











TPS543C20A

SLUSDE0 - DECEMBER 2018

TPS543C20A 4-V_{IN} to 16-V_{IN}, 40-A Stackable, Synchronous Step-Down SWIFT™ Converter With Adaptive Internal Compensation

1 Features

- Internally-Compensated Advanced Current Mode Control 40-A POL
- Input Voltage Range: 4 V to 16 V
- Output Voltage Range: 0.6 V to 5.5 V
- Integrated 3.4/0.9-mΩ Stacked NexFET[™] Power Stage With Lossless Low-Side Current Sensing
- Fixed Frequency Synchronization to an External Clock and/or Sync Out
- Pin Strapping Programmable Switching Frequency
 - 300 kHz to 2 MHz for Standalone
 - 300 kHz to 1 MHz for Stackable
- Stack 2x for up to 80 A With Current Share, Voltage Share, and CLK Sync
- Pin Strapping Programmable Reference from 0.6V to 1.1 V With 0.5% Accuracy
- Differential Remote Sensing
- · Safe Start-Up into Prebiased Output
- High-Accuracy Hiccup Current Limit
- Asynchronous Pulse Injection (API) and Body Braking
- 40-pin, 5-mm x 7-mm LQFN Package with 0.5mm Pitch and Single Thermal Pad
- Create a Custom Design Using the TPS543C20A
 With the WEBENCH® Power Designer

2 Applications

- Wireless and Wired Communications Infrastructure Equipment
- Enterprise Servers, Switches, and Routers
- Enterprise Storage, SSD
- ASIC, SoC, FPGA, DSP Core, and I/O Rails

3 Description

The TPS543C20A uses an internally compensated emulated peak-current-mode control, with a clock synchronizable, fixed-frequency modulator for EMIsensitive POL. The internal integrator and directly amplifying ramp tracking loop eliminate the need for external compensation over a wide range of frequencies thereby making the system design flexible, dense, and simple. Optional API and body braking help improve transient performance by significantly reducing undershoot and overshoot, respectively. Integrated NexFET™ MOSFETs with low-loss switching facilitate high efficiency and deliver up to 40 A in a 5-mm × 7-mm PowerStack™ package with a layout friendly thermal pad. Two TPS543C20A devices can be stacked together to provide up to 80-A point-of-load.

Device Information

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPS543C20A	LQFN-CLIP (40)	5.00 mm × 7.00 mm

 For all available packages, see the orderable addendum at the end of the data sheet.

Simplified Schematic

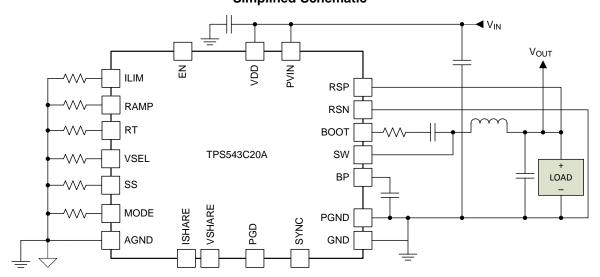




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4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

DATE	REVISION	NOTES
December 2018	*	Initial release

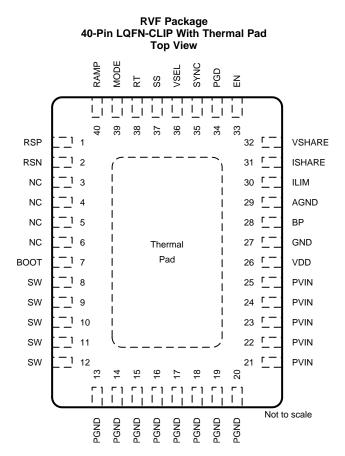
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5 Device Comparison Table

DEVICE	OUTPUT CURRENT
TPS543B20	25 A
TPS543C20	40 A
TPS543C20A	40 A

6 Pin Configuration and Functions



Pin Functions

PIN		(4)		
NO.	NAME	I/O/P ⁽¹⁾	DESCRIPTION	
1	RSP	I	The positive input of the remote sense amplifier. Connect RSP pin to the output voltage at the load. For multi-phase configuration, the remote sense amplifier is not needed for slave devices.	
2	RSN	I	The negative input of the remote sense amplifier. Connect RSN pin to the ground at load side. For multi-phase configuration, the remote sense amplifier is not needed for slave devices.	
3,4,5,6	NC	_	Not connected	
7	воот	I	Bootstrap pin for the internal flying high-side driver. Connect a typical 100-nF capacitor from this pin to SW. To reduce the voltage spike at SW, a BOOT resistor with a value between 1 Ω to 10 Ω may be placed in series with the BOOT capacitor to slow down turnon of the high-side FET.	
8,9,10,11,12	SW	В	Output of converted power. Connect this pin to the output Inductor.	
13,14,15,16,17,18,19, 20	PGND	G	These ground pins are connected to the return of the internal low-side MOSFET	
21,22,23,24,25	PVIN	I	Input power to the power stage. Low impedance bypassing of these pins to PGND is critical. A 10-nF to 100-nF capacitor from PVIN to PGND close to IC is required.	
26	VDD	I	Controller power supply input	
27	GND	G	Ground return for the controller. This pin should be directly connected to the thermal pad on the PCB board. A 10-nF to 100-nF capacitor from PVIN to GND close to IC is required.	
28	BP	0	Output of the 5 V on board regulator. This regulator powers the driver stage of the	
29	AGND	G	GND return for internal analog circuits.	
30	ILIM	0	Current protection pin; connect a resistor from this pin to AGND sets current limit level.	
31	ISHARE	I	Current sharing signal for multi-phase operation. Float this pin for single phase	
32	VSHARE	В	Voltage sharing signal for multi-phase operation. Float this pin for single phase.	
33	EN	I	The enable pin turns on the switcher.	
34	PGD	0	Open-drain power-good status signal which provides start-up delay after the FB voltage falls within the specified limits. After the FB voltage moves outside the specified limits, PGOOD goes low.	
35	SYNC	В	For frequency synchronization. This pin can be configured as sync in or sync out by MODE pin and RT pin for master and slave devices.	
36	VSEL	I	Connect a resistor from this pin to AGND to select internal reference voltage.	
37	SS	0	Connect a resistor from this pin to AGND to select soft-start time.	
38	RT	0	Frequency setting pin. Connect a resistor from this pin to AGND to program the switching frequency. This pin also selects sync point for devices in stackable applications	
39	MODE	В	Enable or disable API or body brake function, choose API threshold, also selects the operation mode in stackable applications	
40	RAMP	В	Ramp level selection, with a resistor to AGND to adjust internal loop.	
Thermal Pad	Thermal Tab	_	Package thermal tab, internally connected to PGND. The thermal tab must have adequate solder coverage for proper operation.	

⁽¹⁾ I = Input, O = Output, B = Bidirectional, P = Supply, G = Ground

7 Specifications

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7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) (1)(2)

			MIN	MAX	UNIT
	VIN		-0.3	18	
	VIN to SW ⁽³⁾			25	
VIN to SW ⁽³⁾ VDD BOOT	VDD		-0.3	18	
	BOOT		-0.3	34.5	
	DOOT to SW	DC	-0.3	6.5	
	BOOT to SW	< 10 ns	-0.3	7	
	VSEL, SS, MODE, RT, SYNC, EN, ISHARE, ILIM		-0.3	7	V
	RSP		-0.3	3.6	
	RSN		-0.3	0.3	
	PGND, GND	PGND, GND		0.3	
	SW to DOND(4)	DC	-0.3	20	
	SW to PGND	< 10 ns	-5	20	
	BP, RAMP		-0.3	7	
Output voltage	PGD		-0.3	7	V
	VSHARE	VSHARE		3.6	
Junction temperature	, T _J		-55	150	°C
Storage temperature,	T _{stg}		-55	150	°C

⁽¹⁾ Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

7.2 ESD Ratings

			VALUE	UNIT
\/	Floatroototic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 (1)	±2500	V
V _(ESD)	Electrostatic discharge	Charged-device model (CDM), per JEDEC specification JESD22-C101 ⁽²⁾	±1500	V

⁽¹⁾ JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process. Manufacturing with less than 500-V HBM is possible with the necessary precautions.

Product Folder Links: TPS543C20A

⁽²⁾ All voltage values are with respect to the network ground terminal unless otherwise noted.

⁽³⁾ VIN to SW must not exceed 25 V.

⁽⁴⁾ SW to PGND must not exceed 20 V.

⁽²⁾ JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process. Manufacturing with less than 250-V CDM is possible with the necessary precautions.

STRUMENTS

7.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)(1)

	. 3 (MIN	MAX	UNIT
Input voltage (2) Output voltage (2)	VIN		4	16	
	VIN to SW ⁽³⁾	DC	-0.1	22	
	VDD BOOT	< 10 ns		22	
			4	16	
	BOOT		-0.1	23.5	
	BOOT to SW	DC	-0.1	5.5	
	< 10 ns	-0.1	6	V	
input voltage	VSEL, SS, MODE, RT, SYNC, EN, ISHARE, ILIM		-0.1	5.5	v
			-0.1	1.7	
	RSN		-0.1	0.1	
	PGND, GND		-0.1	0.1	
	SW to PGND	DC	-0.1	18	
	SW to FGND	< 10 ns	- 5	18	
	BP, RAMP		-0.3	7	
Output voltage (2)	PGD		-0.3	7	V
	VSHARE		-0.3	3.6	
Junction temperature,	T _J		-40	125	°C
Storage temperature, 7	T _{stg}		– 55	125	°C

Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. All voltage values are with respect to the network ground terminal unless otherwise noted.

7.4 Thermal Information

		TPS543C20A	
	THERMAL METRIC ⁽¹⁾	RVF (LQFN)	UNIT
		40 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	28.9	°C/W
$R_{\theta JA}$	Junction-to-ambient thermal resistance EVM (TPS543C20AEVM-054:6-layer, 2-oz Cu per layer, 2.75 inch by 3 inch)	12	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	18.9	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	4.1	°C/W
ΨЈТ	Junction-to-top characterization parameter	1.3	°C/W
ΨЈВ	Junction-to-board characterization parameter	4.1	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	1	°C/W

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

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See Layout Guidelines for VIN capacitor placement requirement to reduce MOSFET voltage stress.

