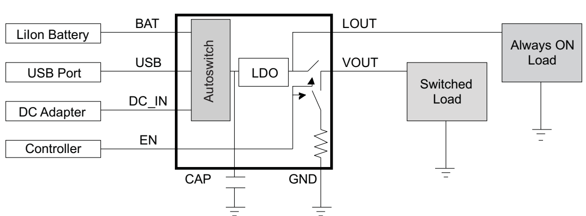
Small, Triple-Input Power Multiplexer with Auto-Select and Low Drop-out Voltage Regulator

Check for Samples: TPS22933

FEATURES

- **Three Integrated Load Switches Automatically Choose Highest Input**
- **Integrated 3.6-V fixed LDO**
- **Switched and Always on LDO Outputs**
- **Small μQFN package 1.5mm × 1.5mm**
- **Input Voltage Range: 2.5-V to 12-V**
- **Low ON-Resistance (r_{ON})**
  - **r_{ON} = 2.4Ω at VIN = 5.0-V**
  - **r_{ON} = 2.6Ω at VIN = 4.2-V**
- **50-mA Maximum Continuous Current**
- **Low Threshold Control Input (EN)**
- **Switchover time 18-μs Typical**

TYPICAL APPLICATION



APPLICATIONS

- **Smart Phones**
- **GPS Devices**
- **Digital Cameras**
- **Portable Industrial Equipment**
- **Portable Medical Equipment**
- **Portable Media Players**
- **Portable Instrumentation**

DESCRIPTION

The TPS22933 is a small, low r_{ON}, triple-input power multiplexer with auto-input selection and a Low Drop-Out linear regulator. The device contains three P-channel MOSFETs that can operate over an input voltage range of 2.5-V to 12-V. The TPS22933 automatically selects the highest level (from BAT, USB, and DC_IN) and enables that input to source the LDO. LOUT is an always-on output from the LDO. The Enable function (EN pin) allows VOUT to be switched on or off, enables a quick discharge resistor, and is capable of interfacing directly with low-voltage control signals.

The TPS22933 is available in a small, space-saving 8-pin μQFN package and is characterized for operation over the free-air temperature range of –40°C to 85°C.

FEATURE LIST(1)

	r_{ON} (typical) at 5.0 V	OUTPUT VOLTAGE	QUICK OUTPUT DISCHARGE	MAXIMUM OUTPUT CURRENT	VOUT ENABLE
TPS22933A	2.4 Ω	3.6 V	yes	50 mA	Active High

(1) This feature discharges the output of the switch to ground through a 64-Ω resistor, preventing the output from floating

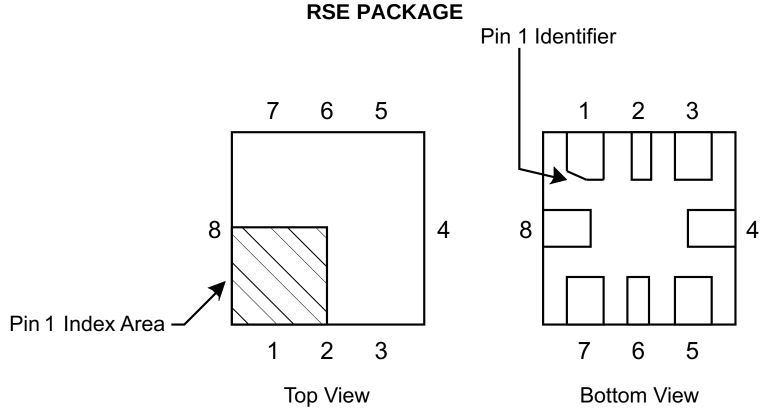
These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

ORDERING INFORMATION

T_A	PACKAGE[1]		ORDERABLE PART NUMBER	LDO VOLTAGE	TOP-SIDE MARKING
–40°C to 85°C	RSE (0.5mm pitch)	Reel of 3,000	TPS22933ARSER	3.6 V	4Q
		Reel of 250	TPS22933ARSET		

(1) Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

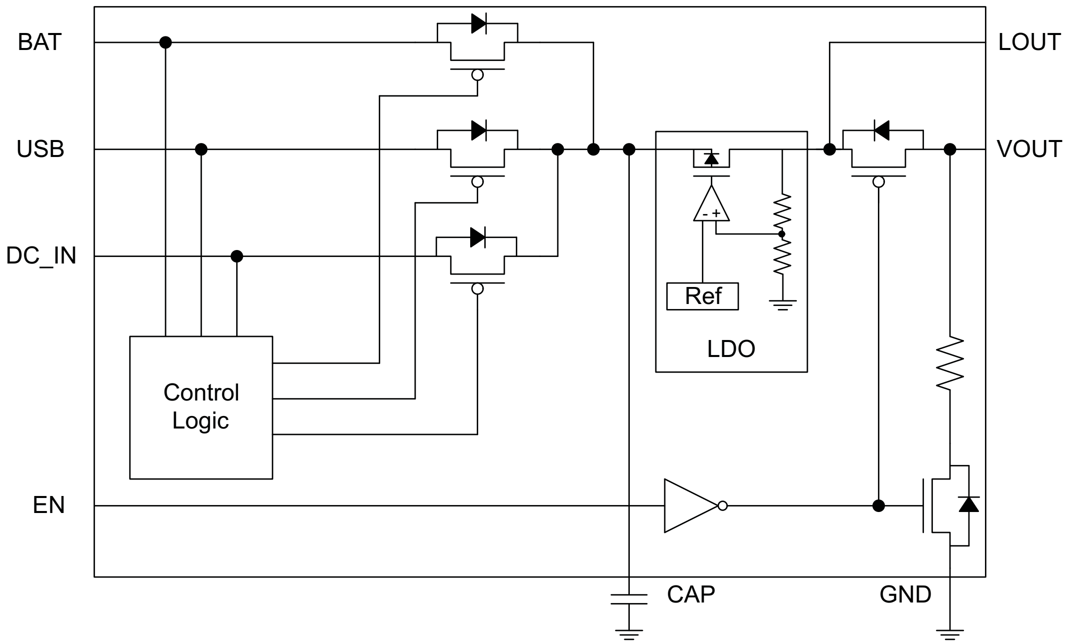
RSE PACKAGE



PIN FUNCTIONS

PIN		
NUMBER	NAME	DESCRIPTION
1	BAT	Source Voltage 1 (Battery)
2	USB	Source Voltage 2 (V+ USB)
3	DC_IN	Source Voltage 3 (DC Adapter)
4	GND	Ground
5	EN	VOUT Enable (Cannot be left floating)
6	CAP	Capacitor for LDO
7	VOUT	Switched LDO Output
8	LOUT	Always on LDO Output

BLOCK DIAGRAM



FUNCTION TABLE

EN	LDO to LOUT	LDO to VOUT	VOUT to GND
L	ON	OFF	ON
H	ON	ON	OFF

INPUT SELECTION TABLE (V1 > V2 > V3)

BAT	USB	DC_IN	LDO Supply
V1	V2 or V3	V2 or V3	BAT
V2 or V3	V1	V2 or V3	USB
V2 or V3	V2 or V3	V1	DC_IN
V1	V1	V1	See (1)

(1) Whichever source achieves the highest level the fastest will supply the LDO.

