SN6505 Low-Noise 1-A Transformer Drivers for Isolated Power Supplies

1 Features

- Push-Pull Driver for transformers
- Wide Input Voltage Range: 2.25 V to 5.5 V
- High Output Drive: 1 A at 5 V Supply
- Low R_{ON} 0.25 Ω Max at 4.5 V Supply
- Ultra-Low EMI
- Spread Spectrum Clocking
- Precision Internal Oscillator Options: 160 kHz (SN6505A) and 420 kHz (SN6505B)
- Synchronization of Multiple Devices with External Clock Input
- Slew-Rate Control
- 1.7 A Current-Limit
- Low Shutdown Current: <1 μA
- Thermal Shutdown
- Wide Temperature Range: –55°C to 125°C
- Small 6-Pin SOT23/DBV Package
- Soft Start to reduce In-rush current

2 Applications

- Isolated Power Supply for CAN, RS-485, RS-422, RS-232, SPI, I2C, Low-Power LAN
- Low-Noise Isolated USB Supplies
- Process Control
- Telecom Supplies
- Radio Supplies
- Distributed Supplies
- Medical Instruments
- Precision Instruments
- Low-Noise Filament Supplies

3 Description

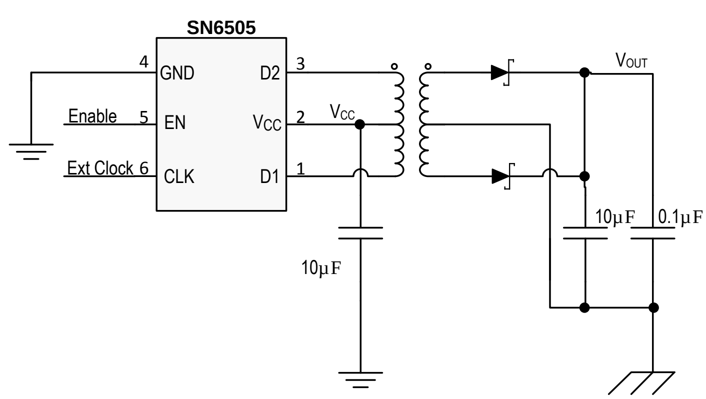
The SN6505 is a low-noise, low-EMI push-pull transformer driver, specifically designed for small form factor, isolated power supplies. It drives low-profile, center-tapped transformers from a 2.25 V to 5 V DC power supply. Ultra-low noise and EMI are achieved by slew rate control of the output switch voltage and through Spread Spectrum Clocking (SSC). The SN6505 consists of an oscillator followed by a gate drive circuit that provides the complementary output signals to drive ground-referenced N-channel power switches. The device includes two 1-A Power-MOSFET switches to ensure start-up under heavy loads. The switching clock can also be provided externally for accurate placement of switcher harmonics, or when operating with multiple transformer drivers. The internal protection features include a 1.7A current limiting, under-voltage lockout, thermal shutdown, and break-before-make circuitry. SN6505 includes a soft-start feature that prevents high inrush current during power up with large load capacitors. The SN6505 is available in a small 6-pin SOT23/DBV package. The device operation is characterized for a temperature range from –55°C to 125°C.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
SN6505A	SOT23 (6 Pin)	2.90 mm x 1.60 mm
SN6505B		

(1) For all available packages, see the orderable addendum at the end of the datasheet.

Simplified Schematic



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4 Revision History

Changes from Revision E (August 2016) to Revision F	Page
• Changed text From: "connected as possible" To: "connected as close as possible" in *Power Supply Recommendations*	27

Changes from Revision D (August 2016) to Revision E	Page
• Changed Table 3, and added Note 1	24

Changes from Revision C (August 2016) to Revision D	Page
• *Typical Characteristics, SN6505A*, added Figure 1 and Figure 2 back into the datasheet	7
• *Typical Characteristics, SN6505A*, added Figure 9 to Figure 33 back into the datasheet	7
• *Typical Characteristics, SN6505B*, added Figure 11 and Figure 12 back into the datasheet	9
• *Typical Characteristics, SN6505B*, added Figure 31 and Figure 32 back into the datasheet	11
• Changed Table 3	24

Changes from Revision B (February 2016) to Revision C	Page
• Changed the *Typical Characteristics, SN6505A* section	7
• Added the *Typical Characteristics, SN6505B* section	9
• Changed Table 3	24

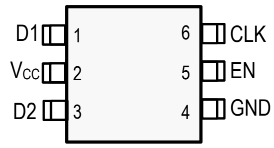
Changes from Revision A (October 2015) to Revision B	Page
• Changed the *Thermal Information* table From: 16 Pin DW (SOIC) To: 6 Pin DBV (SOT-23)	5

Changes from Original (September 2015) to Revision A **Page**

- Production Release 1

5 Pin Configuration and Functions

DBV Package
SOT-23 (6 Pin)
Top View



Pin Functions

PIN			DESCRIPTION
NAME	NO.	TYPE	
D1	1	O	Open drain output of the first power MOSFETs. Typically connected to the outer terminals of the center tap transformer. Because large currents flow through these pins, their external traces should be kept short.
V_{CC}	2	P	This is the device supply pin. It should be bypassed with a 4.7 µF or greater, low ESR capacitor. When V_{CC} ≤ 2.25 V, an internal undervoltage lockout circuit trips and turns both outputs off.
D2	3	O	Open drain output of the second power MOSFETs. Typically connected to the outer terminals of the center tap transformer. Because large currents flow through these pins, their external traces should be kept short.
GND	4	P	GND is connected to the source of the power MOSFET switches via an internal sense circuit. Because large currents flow through it, the GND terminals must be connected to a low-inductance quality ground plane.
EN	5	I	The EN pin turns the device on or off. Grounding or leaving this pin floating disables all internal circuitry. If unused this pin should be tied directly to V_{CC}.
CLK	6	I	This pin is used to run the SN6505 with external clock. Internally it is pulled down to GND . If valid clock is not detected on this pin, the SN6505 shifts automatically to internal clock.

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1) .All typical values are at TA = 25°C, V_{CC} = 5 V.

		MIN	MAX	UNIT
Supply voltage (2)	V_{CC}	–0.5	6	V
Voltage	EN, CLK	–0.5	V_{CC} + 0.5(3)	
Output switch voltage	D1, D2		16	V
Peak output switch current	$I_{(D1)Pk}$, $I_{(D2)Pk}$		2.4	A
Junction temperature, T_J		-55	150	°C
Storage temperature range, T_{stg}		–65	150	°C

(1) Stresses beyond those listed under Absolute Maximum Ratings cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods affects device reliability.
(2) All voltage values except differential I/O bus voltages are with respect to the local ground terminal (GND) and are peak voltage values.
(3) Maximum voltage of 6V.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins(1)	±6000	V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins(2)	±1500	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

			MIN	TYP	MAX	UNIT
V_{CC}	Supply voltage		2.25		5.5	V
I_{D1}, I_{D2}	Output switch current - Primary side	2.25 V < V_{CC} < 2.8 V			0.75	A
		2.8 V < V_{CC} < 5.5 V			1	
T_A	Ambient temperature		–55		125	°C

6.4 Thermal Information

THERMAL METRIC(1)		DBV (SOT-23)	UNIT
		6 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	137.7	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	57.7	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	46.0	°C/W
ψ_{JT}	Junction-to-top characterization parameter	13.4	°C/W
ψ_{JB}	Junction-to-board characterization parameter	44.9	°C/W
$R_{\theta JC(bottom)}$	Junction-to-case(bottom) thermal resistance	N/A	°C/W

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

6.5 Electrical Characteristics

over full-range of recommended operating conditions, unless otherwise noted. All typical values are at T_A = 25°C, V_{CC} = 5 V.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
VOLTAGE SUPPLY						
$I_{(VCC)}$	Supply Current (2.8 V < VC_C < 5.5) (SN6505A)	R_L = 50 Ω		1	1.4	mA
	Supply Current (2.8 V < VC_C < 5.5) (SN6505B)			1.56	2.3	mA
I_{IH}	Leakage Current on EN and CLK pin	EN / CLK = V_{CC}		10	20	µA
I_{DIS}	V_{CC} current for EN = 0			0.1		µA
$I_{LKG(D1)}$ $I_{LKG(D2)}$	Leakage Current on D1,D2 for EN=0	Voltage of D1,D2 = V_{CC}		0.1		µA
$V_{CC+ (UVLO)}$	Positive-going UVLO threshold				2.25	V
$V_{CC- (UVLO)}$	Negative-going UVLO threshold		1.7			V
$V_{HYS (UVLO1)}$	UVLO threshold hysteresis			0.3		V
$V_{IN(ON)}$	EN, CLK pin logic high threshold				0.7	V_{CC}
$V_{IN(OFF)}$	EN, CLK pin logic low threshold		0.3			V_{CC}
$V_{IN(HYS)}$	EN, CLK pin threshold hysteresis			0.2		V_{CC}
CLK						
F_{SW}	D1, D2 average switching Frequency (SN6505A)	R_L = 50 Ω to V_{CC}; Refer to Figure 36	138	160	203	Khz
	D1, D2 average switching Frequency (SN6505B)	R_L = 50 Ω to V_{CC}; Refer to Figure 36.	363	424	517	kHz
$F_{(EXT)}$	External clock frequency on CLK pin (SN6505A)		100		600	kHz
	External clock frequency on CLK pin (SN6505B)		100		1600	kHz
OUTPUT STAGE						
DMM	Average ON time mismatch between D1 and D2	R_L = 50 Ω		0%		
$R_{(ON)}$	Output switch on resistance	V_{CC} = 4.5 V, ID1,ID2 = 1 A		0.16	0.25	Ω
		V_{CC} = 2.8 V, ID1,ID2 = 1 A		0.19	0.31	Ω
		V_{CC} = 2.25 V, ID1,ID2 = 0.5 A		0.21	0.45	Ω

Electrical Characteristics (continued)

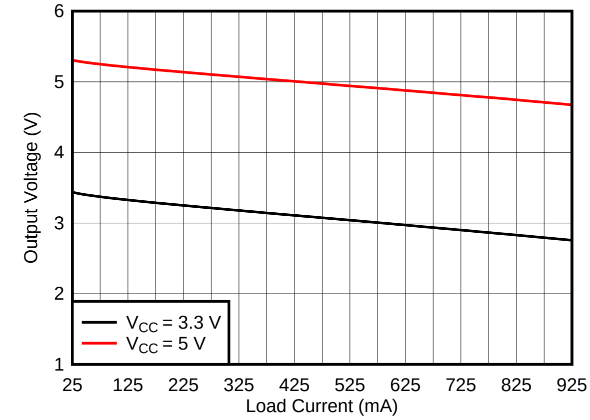
over full-range of recommended operating conditions, unless otherwise noted. All typical values are at T_A = 25°C, V_{CC} = 5 V.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{(SLEW)}$	Voltage slew rates on D1 and D2 for SN6505A	R_L = 50 Ω to V_{CC}; Refer to Figure 36		48		V/µs
$I_{(SLEW)}$	Current slew rates at D1 and D2 for SN6505A	R_L = 5 Ω through transformer; Refer to Figure 37		11		A/µs
$V_{(SLEWHF)}$	Voltage slew rates on D1 and D2 for SN6505B	R_L = 50 Ω to V_{CC}; Refer to Figure 36		152		V/µs
$I_{(SLEWHF)}$	Current slew rates at D1 and D2 for SN6505B	R_L = 5 Ω through transformer; Refer to Figure 37		41		A/µs
I_{LIM}	Current clamp limit (2.8 V < V_{CC} < 5.5V)		1.42	1.75	2.15	A
	Current clamp limit (2.25 V < V_{CC} < 2.8 V)		0.65		1.85	A
THERMAL SHUT DOWN						
T_{SD+}	T_{SD} turn on temperature		154	168	181	°C
T_{SD-}	T_{SD} turn off temperature		135	150	166	°C
T_{SD-}	T_{SD} hysteresis		13	17		°C

6.6 Timing Requirements

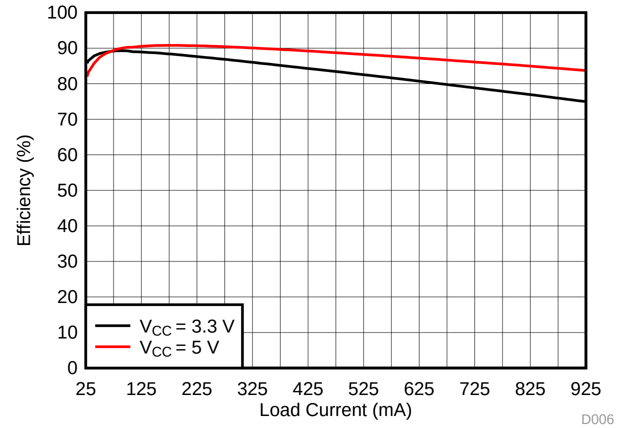
			MIN	NOM	MAX	UNIT
CLK						
$t_{CLKTIMER}$	Duration after which device switches to internal clock in case of invalid external clock		10		25	µs
OUTPUT STAGE						
t_{BBM}	Break-before-make time(SN6505A)	Measured as voltage with R_L = 50 Ω to V_{CC}, Refer to Figure 36		115		ns
	Break-before-make time (SN6505B)			90		ns
SOFT START						
t_{SS}	Soft start time	10% to 90% transition time on V_{OUT} With transformer C_{LOAD} = 40 µF R_L = 5 Ω	1	4.25	8	ms
$t_{SSdelay}$	Soft start time delay	From power up to 90% transition time on V_{OUT} With transformer C_{LOAD} = 40 µF R_L = 5 Ω	3.5	8.5	18	ms

