18V 720KHz 3A Fast-PWM Synchronous Step-Down Converter
Data Sheet

General Description

The MxL76503 is a fully integrated, high-efficiency synchronous step-down converter that requires a minimum number of external components. It offers a very compact solution with up to 3A continuous output current over a wide input range.

The MxL76503 uses a proprietary constant on-time (COT) control scheme that provides a superior transient response and maintains a constant switching frequency during continuous conduction mode (CCM) operation. The external ramp compensation network enables stable operation with ultra-low equivalent series resistance (ESR) output ceramic capacitors. An internal compensated error amplifier in the control loop provides excellent line and load regulation.

The MxL76503 integrates extensive protection functions, including under-voltage lockout (UVLO), over-current protection (OCP), under-voltage protection (UVP), and thermal shutdown.

The MxL76503 offers two modes of operation, PFM (MxL76503N) and forced PWM—FPWM—(MxL76503A), to suit different applications. PFM mode provides high efficiency at light loads and low standby power. FPWM mode provides low ripple voltage and fast transient, even at light loads.

The converter is available in a small 6-pin SOT23-6L package.

Features

- Input voltage range: 4.5V to 18V
- Output voltage range: 0.6V to 18V
- 3A continuous output current
- Supports 100% duty cycle low-dropout operation
- Stable operation with low ESR ceramic output capacitors
- Fast pulse-width modulation (PWM) COT control with superior transient performance
- 720KHz switching frequency
- 1.2ms internal soft-start
- 80mΩ/56mΩ integrated high-side (HS)/low-side (LS) power switches
- Accurate EN/UVLO threshold
- High-efficiency operation at light load (MxL76503N)
- FPWM mode of operation (MxL76503A)
- Thermal shutdown with auto-recovery
- Hiccup mode short-circuit protection
- Available in a 6-pin SOT23-6L package

Applications

- Laptop computers
- Tablet PCs
- Networking systems
- Personal video recorders
- Flat panel television and monitors
- Distributed power systems

Typical Application

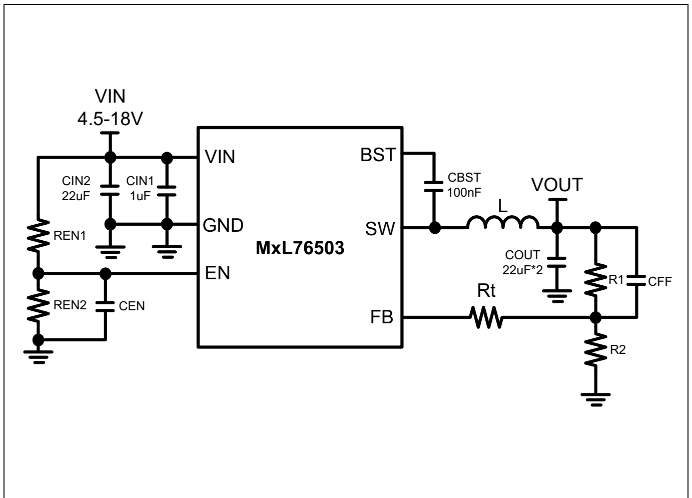

Figure 1: Typical Application Schematic

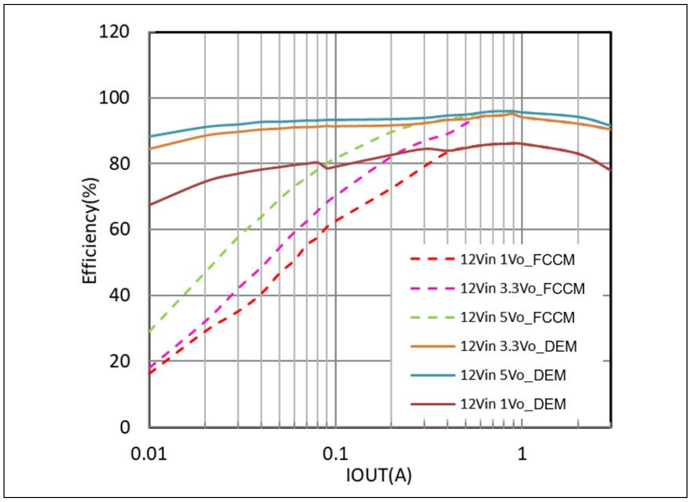

Figure 2: MxL76503 Efficiency

Revision History

Document No.	Release Date	Change Description
285-76503DSR01	March 7, 2025	Initial release.