ABSOLUTE MAXIMUM RATINGS

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

			VALUE	UNIT
VIN	Input voltage range	BAT, USB, DC_IN	–0.3 to 14.0	V
VOUTPUT	Output voltage range	VOUT, LOUT	–0.3 to 6.0	V
VEN	Input voltage range	EN	–0.3 to 6.0	V
IMAX	Maximum continuous switch current		75	mA
IPLS	Maximum pulsed switch current, pulse <300 µs, 2% duty cycle		100	mA
T_A	Operating free-air temperature range		–40 to 85	°C
T_{stg}	Storage temperature range		–65 to 150	°C
T_{lead}	Maximum lead temperature (10-s soldering time)		300	°C
ESD	Electrostatic discharge protection	Human-Body Model (HBM)	2000	V
		Charged-Device Model (CDM)	1000	

THERMAL INFORMATION

THERMAL METRIC[1]		TPS22933 RSE (7 PINS)	UNITS
θ_{JA}	Junction-to-ambient thermal resistance	115.6	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance	59.9	
θ_{JB}	Junction-to-board thermal resistance	27.4	
ψ_{JT}	Junction-to-top characterization parameter	2.1	
ψ_{JB}	Junction-to-board characterization parameter	27.3	
θ_{JCbot}	Junction-to-case (bottom) thermal resistance	–	

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

RECOMMENDED OPERATING CONDITIONS

			MIN	TYP	MAX	UNIT
V_{IN}	Input voltage range	BAT, USB, DC_IN	2.5		12.0	V
V_{EN}		EN	0.0		5.5	V
V_{IH}	EN pin High-level input voltage, (EN > V_{IH} Min, VOUT = LDO Output)	BAT = 2.5-V to 5.5-V, USB, DC_IN = 2.5-V to 12-V	1.15		5.5	V
V_{IL}	EN pin Low-level input voltage, (EN< V_{IL} Max, VOUT = pull-down)	BAT = 2.5-V to 5.5-V, USB, DC_IN = 2.5-V to 12-V	0.0		0.6	V
$I_{OUT\text{-}LOUT}$	LOUT Current	V_{BAT} = 4.2 V OR V_{USB} = 5 V OR V_{DC_IN} = 5 V, EN = 3.4 V, $I_{OUT\text{-}VOUT}$ = 0 mA			50	mA
$I_{OUT\text{-}VOUT}$	VOUT Current	V_{BAT} = 4.2 V OR V_{USB} = 5 V OR V_{DC_IN} = 5 V, EN = 3.4 V, $I_{OUT\text{-}LOUT}$ = 0 mA			50	mA
$I_{OUT\text{-}TOTAL}$	LOUT + VOUT current	V_{BAT} = 4.2 V OR V_{USB} = 5 V OR V_{DC_IN} = 5 V, EN = 3.4 V			50	mA
CAP	LDO Capacitor (on CAP pin)		20[1]			nF
	LOUT Capacitor			1		μF
	VOUT Capacitor			1		μF

(1) Refer to the application section

ELECTRICAL CHARACTERISTICS

BAT = 2.5-V to 12.0-V, USB = 2.5-V to 12.0-V, DC_IN = 2.5-V to 12.0-V, T_A = –40ºC to 85ºC (unless otherwise noted)

PARAMETER		TEST CONDITIONS[1] [2] [3]	T_A	MIN	TYP[4]	MAX	UNIT
$I_{IN\text{-}BAT}$	Operating current	I_{OUT} = 0 mA, V_{BAT} = 4.2 V, V_{USB} = 3 V, V_{DC_IN} = 3 V, EN = 3.4 V	Full		9.2	15	µA
	Quiescent current	I_{OUT} = 0, V_{BAT} = 4.2 V, V_{USB} = 5 V, V_{DC_IN} = 3 V, EN = 3.4 V			0.7	2	
$I_{IN\text{-}USB}$	Operating current	I_{OUT} = 0 mA, V_{BAT} = 4.2 V, V_{USB} = 5 V, V_{DC_IN} = 3 V, EN = 3.4 V	Full		9.2	15	µA
	Quiescent current	I_{OUT} = 0, V_{BAT} = 4.2V, V_{USB} = 5V, V_{DC_IN} = 5.5V, EN = 3.4 V			0.7	2	
$I_{IN\text{-}DC\_IN}$	Operating current	I_{OUT} = 0 mA, V_{BAT} = 4.2 V, V_{USB} = 3 V, V_{DC_IN} = 5 V, EN = 3.4 V	Full		9.2	15	µA
	Quiescent current	I_{OUT} = 0, V_{BAT} = 4.2V, V_{USB} = 5.5V, V_{DC_IN} = 5V, EN = 3.4 V			0.7	2	
$I_{IN\text{-}USB}$	Hi-Voltage operating current	I_{OUT} = 0 mA, V_{BAT} = 4.2 V, V_{USB} = 12 V, V_{DC_IN} = 5 V, EN = 3.4 V	Full		10.8	20	µA
$I_{IN\text{-}DC\_IN}$	Hi-Voltage operating current	I_{OUT} = 0 mA, V_{BAT} = 4.2 V, V_{USB} = 5 V, V_{DC_IN} = 12 V, EN = 3.4 V	Full		10.8	20	µA
R_{ON}	ON resistance (USB to CAP, BAT to CAP, DC_IN to CAP)	V_{IN} = 5.0 V, I_{OUT} = 10 mA	25ºC		2.4	3.3	Ω
			Full			3.5	
		V_{IN} = 4.2 V, I_{OUT} = 10 mA	25ºC		2.6	3.5	Ω
			Full			4	
		V_{IN} = 2.5 V, I_{OUT} = 10 mA	25ºC		3.8	5	Ω
			Full			6	
R_{ONVOUT}	ON resistance (LDO output to VOUT)	V_{IN} = 4.2 V, $I_{OUT\text{-}VOUT}$ = 10 mA	25ºC		1.3	2.5	Ω
			Full			3.0	
R_{PD}	Output pull down resistance	V_{IN} = 4.2 V, V_{EN} = 0 V, I(into VOUT) = 10 mA	25ºC		63.8	120	Ω
I_{EN}	EN input leakage	V_{EN} = 1.6 V to 5.5 V or GND	Full			1	µA
$V_{DO\text{-}VOUT}$	Dropout voltage VOUT [5][6]	I_{OUT} = 10 mA	Full		0.11		V
$V_{DO\text{-}LOUT}$	Dropout voltage LOUT	I_{OUT} = 10 mA[5][6]	Full		0.10		V
V_{LOUT}	Always on LDO output voltage (LOUT pin)	V_{IN} < 3.4 V, I_{OUT} = 10 mA, V_{EN} = 1.8 V	Full		V_{IN} – $V_{DO\text{-}LOUT}$		V
		V_{IN} > 4 V, I_{OUT} = 10 mA, V_{EN} = 1.8 V	Full	3.42	3.6	3.78	
V_{VOUT}	Switched LDO output voltage (VOUT pin)	V_{IN} < 3.4 V, I_{OUT} = 10 m A, V_{EN} = 1.8 V	Full		V_{IN} – $V_{DO\text{-}VOUT}$		V
		V_{IN} > 4 V, I_{OUT} = 10 mA, V_{EN} = 1.8 V	Full	3.39	3.57	3.75	
V_{CO}	Changeover voltage	V_{BAT} = 4.2 V, V_{USB} = 4.0 V rising to 4.4 V	Full		0.15		V
t_{CO}	Changeover time	VBAT=4.2 V, V_{USB} = 4.0 V rising to 4.4 V, CAP = 0.01 µF, I_{OUT} = 10 mA	25ºC		18		µs
			Full			50	
t_{OFF}	VOUT off time	EN high to low, C(VOUT) = 1 µF, VOUT load = 360 Ω	Full		32		µs
t_{ON}	VOUT on time	EN low to high, C(VOUT) = open, VOUT load = 360 Ω	Full		65		µs