7.5 Electrical Characteristics

over operating free-air temperature range (unless otherwise noted)

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
MOSFET R _{DS(OI}	N)				•	
R _{DS(on)HS}	HS FET	VBST – VSW = 5 V, I _D = 20 A, T _J = 25°C		3.4		mΩ
R _{DS(on)LS}	LS FET	VDD = 5 V, I _D = 20 A, T _J = 25°C		0.9		mΩ
t _{DEAD(LtoH)}	Power stage driver dead-time from Low-side off to High-side on ⁽¹⁾	VDD ≥ 12 V, T _J = 25°C		12		ns
t _{DEAD(HtoL)}	Power stage driver dead-time from High-side off to Low-side on ⁽¹⁾	VDDN ≥ 12 V, T _J = 25°C		15		ns
INPUT SUPPLY	and CURRENT				J.	
V_{VIN}	Power stage voltage		4		16	
V_{VDD}	VDD supply voltage		4		16	
I _{VDD}	VDD bias current	T _A = 25°C, no load, power conversion enabled (no switching)		4.3		mA
I _{VDDSTBY}	VDD standby current	T _A = 25°C, no load, power conversion disabled		4.3		mA
UNDERVOLTA	GE LOCKOUT					
V_{VDD_UVLO}	VDD UVLO rising threshold			3.8		V
V _{VDD_UVLO_HYS}	VDD UVLO hysteresis			0.2		٧
V_{VIN_UVLO}	VIN UVLO rising threshold			3.2		V
V _{VIN_UVLO_HYS}	VIN UVLO hysteresis			0.2		V
V _{EN_ON_TH}	EN on threshold		1.45	1.6	1.75	V
V_{HYS}	EN hysteresis		270	300	330	mV
I _{EN_LKG}	EN input leakage current		-1	0	1	μΑ
INTERNAL REF	ERENCE VOLTAGE					
V _{INTREF}	Internal REF voltage	R _{VSEL} = OPEN		1000		mV
V _{INTREFTOL}	Internal REF voltage tolerance	$T_J = -40$ °C to 125°C	-0.5%		0.5%	
V _{INTREF_VSEL}	Internal REF voltage range	Programable by VSEL (pin 36)	0.6		1.1	V
OUTPUT VOLT	AGE					
I _{RSP}	RSP input current	V _{RSP} = 600 mV	-1		1	μΑ
DIFFERENTIAL	REMOTE SENSE AMPLIFIER					
f _{UGBW}	Unity gain bandwidth ⁽¹⁾		5	8.5		MHz
A0	Open loop gain ⁽¹⁾		75			dB
SR	SLew rate ⁽¹⁾			±10		V/µs
V _{ICM}	Input common mode range ⁽¹⁾		-0.2		1.7	V
	Input offset voltage ⁽¹⁾	V _{RSN-VGND} = 0 mV	-1		1	m\/
V _{OFFSET}	input onset voitage.	V _{RSN-VGND} = ±100 mV	-1.9		1.9	mV

⁽¹⁾ Specified by design. Not production tested.

TEXAS INSTRUMENTS

Electrical Characteristics (continued)

over operating free-air temperature range (unless otherwise noted)

	PARAMETER	TES	T CONDITIONS	MIN	TYP	MAX	UNIT
SWITCHING	FREQUENCY						
		V _{IN} = 12 V, V _{VO} =	= 1 V, RT = 66.5 kΩ		300		
		V _{IN} = 12 V, V _{VO} =	= 1 V, RT = 48.7 kΩ		400		
		V _{IN} = 12 V, V _{VO} =	= 1 V, RT = 39.2 kΩ		500		
_	V _O switching frequency	V _{IN} = 12 V, V _{VO} =	= 1 V, RT = 28.0 kΩ		700		
F _{SW}	maximum frequency for multi- phase is 1MHz	V _{IN} = 12 V, V _{VO} =	= 1 V, RT = 22.6 kΩ		850		kHz
Í	F.1.000 10 1111 12	V _{IN} = 12 V, V _{VO} =	= 1 V, RT = 19.1 kΩ		1000		
Í		V _{IN} = 12 V, V _{VO} =	= 1 V, RT = 15.4 kΩ		1200		
		V _{IN} = 12 V, V _{VO} =	= 1 V, RT = 8.06 kΩ		2000		
t _{ON(min)}	Minimum on-time ⁽¹⁾	DRVH rising to fa	alling		30		ns
t _{OFF(min)}	Minimum off-time ⁽¹⁾	DRVH falling to r	ising		250		ns
INTERNAL I	BOOTSTRAP SWITCH	1					
V _F	Forward voltage	$V_{BP-VBST}$, $T_A = 25$	5°C, I _F = 5 mA		0.1	0.2	V
VSEL				<u>!</u>		*	
		$R_{VSEL} = 0 k\Omega$	$R_{VSEL} = 0 k\Omega$		0.6		
		$R_{VSEL} = 8.66 \text{ k}\Omega$			0.7		
		$R_{VSEL} = 15.4 \text{ k}\Omega$			0.75		
		$R_{VSEL} = 23.7 \text{ k}\Omega$			0.8		
\ (OE)		$R_{VSEL} = 34.8 \text{ k}\Omega$			0.85		
VSEL	SEL Internal reference voltage	$R_{VSEL} = 51.1 \text{ k}\Omega$			0.9		V
		$R_{VSEL} = 78.7 \text{ k}\Omega$			0.95		
		R _{VSEL} = OPEN			1		
		$R_{VSEL} = 121 \text{ k}\Omega$			1.05		
		R_{VSEL} = 187 k Ω		1.1			1
SOFT STAR	т	1					
			$R_{SS} = 0 k\Omega$		0.5		
			$R_{SS} = 8.66 \text{ k}\Omega$		1		
			$R_{SS} = 15.4 \text{ k}\Omega$		2		
			R _{SS} = Open		4		
	0 %	Vo rising from 0	$R_{SS} = 23.7 \text{ k}\Omega$		5		
t _{SS}	Soft-start time	V to 95% of final set point	R _{SS} = 34.8 kΩ		8		ms
			R _{SS} = 51.1 kΩ		12		
			R _{SS} = 78.7 kΩ		16		
			R _{SS} = 121 kΩ		24		
			R _{SS} = 187 kΩ		32		
POWER ON	DELAY	·	•				
t _{PODLY}	Power-on delay time	Delay from enab	le to switching		512		μs

Electrical Characteristics (continued)

over operating free-air temperature range (unless otherwise noted)

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
PGOOD COM	IPARATOR					
Voor	OV warning threshold on RSP pin, PGOOD fault threshold on rising	VREF = 600 mV	108	112	116	%V _{REF}
V _{PG(thresh)}	UV warning threshold on RSP pin, PGOOD fault threshold on falling	VREF = 600 mV	84	88	92	70 V REF
$V_{PGD(rise)}$	PGOOD threshold on rising and UV warning threshold de- assertion threshold at RSP pin	VREF = 600 mV		95		%V _{REF}
$V_{PGD(fall)}$	PGOOD threshold on falling and OV warning threshold de- assertion threshold at RSP pin	VREF = 600 mV		105		%V _{REF}
R_{PGD}	PGOOD pulldown resistance	I _{PGOOD} = 5 mA, VRSP = 0 V	30	45	60	Ω
•	PGOOD delay time	Delay for PGOOD going in		1.024		ms
t _{PGDLY}	FGOOD delay time	Delay for PGOOD coming out			2	μs
$V_{PGD(OL)}$	PGOOD output low level voltage at no supply voltage	VDD=0, I _{PGOOD} = 80 μA			0.8	V
I _{PGLK}	PGOOD leakage current	V _{PGOOD} = 5 V			15	μΑ
CURRENT S	HARE ACCURACY					
	Output current sharing accuracy	I _{OUT} ≥ 20 A/phase	-15%		15%	
I _{SHARE(acc)}	among stackable devices, defined as the ratio of the current difference between devices to total current(sensing error only) ⁽¹⁾	I _{OUT} ≤ 20 A/phase		±3		Α
CURRENT D	ETECTION					
V_{ILIM}	V _{TRIP} voltage range	R _{dson} sensing	0.1		1.2	V
	Low-side FET current protection	R _{ILIM} = 33.2 kΩ		35		Α
I _{OCP}	threshold and tolerance	OC tolerance		±10%		
	Low-Side FET current protection	R _{ILIM} = 23.7 kΩ		25		Α
I _{OCP}	threshold and tolerance	OC tolerance		±15%		
I _{OCP_N}	Negative current limit threshold	Valley-point current sense		-23		Α
I _{CLMP_LO}	Clamp current at V _{TRIP} clamp at lowest	25°C, V _{TRIP} = 0.1 V	5.5	6.5	7.5	Α

Electrical Characteristics (continued)

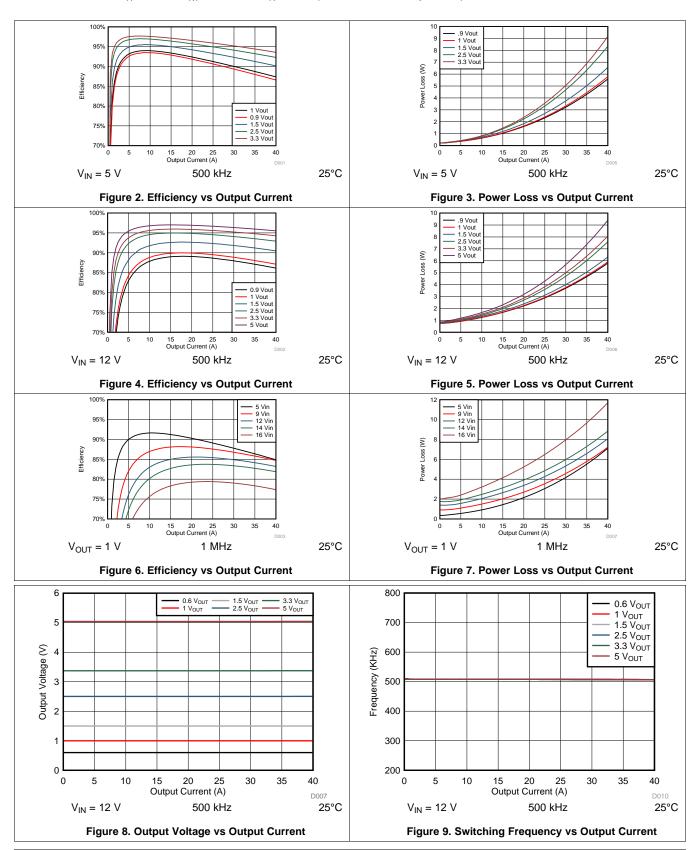
over operating free-air temperature range (unless otherwise noted)

