2.1.2.5 R<sub>PU</sub> - RESET Pull Up Resistor

While RESET is rated to sink up to 8 mA, under low, 1.5-V input voltage conditions, a low output level is only ensured with loads of 50 μA. If accurate RESET output is needed with 1.5-V input voltage, 100 kΩ should be used to pull up to 5 V, or a 66-kΩ resistor should be used when pulling up to a 3.3-V supply. If input voltage is above 3.8 V, values as low as 10 kΩ or 6.6 kΩ can be used to pull up to 5 V or 3.3 V, respectively. Other considerations, such as power consumption may increase any of the values listed above.

#### 9.2.1.3 Application Curves

The following characteristics apply only to the circuit shown in [Figure 15](#). *These parameters are not tested and represent typical performance only.* Unless otherwise stated, the following conditions apply: V<sub>IN</sub> = 13.5 V, T<sub>A</sub> = 25°C.

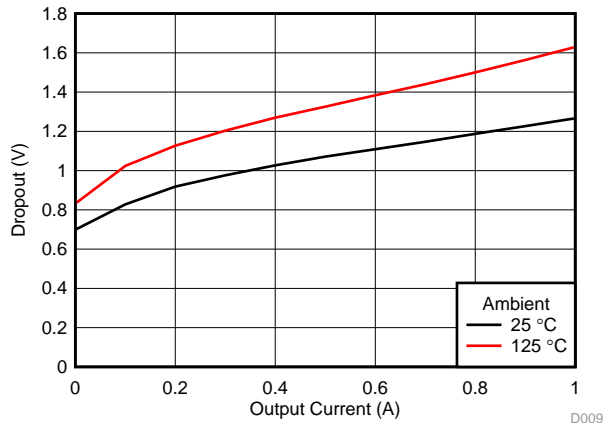




LM53600-Q1, LM53601-Q1

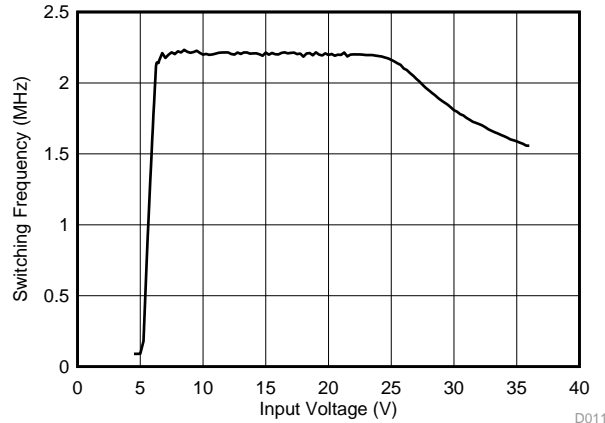
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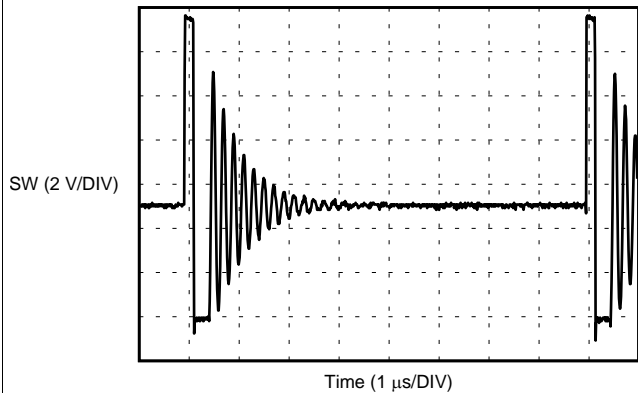
Device Type = 1 A  
5-V Fixed Output  
Frequency drops to 1.85MHz  
92-mΩ inductor

Figure 20. Entry into Dropout



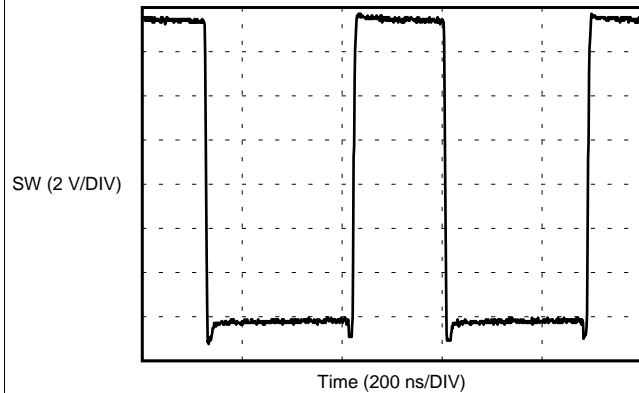
Device Type = 1 A  
5-V Fixed Output  
Spread Spectrum  
Load = 500 mA