(1) V_{IN} is defined as the highest voltage present on the BAT, USB and DC_IN pins.
(2) One of the voltages on BAT, USB and DC_IN must be > VIN (Min), others can be 0 V.
(3) V_{BAT}, V_{USB} and V_{DC_IN} refer to the voltages on BAT, USB and DC_IN respectively. OUT, IOUT-VOUT and IOUT-LOUT refer to the currents for the combined output current for VOUT and LOUT, the current on VOUT and the current on LOUT respectively.
(4) TYP is 25ºC, BAT = 4.2-V, USB = 0-V, DC_IN = 0-V.
(5) Dropout voltage is the minimum input to output voltage differential needed to maintain regulation at a specified output current. In dropout, the output voltage is equal to: $V_{IN} – V_{DROPOUT}$.
(6) Dropout voltage is measured at the VIN that causes the output to drop to 100mV below its nominal voltage. For VOUT, the voltage drop across the output switch is included (10mA × R_{ONVOUT}).

PARAMETRIC MEASUREMENT INFORMATION

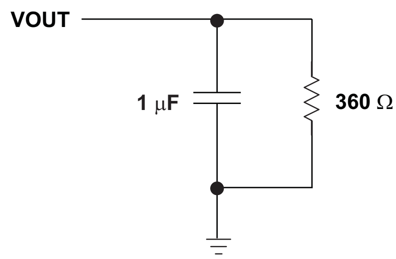


Figure 1. Test Circuit and t_{ON} / t_{OFF} Waveforms

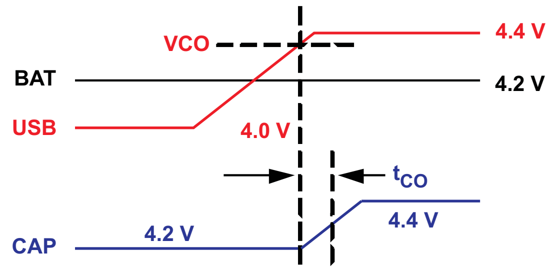


Figure 2. Switchover Timing

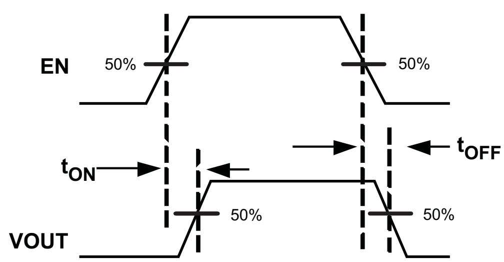


Figure 3. VOUT Enable Timing

APPLICATION INFORMATION

POWER CHANGEOVER

The TPS22933 LDO is powered by the highest level input. When input voltages change, the TPS22933 may change which input powers the LDO. During initial power up, the input that reaches the highest value first will power the LDO. Once that decision is made, changing between input sources is based on VCO. When an input source becomes VCO over the input currently supplying power to the LDO, changeover will occur and the new, higher input will power the LDO.

TPS22933A EXAMPLE:

Initial power up:
DC_IN = 0V; USB = 0V; EN = 0V
BAT is applied at 4.2V
LDO power comes from BAT
LOUT = 3.6V; CAP = 4.2V; VOUT = 0V

USB power is connected at 5.0V, BAT remains 4.2V and DC_IN remains 0V
LDO power is changed from BAT to USB in t_{CO}

LOUT = 3.6V; CAP = 5.0V; VOUT = 0V

DC_IN power is connected at 5.0V, BAT remains 4.2V and USB remains 5V
No change in LDO power

LOUT = 3.6V; CAP = 5.0V; VOUT = 0V

EN = VIH, BAT remains 4.2V, USB remains 5.0V and DC_IN remains 5V
LOUT = 3.6V, CAP = 5.0V; VOUT = 3.6V

USB power is removed, BAT remains 4.2V and DC_IN remains 5.0V
LDO power is changed from USB to DC_IN

LOUT = 3.6V; CAP = 5.0V; VOUT = 3.6V

DC_IN power is removed, BAT remains 4.2V and USB remains 0V:
LDO power is changed from DC_IN to BAT

LOUT = 3.6V; CAP = 4.2V; VOUT = 3.6V

ON/OFF CONTROL

The EN pin controls the state of the VOUT switch and VOUT pull-down switch. EN has no control over LOUT. Asserting EN enables the VOUT switch and disables the Quick Output Discharge (QOD) switch. Deasserting EN disables the VOUT switch and enables the QOD switch. EN is active high and has a low threshold making it capable of interfacing with low voltage signals. The EN pin is compatible with standard GPIO Logic threshold and can be used with any microcontroller with 1.2-V, 1.8-V, 2.5-V or 3.3-V GPIOs.

LDO CAPACITOR (for CAP pin)

An optional capacitor on the CAP pin helps stabilize the integrated LDO. Care should be taken in capacitor sizing to reduce inrush currents. The voltage on the CAP pin will follow the highest input. Since the max input voltage is 12-V, the capacitor voltage rating must be higher than 12-V.

BOARD LAYOUT

For best performance, all traces should be as short as possible. To be most effective, the input and output capacitors should be placed close to the device to minimize the effects that parasitic trace inductances may have on normal and short-circuit operation. Using wide traces for BAT, USB, DC_IN, LOUT, VOUT, and GND will help minimize the parasitic electrical effects along with minimizing the case to ambient thermal impedance.