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
HIGH-SIDE SHO	ORT-CIRCUIT PROTECTION					
I _{HSOC}	High-side short circuit protection fault threshold (1)			55		А
OV / UV PROTE	CTION					
V _{OVP}	OVP threshold voltage	OVP detect voltage	113	117	121	%VREF
t _{OVPDLY}	OVP response time ⁽¹⁾	OVP response time with 100-mV overdrive			1	μs
V _{UVP}	UVP threshold voltage	UVP detect voltage	79	83	87	%VREF
t _{UVPDLY}	UVP delay ⁽¹⁾	UVP delay			1.5	μs
t _{HICDLY}	Hiccup delay time	Regular t _{SS} setting		7 × t _{SS}		ms
BP LDO REGUI	_ATOR					
BP	LDO output voltage	V _{IN} = 12 V, I _{LOAD} = 0 to 10 mA	4.5	5	5.5	V
V	DD IIV/I O through and walte me	Wakeup 3	3.32		V	
V_{BPUVLO}	BP UVLO threshold voltage	Shutdown		3.11		V
VLDO _{BP}	LDO low dropout voltage	V _{IN} = 4.5 V, I _{LOAD} = 30 mA, T _A = 25°C			365	mV
I _{LDOMAX}	LDO overcurrent limit	V _{IN} = 12 V, T _A = 25°C		100		mA
SYNCHRONIZA	TION					
V _{IH(SYNC)}	High-level input voltage		2			V
V _{IL(SYNC)}	Low-level input voltage				0.8	V
t _{PSW(SYNC)}	Sync input minimum pulse width				100	ns
_	Synchronization frequency		300		2000	1.1.1-
F _{SYNC}	Dual-phase		300		1000	kHz
t _{SYNC to SW}	Sync to SW delay tolerance, percentage from phase-to-phase ⁽¹⁾	F _{SYNC} = 300 kHz to 1 MHz,		10%		
t _{Lose_SYNC_delay}	Delay when lose sync clock ⁽¹⁾	F _{SYNC} = 300 kHz		5		μs
THERMAL SHU	TDOWN					
-	Built-in thermal shutdown Shutdown temperature 155		165		00	
T _{SDN}	threshold (1)	Hysteresis		30		°C

10

7.6 Typical Characteristics

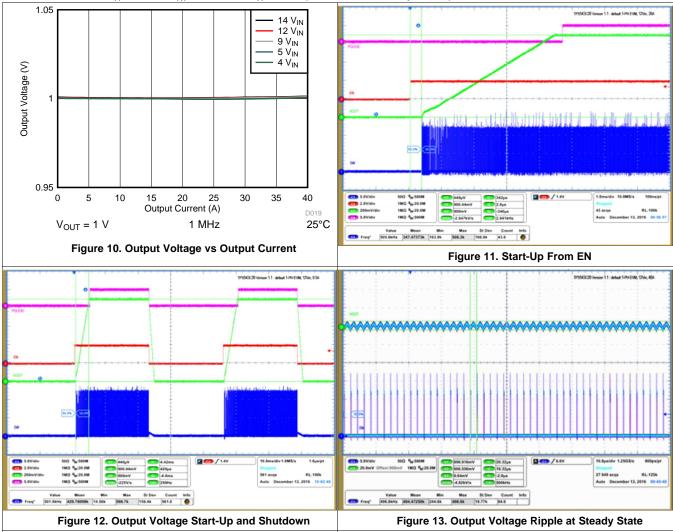
VIN = VDD = 12 V, $T_A = 25$ °C, $R_{RT} = 40.2 \text{ k}\Omega$, $T_A = 25$ °C (unless otherwise specified)



TEXAS INSTRUMENTS

Typical Characteristics (continued)

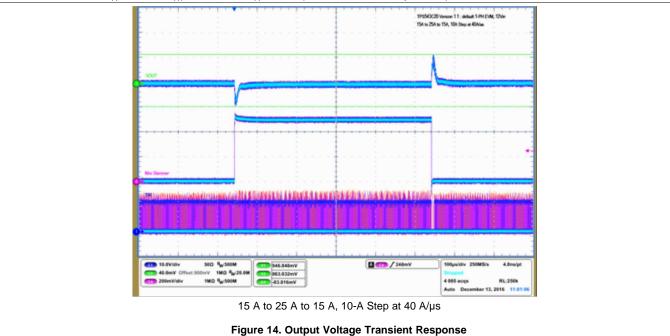
VIN = VDD = 12 V, T_A = 25°C, R_{RT} = 40.2 k Ω , T_A = 25°C (unless otherwise specified)





Typical Characteristics (continued)

VIN = VDD = 12 V, T_A = 25°C, R_{RT} = 40.2 k Ω , T_A = 25°C (unless otherwise specified)



TEXAS INSTRUMENTS

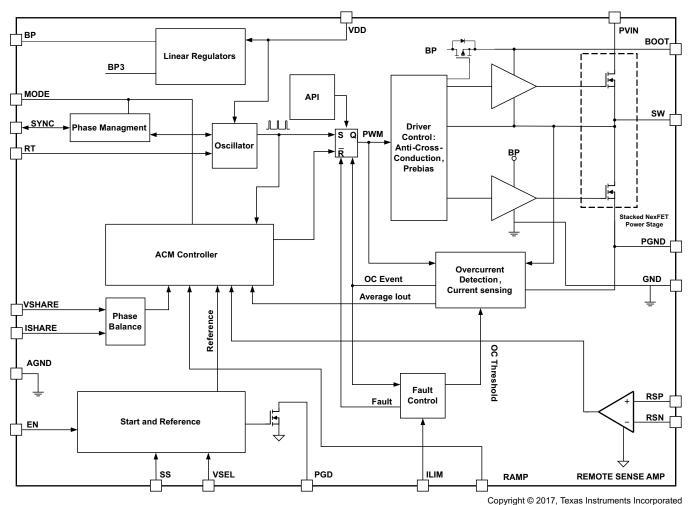
8 Detailed Description

8.1 Overview

The device is 40-A, high-performance, synchronous buck converter with two integrated N-channel NexFET™ power MOSFETs. These devices implement the fixed frequency non-compensation mode control. Safe pre-bias capability eliminates concerns about damaging sensitive loads. Two devices can be paralleled together to provide up to -A load. Current sensing for over-current protection and current sharing between devices is done by sampling a small portion of the power stage current providing accurate information independent on the device temperature.

Advanced Current Mode (ACM) is an emulated peak current control topology. It supports stable static and transient operation without complex external compensation design. This control architecture includes an internal ramp generation network that emulates inductor current information, enabling the use of low ESR output capacitors such as multi-layered ceramic capacitors (MLCC). The internal ramp also creates a high signal to noise ratio for good noise immunity. The has 10 ramp options (see *Ramp Selections* for detail) to optimize internal loop for various inductor and output capacitor combinations with only a simple resistor to GND. The is easy to use and allows low external component count with fast load transient response. Fixed-frequency modulation also provides ease-of-filter design to overcome EMI noise.

8.2 Functional Block Diagram



8.3 Feature Description

The device is a high-performance, integrated FET converter supporting current rating up to 40-A thermally. It integrates two N-channel NexFET™ power MOSFETs, enabling high power density and small PCB layout area. The drain-to-source breakdown voltage for these FETs is 25-V DC and transient. Avalanche breakdown occurs if the absolute maximum voltage rating exceeds 25 V. In order to limit the switch node ringing of the device, TI recommends adding a R-C snubber from the SW node to the PGND pins. Also a 10~100nF capacitor from VIN (Pin 25) to GND (Pin2 7) is mandatory to reduce high side FET stress. Refer to Layout Guidelines for the detailed recommendations.

The typical on-resistance (RDS(on)) for the high-side MOSFET is 3.4 m Ω and typical on-resistance for the low-side MOSFET is 0.9 m Ω with a nominal gate voltage (VGS) of 5 V.

8.4 Device Functional Modes

8.4.1 Soft-Start Operation

In the TPS543C20A device, the soft-start time controls the inrush current required to charge the output capacitor bank during start-up. The device offers 10 selectable soft-start options ranging from 0.5 ms to 32 ms. When the device is enabled the reference voltage ramps from 0 V to the final level defined by VSEL pin strap configuration, in a given soft-start time, which can be selected by SS pin. See Table 1 for details.

	3
SS TIME (ms)	RESISTOR VALUE (kΩ) ⁽¹⁾
0.5	0
1	8.66
2	15.4
5	23.7
4	OPEN
8	34.8
12	51.1
16	78.7
24	121
32	187

Table 1. SS Pin Configuration

8.4.2 Input and VDD Undervoltage Lockout (UVLO) Protection

The provides fixed VIN and VDD undervoltage lockout threshold and hysteresis. The typical VIN turnon threshold is 3.2 V and hysteresis is 0.2 V. The typical VDD turnon threshold is 3.8 V and hysteresis is 0.2 V. No specific power-up sequence is required.

8.4.3 Power Good and Enable

The has power-good output that indicates logic high when output voltage is within the target. The power-good function is activated after soft-start has finished. When the soft-start ramp reaches 90% of setpoint, PGOOD detection function will be enabled. If the output voltage becomes within ±8% of the target value, internal comparators detect power-good state and the power good signal becomes high after a delay. If the output voltage goes outside of ±12% of the target value, the power good signal becomes low after an internal delay. The power-good output is an open-drain output and must be pulled up externally.

This part has internal pull up for EN. EN is internally pulled up to BP when EN pin is floating. EN can be pulled low through external grounding. When EN pin voltage is below its threshold, enters into shutdown operation, and the minimum time for toggle EN to reset is $5 \, \mu s$.

⁽¹⁾ The E48 series resistors with no more than 1% tolerance are recommended.

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8.4.4 Voltage Reference

VSEL pin strap is used to program initial boot voltage value from 0.6 V to 1.1 V by the resistor connected from VSEL to AGND. The initial boot voltage is used to program the main loop voltage reference point. VSEL voltage settings provide TI designated discrete internal reference voltages. Table 2 lists internal reference voltage selections.

rable 2. VOLL I in Configuration							
DEFAULT Vref (V)	RESISTOR VALUE (kΩ) ⁽¹⁾						
0.6	0						
0.7	8.66						
0.75	15.4						
0.8	23.7						
0.85	34.8						
0.9	51.1						
0.95	78.7						
1.0	OPEN						
1.05	121						
1.1	187						

Table 2. VSEL Pin Configuration

8.4.5 Prebiased Output Start-up

The device prevent current from being discharged from the output during start-up, when a pre-biased output condition exists. No SW pulses occur until the internal soft-start voltage rises above the error amplifier input voltage, if the output is pre-biased. As soon as the soft-start voltage exceeds the error amplifier input, and SW pulses start, the device limits synchronous rectification after each SW pulse with a narrow on-time. The low-side MOSFET on-time slowly increases on a cycle-by-cycle basis until 128 pulses have been generated and the synchronous rectifier runs fully complementary to the high-side MOSFET. This approach prevents the sinking of current from a pre-biased output, and ensures the output voltage start-up and ramp-to regulation sequences are smooth and monotonic.

8.4.6 Internal Ramp Generator

Internal ramp voltage is generated from duty cycle that contains emulated inductor ripple current information and then feed it back for control loop regulation and optimization according to required output power stage, duty ratio and switching frequency. Internal ramp amplitude is set by RAMP pin by adjusting an internal ramp generation capacitor C_{RAMP}, selected by the resistor connected from MODE pin to GND. For best performance, we recommend ramp signal to be no more than 4 times of output ripple signal for all Low ESR output capacitor (MLCC) applications, or no more than 2 times larger than output ripple signal for regular ESR output capacitor (Pos-cap) applications. For design recommendation, see the design tool at www.ti.com/WEBENCH.