6.7 Typical Characteristics, SN6505A



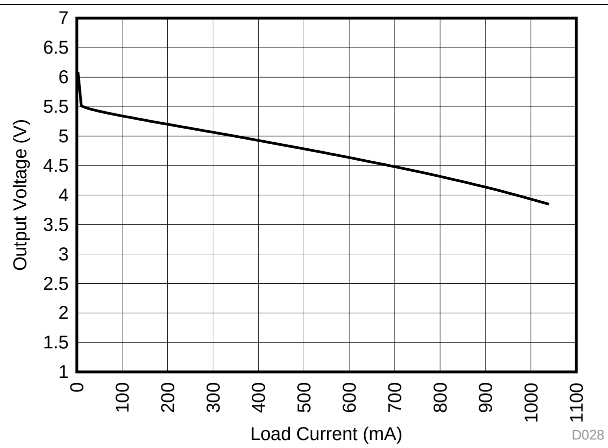
SN6505A + Wurth 750315240

Figure 1. Output Voltage vs Load Current



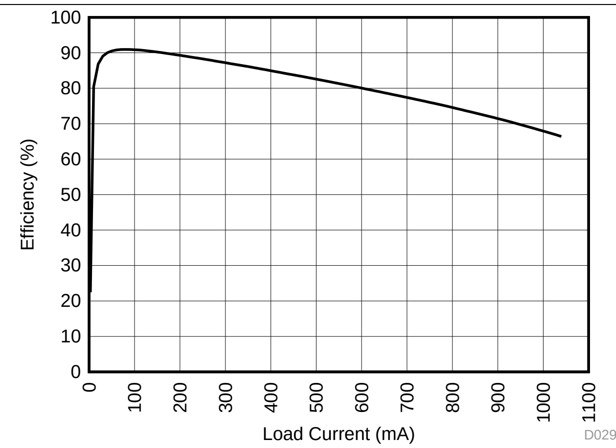
SN6505A + Wurth 750315240

Figure 2. Efficiency vs Load Current



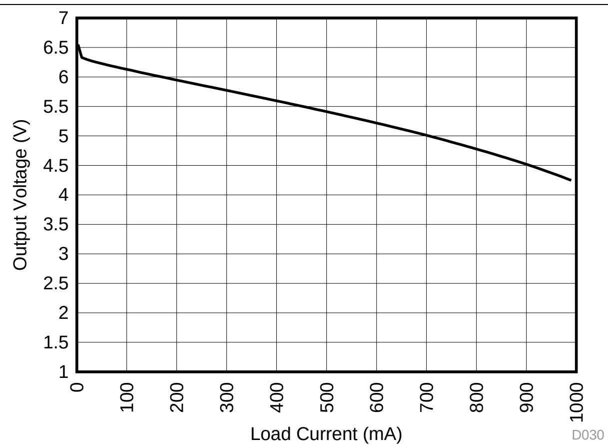
SN6505A + Wurth 750316031 V_{CC} = 3.3 V

Figure 3. Output Voltage vs Load Current



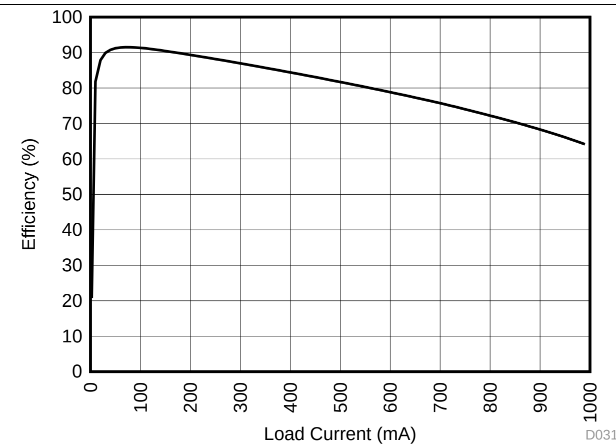
SN6505A + Wurth 750316031 V_{CC} = 3.3 V

Figure 4. Efficiency vs Load Current



SN6505A + Wurth 750316032 V_{CC} = 3.3 V

Figure 5. Output Voltage vs load Current



SN6505A + Wurth 750316032 V_{CC} = 3.3 V

Figure 6. Efficiency vs Load Current

Typical Characteristics, SN6505A (continued)

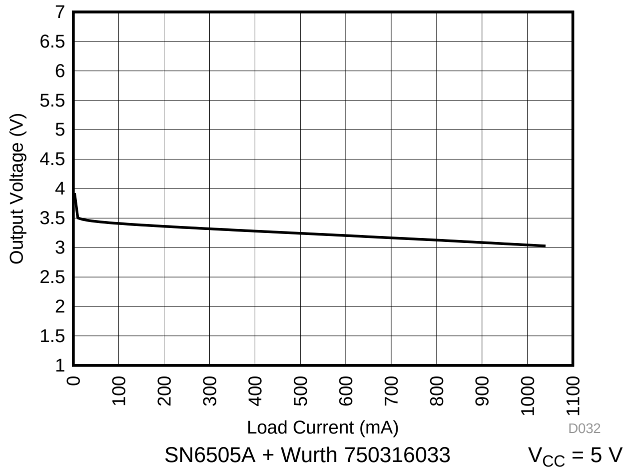


Figure 7. Output Voltage vs Load Current

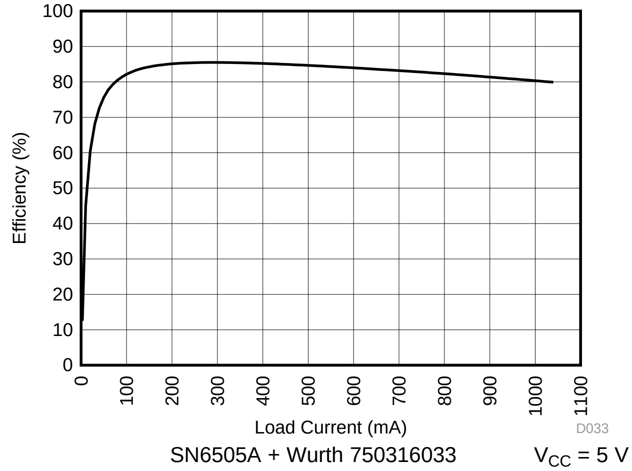


Figure 8. Efficiency vs Load Current

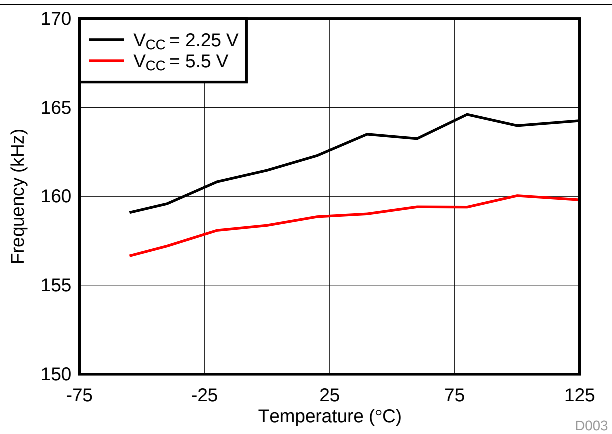


Figure 9. Frequency vs Free-Air Temperature

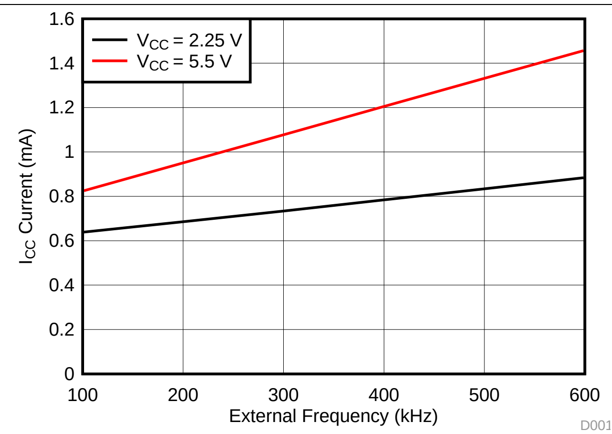
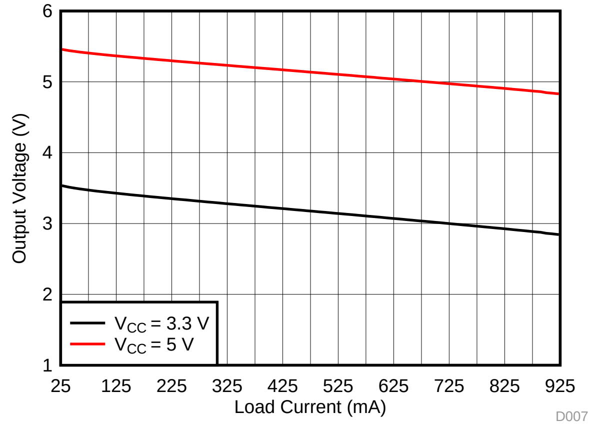


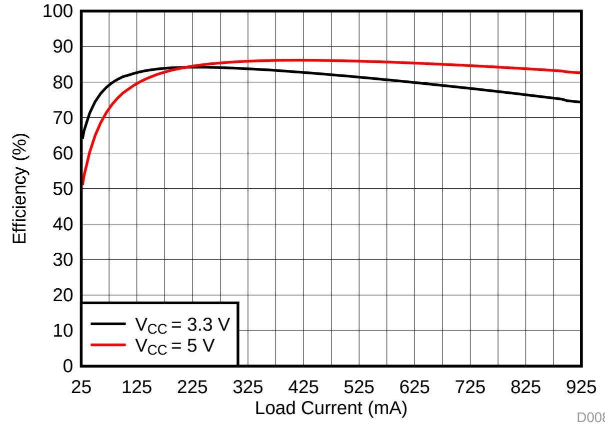
Figure 10. Current vs External Frequency

6.8 Typical Characteristics, SN6505B



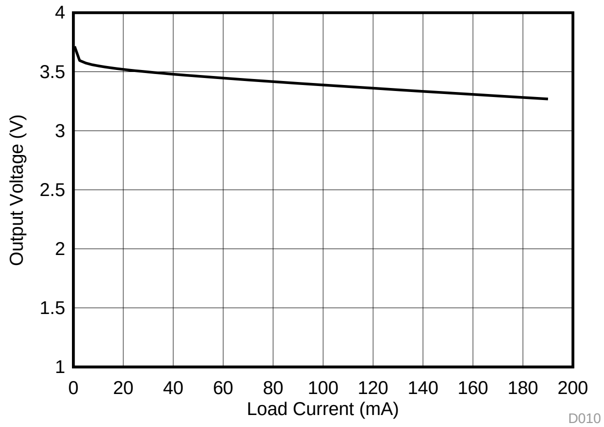
SN6505B + Wurth 750315371

Figure 11. Output Voltage vs Load Current



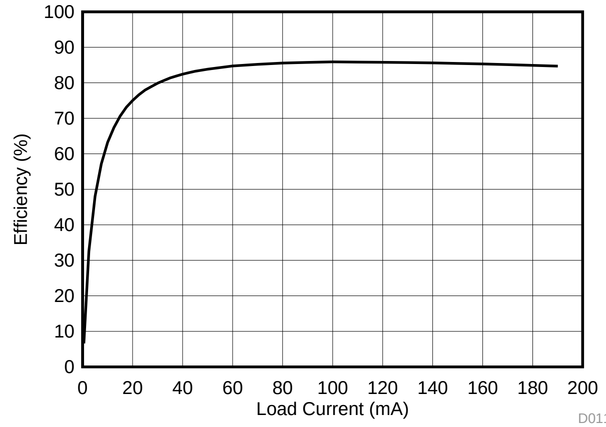
SN6505B + Wurth 750315371

Figure 12. Efficiency vs Load Current



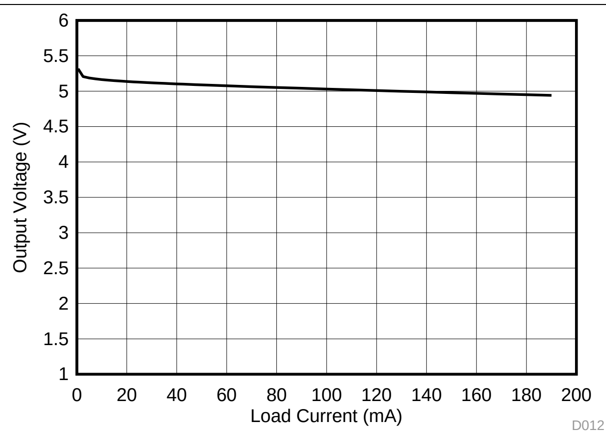
SN6505B + Wurth 760390011 V_{CC} = 3.3 V