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Specifications

Absolute Maximum Ratings

Important: The stresses above what is listed under the following table may cause permanent damage to the device. This is a stress rating only—functional operation of the device above what is listed under the following table or any other conditions beyond what MaxLinear recommends is not implied. Exposure to conditions above the recommended extended periods of time may affect device reliability.

Table 1: Absolute Maximum Ratings

Parameter	Min	Max	Units
VIN Voltage, EN	–0.3	19	V
SW Voltage	–0.3	V_{IN} + 0.3	V
Dynamic V_{SW} in 10ns Duration	–3	V_{IN} + 3	V
BS-SW Voltage	–0.3	6	V
FB Voltage	–0.3	6	V
Junction Temperature Range	–40	150	°C
Storage Temperature Range	–65	150	°C
Lead Temperature (Soldering 10s)	-	260	°C

Note: The voltage measured across each pin to GND should not exceed the maximum and minimum range.

Recommended Operating Conditions

Table 2: Recommended Operating Conditions

Symbol	Parameter	Min	Max	Units
V_{IN}	Input Voltage	4.5	18	V
T_A	Operating Ambient Temperature Range	–40	85	°C
T_J	Operating Junction Temperature Range	–40	125	°C

Note: The device is not guaranteed to function outside of the recommended operating conditions.

Thermal Specifications

Thermal information is measured on a 4-layer JESD51-7 PCB.

The maximum allowable power dissipation (T_A = 25°C) is a function of the maximum junction temperature T_{J_MAX}, the junction-to-ambient thermal resistance θ_{JA}, and the ambient temperature T_A. The maximum allowable continuous power dissipation at any ambient temperature is calculated by $P_{D\_MAX} = (T_{J\_MAX} – T_A)/\theta_{JA}$. Exceeding the maximum allowable power dissipation causes excessive die temperature, and the regulator goes into thermal shutdown. The internal thermal shutdown circuitry protects the device from permanent damage.

Table 3: Thermal Performance

Symbol	Parameter	Package	Typ	Max	Units
-	Package Power Dissipation	SOT23-6L	-	0.91	W
θ_{JA}	Junction-to-Ambient Thermal Resistance	SOT23-6L	-	137	°C/W
θ_{JC}	Junction-to-Case Thermal Resistance	SOT23-6L	93	-	°C/W

Electrical Characteristics

Electrical characteristics at V_{IN} = 12V, V_{EN} = 5V, V_{OUT} = 5V, T_A = 25°C, unless otherwise specified. The • denotes the specifications that apply over the temperature range of –40°C to 85°C, unless otherwise specified.