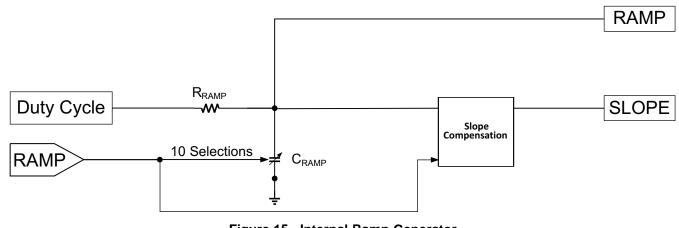


Figure 15. Internal Ramp Generator

The E48 series resistors with no worse than 1% tolerance are recommended



8.4.6.1 Ramp Selections

RAMP pin sets internal ramp amplitude for the control loop. RAMP amplitude is determined by internal RC, selected by the resistor connected from MODE pin to GND, to optimize the control loop. See Table 3.

Table 3. RAMP	Pin-Strapping	Selection
---------------	---------------	-----------

C _{RAMP} (pF)	RESISTOR VALUE (kΩ) ⁽¹⁾
1	0
1.42	8.66
1.94	15.4
2.58	23.7
3.43	34.8
4.57	51.1
6.23	78.7
8.91	121
14.1	187
29.1	Open

The E48 series resistors with tolerance of 1% or less are recommended.

8.4.7 Switching Frequency

The converter supports analog frequency selections from 300 kHz to 2 MHz, for stand alone device and sync frequency from 300 kHz to 1 MHz for stackable configuration. The RT pin also sets clock sync point (SP) for the slave device.

Switching Frequency Configuration for Stand-alone and Master Device in Stackable Configuration

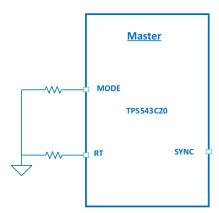


Figure 16. Standalone: RT Pin Sets the Switching Frequency

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(1)

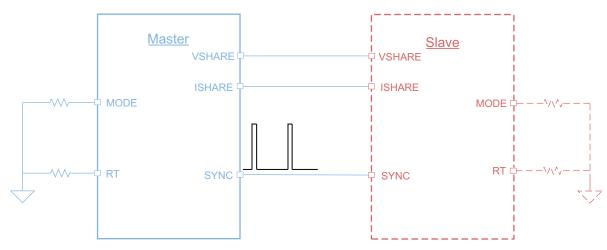


Figure 17. Stackable: Master (as Clock Master) RT Pin Sets Switching Frequency, and passes it to Slave

Resistor R_{RT} sets the continuous switching frequence selection by

$$R_{RT} = \frac{20 \times 10^9}{f_{SW}} - \frac{f_{SW} \times 2}{2000}$$

where

- R is the resistor from RT pin to GND, in Ω
- f_{SW} is the desired switching frequency, in Hz

8.4.8 Clock Sync Point Selection

The device implements an unique clock sync scheme for phase interleaving during stackable configuration. The device will receive the clock through sync pin and generate sync points for another device to sync to one of them to achieve phase interleaving. Sync point options can be selected through RT pin when 1) device is configurated as master sync in, 2) device is configured as slave. See Table 5 for control mode selection.

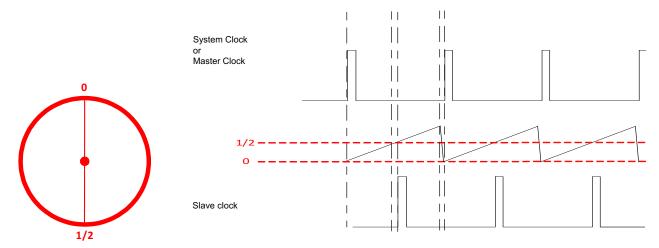


Figure 18. 2-Phase Stackable with 180° Clock Phase Shift

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CLOCK SYNC OPTIONS	RESISTOR VALUE (kΩ)
0 (0° Interleaving)	0
1/4 (90° Interleaving)	8.66
1/3 (120° Interleaving)	15.4
2/3 (240° Interleaving)	23.7
3/4 (270° Interleaving)	34.8
1/2 (180° Interleaving)	OPEN

8.4.9 Synchronization and Stackable Configuration

The device can synchronize to an external clock which must be equal to or higher than internal frequency setting. For stand alone device, the external clock should be applied to the SYNC pin before VDD ramps up. A sudden change in synchronization clock frequency causes an associated control loop response, resulting in an overshoot or undershoot on the output voltage.

In dual phase stackable configuration:

- 1. when there is no external system clock applied, the master device will be configured as clock master, sending out pre-set switching frequency clock to slave device through SYNC pin. Slave receives this clock as switching clock with phase interleaving.
- 2. when a system clock is applied, both master and slave devices will be configured as clock slave, they sync to the external system clock as switching frequency with proper phase shift

8.4.10 Dual-Phase Stackable Configurations

8.4.10.1 Configuration 1: Master Sync Out Clock-to-Slave

- Direct SYNC, VSHARE and ISHARE connections between master and slave.
- Switching frequency is set by RT pin of master, and pass to slave through SYNC pin. SYNC pin of master will be configured as sync out by it's MODE pin.
- Slave receives clock from SYNC pin. Its RT pin determines the sync point for clock phase shift.

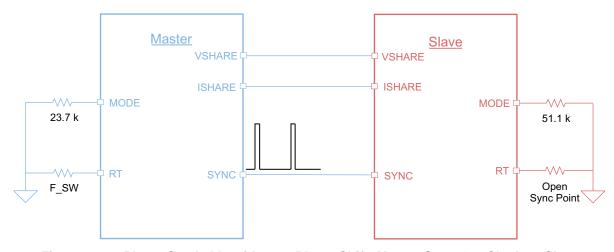


Figure 19. 2-Phase Stackable with 180° Phase Shift: Master Sync Out Clock-to-Slave

8.4.10.2 Configuration 2: Master and Slave Sync to External System Clock

- Direct connection between external clock and SYNC pin of master and slave.
- Direct VSHARE and ISHARE connections between master and slave.
- SYNC pin of master is configured as sync in by its MODE pin.
- Master and slave receive external system clock from SYNC pin. Their RT pin determine the sync point for clock phase shift.



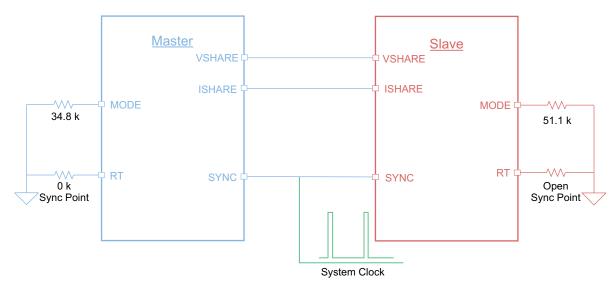


Figure 20. 2-Phase Stackable with 180° Phase Shift: Master and Slave Sync to External System Clock

8.4.11 Operation Mode

The operation mode and API/body brake feature is set by the MODE pin. They are selected by the resistor connected from MODE pin to GND. Mode pin sets the device to be stand-alone mode or stackable mode. In stand-alone mode, MODE pin sets the API on/off or trigger point sensitivity of API (1x stands for most sensitive and 4x stands for least sensitive). In stackable mode, the MODE pin sets the device as master or slave, as well as SYNC pin function (sync in or sync out) of the master device.

Table of Medal 1 in Strapping Colocium							
CONTROL MODE SELECTION API/BODY BRAKE		RESISTOR VALUE ($k\Omega$) and API/BB Threshold (1)	NOTE				
	API OFF BB OFF	Open					
Ctandalana	API ON BB OFF	15.4, API = 35 mV	Supposition to receive electric				
Standalone API/body brake	API ON BB ON (API Threshold Setting) 187, API = 25 mV, BB = 3 8.66, API = 35 mV, BB = 3	121, API = 15 mV, BB = 30 mV	Sync pin to receive clockRT pin to set frequency				
		187, API = 25 mV, BB = 30 mV	,				
		8.66, API = 35 mV, BB = 30 mV					
		78.7, API = 45 mV, BB = 30 mV					
(Master sync out)		23.7	Sync pin to send out clockRT pin to set frequency				
(Master sync in)	API OFF BB OFF	34.8	Sync pin to receive clockRT pin to set sync point				
(Slave sync In)		51.1	Sync pin to receive clockRT pin to set sync point				

Table 5. MODE Pin-Strapping Selection

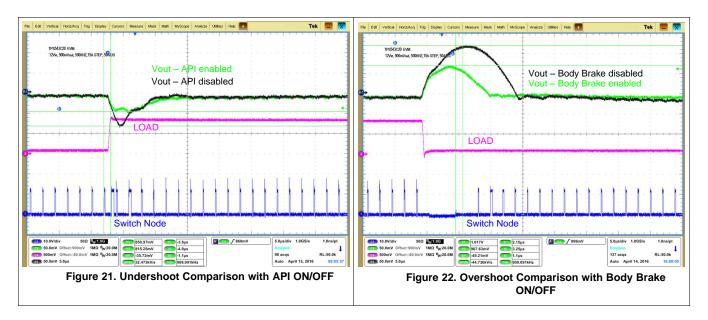
8.4.12 API/Body Brake

is a true fixed frequency converter. The major limitation for any fixed frequency converter is that during transient load step up, the converter needs to wait for the next clock cycle to response to the load change, depending on loop bandwidth design and the timing of load transient, this delay time could cause additional output voltage drop, implements a special circuitry to improve transient performance. During load step up, the converter senses both the speed and the amplitude of the output voltage change, if the output voltage change is fast and big enough, the converter will issue an additional PWM pulse before the next available clock cycle to stop output voltage from further dropping, thus reducing the undershoot voltage.

⁽¹⁾ The E48 series resistors with tolerance of 1% or less are recommended.

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During load step-down, implements a body-brake function, that turns off both high-side and lowside FET, and allows power to dissipate through the low-side body diode, reducing overshoot. This approach is very effective while having some impact on efficiency during transient. See Figure 21 and Figure 22.



8.4.13 Sense and Overcurrent Protection

8.4.13.1 Low-Side MOSFET Overcurrent Protection

The utilizes ILIM pin to set the OCP level. The ILIM pin must be connected to AGND through the ILIM voltage setting resistor, RILIM. The ILIM terminal sources IILIM current, which is around 11.2 µA typically at room temperature, and the ILIM level is set to the OCP ILIM voltage VILIM as shown in Equation 2. In order to provide both good accuracy and cost effective solution, supports temperature compensated MOSFET R_{DS(on)} sensing.

$$V_{ILIM}(mV) = R_{ILIM}(k\Omega) \times I_{ILIM}(\mu A)$$
Consider $R_{DS(on)}$ variation vs VDD in calculation (2)

Also, performs both positive and fixed negative inductor current limiting.