APPLICATION EXAMPLES

Below are two diagrams of typical applications for the TPS22933A. In all cases, the unused power inputs can be left floating or tied to ground. The EN pin must not be left floating.

Figure 4 shows three power inputs multiplexed to source the LDO. The LDO always on output (LOUT) is tied to an MSP430. The MSP430 then determines when to enable the switched output (VOUT) by driving the EN pin.

Figure 5 shows three power inputs multiplexed to source only through the CAP pin. In this case, the LDO outputs are not used (EN is tied low). The highest of the inputs is chosen to drive the voltage at the CAP pin.

Note that these two applications are not mutually exclusive. An application could use the CAP pin as a power output and use one or both of the LDO outputs.

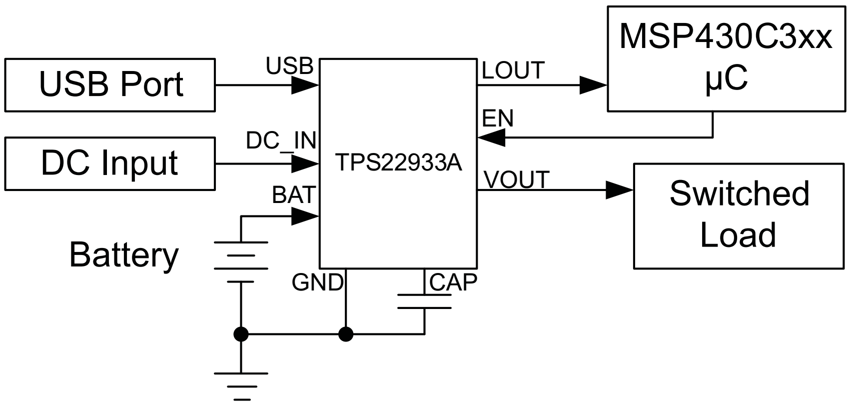


Figure 4. Application Example 1

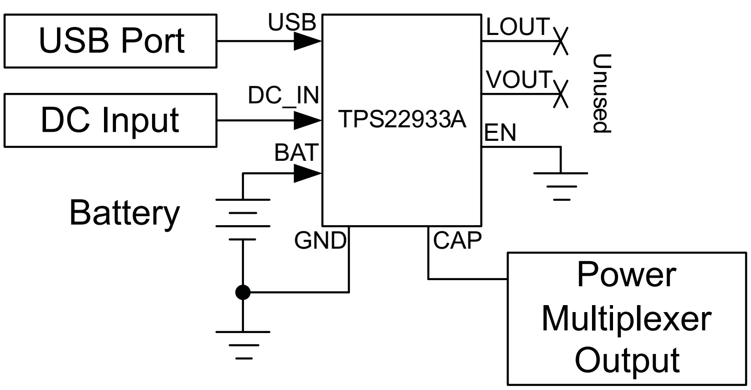


Figure 5. Application Example 2

PERFORMANCE GRAPHS

Table 1. Performance Graphs and Plots

Type	Description	Figure
Scope Plot	DC_IN to BAT switchover	Figure 6
Graph	RON versus VIN (BAT, USB, DC_IN) 25°C	Figure 7
Graph	RON versus VIN (Any input)	Figure 8
Graph	Quiescent Current versus Input Voltage (Any input)	Figure 9
Graph	Operating Current versus Input Voltage (Any Input)	Figure 10
Scope Plot	t_{OFF} (VIN = 4.2-V, C(VOUT) = 1uF, 25°C)	Figure 11
Scope Plot	t_{OFF} (VIN = 4.2-V, C(VOUT) = open, 25°C)	Figure 12
Scope Plot	t_{ON} (VIN = 4.2-V, C(VOUT) = 1uF, 25°C)	Figure 13
Scope Plot	t_{ON} (VIN = 4.2-V, C(VOUT) = open, 25°C)	Figure 14
Graph	LOUT and VOUT versus Temperature at VIN = 4.2-V	Figure 15
Graph	LOUT and VOUT versus IOUT (VIN = 4.2-V, Temp = 25°C)	Figure 16
Graph	LOUT Dropout Voltage versus Temperature (VIN = 2.5-V)	Figure 17
Graph	VOUT Dropout Voltage versus Temperature (VIN = 2.5-V)	Figure 18
Graph	Output Pull-down Resistance (R_{PD}) versus Temperature (10mA into VOUT)	Figure 19

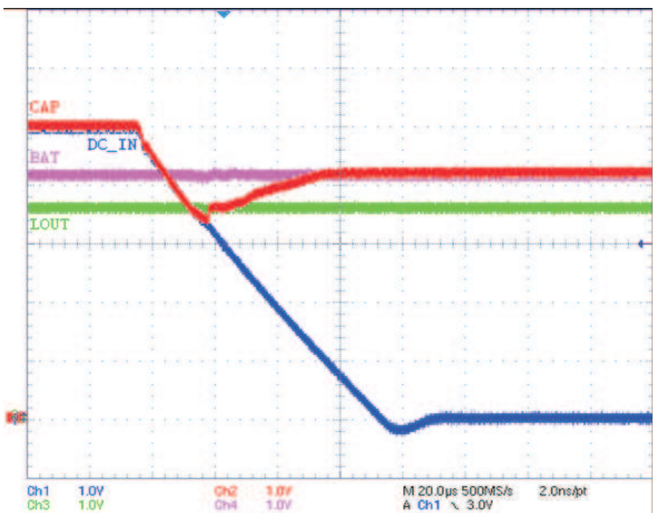


Figure 6. DC_IN Removed, BAT Powers LDO (LOUT = 3.6-V)