Figure 13. Output Voltage vs Load Current



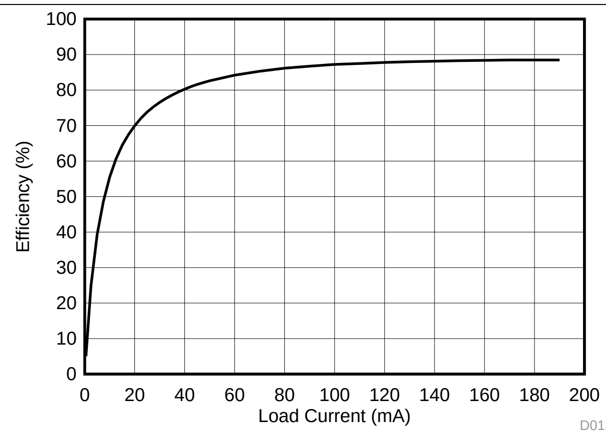
SN6505B + Wurth 760390011 V_{CC} = 3.3 V

Figure 14. Efficiency vs Load Current



SN6505B + Wurth 760390012 V_{CC} = 5 V

Figure 15. Output Voltage vs Load Current



SN6505B + Wurth 760390012 V_{CC} = 5 V

Figure 16. Efficiency vs Load Current

Typical Characteristics, SN6505B (continued)

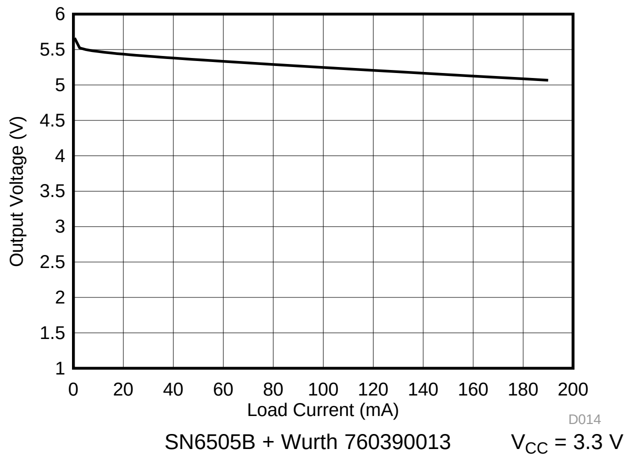


Figure 17. Output Voltage vs Load Current

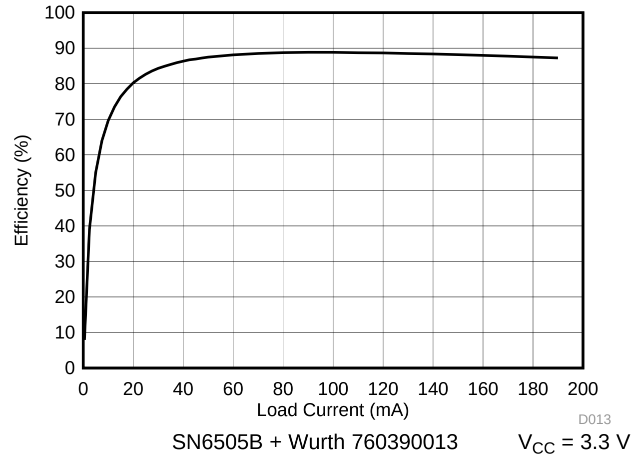


Figure 18. Efficiency vs Load Current

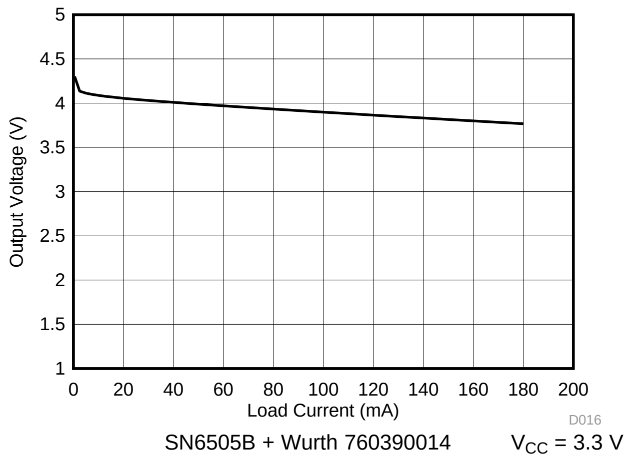


Figure 19. Output Voltage vs Load Current

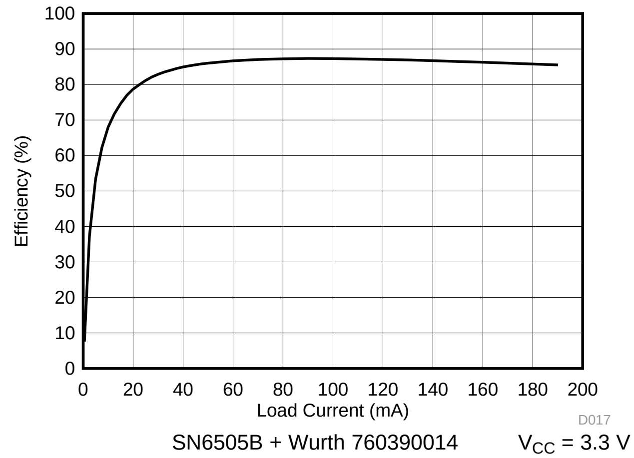


Figure 20. Efficiency vs Load Current

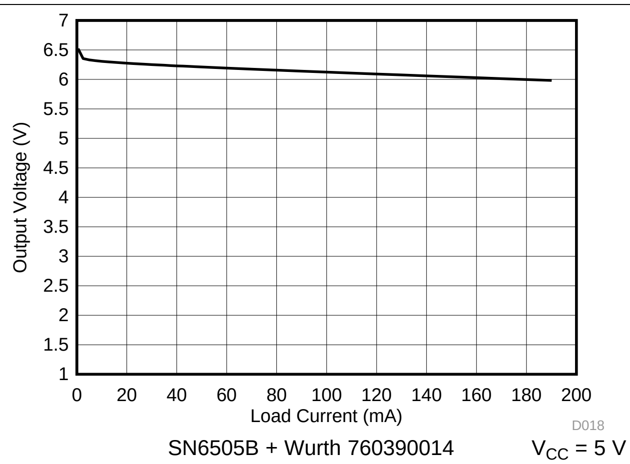


Figure 21. Output Voltage vs Load Current

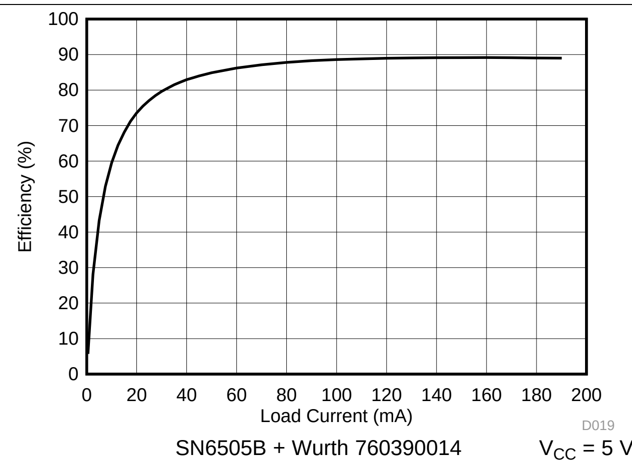
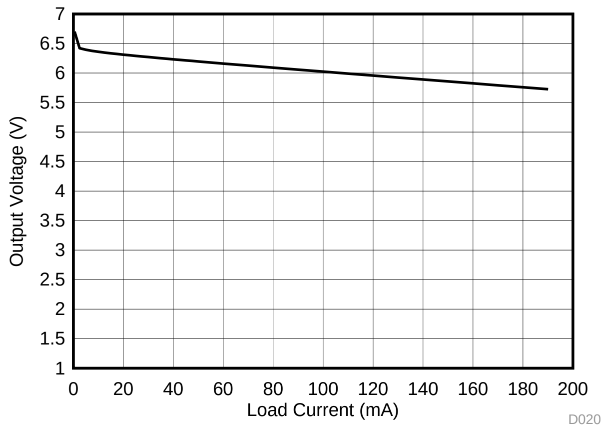


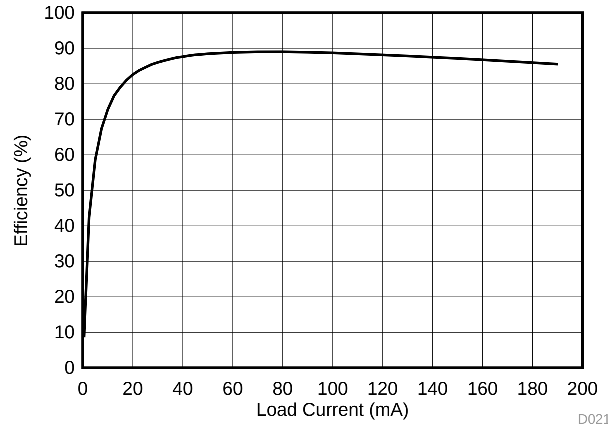
Figure 22. Efficiency vs Load Current

Typical Characteristics, SN6505B (continued)



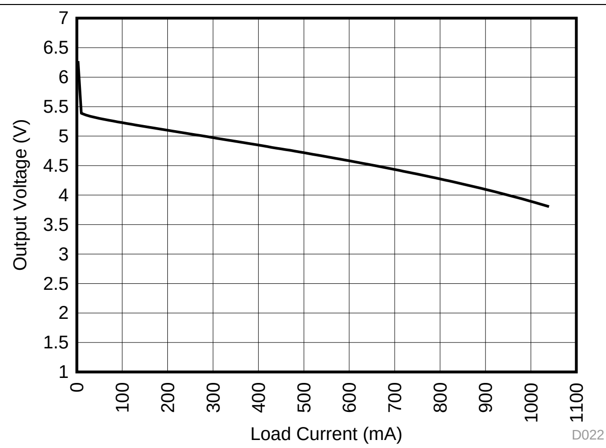
SN6505B + Wurth 760390015 V_{CC} = 3.3 V

Figure 23. Output Voltage vs Load Current



SN6505B + Wurth 760390015 V_{CC} = 3.3 V

Figure 24. Efficiency vs Load Current

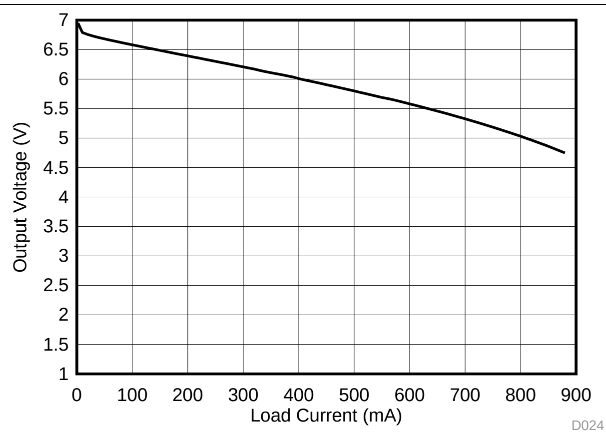


SN6505B + Wurth 750316028 V_{CC} = 3.3 V

Figure 25. Output Voltage vs Load Current

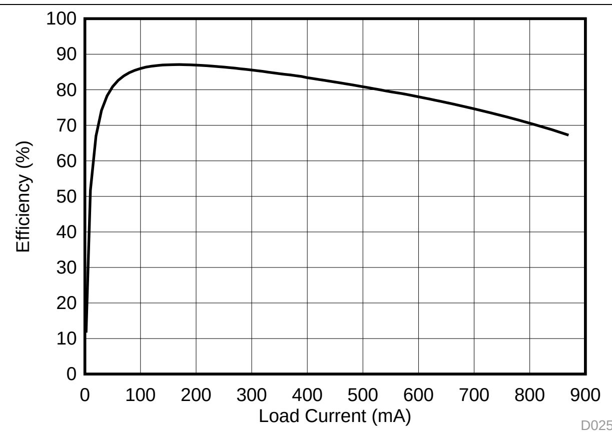
SN6505B + Wurth 750316028 V_{CC} = 3.3 V

Figure 26. Efficiency vs Load Current



SN6505B + Wurth 750316029 V_{CC} = 3.3 V

Figure 27. Output Voltage vs Load Current



SN6505B + Wurth 750316029 V_{CC} = 3.3 V

Figure 28. Efficiency vs Load Current

Typical Characteristics, SN6505B (continued)