The inductor current is monitored by the voltage between GND pin and SW pin during the OFF time. ILIM has 1200 ppm/°C temperature slope to compensate the temperature dependency of the R_{DS(on)}. The GND pin is used as the positive current sensing node.

The device has cycle-by-cycle over-current limiting control. The inductor current is monitored during the OFF state and the controller maintains the OFF state during the period that the inductor current is larger than the overcurrent ILIM level. VILIM sets the peak level of the inductor current. Thus, the load current at the overcurrent threshold, I_{OCP}, can be calculated as shown in .

$$\begin{split} &I_{\text{OCP}} = V_{\text{ILIM}}/(16 \times R_{\text{DS(on)}}) - I_{\text{IND(ripple)}}/2 \\ &= \frac{V_{\text{ILIM}}}{16 \times R_{\text{DS(on)}}} - \frac{1}{2 \times L \times f_{\text{SW}}} \times \frac{(V_{\text{IN}} - V_{\text{OUT}}) \times V_{\text{OUT}}}{V_{\text{IN}}} \end{split}$$

where

R_{DS(on)} is the on-resistance of the low-side MOSFET. (3)

Equation 3 is valid for VDD \geq 5 V. Use 0.58 m Ω for R_{DS(on)} in calculation, which is the pure on-resistance for current sense.

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If an overcurrent event is detected in a given switching cycle, the device increments an overcurrent counter. When the device detects three consecutive overcurrent (either high-side or low-side) events, the converter responds, entering continuous restart hiccup. In continuous hiccup mode, the device implements a 7 soft-start cycle timeout, followed by a normal soft-start attempt. When the overcurrent fault clears, normal operation resumes; otherwise, the device detects overcurrent and the process repeats.

8.4.13.2 High-Side MOSFET Overcurrent Protection

The device also implements a fixed high-side MOSFET overcurrent protection to limit peak current, and prevent inductor saturation in the event of a short circuit. The device detects an overcurrent event by sensing the voltage drop across the high-side MOSFET during ON state. If the peak current reaches the IHOSC level on any given cycle, the cycle terminates to prevent the current from increasing any further. High-side MOSFET overcurrent events are counted. If the devices detect three consecutive overcurrent events (high-side or low-side), the converter responds by entering continuous restart hiccup.

8.4.14 Output Overvoltage and Undervoltage Protection

The device includes both output overvoltage protection and output undervoltage protection capability. The devices compare the RSP pin voltage to internal selectable pre-set voltages. If the RSP voltage with respect to RSN voltage rises above the output overvoltage protection threshold, the device terminates normal switching and turns on the low-side MOSFET to discharge the output capacitor and prevent further increases in the output voltage. Then the device enters continuous restart hiccup.

If the RSP pin voltage falls below the undervoltage protection level, after soft-start has completed, the device terminates normal switching and forces both the high-side and low-side MOSFETs off, then enters hiccup time-out delay prior to restart.

8.4.15 Overtemperature Protection

An internal temperature sensor protects the devices from thermal runaway. The internal thermal shutdown threshold, T_{SD} , is fixed at 165°C typical. When the devices sense a temperature above T_{SD} , power conversion stops until the sensed junction temperature falls by the thermal shutdown hysteresis amount; then, the device starts up again.

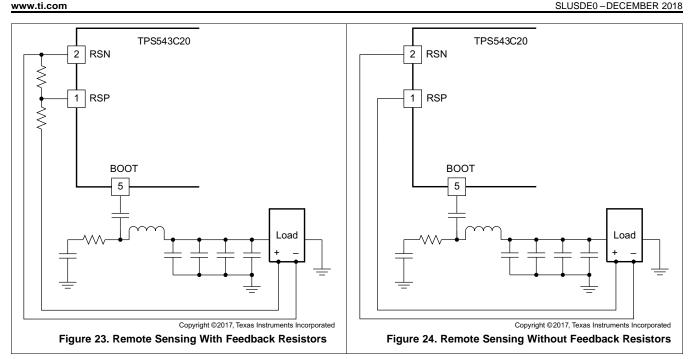
8.4.16 RSP/RSN Remote Sense Function

RSP and RSN pins are used for remote sensing purpose. In the case where feedback resistors are required for output voltage programming, the RSP pin should be connected to the mid-point of the resistor divider and the RSN pin should always be connected to the load return.

When feedback resistors are not required as when the VSEL programs the output voltage set point, connect the RSP pin to the positive sensing point of the load and the RSN pin should always be connected to the load return. RSP and RSN pins are extremely high-impedance input terminals of the true differential remote sense amplifier. The feedback resistor divider should use resistor values much less than $100 \text{ k}\Omega$. A simple rule of thumb is to use a $10\text{-k}\Omega$ lower divider resistor and then size the upper resistor to achieve the desired ratio.

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8.4.17 Current Sharing

When devices operate in dual-phase stackable application, a current sharing loop maintains the current balance between devices. Both devices share the same internal control voltage through VSHARE pin. The sensed current in each phase is compared first in a current share block by connecting ISHARE pin of each device, then the error current is added into the internal loop. The resulting voltage is compared with the PWM ramp to generate the PWM pulse.

8.4.18 Loss of Synchronization

During sync clock condition, each individual converter will continuously compare current falling edge and previous falling edge, if current falling edge exceeded a 1us delay versus previous pulse, converter will declare a lost sync fault, and response by pulling down ISHARE to shut down all phases.

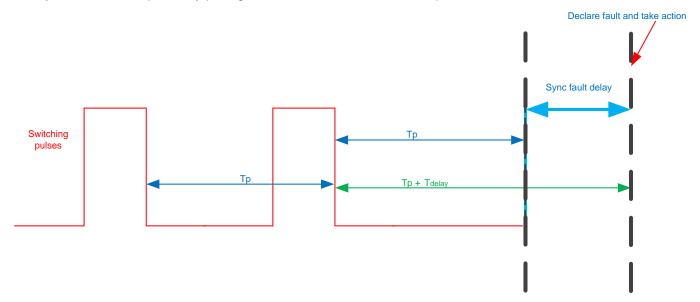


Figure 25. Switching Response When Sync Clock Lost

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9 Application 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 TPS543C20A device is a highly-integrated synchronous step-down DC/DC converter. The device is used to convert a higher DC input voltage to a lower DC output voltage, with a maximum output current of 40 A. Use the following design procedure to select key component values for this device.

9.2 Typical Application: TPS543C20A Stand-alone Device

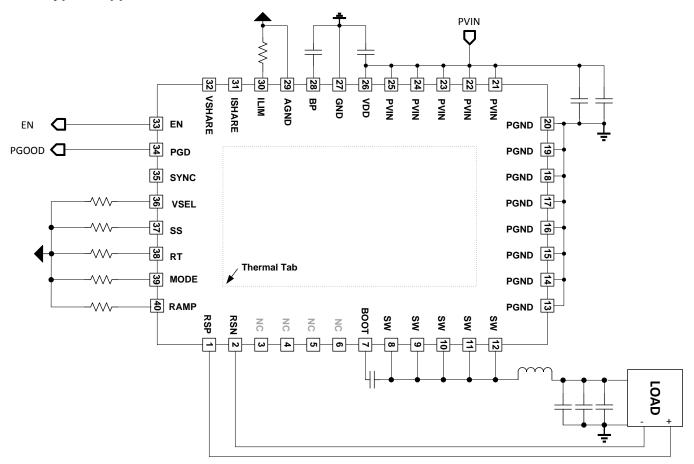


Figure 26. 4.5-V to 16-V Input, 1-V Output, 40-A Converter

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9.2.1 Design Requirements

For this design example, use the input parameters shown in Table 6.

Table 6. Design Example Specifications

	PARAMETER	TEST CONDITION	MIN	TYP	MAX	UNIT
V _{IN}	Input voltage		4	12		V
V _{IN(ripple)}	Input ripple voltage	I _{OUT} = A			0.4	V
V _{OUT}	Output voltage			0.9		V
	Line regulation	5 V ≤ V _{IN} ≤ 16 V			0.5%	
	Load regulation	0 V ≤ I _{OUT} ≤ A			0.5%	
V _{PP}	Output ripple voltage	I _{OUT} = A		20		mV
V _{OVER}	Transient response overshoot	I _{STEP} = 10 A		50		mV
V _{UNDER}	Transient response undershoot	I _{STEP} = 10A		50		mV
I _{OUT}	Output current	5 V ≤ V _{IN} ≤ 16 V		35	40	Α
t _{SS}	Soft-start time	V _{IN} = 12 V		4		ms
loc	Overcurrent trip point ⁽¹⁾			45		Α
η	Peak efficiency	I _{OUT} = A, V _{IN} = 12 V, V _{DD} = 5 V		90%		
f _{SW}	Switching frequency		300	500	700	kHz

⁽¹⁾ DC overcurrent level

9.2.2 Detailed Design Procedure

9.2.2.1 Custom Design With WEBENCH® Tools

Click here to create a custom design using the TPS543C20A device with the WEBENCH® Power Designer.

- 1. Start by entering the input voltage (V_{IN}), output voltage (V_{OUT}), and output current (I_{OUT}) requirements.
- 2. Optimize the design for key parameters such as efficiency, footprint, and cost using the optimizer dial.
- 3. Compare the generated design with other possible solutions from Texas Instruments.

The WEBENCH Power Designer provides a customized schematic along with a list of materials with real-time pricing and component availability.

In most cases, these actions are available:

- Run electrical simulations to see important waveforms and circuit performance
- Run thermal simulations to understand board thermal performance
- Export customized schematic and layout into popular CAD formats
- · Print PDF reports for the design, and share the design with colleagues

Get more information about WEBENCH tools at www.ti.com/WEBENCH.

9.2.2.2 Switching Frequency Selection

Select a switching frequency for the TPS543C20A. There is a trade off between higher and lower switching frequencies. Higher switching frequencies may produce smaller solution size using lower valued inductors and smaller output capacitors compared to a power supply that switches at a lower frequency. However, the higher switching frequency causes extra switching losses, which decrease efficiency and impact thermal performance. In this design, a moderate switching frequency of 500 kHz achieves both a small solution size and a high efficiency operation is selected. The device supports continuous switching frequency programming; see Equation 4. additional considerations (internal ramp compensation) other than switching frequency need to be included.

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$$R_{RT} = \frac{20 \times 10^9}{500 \times 10^3} - 2 \times \frac{500 \times 10^3}{2000} = 39.5 \text{ k}\Omega$$
(4)

In this case, a standard resistor value of 40.2 k Ω is selected.