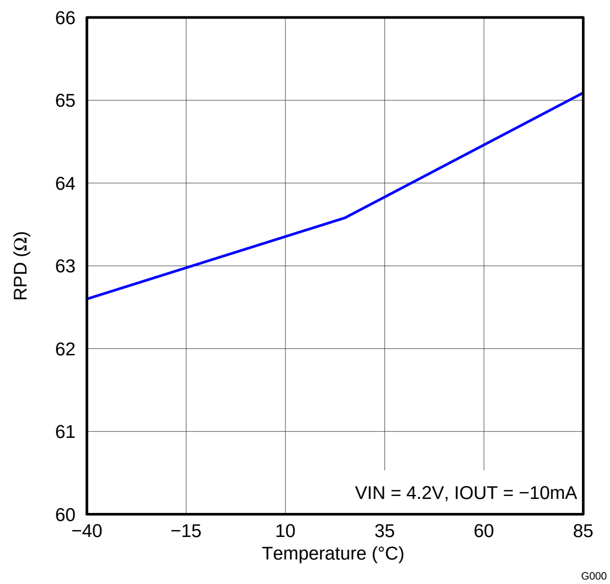


Figure 7. RPD vs Temp

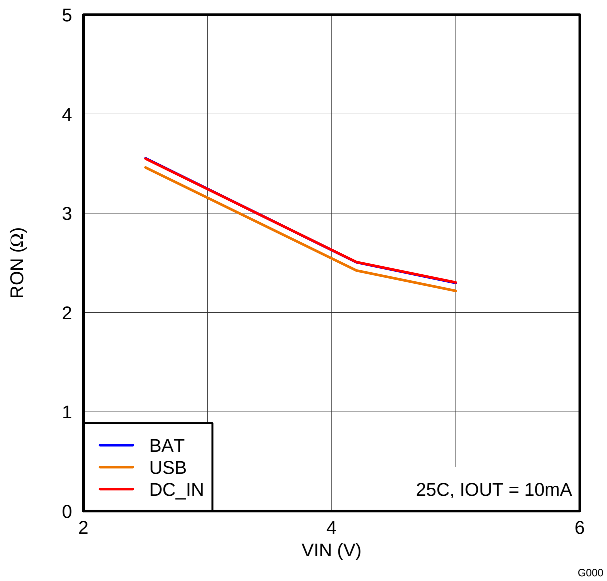


Figure 8. R_{ON} vs VIN (Typical)

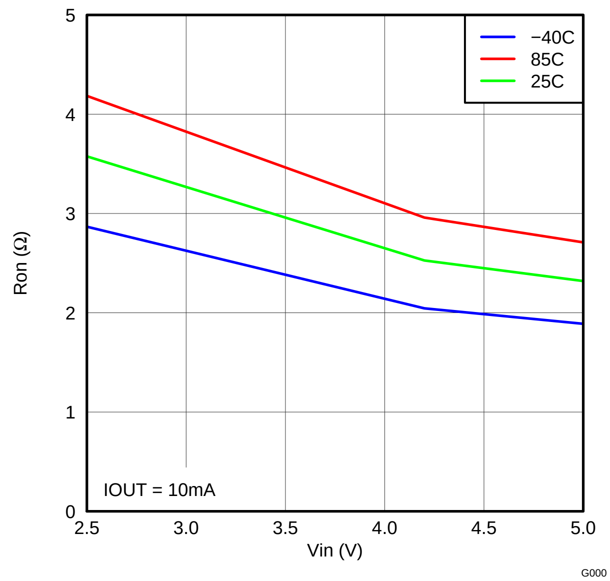


Figure 9. R_{ON} vs VIN

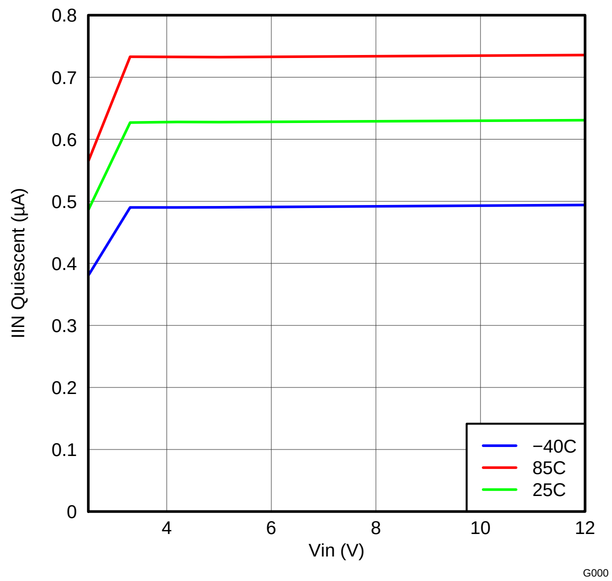


Figure 10. I_{IN}(Quiescent) vs VIN

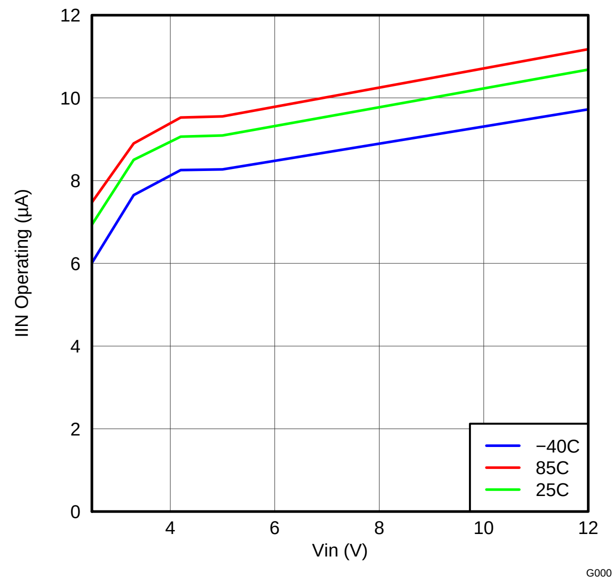


Figure 11. I_{IN}(Operating) vs VIN

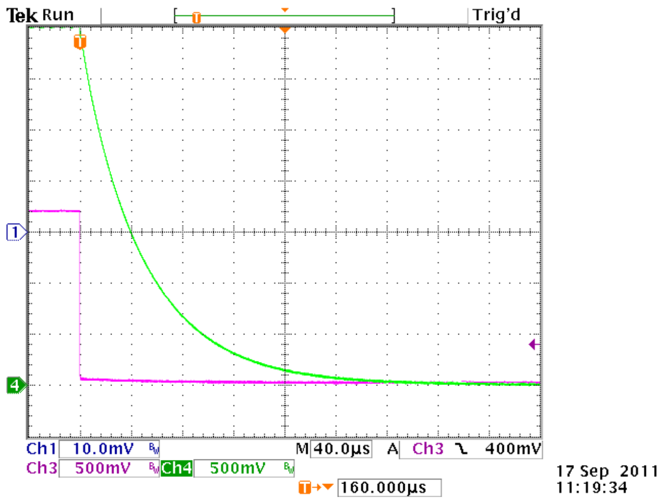


Figure 12. VOUT t_{OFF} (1µF on VOUT)

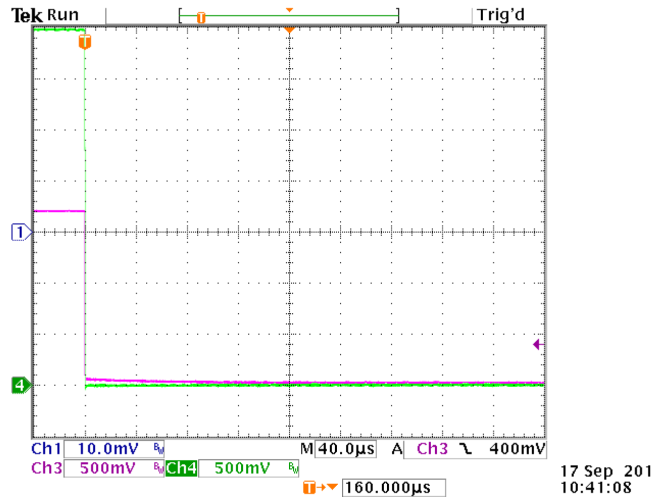


Figure 13. VOUT t_{OFF} (No Capacitor on VOUT)