Figure 21. Frequency vs. Input Voltage



Device Type = 1 A  
5-V Fixed Output  
Mode = Auto  
Load = 10 mA

Figure 22. SW Node Operation



Device Type = 1 A  
5-V Fixed Output  
Mode = Auto  
Load = 500 mA

Figure 23. SW Node Operation

## 9.2.2 Off-Battery 3.3 V, 1 A Output Automotive Converter with Spread Spectrum

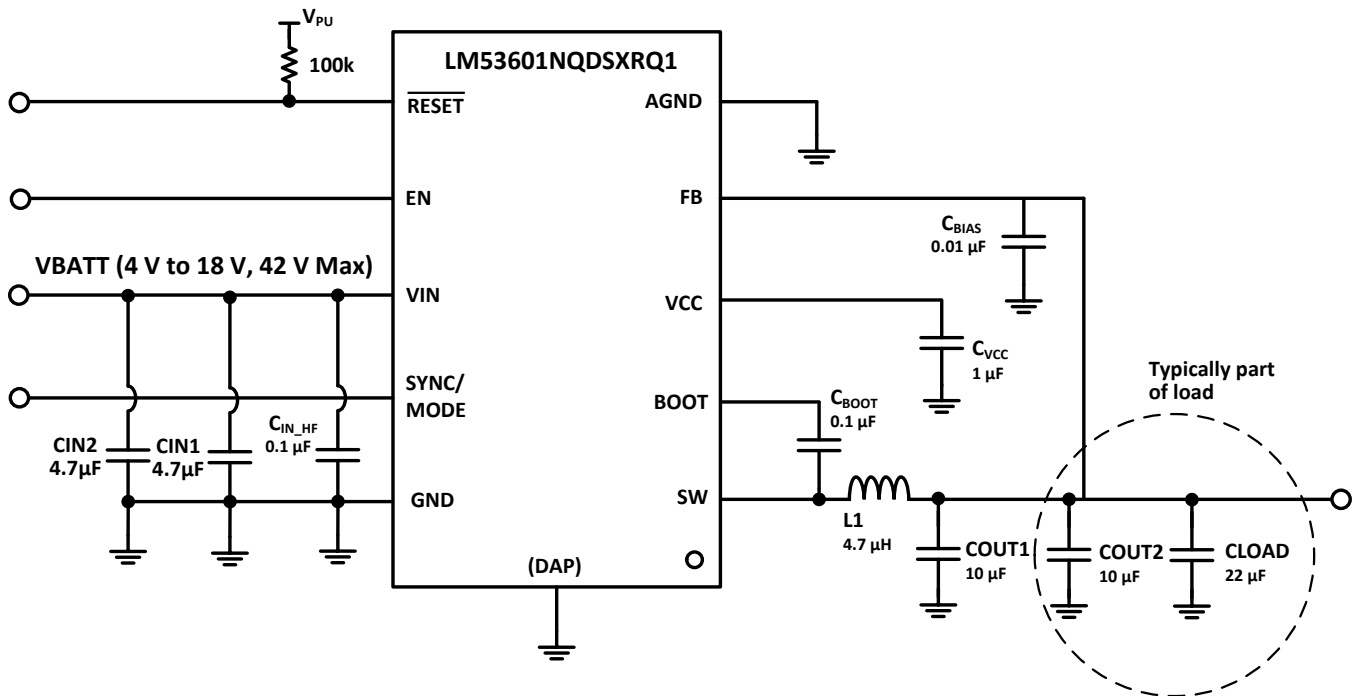


Figure 24. Typical LM53601NQDSXRQ1 Application Schematic

### 9.2.2.1 Design Requirements

For this design example, use the parameters in [Table 6](#) as the input parameters.

Table 6. Design Parameters

DESIGN PARAMETER	VALUE	COMMENT
Input voltage range	4 V to 18 V with excursions to 42 V	This converter will run continuously up to 36 V
Output voltage	3.3 V	Fixed option used
Output current range	No load to 1 A	
Light load mode	Switchable	
Spread spectrum	Enabled	Factory option

### 9.2.2.2 Design Procedure

The same detailed design procedure as shown starting in section 7.1.2.1 is used to create the schematic for this example. The most important difference is that the LM53601NQDSXRQ1 is used in place of the LM53601LQDSXRQ1. In addition, more output capacitance is recommended for this option. Most output capacitance will be part of the load and be used as input bypassing for the load.

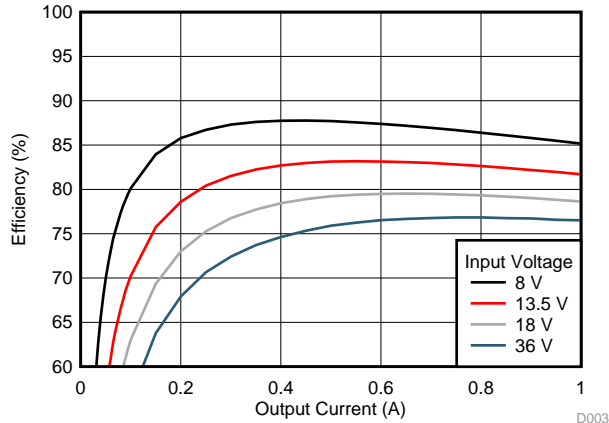
### 9.2.2.3 Application Curves

The following characteristics apply only to the circuit shown in [Figure 24](#). These parameters are not tested and represent typical performance only. Unless otherwise stated, the following conditions apply:  $V_{IN} = 13.5$  V,  $T_A = 25^\circ\text{C}$ .

LM53600-Q1, LM53601-Q1

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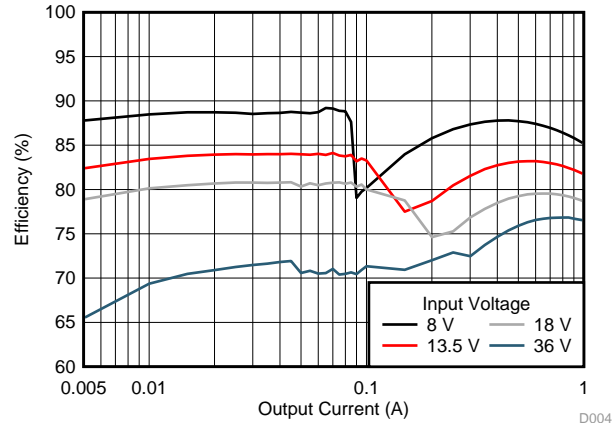
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Device Type = 1 A Mode = FPWM  
3.3-V Fixed Output