9.2.2.3 Inductor Selection

To calculate the value of the output inductor (L), use Equation 5. The coefficient K_{IND} represents the amount of inductor-ripple current relative to the maximum output current. The output capacitor filters the inductor-ripple current. Therefore, selecting a high inductor-ripple current impacts the selection of the output capacitor because the output capacitor must have a ripple-current rating equal to or greater than the inductor-ripple current. Generally, the K_{IND} must be kept between 0.1 and 0.3 for balanced performance. Using this target ripple current, the required inductor size can be calculated as shown in .

$$L = \frac{V_{OUT}}{V_{IN} \times f_{SW}} - \frac{V_{IN} - V_{OUT}}{I_{OUT} \times KIND} = \frac{1 \text{ V} \times (12 \text{ V} - 1 \text{V})}{12 \text{ V} \times 500 \text{ kHz} \times 40 \text{ A} \times 0.1} = 458 \text{ nH}$$
(5)

A standard inductor value of 470 nH is selected. For this application, Wurth 744309047 was used from the weborderable EVM.

9.2.2.4 Input Capacitor Selection

The TPS543C20A devices require a high-quality, ceramic, type X5R or X7R, input decoupling capacitor with a value of at least 1 µF of effective capacitance on the VDD pin, relative to AGND. The power stage input decoupling capacitance (effective capacitance at the PVIN and PGND pins) must be sufficient to supply the high switching currents demanded when the high-side MOSFET switches on, while providing minimal input voltage ripple as a result. This effective capacitance includes any DC bias effects. The voltage rating of the input capacitor must be greater than the maximum input voltage. The capacitor must also have a ripple current rating greater than the maximum input current ripple to the device during full load. The input ripple current can be calculated using Equation 6.

$$I_{CIN(rms)} = I_{OUT(max)} \times \sqrt{\frac{V_{OUT}}{V_{IN}}} \times \frac{(V_{IN} - V_{OUT})}{V_{IN}} = 16 \text{ Arms}$$
(6)

The minimum input capacitance and ESR values for a given input voltage ripple specification, $V_{IN(ripple)}$, are shown in Equation 7 and Equation 8. The input ripple is composed of a capacitive portion, V_{RIPPLE(cap)}, and a

shown in Equation 7 and Equation 8. The input ripple is composed of a capacitive portion,
$$V_{RIPPLE(cap)}$$
, and a resistive portion, $V_{RIPPLE(esr)}$.

$$C_{IN(min)} = \frac{I_{OUT\,(max)} \times V_{OUT}}{V_{RIPPLE\,(cap)} \times V_{IN\,(max)} \times f_{SW}} = 38.5 \, \mu F \tag{7}$$

$$ESR_{CIN (max)} = \frac{V_{RIPPLE(ESR)}}{I_{OUT (max)} + \left(\frac{I_{RIPPLE}}{2}\right)} = 7 \text{ m}\Omega$$
(8)

The value of a ceramic capacitor varies significantly over temperature and the amount of DC bias applied to the capacitor. The capacitance variations due to temperature can be minimized by selecting a dielectric material that is stable over temperature. X5R and X7R ceramic dielectrics are usually selected for power regulator capacitors because they have a high capacitance to volume ratio and are fairly stable over temperature. The input capacitor must also be selected with the DC bias taken into account. For this example design, a ceramic capacitor with at least a 25-V voltage rating is required to support the maximum input voltage. For this design, allow 0.1-V input ripple for $V_{RIPPLE(cap)}$, and 0.3-V input ripple for $V_{RIPPLE(esr)}$. Using Equation 7 and Equation 8, the minimum input capacitance for this design is 38.5 μ F, and the maximum ESR is 9.4 $m\Omega$. For this example, four 22- μ F, 25-V ceramic capacitors and one additional 100-μF, 25-V low-ESR polymer capacitors in parallel were selected for the power stage.

9.2.2.5 Bootstrap Capacitor Selection

A ceramic capacitor with a value of 0.1 µF must be connected between the BOOT and SW pins for proper operation. It is recommended to use a ceramic capacitor with X5R or better grade dielectric. Use a capacitor with a voltage rating of 25 V or higher.

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9.2.2.6 BP Pin

Bypass the BP pin to GND with $4.7-\mu F$ of capacitance. In order for the regulator to function properly, it is important that these capacitors be localized to the TPS543C20A, with low-impedance return paths. See *Power Good and Enable* section for more information.

9.2.2.7 R-C Snubber and VIN Pin High-Frequency Bypass

Though it is possible to operate the TPS543C20A within absolute maximum ratings without ringing reduction techniques, some designs may require external components to further reduce ringing levels. This example uses two approaches: a high frequency power stage bypass capacitor on the VIN pins, and an R-C snubber between the SW area and GND.

The high-frequency VIN bypass capacitor is a lossless ringing reduction technique which helps minimizes the outboard parasitic inductances in the power stage, which store energy during the low-side MOSFET on-time, and discharge once the high-side MOSFET is turned on. For this example twin 2.2-nF, 25-V, 0603-sized high-frequency capacitors are used. The placement of these capacitors is critical to its effectiveness.

Additionally, an R-C snubber circuit is added to this example. To balance efficiency and spike levels, a 1-nF capacitor and a 1- Ω resistor are chosen. In this example a 0805-sized resistor is chosen, which is rated for 0.125 W, nearly twice the estimated power dissipation. See SLUP100 for more information about snubber circuits.

9.2.2.8 Output Capacitor Selection

There are three primary considerations for selecting the value of the output capacitor. The output capacitor affects three criteria:

- Stability
- · Regulator response to a change in load current or load transient
- Output voltage ripple

These three considerations are important when designing regulators that must operate where the electrical conditions are unpredictable. The output capacitance needs to be selected based on the most stringent of these three criteria.

9.2.2.8.1 Response to a Load Transient

The output capacitance must supply the load with the required current when current is not immediately provided by the regulator. When the output capacitor supplies load current, the impedance of the capacitor greatly affects the magnitude of voltage deviation (such as undershoot and overshoot) during the transient.

Use Equation 9 and Equation 10 to estimate the amount of capacitance needed for a given dynamic load step and release.

NOTE

There are other factors that can impact the amount of output capacitance for a specific design, such as ripple and stability.

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$$C_{OUT(min_under)} = \frac{L \times \Delta I_{LOAD(max)}^{2}}{2 \times \Delta V_{LOAD(INSERT)} \times (V_{IN}^{-}V_{VOUT})} + \frac{\Delta I_{LOAD(max)} \times (1-D) \times t_{SW}}{\Delta V_{LOAD(INSERT)}}$$

$$C_{OUT(min_over)} = \frac{L_{OUT} \times \left(\Delta I_{LOAD(max)}\right)^{2}}{2 \times \Delta V_{LOAD(release)} \times V_{OUT}}$$
(9)

where

- C_{OUT(min under)} is the minimum output capacitance to meet the undershoot requirement
- C_{OUT(min_over)} is the minimum output capacitance to meet the overshoot requirement
- D is the duty cycle
- L is the output inductance value (0.47 μH)
- $\Delta I_{LOAD(max)}$ is the maximum transient step (10 A)
- V_{OUT} is the output voltage value (900 mV)
- t_{SW} is the switching period (2 μs)
- \bullet V_{IN} is the minimum input voltage for the design (12 V)
- ΔV_{LOAD(insert)} is the undershoot requirement (50 mV)
- ΔV_{LOAD(release)} is the overshoot requirement (50 mV)
- This example uses a combination of POSCAP and MLCC capacitors to meet the overshoot requirement.
 - POSCAP bank #1: 2 x 330 μF, 2.5 V, 3 mΩ per capacitor
 - MLCC bank #2: $3 \times 100 \mu F$, 6.3 V, 1 m Ω per capacitor

9.2.2.8.2 Ramp Selection Design to Ensure Stability

Certain criteria is recommended for to achieve optimized loop stability, bandwidth and switching jitter performance. As a rule of thumb, the internal ramp voltage should be $2{\sim}4$ times bigger than the output capacitor ripple(capacitive ripple only). is defined to be ease-of-use, for most applications, TI recommends ramp resistor to be 187 k Ω to achieve the optimized jitter and loop response. For detailed design procedure, see the WEBENCH® Power Designer.

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STRUMENTS

(10)

9.2.3 Application Curves

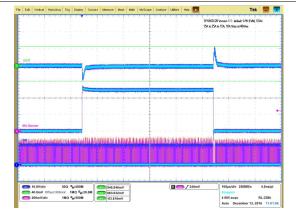


Figure 27. Transient Response of 0.9-V Output at 12-V_{IN}, Transient is 15 A to 25 A to 15 A, the Step is 10 A at 40 A/µs

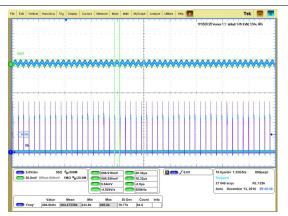


Figure 28. Output Ripple and SW Node of 0.9-V Output at 12-V_{IN}, -A Output

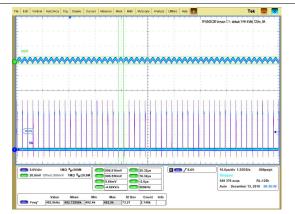


Figure 29. Output Ripple and SW Node of 0.9-V Output at 12-V_{IN}, 0-A Output

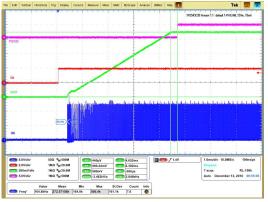


Figure 30. Start up from Control, 0.9-V Output at 12-V_{IN}, 10-mA Output

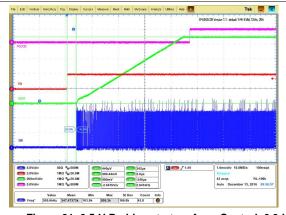


Figure 31. 0.5-V Prebias start up from Control, 0.9-V Output at 12-V_{IN}, 20-A Output

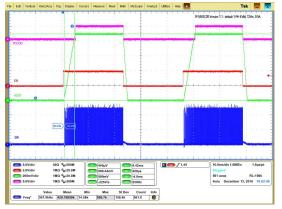


Figure 32. Output Voltage Start-up and Shutdown, 0.9-V Output at 12-V_{IN}, 0.5-A Output