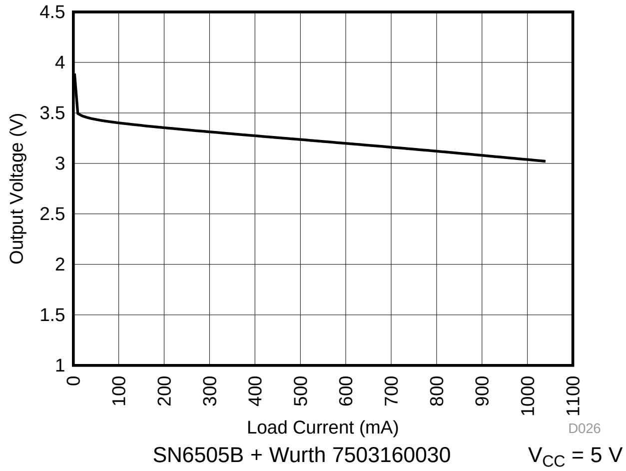


Figure 29. Output Voltage vs Load Current

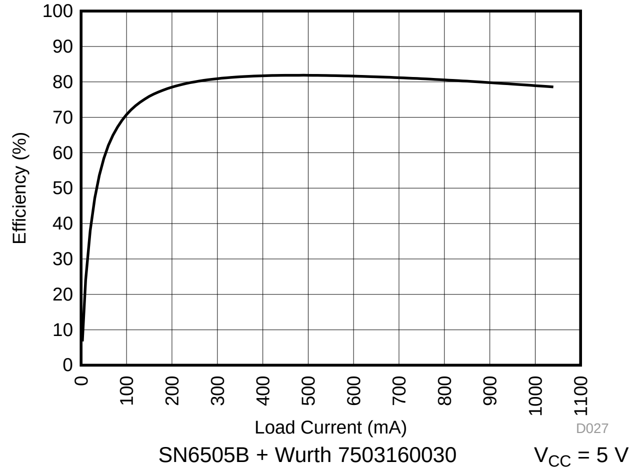


Figure 30. Efficiency vs Load Current

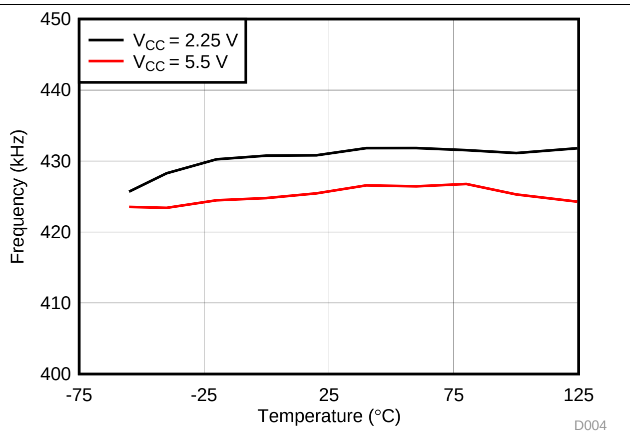


Figure 31. Frequency vs Free-Air Temperature

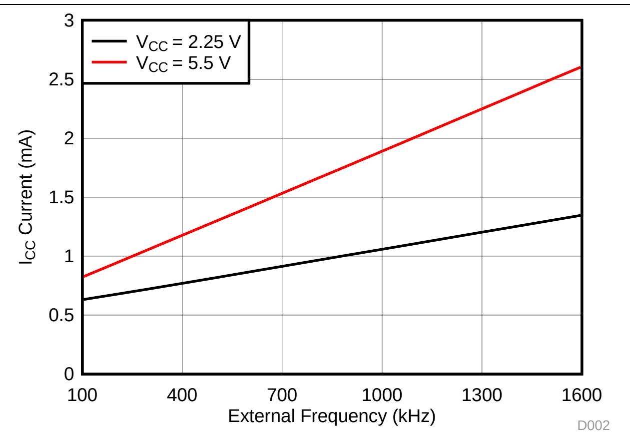


Figure 32. Current vs External Frequency

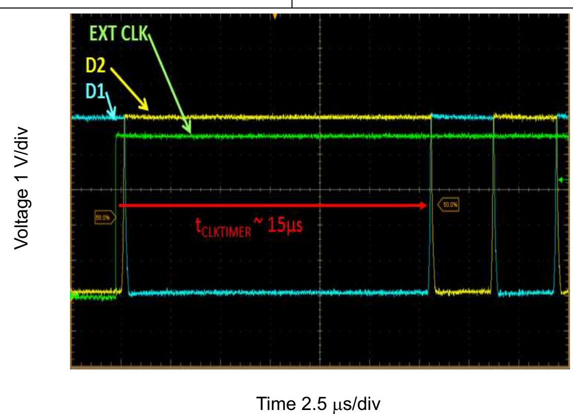


Figure 33. Scope Capture of SN6505 Switching from External to Internal Clock

7 Parameter Measurement Information

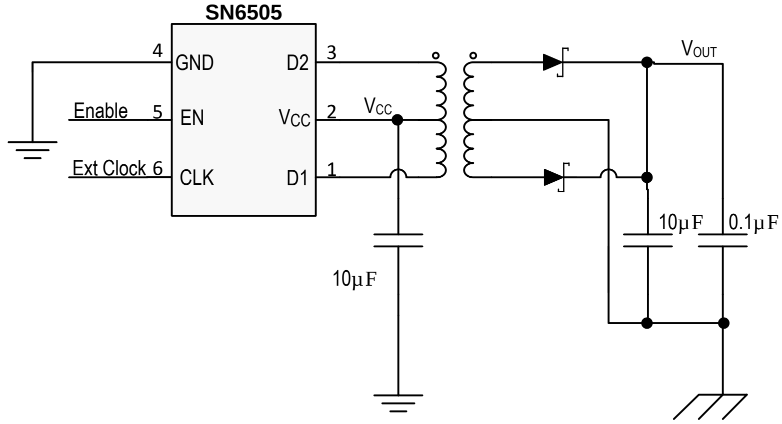


Figure 34. Measurement Circuit for Unregulated Output (TP1)

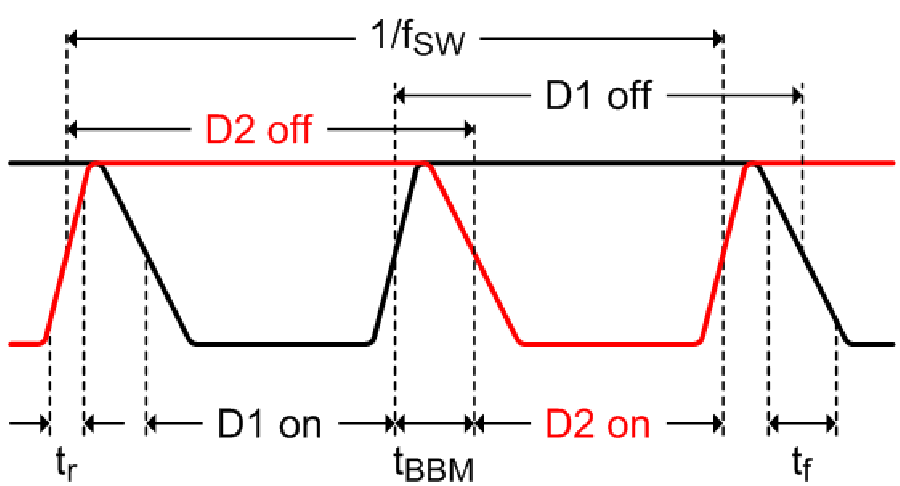


Figure 35. Timing Diagram

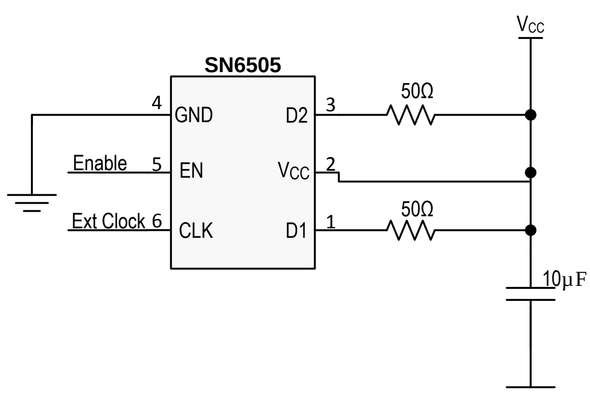


Figure 36. Test Circuit for F_{SW}, $V_{(slew)}$, t_{BBM}

Parameter Measurement Information (continued)

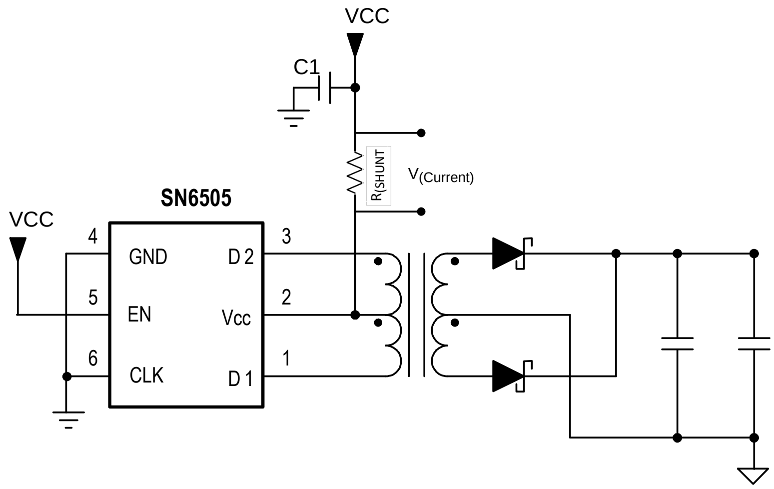


Figure 37. $I_{(slew)}$ Test Setup

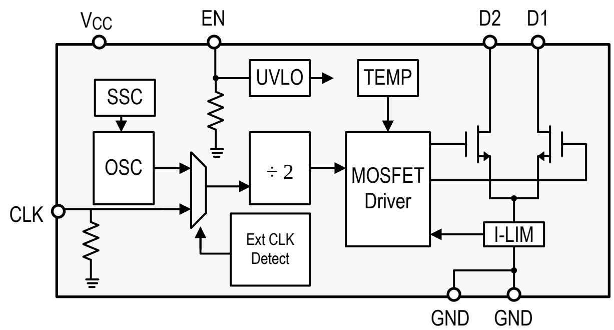
8 Detailed Description

8.1 Overview

The SN6505 is a transformer driver designed for low-cost, small form-factor, isolated DC-DC converters utilizing the push-pull topology. The device includes an oscillator that feeds a gate-drive circuit. The gate-drive, comprising a frequency divider and a break-before-make (BBM) logic, provides two complementary output signals which alternately turn the two output transistors on and off.

The output frequency of the oscillator is divided down by two . A subsequent break-before-make logic inserts a dead-time between the high-pulses of the two signals. Before either one of the gates can assume logic high, the BBM logic ensures a short time period during which both signals are low and both transistors are high-impedance. This short period, is required to avoid shorting out both ends of the primary. The resulting output signals, present the gate-drive signals for the output transistors.

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Push-Pull Converter

Push-pull converters require transformers with center-taps to transfer power from the primary to the secondary (see Figure 38).

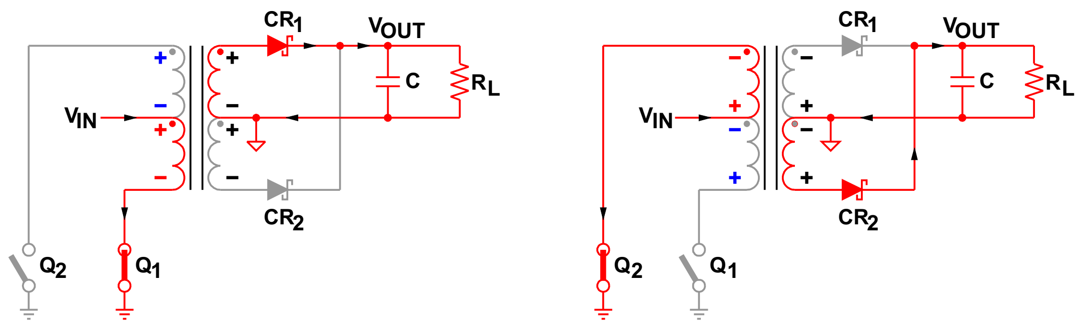


Figure 38. Switching Cycles of a Push-Pull Converter

When Q_1 conducts, V_{IN} drives a current through the lower half of the primary to ground, thus creating a negative voltage potential at the lower primary end with regards to the V_{IN} potential at the center-tap.

At the same time the voltage across the upper half of the primary is such that the upper primary end is positive with regards to the center-tap in order to maintain the previously established current flow through Q_2, which now has turned high-impedance. The two voltage sources, each of which equaling V_{IN}, appear in series and cause a voltage potential at the open end of the primary of $2 \times V_{IN}$ with regards to ground.

Feature Description (continued)

Per dot convention the same voltage polarities that occur at the primary also occur at the secondary. The positive potential of the upper secondary end therefore forward biases diode CR_1. The secondary current starting from the upper secondary end flows through CR_1, charges capacitor C, and returns through the load impedance R_L back to the center-tap.

When Q_2 conducts, Q_1 goes high-impedance and the voltage polarities at the primary and secondary reverse. Now the lower end of the primary presents the open end with a $2 \times V_{IN}$ potential against ground. In this case CR_2 is forward biased while CR_1 is reverse biased and current flows from the lower secondary end through CR_2, charging the capacitor and returning through the load to the center-tap.

8.3.2 Core Magnetization

Figure 39 shows the ideal magnetizing curve for a push-pull converter with B as the magnetic flux density and H as the magnetic field strength. When Q_1 conducts the magnetic flux is pushed from A to A’, and when Q_2 conducts the flux is pulled back from A’ to A. The difference in flux and thus in flux density is proportional to the product of the primary voltage, V_P, and the time, t_{ON}, it is applied to the primary: $B \approx V_P \times t_{ON}$.