D003

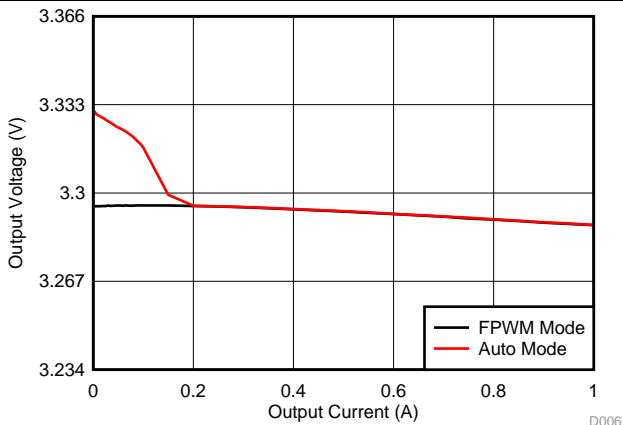
Figure 25. Efficiency



Device Type = 1 A Mode = Auto  
3.3-V Fixed Output

D004

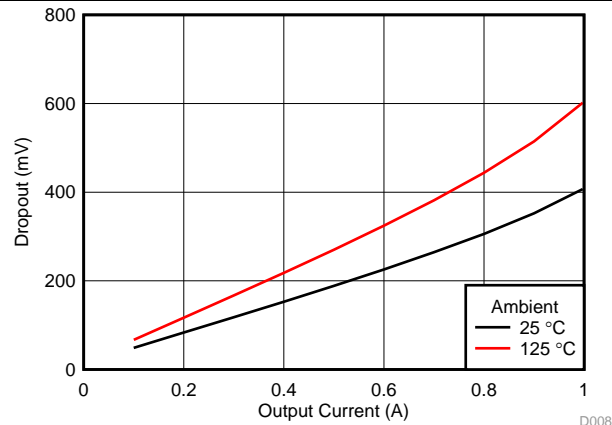
Figure 26. Efficiency



Device Type = 1 A  
3.3-V Fixed Output

D006

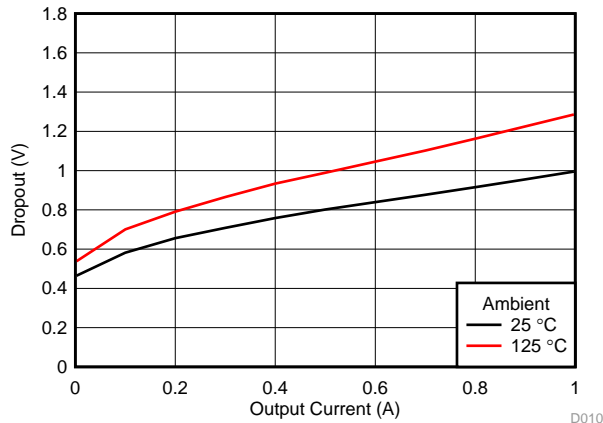
Figure 27. Load Regulation



Device Type = 1 A  
3.3-V Fixed Output  
Output = 3.2 V  
92-mΩ Inductor

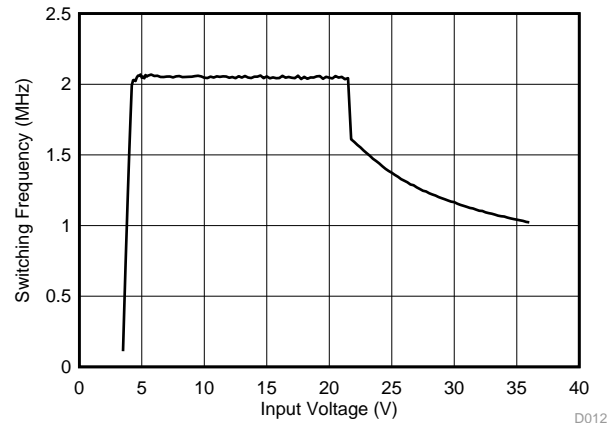
D008

Figure 28. Dropout Voltage



Device Type = 1 A  
3.3-V Fixed Output  
Frequency Drops to 1.85 MHz  
92-mΩ Inductor

**Figure 29. Entry into Dropout**



Device Type = 1 A  
3.3-V Fixed Output  
Spread Spectrum  
Load = 500 mA

**Figure 30. Frequency vs. Input Voltage**

### 9.3 Do's and Don't's

- Don't: Exceed the [Absolute Maximum Ratings](#).
- Don't: Exceed the [ESD Ratings](#).
- Don't: Exceed the [Recommended Operating Conditions](#).
- Don't: Allow the EN, FPWM or SYNC input to float.
- Don't: Allow the output voltage to exceed the input voltage, nor go below ground.
- Don't: Use the thermal data given in the Thermal Information table to design your application.
- Do: Follow all of the guidelines and/or suggestions found in this data sheet, before committing your design to production. TI Application Engineers are ready to help critique your design and PCB layout to help make your project a success.
- Do: Refer to the helpful documents found in [Table 7](#) and [Table 8](#).

## 10 Power Supply Recommendations

The LM53600-Q1 and LM53601-Q1 devices are designed for automotive direct off battery applications needing minimal protection. Protection recommended includes reverse battery protection and EMI/ESD filtering. The LM53600-Q1 and LM53601-Q1 devices are able to continue regulating during load dump with peak voltage less than 42 V, double battery (jump start) conditions down to input voltage as low as  $V_{\text{DROP}}$  above the selected output voltage. In addition, the LM53600-Q1 and LM53601-Q1 devices continue to operate though may be out of regulation with input voltage as low as 3.8 V. This allows the LM53600-Q1 and LM53601-Q1 devices to operate through cranking in all but the most demanding systems.

If the regulator is connected to the input supply through long wires or PCB traces, special care is required to achieve good performance. The parasitic inductance and resistance of the input cables can have an adverse effect on the operation of the regulator. The parasitic inductance, in combination with the low ESR ceramic input capacitors, can form an under-damped resonant circuit. This circuit may cause over-voltage transients at the VIN pin, each time the input supply is cycled on and off. The parasitic resistance will cause the voltage at the VIN pin to dip when the load on the regulator is switched on, or exhibits a transient. If the regulator is operating close to the minimum input voltage, this dip may cause the device to shutdown and/or reset. The best way to solve these kinds of issues is to reduce the distance from the input supply to the regulator and/or use an aluminum or tantalum input capacitor in parallel with the ceramics. The moderate ESR of these types of capacitors will help to damp the input resonant circuit and reduce any voltage overshoots. A value in the range of 20  $\mu\text{F}$  to 100  $\mu\text{F}$  is usually sufficient to provide input damping and help to hold the input voltage steady during large load transients.

Sometimes, for other system considerations, an input filter is used in front of the regulator. This can lead to instability, as well as some of the effects mentioned above, unless it is designed carefully. The *Simple Success with Conducted EMI for DC–DC Converters* User's Guide ([SNVA489](#)) provides helpful suggestions when designing an input filter for any switching regulator

In some cases, a Transient Voltage Suppressor (TVS) is used on the input of regulators. One class of this device has a *snap-back* V-I characteristic (thyristor type). The use of a device with this type of characteristic is not recommended. When the TVS *fires*, the clamping voltage drops to a very low value. If this holding voltage is less than the output voltage of the regulator, the output capacitors will be discharged through the regulator back to the input. This uncontrolled current flow could damage the regulator.