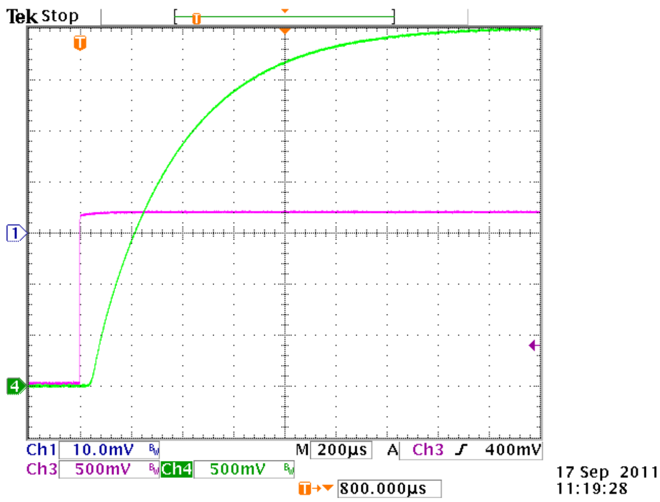


Figure 14. VOUT t_{ON} (1-µF on VOUT)

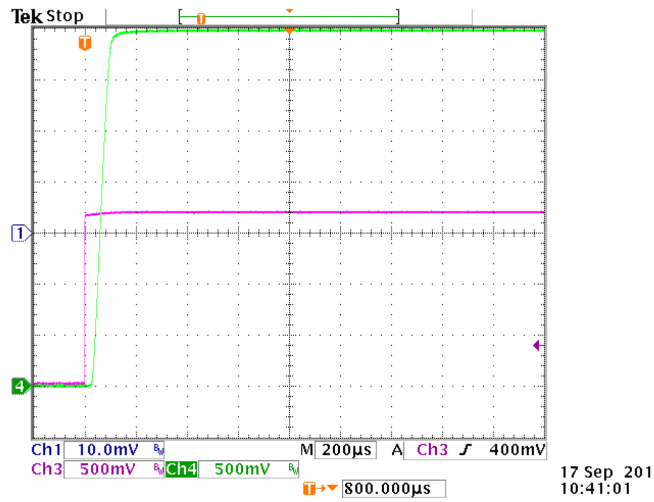


Figure 15. VOUT t_{ON} (No Capacitor on VOUT)

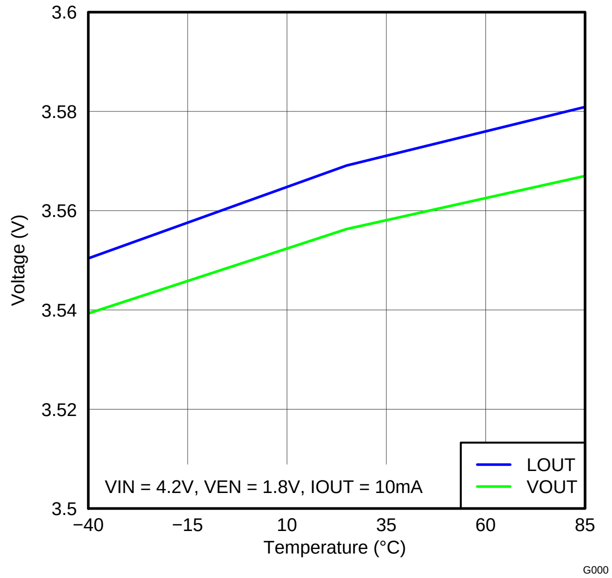


Figure 16. LOUT-VOUT vs Temp VIN 4p2V

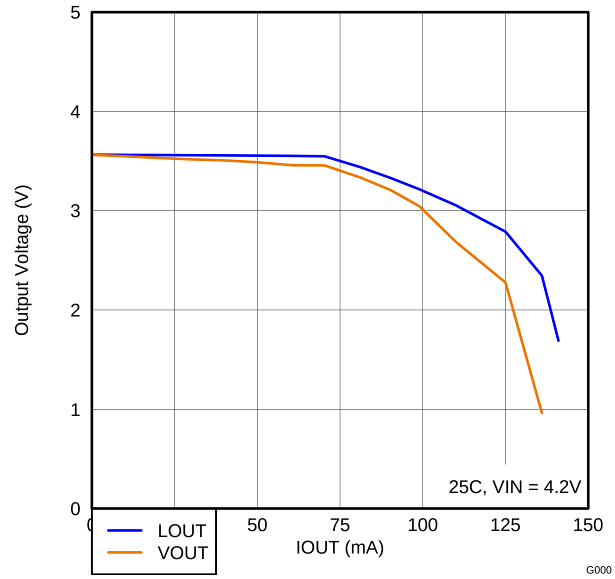


Figure 17. LOUT-VOUT vs IOUT

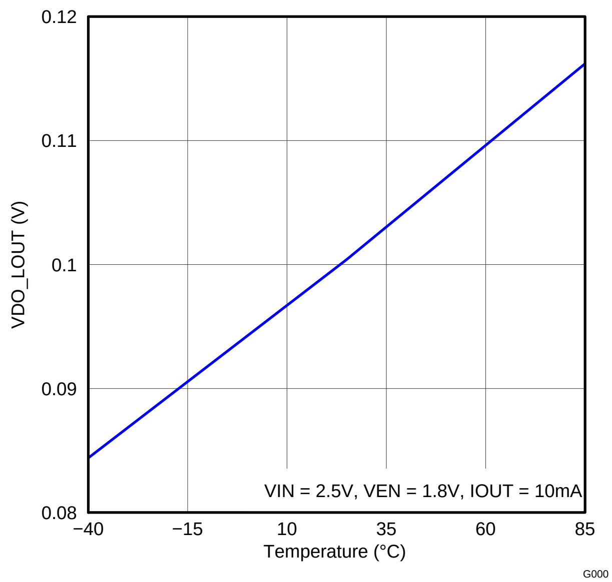


Figure 18. VDOLOUT vs Temp VIN 2p5V

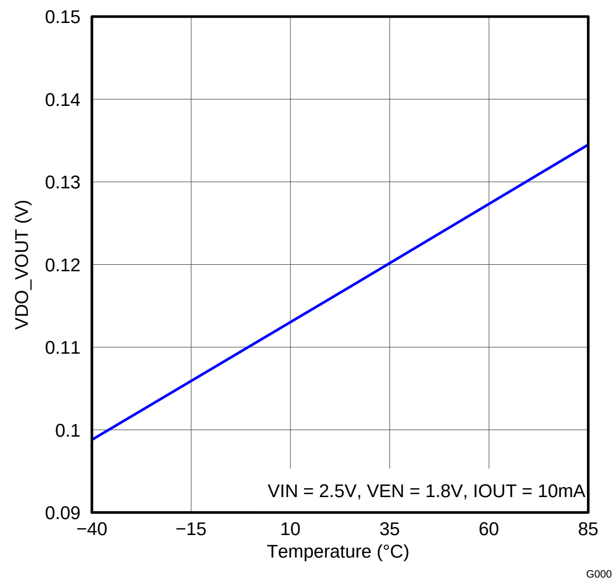


Figure 19. VDOVOUT vs Temp VIN 2p5V

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/ Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
TPS22933ARSER	ACTIVE	UQFN	RSE	8	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TPS22933ARSET	ACTIVE	UQFN	RSE	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	