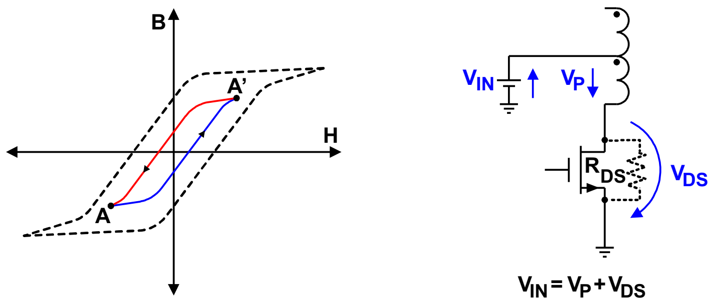


Figure 39. Core Magnetization and Self-Regulation Through Positive Temperature Coefficient of $R_{DS(on)}$

This volt-seconds (V-t) product is important as it determines the core magnetization during each switching cycle. If the V-t products of both phases are not identical, an imbalance in flux density swing results with an offset from the origin of the B-H curve. If balance is not restored, the offset increases with each following cycle and the transformer slowly creeps toward the saturation region.

8.4 Device Functional Modes

The functional modes of the SN6505 are divided into start-up, operating, and off-mode.

8.4.1 Start-Up Mode

When the supply voltage at V_{CC} ramps up to 2.25 V , the internal oscillator starts operating . The output stage begins switching but the amplitude of the drain signals at D1 and D2 has not reached its full maximum yet.

8.4.2 Operating Mode

When the device supply has reached its nominal value ±10% the oscillator is fully operating. However variations over supply voltage and operating temperature can vary the switching frequencies at D1 and D2 .

8.4.3 Shutdown-Mode

SN6505 has a dedicated Enable pin to put the device in very low power mode to save power when not in use. Enable pin has an internal pull down resistor which keeps device disabled when not driven. When disabled or when V_{CC} is < 1.7 V , both drain outputs, D1 and D2, are tri-stated.

8.4.4 Spread Spectrum Clocking

Radiated emissions is an important concern in high current switching power supplies. SN6505 addresses this by modulating its internal clock in way the emitting energy is spread over multiple frequency bins . This Spread Spectrum clocking feature greatly improves the emissions performance of the entire power supply block and hence relieving the system designer of one major concern in isolated power supply design.

8.4.5 External Clock Mode

SN6505 has a CLK pin which can be used to synchronize SN6505 with system clock and in turn with other SN6505 so that the system can control the exact switching frequency of the device. The Rising edge of the CLK is used to divide a clock by two and used to driver the gates. Figure 41, shows the timing diagram for the same. SN6505 also has external clock fail safe feature which automatically switches the device to the internal clock is a valid input clock is not present for long ($t_{CLKTIMER}$).The inbuilt emissions reduction scheme of Spread Spectrum clocking is disabled when external clock is present.

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 SN6505 is a transformer driver designed for low-cost, small form-factor, isolated DC-DC converters utilizing the push-pull topology. The device includes an oscillator that feeds a gate-drive circuit. The gate-drive, comprising a frequency divider and a break-before-make (BBM) logic, provides two complementary output signals which alternately turn the two output transistors on and off.

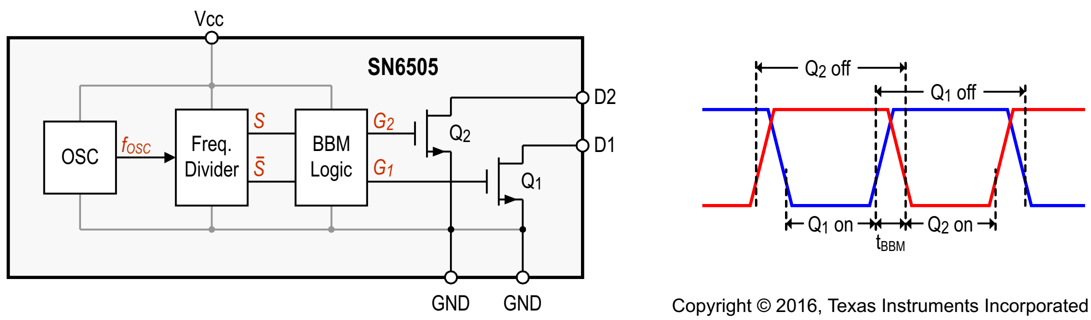


Figure 40. SN6505 Block Diagram And Output Timing With Break-Before-Make Action

The output frequency of the oscillator is divided down by an asynchronous divider that provides two complementary output signals, S and $\overline{S}$, with a 50% duty cycle. A subsequent break-before-make logic inserts a dead-time between the high-pulses of the two signals. The resulting output signals, G_1 and G_2, present the gate-drive signals for the output transistors Q_1 and Q_2. As shown in Figure 41, before either one of the gates can assume logic high, there must be a short time period during which both signals are low and both transistors are high-impedance. This short period, known as break-before-make time, is required to avoid shorting out both ends of the primary.

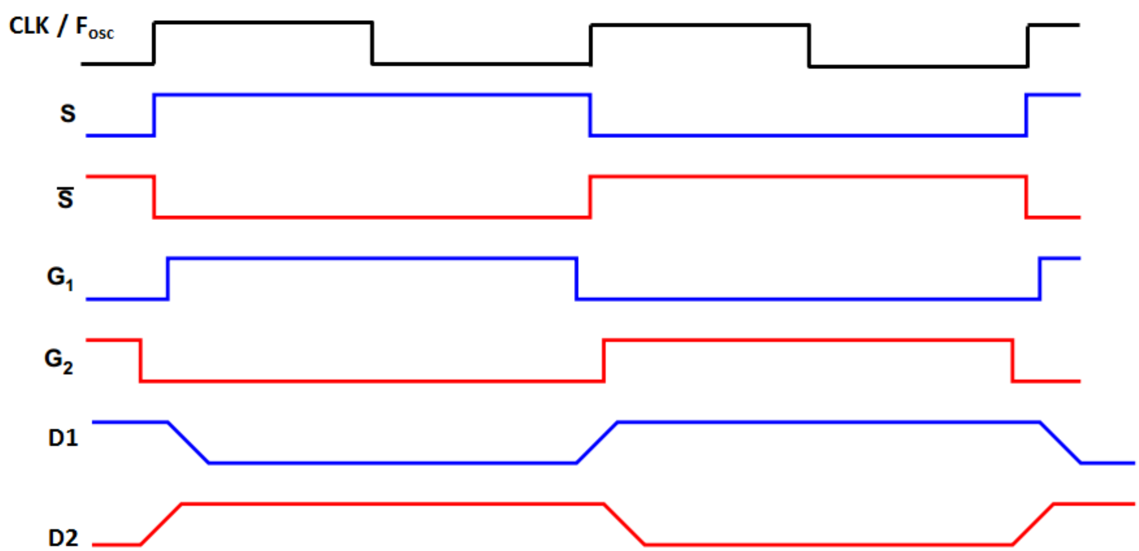


Figure 41. Detailed Output Signal Waveforms

9.2 Typical Application

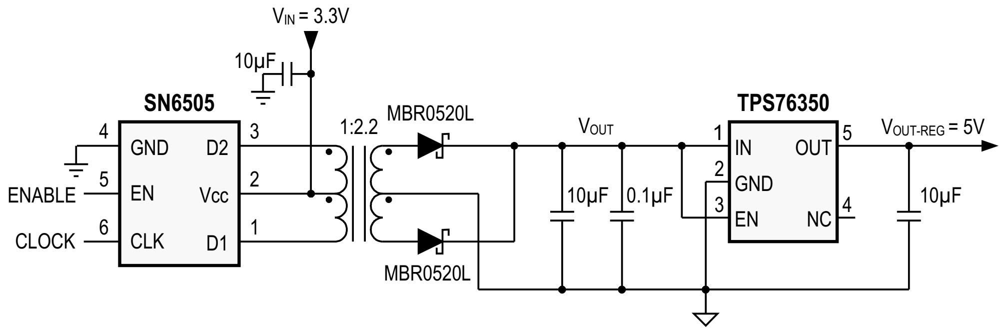


Figure 42. Typical Application Schematic (SN6505)

9.2.1 Design Requirements

For this design example, use the parameters listed in Table 1 as design parameters.

Table 1. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Input voltage range	3.3 V ± 3%
Output voltage	5 V
Maximum load current	100 mA

9.2.2 Detailed Design Procedure

The following recommendations on components selection focus on the design of an efficient push-pull converter with high current drive capability. Contrary to popular belief, the output voltage of the unregulated converter output drops significantly over a wide range in load current. The characteristic curve in Figure 1 and Figure 11 for example, shows that the difference between V_{OUT} at minimum load and V_{OUT} at maximum load exceeds a transceiver's supply range. Therefore, in order to provide a stable, load independent supply while maintaining maximum possible efficiency the implementation of a low dropout regulator (LDO) is strongly advised.

The final converter circuit is shown in Figure 47. The measured V_{OUT} and efficiency characteristics for the regulated and unregulated outputs are shown in Figure 2 and Figure 12.

9.2.2.1 SN6505 Drive Capability

The SN6505 transformer driver is designed for low-power push-pull converters with input and output voltages in the range of 3 V to 5.5 V. While converter designs with higher output voltages are possible, care must be taken that higher turns ratios don't lead to primary currents that exceed the SN6505 specified current limits.

9.2.2.2 LDO Selection

The minimum requirements for a suitable low dropout regulator are:

- Its current drive capability should slightly exceed the specified load current of the application to prevent the LDO from dropping out of regulation. Therefore, for a load current of 100 mA, choose a 100 mA to 150 mA LDO. While regulators with higher drive capabilities are acceptable, they also usually possess higher dropout voltages that will reduce overall converter efficiency.
- The internal dropout voltage, V_{DO}, at the specified load current should be as low as possible to maintain efficiency. For a low-cost 150 mA LDO, a V_{DO} of 150 mV at 100 mA is common. Be aware; however, that this lower value is usually specified at room temperature and can increase by a factor of 2 over temperature, which in turn will raise the required minimum input voltage.
- The required minimum input voltage preventing the regulator from dropping out of line regulation is given with:

$$V_{I\text{-}min} = V_{DO\text{-}max} + V_{O\text{-}max} \quad (1)$$

This means in order to determine V_I for worst-case condition, the user must take the maximum values for V_{DO} and V_O specified in the LDO data sheet for rated output current (that is, 100 mA) and add them together. Also specify that the output voltage of the push-pull rectifier at the specified load current is equal or higher than V_{I-min}. If it is not, the LDO will lose line-regulation and any variations at the input passes straight through to the output. Hence, below V_{I-min} the output voltage follows the input and the regulator behaves like a simple conductor.

- The maximum regulator input voltage must be higher than the rectifier output under no-load. Under this condition there is no secondary current reflected back to the primary, thus making the voltage drop across R_{DS-on} negligible and allowing the entire converter input voltage to drop across the primary. At this point, the secondary reaches its maximum voltage of

$$V_{S-max} = V_{IN-max} \times n \quad (2)$$

with V_{IN-max} as the maximum converter input voltage and n as the transformer turns ratio. Thus to prevent the LDO from damage the maximum regulator input voltage must be higher than V_{S-max}. Table 2 lists the maximum secondary voltages for various turns ratios commonly applied in push-pull converters with 100 mA output drive.

Table 2. Required Maximum LDO Input Voltages for Various Push-Pull Configurations

PUSH-PULL CONVERTER				LDO
CONFIGURATION	V_{IN-max} [V]	TURNS-RATIO	V_{S-max} [V]	V_{I-max} [V]
3.3 V_{IN} to 3.3 V_{OUT}	3.6	1.5 ± 3%	5.6	6 to 10
3.3 V_{IN} to 5 V_{OUT}	3.6	2.2 ± 3%	8.2	10
5 V_{IN} to 5 V_{OUT}	5.5	1.5 ± 3%	8.5	10

9.2.2.3 Diode Selection

A rectifier diode should always possess low-forward voltage to provide as much voltage to the converter output as possible. When used in high-frequency switching applications, such as the SN6505 however, the diode must also possess a short recovery time. Schottky diodes meet both requirements and are therefore strongly recommended in push-pull converter designs. A good choice for low-volt applications and ambient temperatures of up to 85°C is the low-cost Schottky rectifier MBR0520L with a typical forward voltage of 275 mV at 100-mA forward current. For higher output voltages such as ±10 V and above use the MBR0530 which provides a higher DC blocking voltage of 30 V.

Lab measurements have shown that at temperatures higher than 100°C the leakage currents of the above Schottky diodes increase significantly. This can cause thermal runaway leading to the collapse of the rectifier output voltage. Therefore, for ambient temperatures higher than 85°C use low-leakage Schottky diodes, such as RB168M-40.

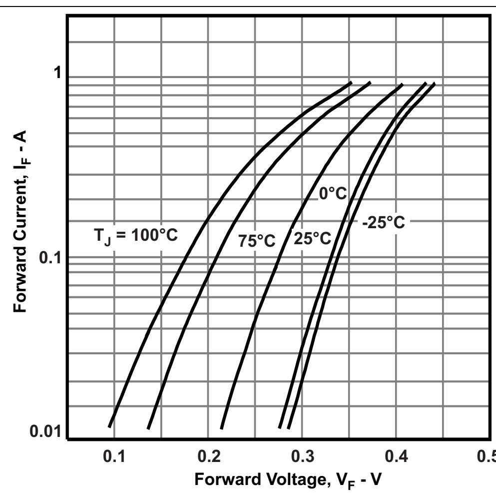


Figure 43. Diode Forward Characteristics for MBR0520L

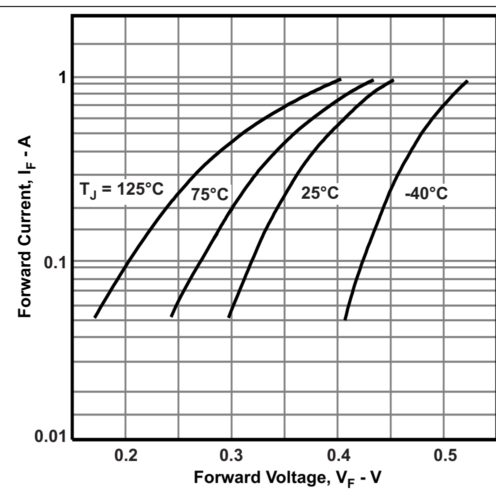


Figure 44. Diode Forward Characteristics MBR0530

9.2.2.4 Capacitor Selection

The capacitors in the converter circuit in Figure 47 are multi-layer ceramic chip (MLCC) capacitors.