## 11 Layout

### 11.1 Layout Guidelines

The following list is in order of importance starting with the most important item:-

- Place high frequency input bypass capacitor, Cinhf, as close to the LM53600-Q1 and LM53601-Q1 devices as possible.
- Connect AGND and GND to the DAP immediately adjacent to the LM53600-Q1 and LM53601-Q1 devices.
- Do not interrupt the ground plain under the loop containing the VIN and GND pins and Cinhf of the LM53600-Q1 and LM53601-Q1 devices.
- The boot capacitor, CBOOT, should be close to the LM53601-Q1 and the loop from the SW pin, through the boot capacitor and into the BOOT pin should be kept as small as possible.
- Keep the SW node as small as possible. It should be wide enough to carry the converter's full current without significant drop.
- 4.7  $\mu\text{F}$  of bypassing should be close to the input of the LM53600-Q1 and LM53601-Q1 devices.
- Place CVCC, the VCC pin's bypass, and CBIAS, the bypass for FB for fixed voltage devices and BIAS for adjustable devices as close to the LM53600-Q1 and LM53601-Q1 devices as possible.
- The first output the trace from the output inductor to the output node should run by an output capacitor before joining the rest of the output node.
- Keep 10  $\mu\text{F}$  close to the output (output inductor and GND) of the LM53600-Q1 and LM53601-Q1 devices.
- Clear the layer beneath the SW node.

Table 7. PCB Layout Resources

TITLE	LINK
AN-1149 <i>Layout Guidelines for Switching Power Supplies</i>	<a href="#">SNVA021</a>
AN-1229 <i>Simple Switcher PCB Layout Guidelines</i>	<a href="#">SNVA054</a>
<i>Constructing Your Power Supply- Layout Considerations</i>	<a href="#">SLUP230</a>
SNVA721 <i>Low Radiated EMI Layout Made SIMPLE with LM4360x and LM4600x</i>	<a href="#">SNVA721</a>

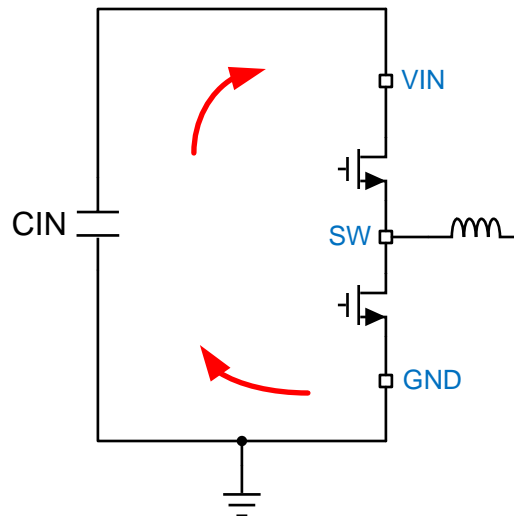


Figure 31. Current Loops with Fast Transients



### 11.1.1 Ground and Thermal Plane Considerations

As mentioned above, it is recommended to use one of the middle layers as a solid ground plane. A ground plane provides shielding for sensitive circuits and traces. It also provides a quiet reference potential for the control circuitry. The AGND and PGND pins should be connected to the ground plane using vias right next to the bypass capacitors. PGND pins are connected to the source of the internal low side MOSFET switch. They should be connected directly to the grounds of the input and output capacitors. The PGND net contains noise at the switching frequency and may bounce due to load variations. The PGND trace, as well as PVIN and SW traces, should be constrained to one side of the ground plane. The other side of the ground plane contains much less noise and should be used for sensitive routes.

It is recommended to provide adequate device heat sinking by utilizing the exposed pad (EP) of the IC as the primary thermal path. Use a minimum 4 by 4 array of 10 mil thermal vias to connect the EP to the system ground plane for heat sinking. The vias should be evenly distributed under the exposed pad. Use as much copper as possible for system ground plane on the top and bottom layers for the best heat dissipation. It is recommended to use a four-layer board with the copper thickness, starting from the top, as: 2 oz / 1 oz / 1 oz / 2 oz. A four-layer board with enough copper thickness and proper layout provides low current conduction impedance, proper shielding and lower thermal resistance.

**Table 8. Resources for Thermal PCB Design**

TITLE	LINK
<i>AN-2020 Thermal Design By Insight, Not Hindsight</i>	<a href="#">SNVA419</a>
<i>AN-1520 A Guide to Board Layout for Best Thermal Resistance for Exposed Pad Packages</i>	<a href="#">SNVA183</a>
<i>SPRA953B Semiconductor and IC Package Thermal Metrics</i>	<a href="#">SPRA953</a>
<i>SNVA719 Thermal Design made Simple with LM43603 and LM43602</i>	<a href="#">SNVA719</a>
<i>SLMA002 PowerPAD™ Thermally Enhanced Package</i>	<a href="#">SLMA002</a>
<i>SLMA004 PowerPAD Made Easy</i>	<a href="#">SLMA004</a>
<i>SBVA025 Using New Thermal Metrics</i>	<a href="#">SBVA025</a>