TEXAS INSTRUMENTS

9.3 System Example

9.3.1 Two-Phase Stackable

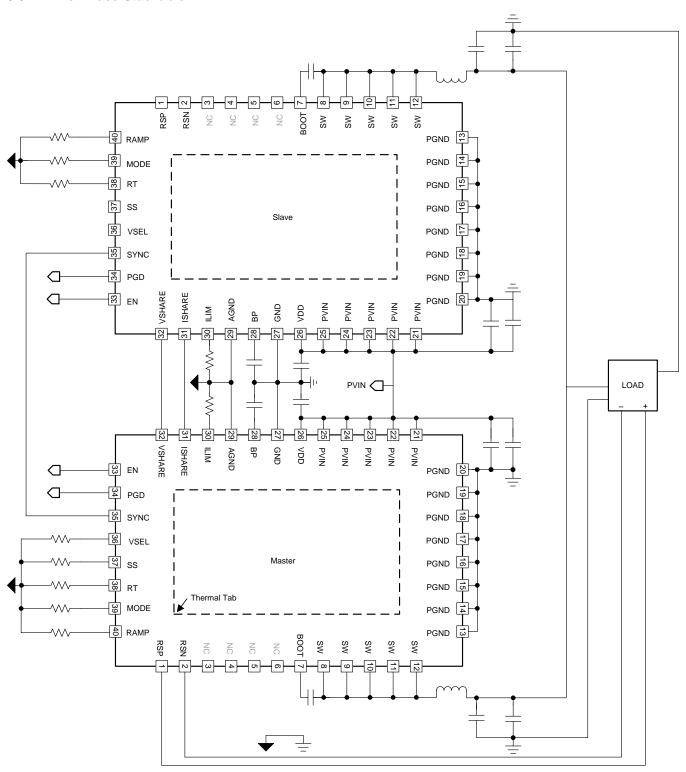


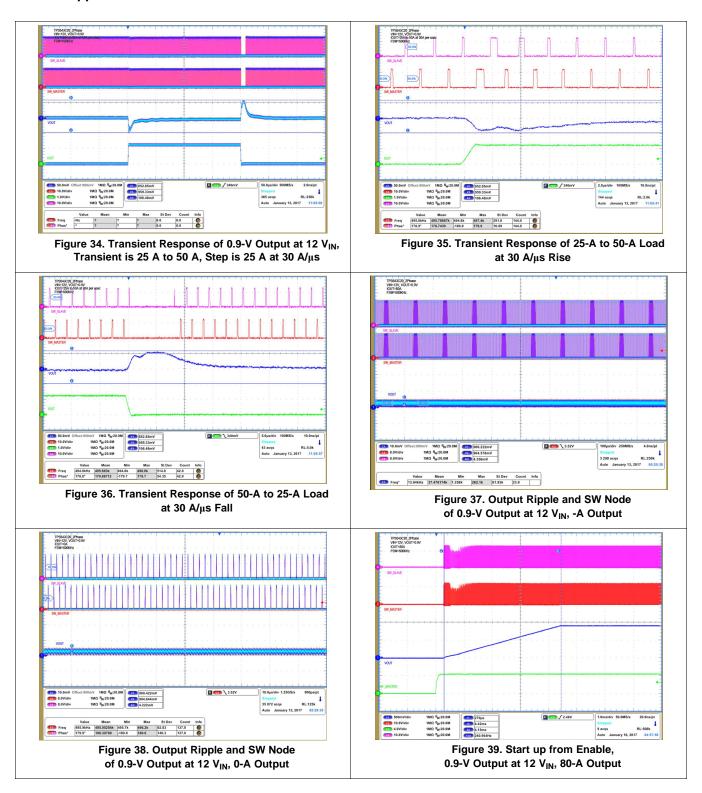
Figure 33. 2-Phase Stackable

See Synchronization and Stackable Configuration section.

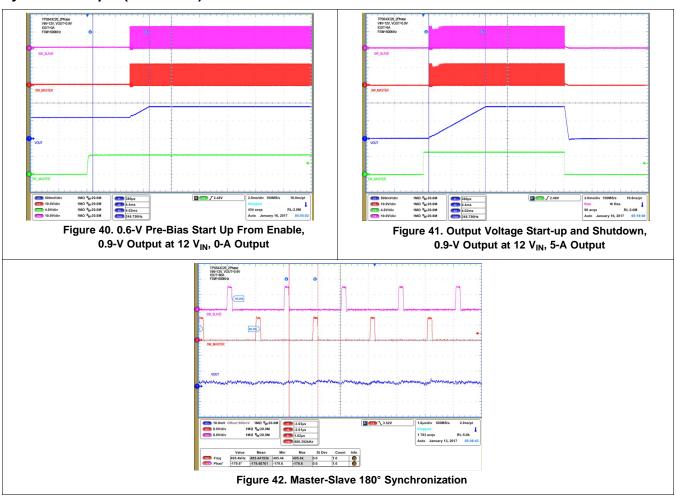
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System Example (continued)

9.3.1.1 Application Curves



System Example (continued)



10 Power Supply Recommendations

This device is designed to operate from an input voltage supply between 4 V and 16 V. Ensure the supply is well regulated. Proper bypassing of input supplies and internal regulators is also critical for noise performance, as is the quality of the PCB layout and grounding scheme. See the recommendations in *Layout*.

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11 Layout

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11.1 Layout Guidelines

- It is absolutely critical that all GND pins, including AGND (pin 29), GND (pin 27), and PGND (pins 13, 14, 15, 16, 17, 18, 19, and 20) are connected directly to the thermal pad underneath the device via traces or plane. The number of thermal vias needed to support 40-A thermal operation should be as many as possible; in the EVM design orderable on the Web, a total of 23 thermal vias are used. The TPS543C20EVM-799 is available for purchase at ti.com.
- Place the power components (including input/output capacitors, output inductor, and TPS543C20 device) on one side of the PCB (solder side). At least one or two innner layers/planes must be inserted, connecting to power ground, in order to shield and isolate the small signal traces from noisy power lines.
- Place the VIN decoupling capacitors as close to the PVIN and PGND as possible to minimize the input AC current loop. The high frequency decoupling capacitor (1 nF to 0.1 μF) should be placed next to the PVIN pin and PGND pin as close as the spacing rule allows. This helps surpressing the switch node ringing.
- Place a 10-nF to 100-nF capacitor close to IC from Pin 25 VIN to Pin 27 GND.
- Place VDD and BP decoupling capacitors as close to the device pins as possible. Do not use PVIN plane
 connection for VDD. VDD needs to be tapped off from PVIN with separate trace connection. Ensure to
 provide GND vias for each decoupling capacitor and make the loop as small as possible.
- The PCB trace defined as switch node, which connects the SW pins and up-stream of the output inductor should be as short and wide as possible. In web orderable EVM design, the SW trace width is 400 mil. Use separate via or trace to connect SW node to snubber and bootstrap capacitor. Do not combine these connections
- All sensitive analog traces and components such as RAMP, RSP, RSN, ILIM, MODE, VSEL and RT should be placed away from any high voltage switch node (itself and others), such as SW and BOOT to avoid noise coupling. In addition, MODE, VSEL, ILIM, RAMP and RT programming resistors should be placed near the device/pins.
- The RSP and RSN pins operate as inputs to a differential remote sense amplifier that operates with very high impedance. It is essential to route the RSP and RSN pins as a pair of diff-traces in Kelvin-sense fashion. Route them directly to either the load sense points (+ and –) or the output bulk capacitors. The internal circuit uses the RSP pin for on-time adjustment. It is critical to tie the RSP pin directly tied to VOUT (load sense point) for accurate output voltage result.
- Use caution when routing of the SYNC, VSHARE and ISHARE traces for 2-phase configurations. The SYNC trace carries a rail-to-rail signal and should be routed away from sensitive analog signals, including the VSHARE, ISHARE, RT, and FB signals. The VSHARE and ISHARE traces should also be kept away from fast switching voltages or currents formed by the PVIN, AVIN, SW, BOOT, and BP pins.

Product Folder Links: TPS543C20A

11.2 Layout Example

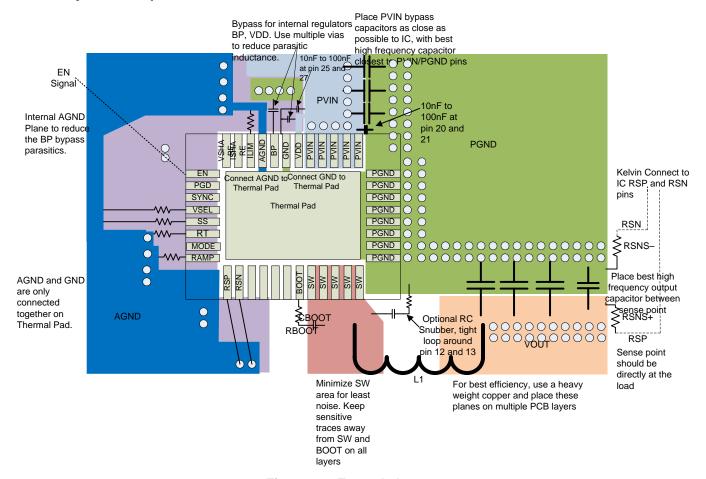


Figure 43. Example Layout

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11.3 Package Size, Efficiency and Thermal Performance

The TPS543C20A device is available in a 5 mm × 7 mm, QFN package with 40 power and I/O pins. It employs TI proprietary MCM packaging technology with thermal pad. With a properly designed system layout, applications achieve optimized safe operating area (SOA) performance. The curves shown in and are based on the orderable evaluation module design.

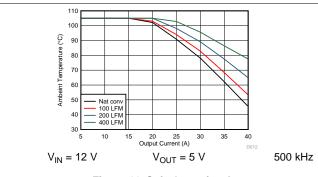


Figure 44. Safe Operating Area

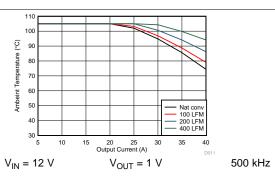


Figure 45. Safe Operating Area

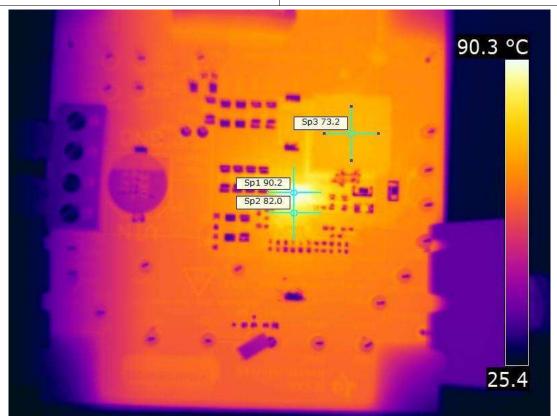


Figure 46. Thermal Image at 1.0-V Output at 12 $V_{\rm IN}$, 40-A Output, at 25°C Ambient

Package Size, Efficiency and Thermal Performance (continued)

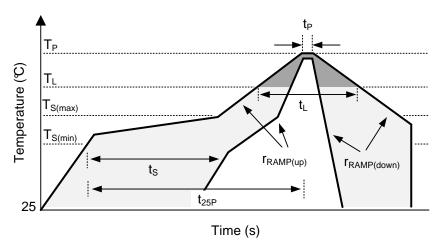


Figure 47. Recommended Reflow Oven Thermal Profile

Table 7. Recommended Thermal Profile Parameters

	PARAMETER	MIN	TYP	MAX	UNIT
RAMP UP	AND RAMP DOWN				
r _{RAMP(up)}	Average ramp-up rate, T _{S(MAX)} to T _P			3	°C/s
r _{RAMP(down)}	Average ramp-down rate, T _P to T _{S(MAX)}			6	°C/s
PRE-HEAT					
T _S	Pre-heat temperature	150		200	°C
t _S	Pre-heat time, T _{S(min)} to T _{S(max)}	60		180	S
REFLOW					
TL	Liquidus temperature		217		°C
T _P	Peak temperature			260	°C
t_	Time maintained above liquidus temperature, T _L	60		150	s
t _P	Time maintained within 5°C of peak temperature, T _P	20		40	s
t _{25P}	Total time from 25°C of peak temperature, T _P			480	S

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12 Device and Documentation Support

12.1 Device Support

12.1.1 Development Support

12.1.1.1 Custom Design With WEBENCH® Tools

Click here to create a custom design using the TPS543C20A device with the WEBENCH® Power Designer.