As with all high speed CMOS ICs, the SN6505 requires a bypass capacitor in the range of 10 nF to 100 nF.

The input bulk capacitor at the center-tap of the primary supports large currents into the primary during the fast switching transients. For minimum ripple make this capacitor 1 μF to 10 μF. In a 2-layer PCB design with a dedicated ground plane, place this capacitor close to the primary center-tap to minimize trace inductance. In a 4-layer board design with low-inductance reference planes for ground and V_{IN}, the capacitor can be placed at the supply entrance of the board. To ensure low-inductance paths use two vias in parallel for each connection to a reference plane or to the primary center-tap.

The bulk capacitor at the rectifier output smoothes the output voltage. Make this capacitor 1 μF to 10 μF.

The small capacitor at the regulator input is not necessarily required. However, good analog design practice suggests, using a small value of 47 nF to 100 nF improves the regulator's transient response and noise rejection.

The LDO output capacitor buffers the regulated output for the subsequent isolator and transceiver circuitry. The choice of output capacitor depends on the LDO stability requirements specified in the data sheet. However, in most cases, a low-ESR ceramic capacitor in the range of 4.7 μF to 10 μF will satisfy these requirements.

9.2.2.5 Transformer Selection

9.2.2.5.1 V-t Product Calculation

To prevent a transformer from saturation its V-t product must be greater than the maximum V-t product applied by the SN6505. The maximum voltage delivered by the SN6505 is the nominal converter input plus 10%. The maximum time this voltage is applied to the primary is half the period of the lowest frequency at the specified input voltage. Therefore, the transformer's minimum V-t product is determined through:

$$Vt_{min} \geq V_{IN\text{-}max} \times \frac{T_{max}}{2} = \frac{V_{IN\text{-}max}}{2 \times f_{min}} \quad (3)$$

Taking an example of f_{min} as 250 kHz at 3.6 V and 300 kHZ at 5.5 V Equation 3 yields the minimum V-t products of:

$$Vt_{min} \geq \frac{3.6\ V}{2 \times 250\ kHz} = 7.2\ V\mu s \quad \text{for 3.3 V, and}$$

$$Vt_{min} \geq \frac{5.5\ V}{2 \times 300\ kHz} = 9.1\ V\mu s \quad \text{for 5 V applications.} \quad (4)$$

Common V-t values for low-power center-tapped transformers range from 22 Vμs to 150 Vμs with typical footprints of 10 mm x 12 mm. However, transformers specifically designed for PCMCIA applications provide as little as 11 Vμs and come with a significantly reduced footprint of 6 mm x 6 mm only.

While Vt-wise all of these transformers can be driven by the SN6505, other important factors such as isolation voltage, transformer wattage, and turns ratio must be considered before making the final decision.

9.2.2.5.2 Turns Ratio Estimate

Assume the rectifier diodes and linear regulator has been selected. Also, it has been determined that the transformer chosen must have a V-t product of at least 11 Vμs. However, before searching the manufacturer web sites for a suitable transformer, the user still needs to know its minimum turns ratio that allows the push-pull converter to operate flawlessly over the specified current and temperature range. This minimum transformation ratio is expressed through the ratio of minimum secondary to minimum primary voltage multiplied by a correction factor that takes the transformer's typical efficiency of 97% into account:

$$V_{P\text{-}min} = V_{IN\text{-}min} - V_{DS\text{-}max} \quad (5)$$

$V_{S\text{-}min}$ must be large enough to allow for a maximum voltage drop, $V_{F\text{-}max}$, across the rectifier diode and still provide sufficient input voltage for the regulator to remain in regulation. From the *LDO Selection* section, this minimum input voltage is known and by adding $V_{F\text{-}max}$ gives the minimum secondary voltage with:

$$V_{S\text{-}min} = V_{F\text{-}max} + V_{DO\text{-}max} + V_{O\text{-}max} \quad (6)$$

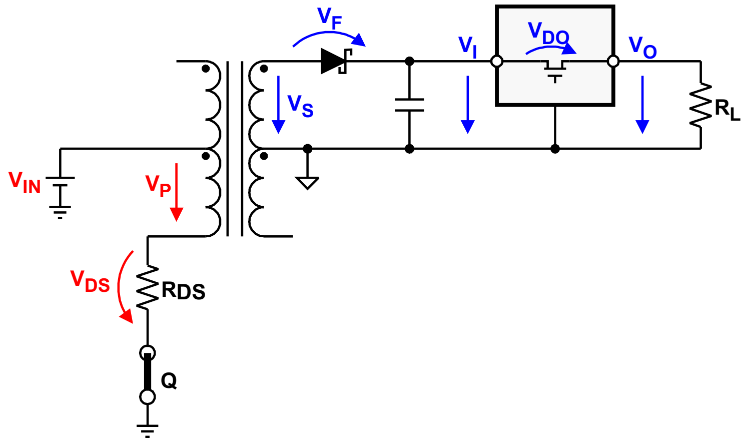


Figure 45. Establishing the Required Minimum Turns Ratio Through N_{min} = 1.031 × $V_{S\text{-}min}$ / $V_{P\text{-}min}$

Then calculating the available minimum primary voltage, $V_{P\text{-}min}$, involves subtracting the maximum possible drain-source voltage of the SN6505, $V_{DS\text{-}max}$, from the minimum converter input voltage $V_{IN\text{-}min}$:

$$V_{P\text{-}min} = V_{IN\text{-}min} - V_{DS\text{-}max} \quad (7)$$

$V_{DS\text{-}max}$ however, is the product of the maximum $R_{DS(on)}$ and I_D values for a given supply specified in the SN6505 data sheet:

$$V_{DS\text{-}max} = R_{DS\text{-}max} \times I_{Dmax} \quad (8)$$

Then inserting Equation 8 into Equation 7 yields:

$$V_{P\text{-}min} = V_{IN\text{-}min} - R_{DS\text{-}max} \times I_{Dmax} \quad (9)$$

and inserting Equation 9 and Equation 6 into Equation 5 provides the minimum turns ration with:

$$n_{min} = 1.031 \times \frac{V_{F\text{-}max} + V_{DO\text{-}max} + V_{O\text{-}max}}{V_{IN\text{-}min} - R_{DS\text{-}max} \times I_{D\text{-}max}} \quad (10)$$

Example:

For a 3.3 V_{IN} to 5 V_{OUT} converter using the rectifier diode MBR0520L and the 5 V LDO, the data sheet values taken for a load current of 100 mA and a maximum temperature of 85°C are $V_{F\text{-}max}$ = 0.2 V, $V_{DO\text{-}max}$ = 0.2 V, and $V_{O\text{-}max}$ = 5.175 V.

Then assuming that the converter input voltage is taken from a 3.3 V controller supply with a maximum ±2% accuracy makes $V_{IN\text{-}min}$ = 3.234 V. Finally the maximum values for drain-source resistance and drain current at 3.3 V are taken from the SN6505 data sheet with $R_{DS\text{-}max}$ = 3 Ω and $I_{D\text{-}max}$ = 150 mA.

Inserting the values above into Equation 10 yields a minimum turns ratio of:

$$n_{min} = 1.031 \times \frac{0.2V + 0.2V + 5.175\ V}{3.234\ V - 3\ \Omega \times 150\ mA} = 2 \quad (11)$$

Most commercially available transformers for 3-to-5 V push-pull converters offer turns ratios between 2.0 and 2.3 with a common tolerance of ±3%.

9.2.2.5.3 Recommended Transformers

Depending on the application, use the minimum configuration in Figure 46 or standard configuration in Figure 47.

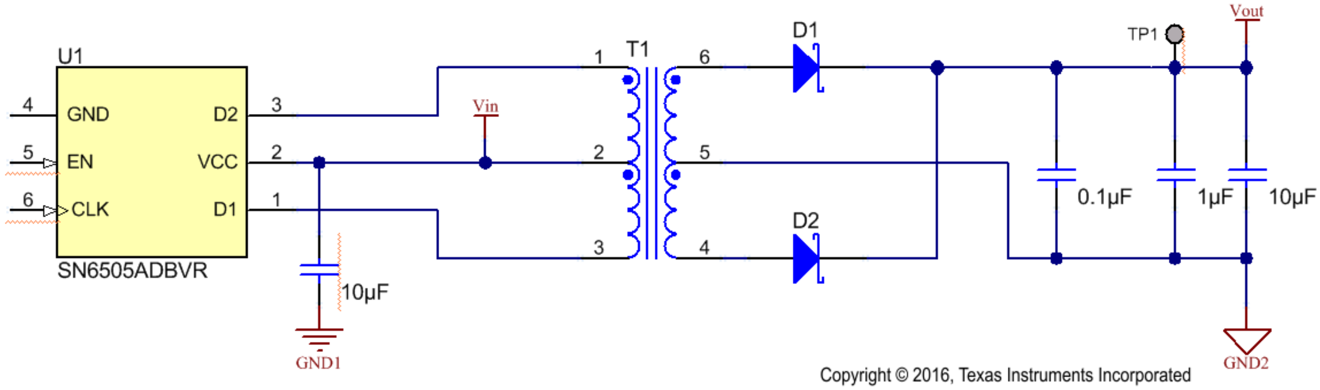


Figure 46. Unregulated Output for Low-Current Loads With Wide Supply Range

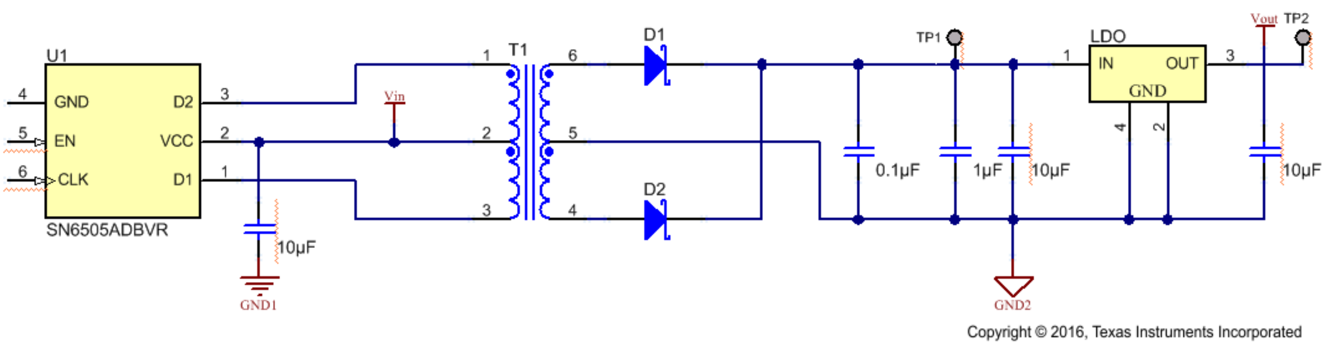


Figure 47. Regulated Output for Stable Supplies and High Current Loads

The Wurth Electronics Midcom isolation transformers in Table 3 are optimized designs for the SN6505, providing high efficiency and small form factor at low-cost.

The 1:1.1 and 1:1.7 turns-ratios are designed for logic applications with wide supply rails and low load currents. These applications operate without LDO, thus achieving further cost-reduction.