## 11.2 Layout Example

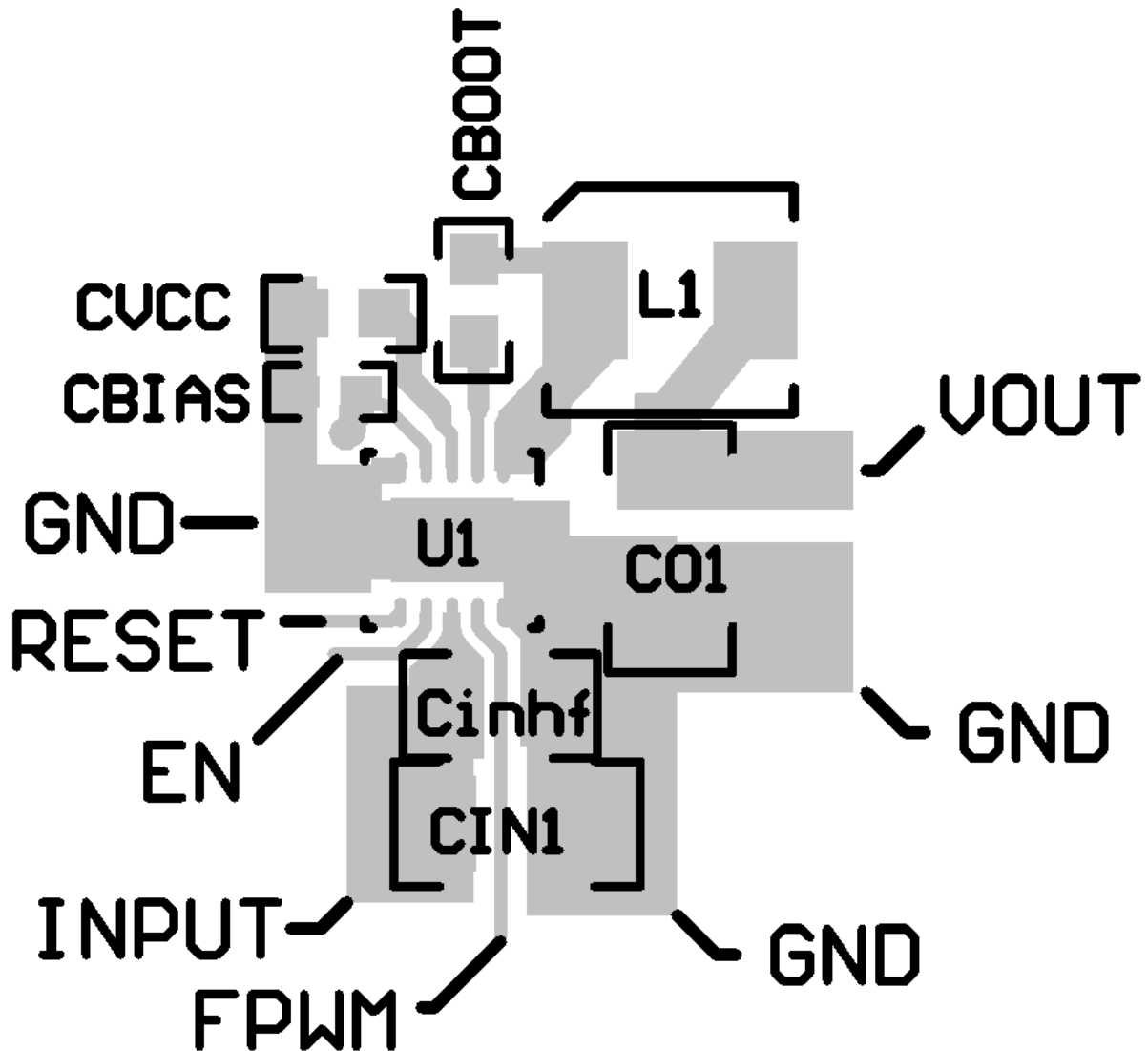


Figure 32. Fixed Output Version

Figure 32 shows an example layout for a fixed output version of the LM53600-Q1 and LM53601-Q1 similar to the one used in the Rev A EVM. Note that the via next to CBIAS connects on the back side of the board to VOUT near C01. This layout shows 10  $\mu\text{F}$  of output capacitance and 4.7  $\mu\text{F}$  of input capacitance. An additional  $>10 \mu\text{F}$  of output capacitance and about 4.7  $\mu\text{F}$  of input capacitance is assumed to be elsewhere in the system. A solid, unbroken ground plane is under this entire circuit except immediately below the SW node.

## 12 器件和文档支持

### 12.1 文档支持

#### 12.1.1 相关文档

相关文档如下：

AN-1149 《开关电源布局指南》（文献编号：[SNVA021](#)）

《使用 LM4360x 与 LM4600x 简化低辐射 EMI 布局》（文献编号：[SNVA721](#)）

《构建电源 - 布局注意事项》（文献编号：[SLUP230](#)）

AN-1229 《SIMPLE SWITCHER PCB 布局指南》（文献编号：[SNVA054](#)）

《使用新的热指标》（文献编号：[SBVA025](#)）

《PowerPAD 速成》（文献编号：[SLMA004](#)）

《PowerPAD™ 耐热增强型封装》（文献编号：[SLMA002](#)）

《使用 LM43603 与 LM43602 简化热设计》（文献编号：[SNVA719](#)）

《半导体和 IC 封装热指标》([SPRA953](#))

AN-2020 《富于洞见的热设计》（文献编号：[SNVA419](#)）

AN-1520 《外露焊盘封装实现最佳热敏电阻特性的电路板布线指南》（文献编号：[SNVA183](#)）

用户指南《轻松抑制 DC-DC 转换器中的传导性 EMI》（文献编号：[SNVA489](#)）

《LM53600-Q1 和 LM53601-Q1 可调版本的 EVM 用户指南》（文献编号：[SNAU190](#)）中对 SNAU190 和 SNAU191 的引用

《LM53600-Q1 和 LM53601-Q1 固定版本的 EVM 用户指南》（文献编号：[SNAU191](#)）

### 12.2 相关链接

以下表格列出了快速访问链接。范围包括技术文档、支持与社区资源、工具和软件，并且可以快速访问样片或购买链接。

表 9. 相关链接

器件	产品文件夹	样片与购买	技术文章	工具与软件	支持与社区
LM53600-Q1	<a href="#">请单击此处</a>	<a href="#">请单击此处</a>	<a href="#">请单击此处</a>	<a href="#">请单击此处</a>	<a href="#">请单击此处</a>
LM53601-Q1	<a href="#">请单击此处</a>	<a href="#">请单击此处</a>	<a href="#">请单击此处</a>	<a href="#">请单击此处</a>	<a href="#">请单击此处</a>

### 12.3 社区资源

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

**TI E2E™ Online Community** *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At [e2e.ti.com](http://e2e.ti.com), you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

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ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

## 12.6 Glossary

[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

### 13 机械、封装和可订购信息

以下页中包括机械、封装和可订购信息。这些信息是针对指定器件可提供的最新数据。这些数据会在无通知且不对本文档进行修订的情况下发生改变。欲获得该数据表的浏览器版本，请查阅左侧的导航栏。