- 1. Start by entering the input voltage (V_{IN}), output voltage (V_{OUT}), and output current (I_{OUT}) requirements.
- 2. Optimize the design for key parameters such as efficiency, footprint, and cost using the optimizer dial.
- 3. Compare the generated design with other possible solutions from Texas Instruments.

The WEBENCH Power Designer provides a customized schematic along with a list of materials with real-time pricing and component availability.

In most cases, these actions are available:

- Run electrical simulations to see important waveforms and circuit performance
- Run thermal simulations to understand board thermal performance
- · Export customized schematic and layout into popular CAD formats
- · Print PDF reports for the design, and share the design with colleagues

Get more information about WEBENCH tools at www.ti.com/WEBENCH.

12.1.2 Documentation Support

12.1.2.1 Related Documentation

For related documentation see the following:

TPS543C20A 40-A Single Phase Synchronous Step-Down Converter

12.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

12.3 Community Resources

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, 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.

12.4 Trademarks

NexFET, PowerStack, E2E are trademarks of Texas Instruments. WEBENCH is a registered trademark of Texas Instruments. All other trademarks are the property of their respective owners.

12.5 Electrostatic Discharge Caution



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

SLUSDE0 – DECEMBER 2018 www.ti.com

TEXAS INSTRUMENTS

12.6 Glossary

SLYZ022 — TI Glossary.

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

13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

www.ti.com 10-Nov-2025

PACKAGING INFORMATION

Orderable part number	Status	Material type	Package Pins	Package qty Carrier	RoHS	Lead finish/	MSL rating/	Op temp (°C)	Part marking
	(1)	(2)			(3)	Ball material	Peak reflow		(6)
						(4)	(5)		
TPS543C20ARVFR	Active	Production	LQFN-CLIP (RVF) 40	2500 LARGE T&R	ROHS Exempt	NIPDAU SN	Level-2-260C-1 YEAR	-40 to 125	TPS543C20A
TPS543C20ARVFR.A	Active	Production	LQFN-CLIP (RVF) 40	2500 LARGE T&R	ROHS Exempt	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	TPS543C20A
TPS543C20ARVFR.B	Active	Production	LQFN-CLIP (RVF) 40	2500 LARGE T&R	-	Call TI	Call TI	-40 to 125	
TPS543C20ARVFRG4	Active	Production	LQFN-CLIP (RVF) 40	2500 LARGE T&R	ROHS Exempt	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	TPS543C20A
TPS543C20ARVFRG4.A	Active	Production	LQFN-CLIP (RVF) 40	2500 LARGE T&R	ROHS Exempt	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	TPS543C20A
TPS543C20ARVFRG4.B	Active	Production	LQFN-CLIP (RVF) 40	2500 LARGE T&R	-	Call TI	Call TI	-40 to 125	

⁽¹⁾ Status: For more details on status, see our product life cycle.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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⁽²⁾ Material type: When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

⁽³⁾ RoHS values: Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

⁽⁴⁾ Lead finish/Ball material: Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

⁽⁵⁾ MSL rating/Peak reflow: The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

⁽⁶⁾ Part marking: There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.



PACKAGE OPTION ADDENDUM

www.ti.com 10-Nov-2025

PACKAGE MATERIALS INFORMATION

www.ti.com 18-Jun-2025

TAPE AND REEL INFORMATION





A0	Dimension designed to accommodate the component width
В0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing		SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	,	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPS543C20ARVFR	LQFN- CLIP	RVF	40	2500	330.0	16.4	5.35	7.35	1.7	8.0	16.0	Q1
TPS543C20ARVFRG4	LQFN- CLIP	RVF	40	2500	330.0	16.4	5.35	7.35	1.7	8.0	16.0	Q1

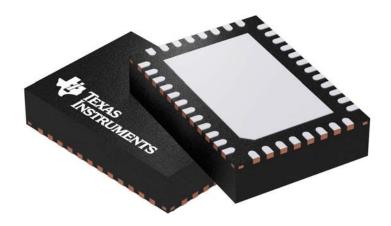
PACKAGE MATERIALS INFORMATION

www.ti.com 18-Jun-2025



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS543C20ARVFR	LQFN-CLIP	RVF	40	2500	367.0	367.0	38.0
TPS543C20ARVFRG4	LQFN-CLIP	RVF	40	2500	367.0	367.0	38.0

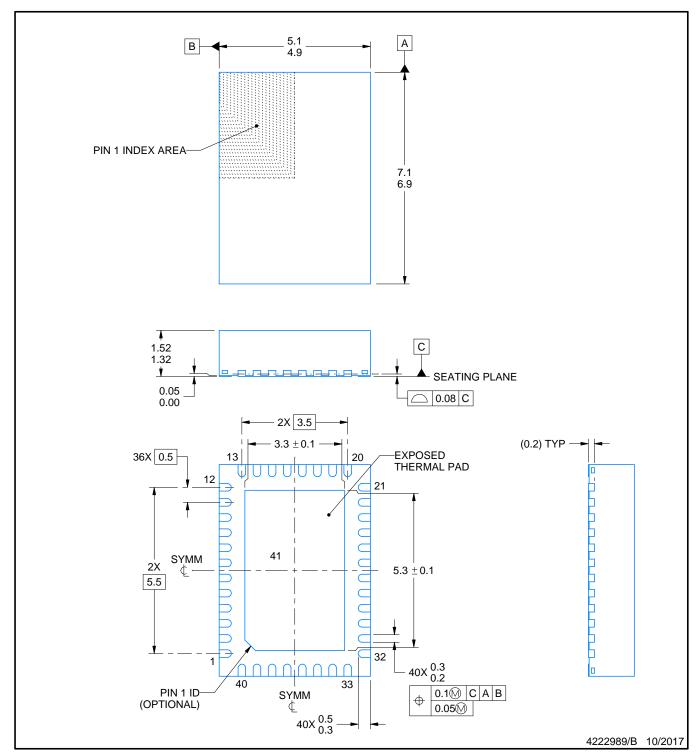


Images above are just a representation of the package family, actual package may vary. Refer to the product data sheet for package details.

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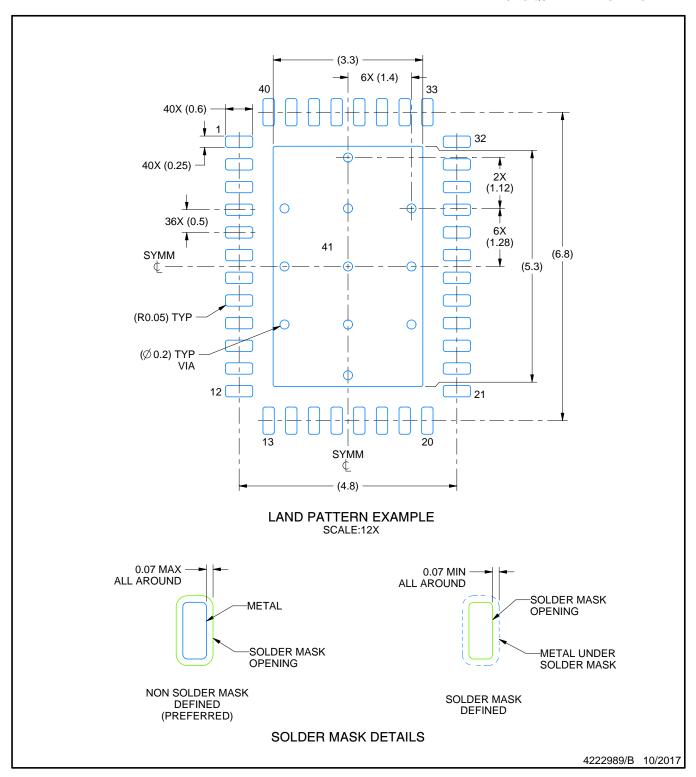




NOTES:

- 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.
- 4. Reference JEDEC registration MO-220.

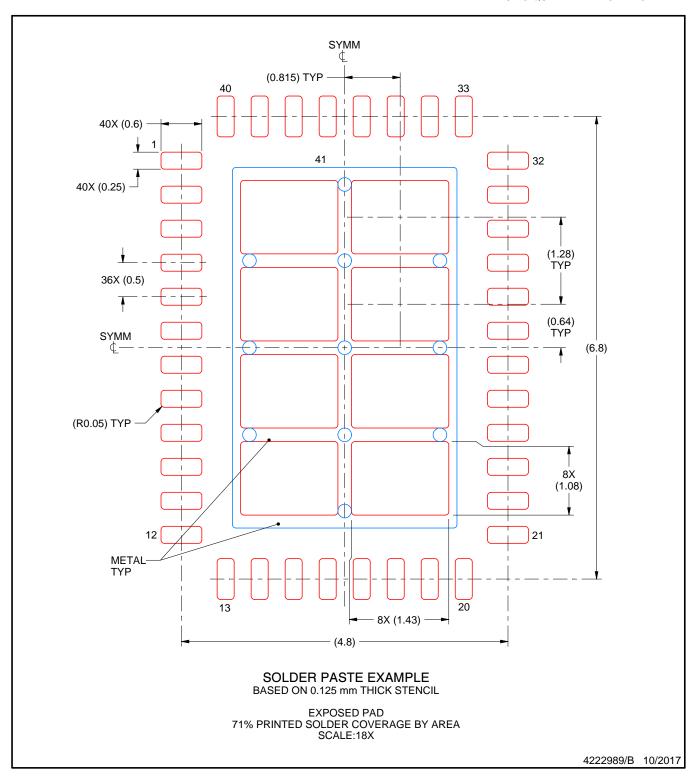




NOTES: (continued)

5. 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).





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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