Table 3. Recommended Isolation Transformers Optimized for SN6505

Turns Ratio	V x T (Vµs)	Isolation (V_{RMS})	Dimensions (mm)	Application	LDO(1)	Order No.	Manufacturer
1:1.1 ±2%	7	2500	6.73 x 10.05 x 4.19	3.3 V → 3.3 V, 100mA, SN6505B Refer to Figure 13 and Figure 14	No	760390011	Wurth Electronics / Midcom
1:1.1 ±2%	11			5 V → 5 V, 100mA, SN6505B Refer to Figure 15 and Figure 16		760390012	
1:1.7 ±2%				3.3 V → 5 V, 100mA, SN6505B Refer to Figure 17 and Figure 18		760390013	
1:1.3 ±2%				3.3 V → 3.3 V, 100mA, SN6505B Refer to Figure 19 and Figure 20	Yes	760390014	
1:1.3 ±2%				5 V → 5 V, 100mA, SN6505B Refer to Figure 21 and Figure 22		760390014	
1:2.1 ±2%				3.3 V → 5 V, 100mA, SN6505B Refer to Figure 23 and Figure 24		760390015	
1.23:1 ±2%				5 V → 3.3 V, 100mA, SN6505B		750313710	
1:1.7 ±2%	8.9		8.3 x 12.6 x 4.1	3.3 V → 3.3 V, 1A, SN6505B Refer to Figure 25 and Figure 26		750316028	
1:2.1 ±2%				3.3 V → 5 V, 1A, SN6505B Refer to Figure 27 and Figure 28	No	750316029	
1.3:1 ±2%	10.8			5 V → 3.3 V, 1A, SN6505B Refer to Figure 29 and Figure 30		750316030	
1:1.1 ±2%	8.6			3.3 V → 3.3 V , 1A , SN6505B 5 V → 5 V , 1A , SN6505B Refer to Figure 11 and Figure 12		750315371	
1:1.1 ±2%	11	5000	9.14 x 12.7 x 7.37	3.3 V → 3.3 V, 100mA, SN6505B		750313734	
1:1.1 ±2%				5 V → 5 V, 100mA, SN6505B		750313734	
1:1.7 ±2%				3.3 V → 5 V, 100mA, SN6505B		750313769	
1:1.3 ±2%				3.3 V → 3.3 V, 100mA, SN6505B 5 V → 5 V, 100mA, SN6505B		750313638	
1:2.1 ±2%				3.3 V → 5 V, 100mA, SN6505B		750313626	
1.3:1 ±2%				5 V → 3.3 V, 100mA , SN6505B		750313638	
1:1.75 ±2%	41		12.32 x 15.41 x 11.05	3.3 V → 3.3 V, 1A, SN6505A Refer to Figure 3 and Figure 4	Yes	750316031	
1:2 ±2%				3.3 V → 5 V, 1A, SN6505A Refer to Figure 5 and Figure 6	No	750316032	
1.3:1 ±2%	42			5.0 V → 3.3 V, 1A, SN6505A Refer to Figure 7 and Figure 8		750316033	
1:1.1 ±2%	23		14.88 x 12.32 x 11.05	3.3 V → 3.3 V, 1A, SN6505A 5 V → 5 V, 1A , SN6505A Refer to Figure 1 and Figure 2		750315240	

(1) For configurations with LDO, a higher voltage than the required output voltage is generated, to allow for LDO drop-out. Figures show the voltage and efficiency at the LDO input.

9.2.3 Application Curve

See the*Typical Characteristics, SN6505A* and *Typical Characteristics, SN6505B* for application curves with transformers optimized for the SN6505, providing high efficiency and small form factor at low-cost.

9.2.4 System Examples

9.2.4.1 Higher Output Voltage Designs

The SN6505 can drive push-pull converters that provide high output voltages of up to 30 V, or bipolar outputs of up to ±15 V. Using commercially available center-tapped transformers, with their rather low turns ratios of 0.8 to 5, requires different rectifier topologies to achieve high output voltages. Figure 48 to Figure 50 show some of these topologies together with their respective open-circuit output voltages.

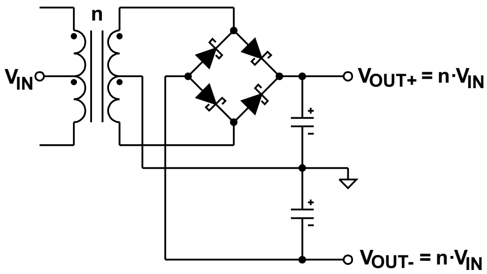


Figure 48. Bridge Rectifier With Center-Tapped Secondary Enables Bipolar Outputs

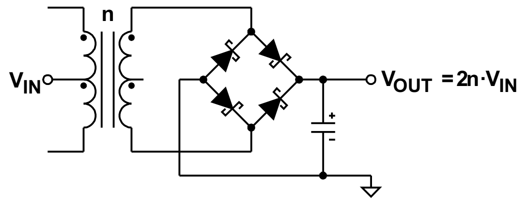


Figure 49. Bridge Rectifier Without Center-Tapped Secondary Performs Voltage Doubling

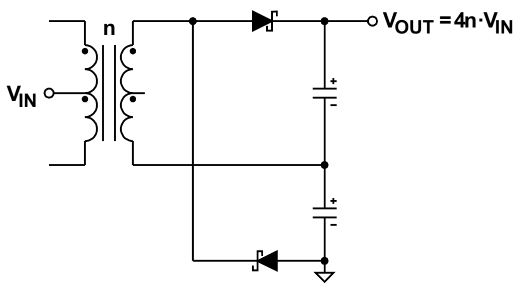


Figure 50. Half-Wave Rectifier Without Centered Ground and Center-Tapped Secondary Performs Voltage Doubling Twice, Hence Quadrupling V_{IN}

9.2.4.2 Application Circuits

The following application circuits are shown for a 3.3 V input supply commonly taken from the local, regulated micro-controller supply. For 5 V input voltages requiring different turn ratios refer to the transformer manufacturers and their web sites listed in Table 4.

Table 4. Transformer Manufacturers

Coilcraft Inc.	http://www.coilcraft.com
Halo-Electronics Inc.	http://www.haloelectronics.com
Murata Power Solutions	http://www.murata-ps.com
Wurth Electronics Midcom Inc	http://www.midcom-inc.com

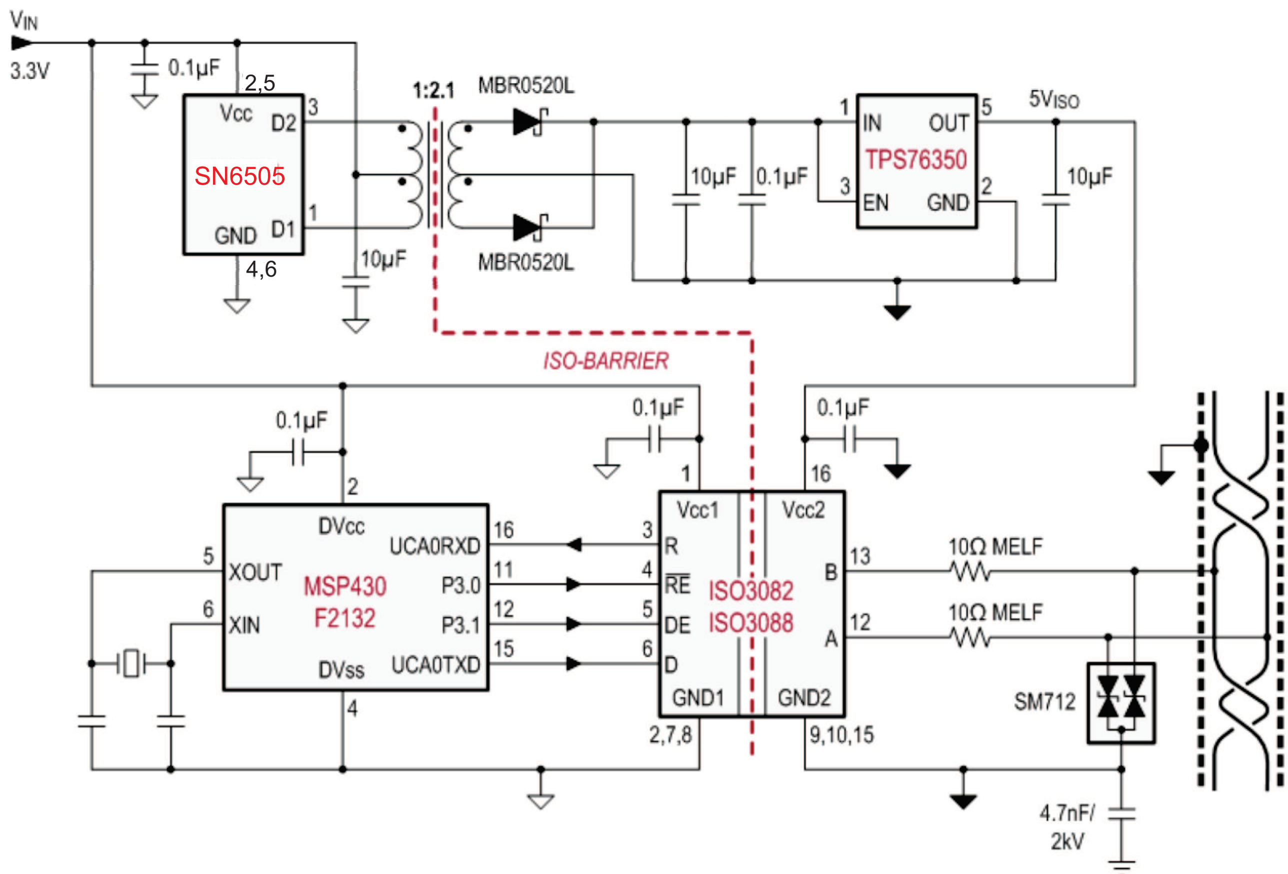


Figure 51. Isolated RS-485 Interface

10 Power Supply Recommendations

The device is designed to operate from an input voltage supply range between 3.3 V and 5 V nominal. This input supply must be regulated within ±10%. If the input supply is located more than a few inches from the SN6505 a 0.1 µF by-pass capacitor should be connected as close as possible to the device V_{CC} pin, and a 10 µF capacitor should be connected close to the transformer center-tap pin.

11 Layout

11.1 Layout Guidelines

- The V_{IN} pin must be buffered to ground with a low-ESR ceramic bypass-capacitor. The recommended capacitor value can range from 1 µF to 10 µF. The capacitor must have a voltage rating of 10 V minimum and a X5R or X7R dielectric.
- The optimum placement is closest to the V_{IN} and GND pins at the board entrance to minimize the loop area formed by the bypass-capacitor connection, the V_{IN} terminal, and the GND pin. See Figure 52 for a PCB layout example.
- The connections between the device D1 and D2 pins and the transformer primary endings, and the connection of the device V_{CC} pin and the transformer center-tap must be as close as possible for minimum trace inductance.
- • The connection of the device V_{CC} pin and the transformer center-tap must be buffered to ground with a low-ESR ceramic bypass-capacitor. The recommended capacitor value can range from 1µF to 10 µF. The capacitor must have a voltage rating of 16 V minimum and a X5R or X7R dielectric.
- The device GND pins must be tied to the PCB ground plane using two vias for minimum inductance.
- The ground connections of the capacitors and the ground plane should use two vias for minimum inductance.
- The rectifier diodes should be Schottky diodes with low forward voltage in the 10 mA to 100 mA current range to maximize efficiency.
- The V_{OUT} pin must be buffered to ISO-Ground with a low-ESR ceramic bypass-capacitor. The recommended capacitor value can range from 1µF to 10 µF. The capacitor must have a voltage rating of 16 V minimum and a X5R or X7R dielectric.

11.2 Layout Example

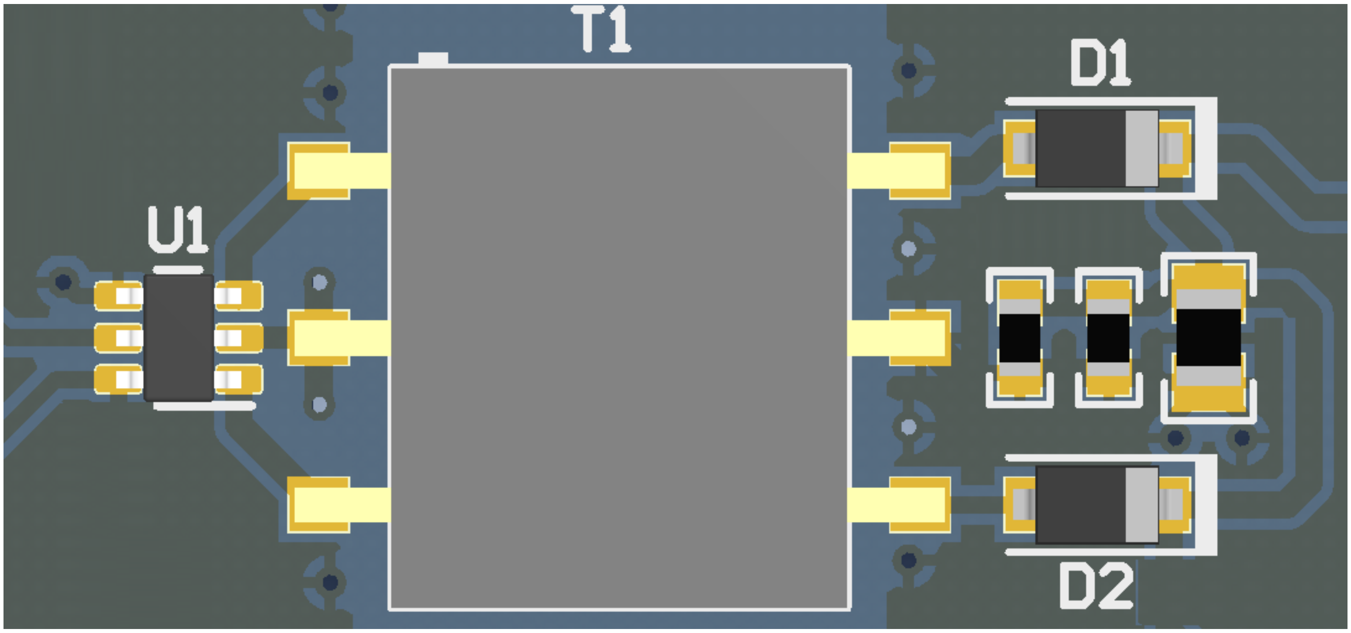


Figure 52. Layout Example of a 2-Layer Board (SN6505)

12 Device and Documentation Support

12.1 Device Support

12.1.1 Third-Party Products Disclaimer

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12.2 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 5. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
SN6505A	Click here	Click here	Click here	Click here	Click here
SN6505B	Click here	Click here	Click here	Click here	Click here

12.3 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.