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	产品		应用
数字音频	<a href="http://www.ti.com.cn/audio">www.ti.com.cn/audio</a>	通信与电信	<a href="http://www.ti.com.cn/telecom">www.ti.com.cn/telecom</a>
放大器和线性器件	<a href="http://www.ti.com.cn/amplifiers">www.ti.com.cn/amplifiers</a>	计算机及周边	<a href="http://www.ti.com.cn/computer">www.ti.com.cn/computer</a>
数据转换器	<a href="http://www.ti.com.cn/dataconverters">www.ti.com.cn/dataconverters</a>	消费电子	<a href="http://www.ti.com.cn/consumer-apps">www.ti.com.cn/consumer-apps</a>
DLP® 产品	<a href="http://www.dlp.com">www.dlp.com</a>	能源	<a href="http://www.ti.com.cn/energy">www.ti.com.cn/energy</a>
DSP - 数字信号处理器	<a href="http://www.ti.com.cn/dsp">www.ti.com.cn/dsp</a>	工业应用	<a href="http://www.ti.com.cn/industrial">www.ti.com.cn/industrial</a>
时钟和计时器	<a href="http://www.ti.com.cn/clockandtimers">www.ti.com.cn/clockandtimers</a>	医疗电子	<a href="http://www.ti.com.cn/medical">www.ti.com.cn/medical</a>
接口	<a href="http://www.ti.com.cn/interface">www.ti.com.cn/interface</a>	安防应用	<a href="http://www.ti.com.cn/security">www.ti.com.cn/security</a>
逻辑	<a href="http://www.ti.com.cn/logic">www.ti.com.cn/logic</a>	汽车电子	<a href="http://www.ti.com.cn/automotive">www.ti.com.cn/automotive</a>
电源管理	<a href="http://www.ti.com.cn/power">www.ti.com.cn/power</a>	视频和影像	<a href="http://www.ti.com.cn/video">www.ti.com.cn/video</a>
微控制器 (MCU)	<a href="http://www.ti.com.cn/microcontrollers">www.ti.com.cn/microcontrollers</a>		
RFID 系统	<a href="http://www.ti.com.cn/rfidsys">www.ti.com.cn/rfidsys</a>		
OMAP应用处理器	<a href="http://www.ti.com/omap">www.ti.com/omap</a>		
无线连通性	<a href="http://www.ti.com.cn/wirelessconnectivity">www.ti.com.cn/wirelessconnectivity</a>	德州仪器在线技术支持社区	<a href="http://www.deyisupport.com">www.deyisupport.com</a>

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**PACKAGING INFORMATION**

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM536003QDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	53603	<a href="#">Samples</a>
LM536003QDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	53603	<a href="#">Samples</a>
LM536005QDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	53605	<a href="#">Samples</a>
LM536005QDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	53605	<a href="#">Samples</a>
LM53600AQDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5360A	<a href="#">Samples</a>
LM53600AQDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5360A	<a href="#">Samples</a>
LM53600LQDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5360L	<a href="#">Samples</a>
LM53600LQDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5360L	<a href="#">Samples</a>
LM53600MQDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5360M	<a href="#">Samples</a>
LM53600MQDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5360M	<a href="#">Samples</a>
LM53600NQDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5360N	<a href="#">Samples</a>
LM53600NQDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5360N	<a href="#">Samples</a>
LM536013QDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	53613	<a href="#">Samples</a>
LM536013QDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	53613	<a href="#">Samples</a>
LM536015QDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	53615	<a href="#">Samples</a>
LM536015QDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	53615	<a href="#">Samples</a>
LM53601AQDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5361A	<a href="#">Samples</a>

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM53601AQDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5361A	<a href="#">Samples</a>
LM53601LQDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5361L	<a href="#">Samples</a>
LM53601LQDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5361L	<a href="#">Samples</a>
LM53601MQDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5361M	<a href="#">Samples</a>
LM53601MQDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5361M	<a href="#">Samples</a>
LM53601NQDSXRQ1	ACTIVE	WSON	DSX	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5361N	<a href="#">Samples</a>
LM53601NQDSXTQ1	ACTIVE	WSON	DSX	10	250	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	-40 to 150	5361N	<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) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device 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 Device Marking for that device.



<sup>(6)</sup> Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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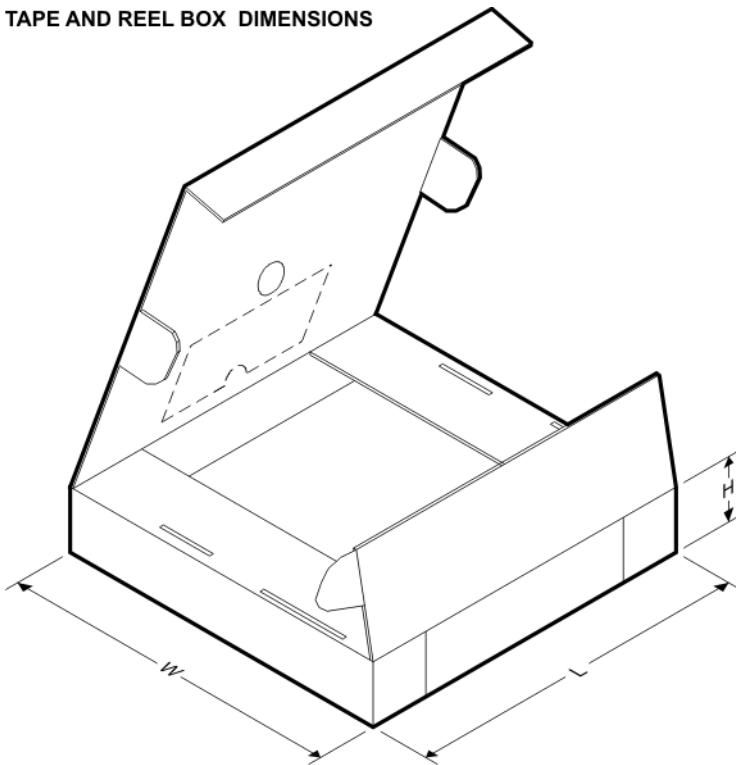
**TAPE AND REEL INFORMATION**