(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.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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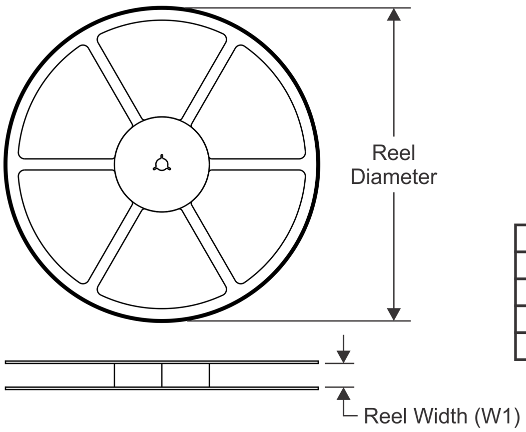
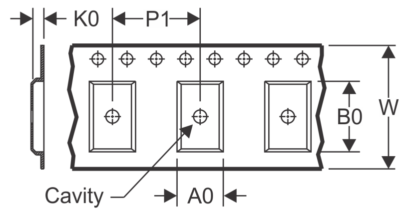
TAPE AND REEL INFORMATION

REEL DIMENSIONS

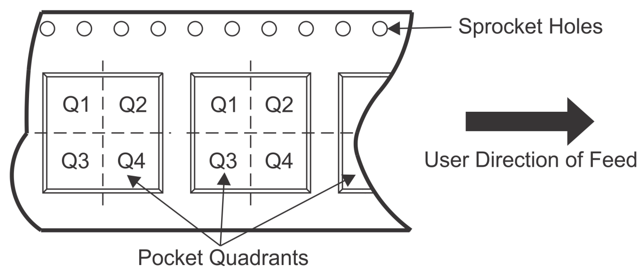


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	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

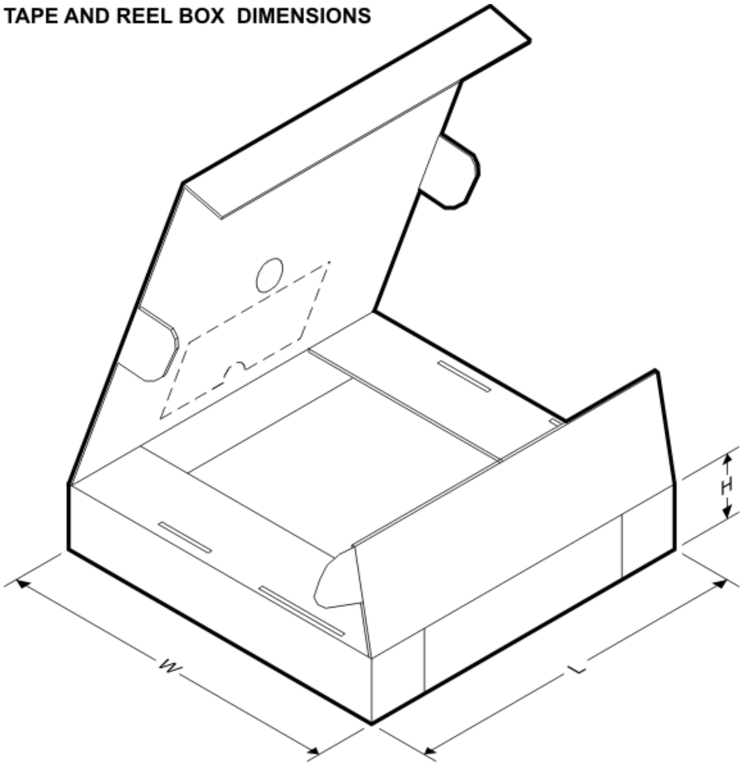
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPS22933ARSER	UQFN	RSE	8	3000	180.0	8.4	1.6	1.6	0.66	4.0	8.0	Q2
TPS22933ARSET	UQFN	RSE	8	250	180.0	8.4	1.6	1.6	0.66	4.0	8.0	Q2