12.4 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.

12.5 Trademarks

E2E is a trademark of Texas Instruments.

12.6 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.

12.7 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.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
SN6505ADBVR	ACTIVE	SOT-23	DBV	6	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-55 to 125	650A	Samples
SN6505ADBVT	ACTIVE	SOT-23	DBV	6	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-55 to 125	650A	Samples
SN6505BDBVR	ACTIVE	SOT-23	DBV	6	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-55 to 125	650B	Samples
SN6505BDBVT	ACTIVE	SOT-23	DBV	6	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-55 to 125	650B	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

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

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

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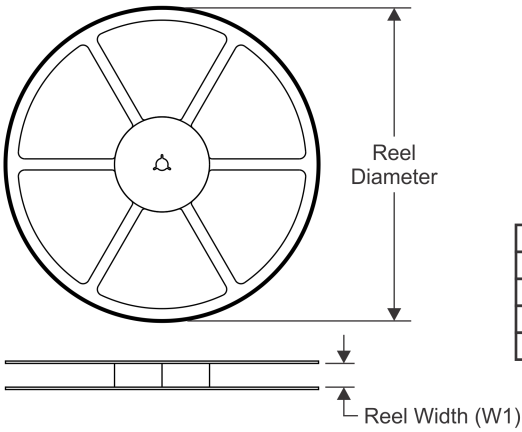
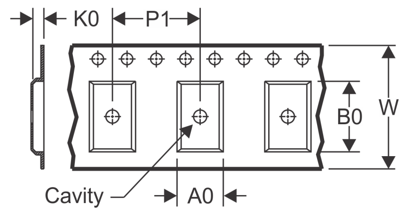
TAPE AND REEL INFORMATION

REEL DIMENSIONS

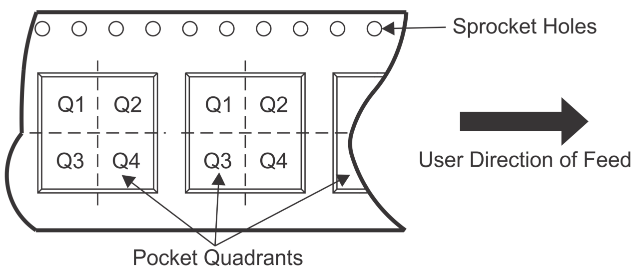


TAPE DIMENSIONS



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

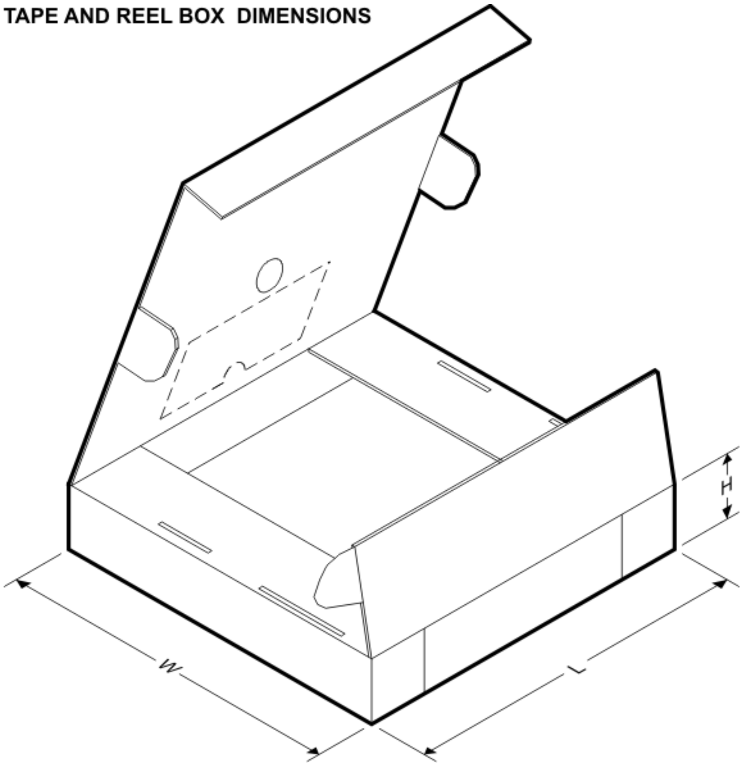
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
SN6505ADBVR	SOT-23	DBV	6	3000	178.0	9.0	3.23	3.17	1.37	4.0	8.0	Q3
SN6505ADBVT	SOT-23	DBV	6	250	178.0	9.0	3.23	3.17	1.37	4.0	8.0	Q3
SN6505BDBVR	SOT-23	DBV	6	3000	178.0	9.0	3.23	3.17	1.37	4.0	8.0	Q3
SN6505BDBVT	SOT-23	DBV	6	250	178.0	9.0	3.23	3.17	1.37	4.0	8.0	Q3

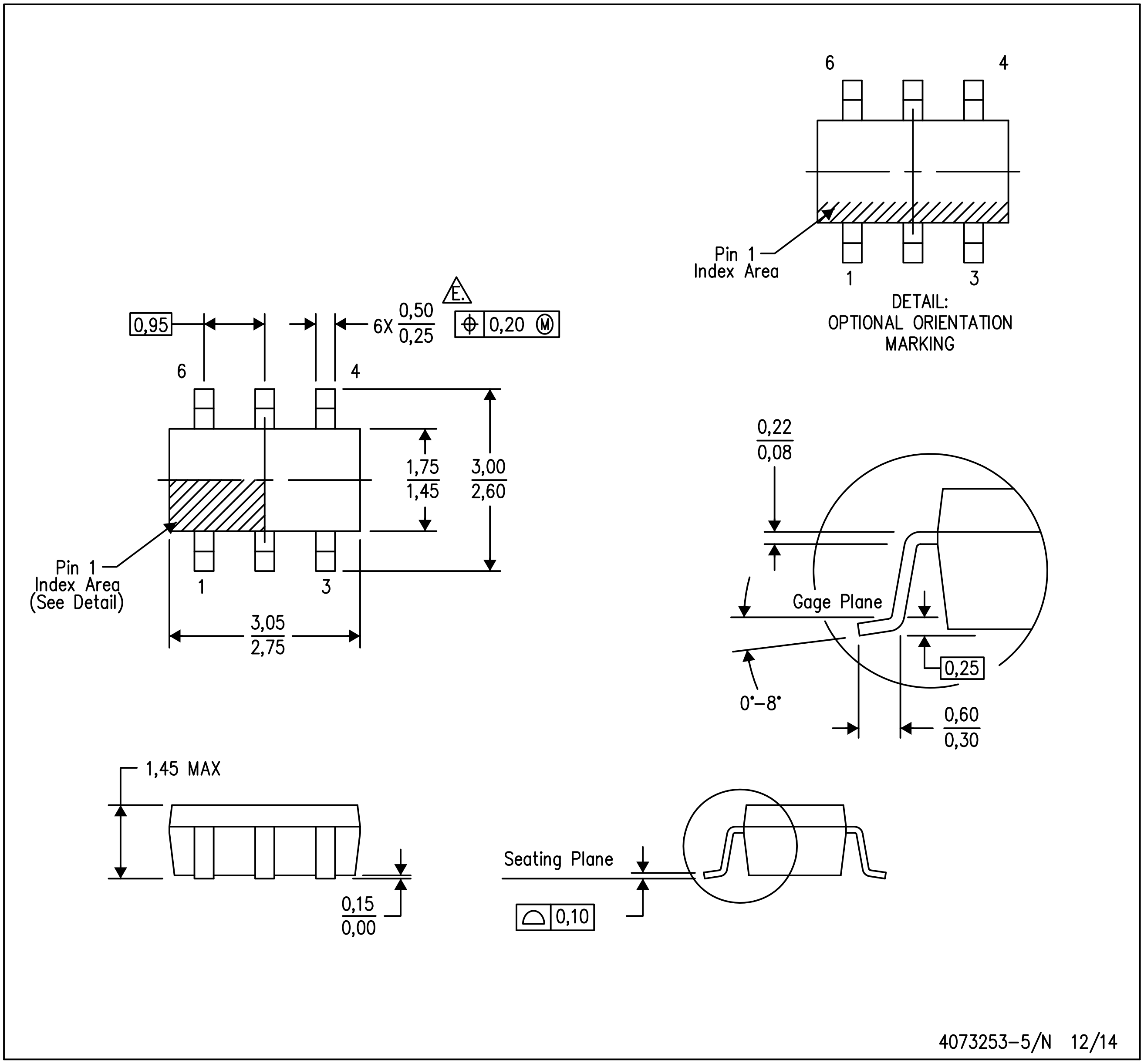
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

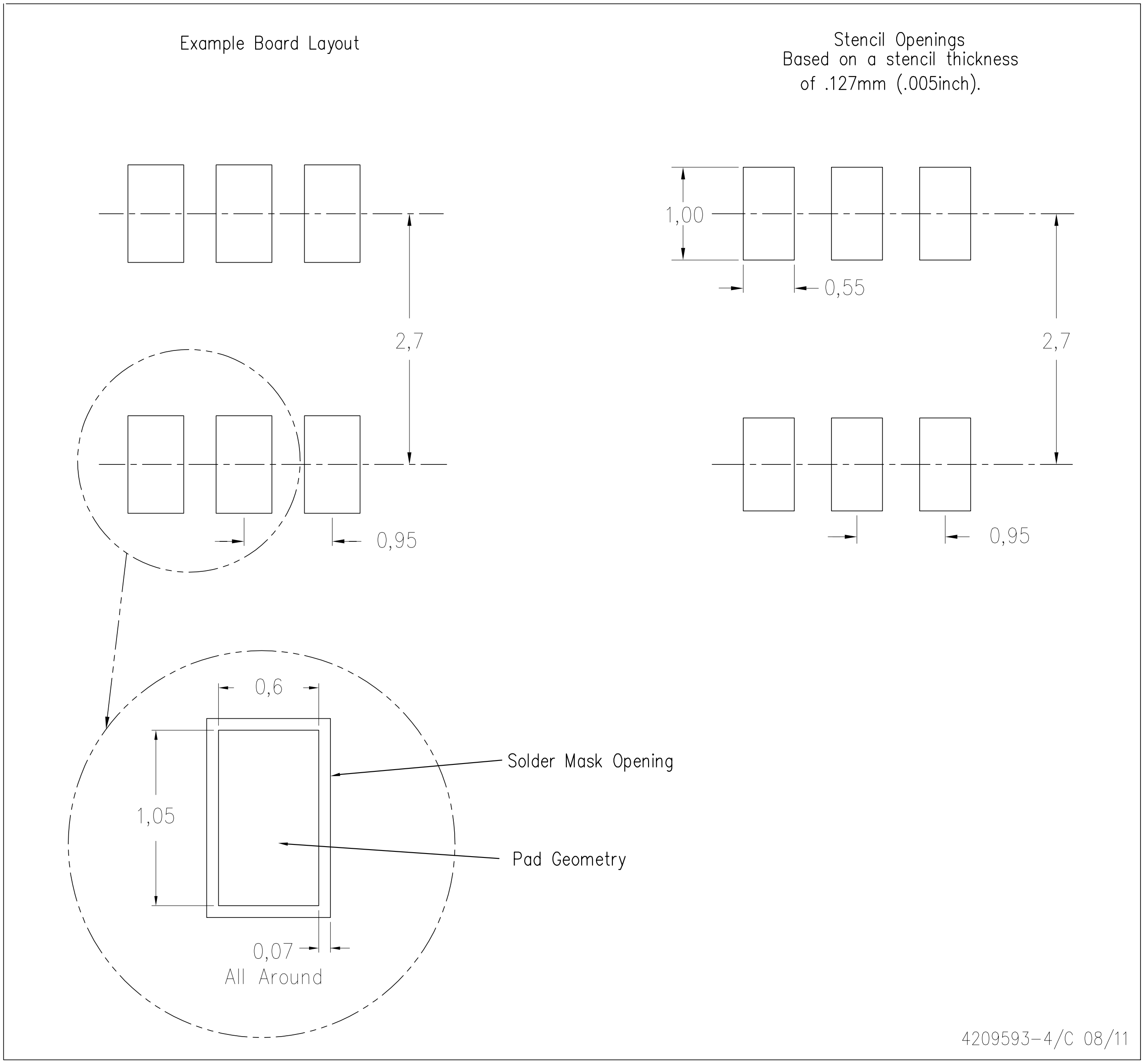
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
SN6505ADBVR	SOT-23	DBV	6	3000	180.0	180.0	18.0
SN6505ADBVT	SOT-23	DBV	6	250	180.0	180.0	18.0
SN6505BDBVR	SOT-23	DBV	6	3000	180.0	180.0	18.0
SN6505BDBVT	SOT-23	DBV	6	250	180.0	180.0	18.0

DBV (R-PDSO-G6) PLASTIC SMALL-OUTLINE PACKAGE



NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
D. Leads 1,2,3 may be wider than leads 4,5,6 for package orientation.
E. Falls within JEDEC MO-178 Variation AB, except minimum lead width.

DBV (R-PDSO-G6) PLASTIC SMALL OUTLINE



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
- D. Publication IPC-7351 is recommended for alternate designs.
- E. 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. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC-7525 for other stencil recommendations.

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