**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
LM536003QDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM536003QDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM536005QDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM536005QDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53600AQDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53600AQDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53600LQDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53600LQDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53600MQDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53600MQDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53600NQDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53600NQDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM536013QDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM536013QDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM536015QDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM536015QDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53601AQDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53601AQDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2

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
LM53601LQDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53601LQDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53601MQDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53601MQDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53601NQDSXRQ1	WSON	DSX	10	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
LM53601NQDSXTQ1	WSON	DSX	10	250	180.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2

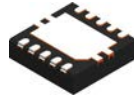
**TAPE AND REEL BOX DIMENSIONS**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM536003QDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM536003QDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM536005QDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM536005QDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM53600AQDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM53600AQDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM53600LQDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM53600LQDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM53600MQDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM53600MQDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM53600NQDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM53600NQDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM536013QDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM536013QDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM536015QDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM536015QDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM53601AQDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM53601AQDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM53601LQDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM53601LQDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM53601MQDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM53601MQDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0
LM53601NQDSXRQ1	WSON	DSX	10	3000	370.0	355.0	55.0
LM53601NQDSXTQ1	WSON	DSX	10	250	195.0	200.0	45.0

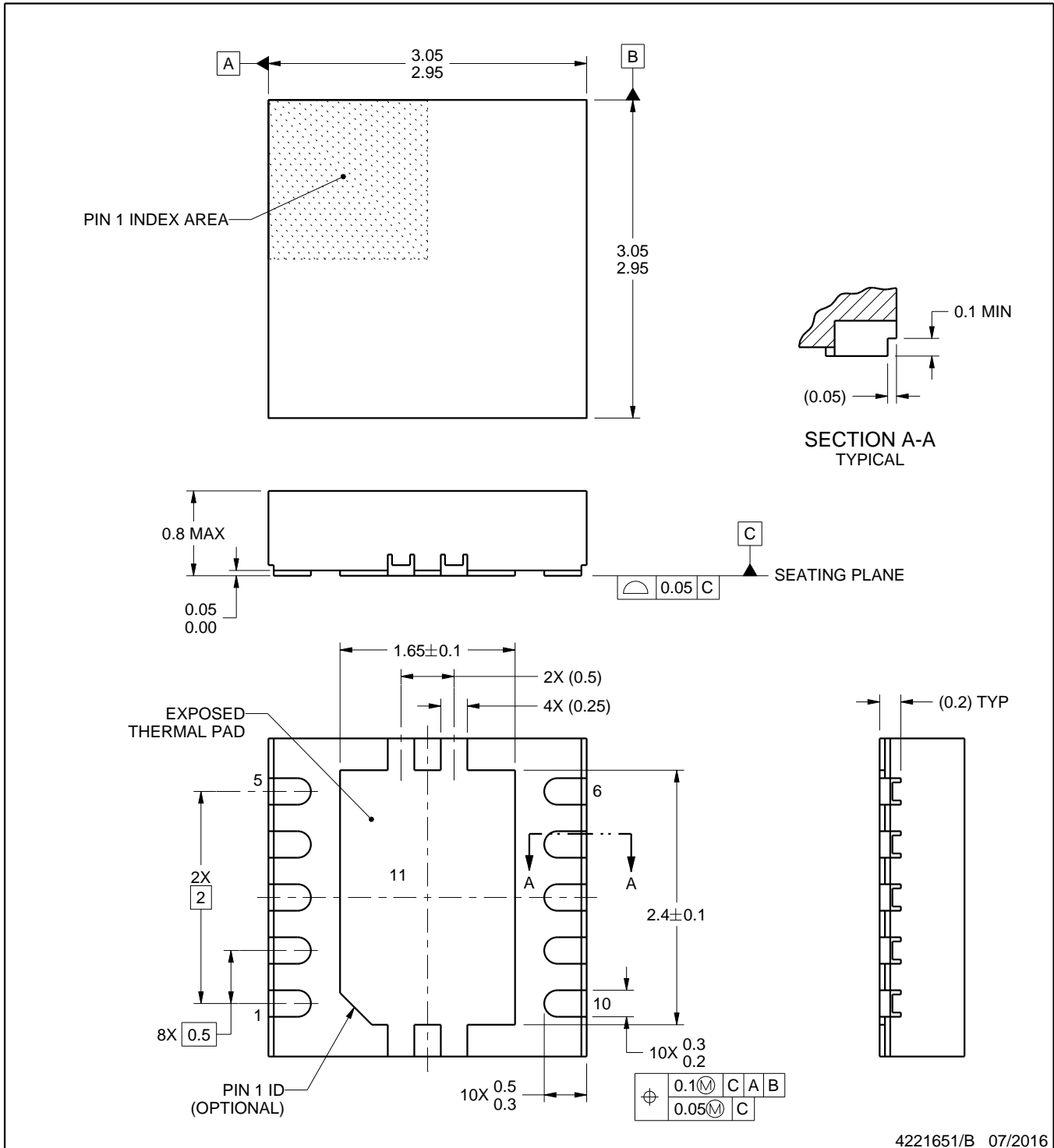
# DSX0010A



# PACKAGE OUTLINE

## WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



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### NOTES:

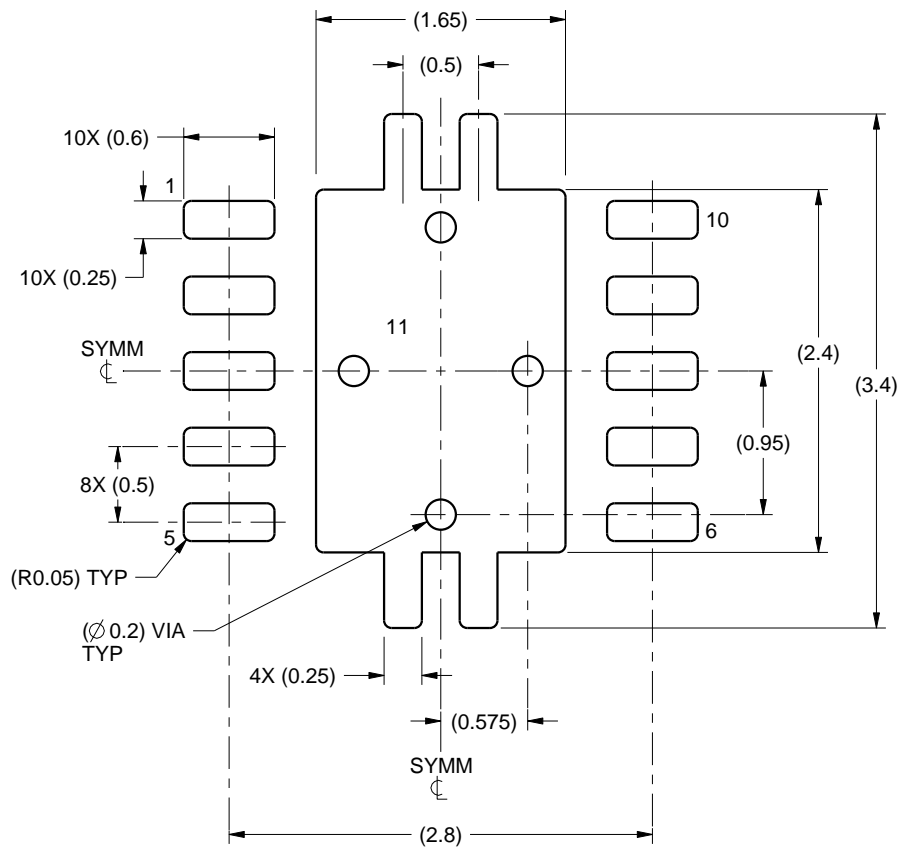
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

# EXAMPLE BOARD LAYOUT

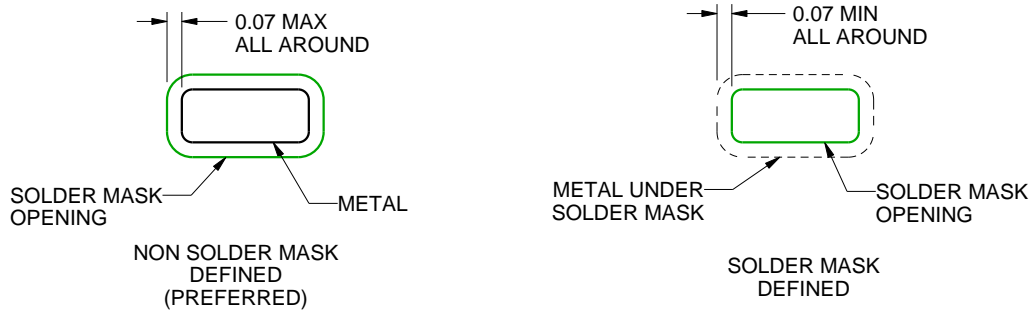
DSX0010A

WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



LAND PATTERN EXAMPLE  
SCALE:20X



SOLDER MASK DETAILS

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NOTES: (continued)

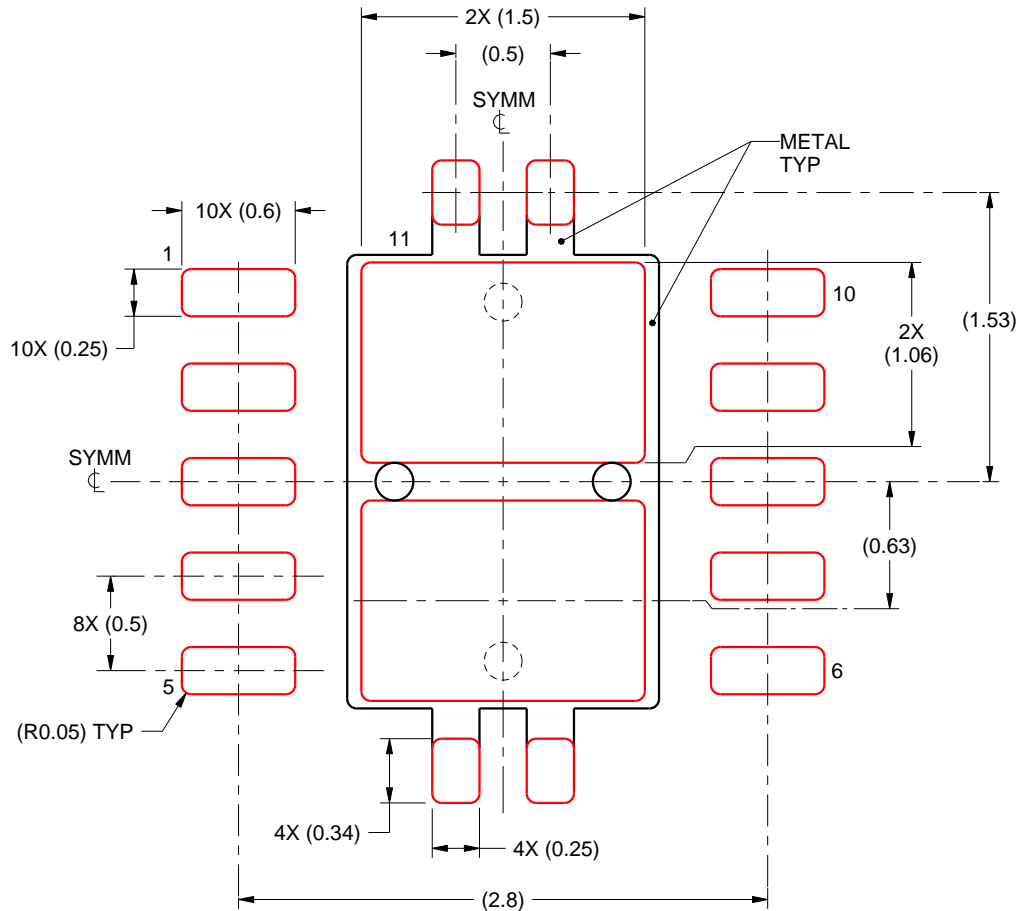
4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/slua271](http://www.ti.com/lit/slua271)).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

# EXAMPLE STENCIL DESIGN

DSX0010A

WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD  
80% PRINTED SOLDER COVERAGE BY AREA  
SCALE:25X

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NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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