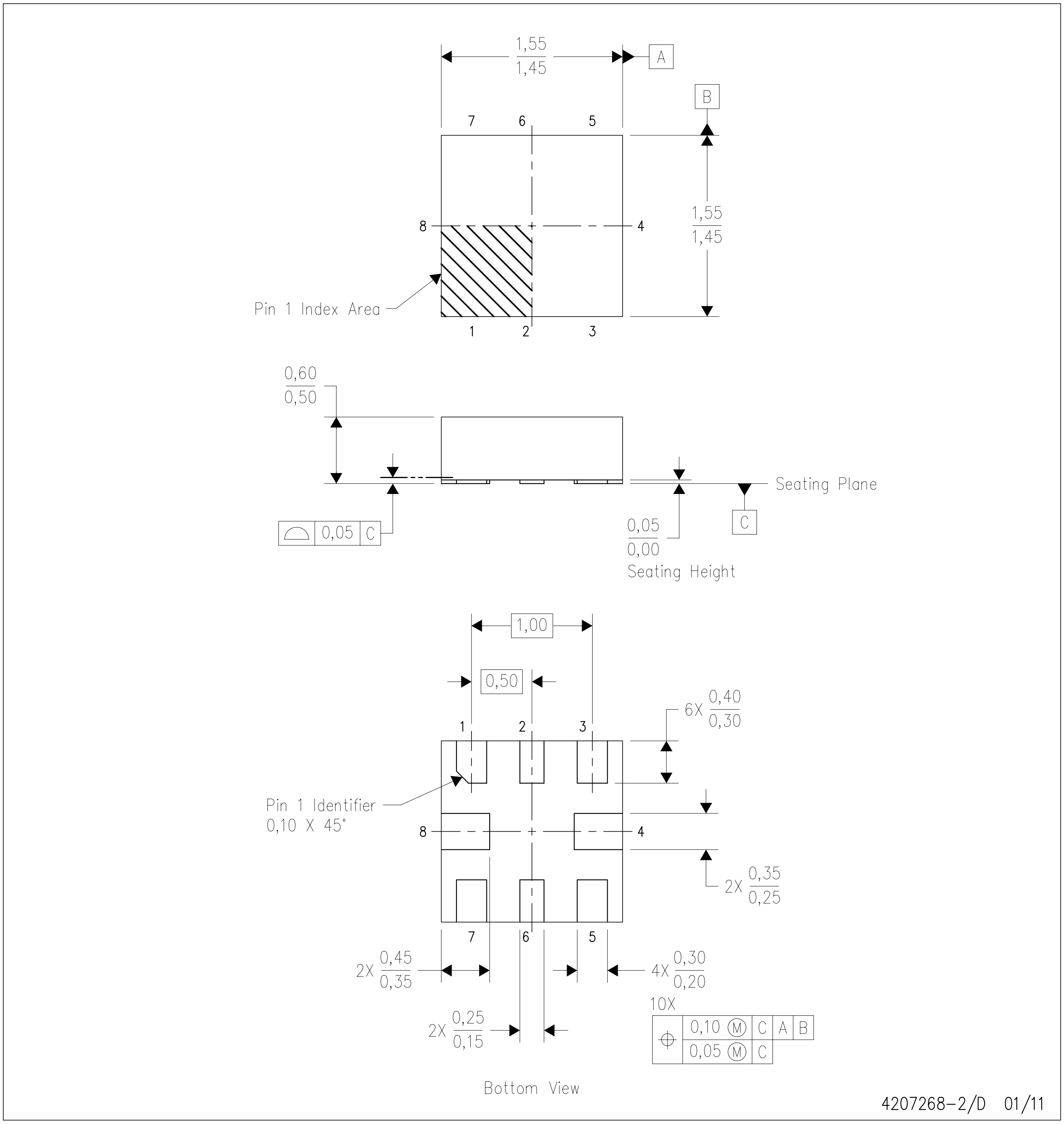
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

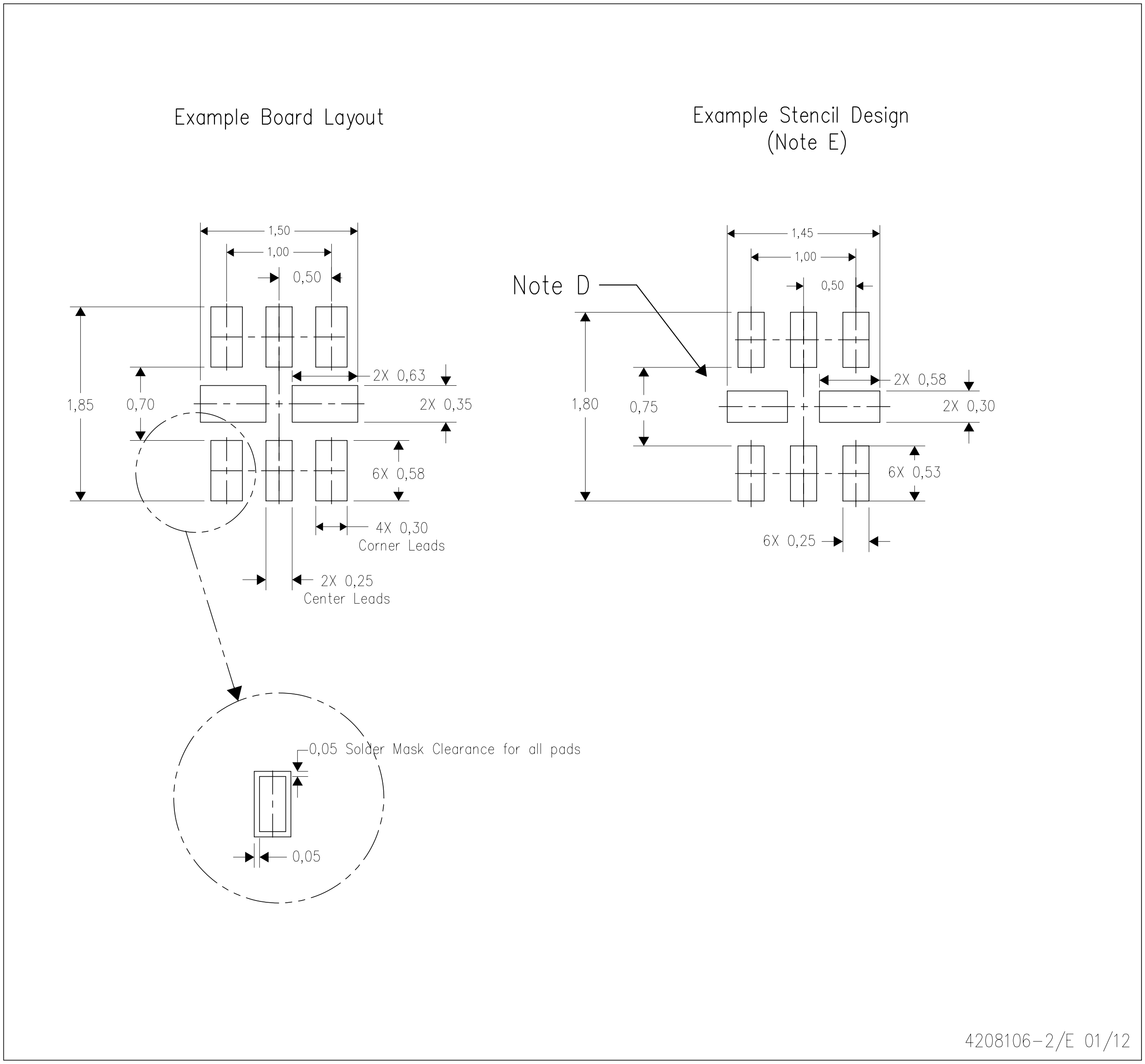
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS22933ARSER	UQFN	RSE	8	3000	202.0	201.0	28.0
TPS22933ARSET	UQFN	RSE	8	250	202.0	201.0	28.0

RSE (S-PUQFN-N8) PLASTIC QUAD FLATPACK NO-LEAD



NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
B. This drawing is subject to change without notice.
C. QFN (Quad Flatpack No-Lead) package configuration.
D. This package complies to JEDEC MO-288 variation UECD.

RSE (S-PUQFN-N8) PLASTIC QUAD FLATPACK NO-LEAD



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC-7351 is recommended for alternate designs.
D. Customers should contact their board fabrication site for minimum solder mask web tolerances between signal pads.
E. Maximum stencil thickness 0,127 mm (5 mils). All linear dimensions are in millimeters.
F. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
G. Side aperture dimensions over-print land for acceptable area ratio > 0.66. Customer may reduce side aperture dimensions if stencil manufacturing process allows for sufficient release at smaller opening.

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