Table 4: Electrical Characteristics

Symbol	Parameter	Conditions		Min	Typ	Max	Units
V_{IN}	Input Voltage Range	-		4.5	-	18	V
I_{SHDN}	Shutdown Current	25°C		-	5	-	µA
		–40°C to 85°C	•	0.9	-	10	
V_{INUVLO}	Input Under-Voltage Lockout Threshold Rising	25°C		3.8	4	4.2	V
		–40°C to 85°C	•	3.685	-	4.315	
$V_{UVLO-HYS}$	Input Under-Voltage Lockout Hysteresis	25°C		-	300	-	mV
I_{IN}	Supply Current (MxL76503N)	25°C		-	250	-	µA
		–40°C to 85°C	•	70	-	330	
I_{IN}	Supply Current (MxL76503A)	25°C		-	600	-	µA
		–40°C to 85°C	•	190	-	2200	
V_{FB_REF}	Feedback Reference Voltage	–40°C to 85°C	•	588	600	612	mV
I_{FB}	Feedback Current	25°C		-	10	50	nA
		–40°C to 85°C	•	-	-	65	
T_{SS}	Internal Soft-Start Time (1)	25°C		-	1.2	-	ms
F_{SW}	Switching Frequency	25°C		-	720	-	kHz
		–40°C to 85°C	•	570	-	870	
T_{OFF_MIN}	Minimum Off Time (1)	25°C		-	140	-	ns
		–40°C to 85°C	•	-	-	250	
D_{MAX}	Maximum Duty Cycle (2)	25°C		-	100	-	%
RON_{HS}	HS Main Switch-On Resistance	25°C		-	80	-	mΩ
HS_SW_{LKG}	HS Switch Leakage Current	25°C		-	0.1	-	µA
		–40°C to 85°C	•	-	-	10	
I_{LIMIT}	Peak Current Limit	25°C		3.8	4.5	5.2	A
		–40°C to 85°C	•	3.6	-	5.3	
I_{ZX}	LS Switch Zero-Cross Current (MxL76503N)	25°C		-	0	-	mA
I_{NEG}	LS Switch Negative Current Limit (MxL76503A)	25°C		-	–1.5	-	A
RON_{LS}	LS Switch-On Resistance	25°C		-	56	-	mΩ
LS_SW_{LKG}	LS Switch Leakage Current	25°C		-	0.1	-	µA
		–40°C to 85°C	•	-	-	10	
V_{IH}	EN On Threshold	V_{EN} ramp up		-	1.21	-	V
V_{IL}	EN Off Threshold	V_{EN} ramp down		-	1.11	-	V
R_{EN}	EN Internal Pull-Down Resistor	25°C		-	1000	-	KΩ

Table 4: Electrical Characteristics (Continued)

Symbol	Parameter	Conditions		Min	Typ	Max	Units
-	Thermal Shutdown [1]	-		-	160	-	°C
-	Thermal Shutdown Hysteresis [1]	-		-	30	-	°C

1. Guaranteed by design, no production test.

2. When the input voltage approaches the output voltage, the MxL76503 device extends the on-time and forces the main high-side switch to remain on for multiple cycles (>10 μsec). The high-side switch is only momentarily turned off, and the low-side switch is forced on shortly (typically 120ns) to refresh the BST capacitor. The high-side switch resumes on after the BST capacitor refresh pulse.

Pin Information

Pin Configuration

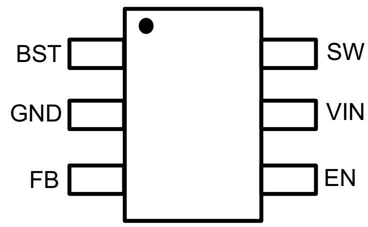


Figure 4: MxL76503 Pinout (Top View)

Pin Description

Table 5: Pin Description

Pin Number	Pin Name	Description
1	BST	Bootstrap pin. A 100nF ceramic capacitor connected between the SW and BST pins is required to form a floating supply for the high-side (HS) switch driver.
2	GND	Power Ground pin.
3	FB	Feedback pin. An external resistor divider from the output to GND, connected to the FB pin, sets the output voltage.
4	EN	Enable pin. The MxL76503 device is shut down when this pin is low and active when this pin is high. The hysteretic enable threshold voltage is 1.21V going up and 1.11V going down. Connect EN to VIN through a pull-up resistor or a resistive voltage divider for automatic startup. You can use an external resistor divider from VIN to program a VIN threshold below which MxL76503 operation is stopped. There is an internal 1000KΩ (typical) pull-down resistor from EN to the internal AGND.
5	VIN	Supply Voltage pin. The VIN pin supplies power for the internal MOSFET and regulator. The MxL76503 device operates from a 4.5V to 18V input rail. An input capacitor is required to decouple the input rail.
6	SW	Switch Output pin. Connect this pin to the inductor and bootstrap capacitor. The SW node must be kept small on the PCB for good performance and low electro-magnetic interference (EMI).

Block Diagram

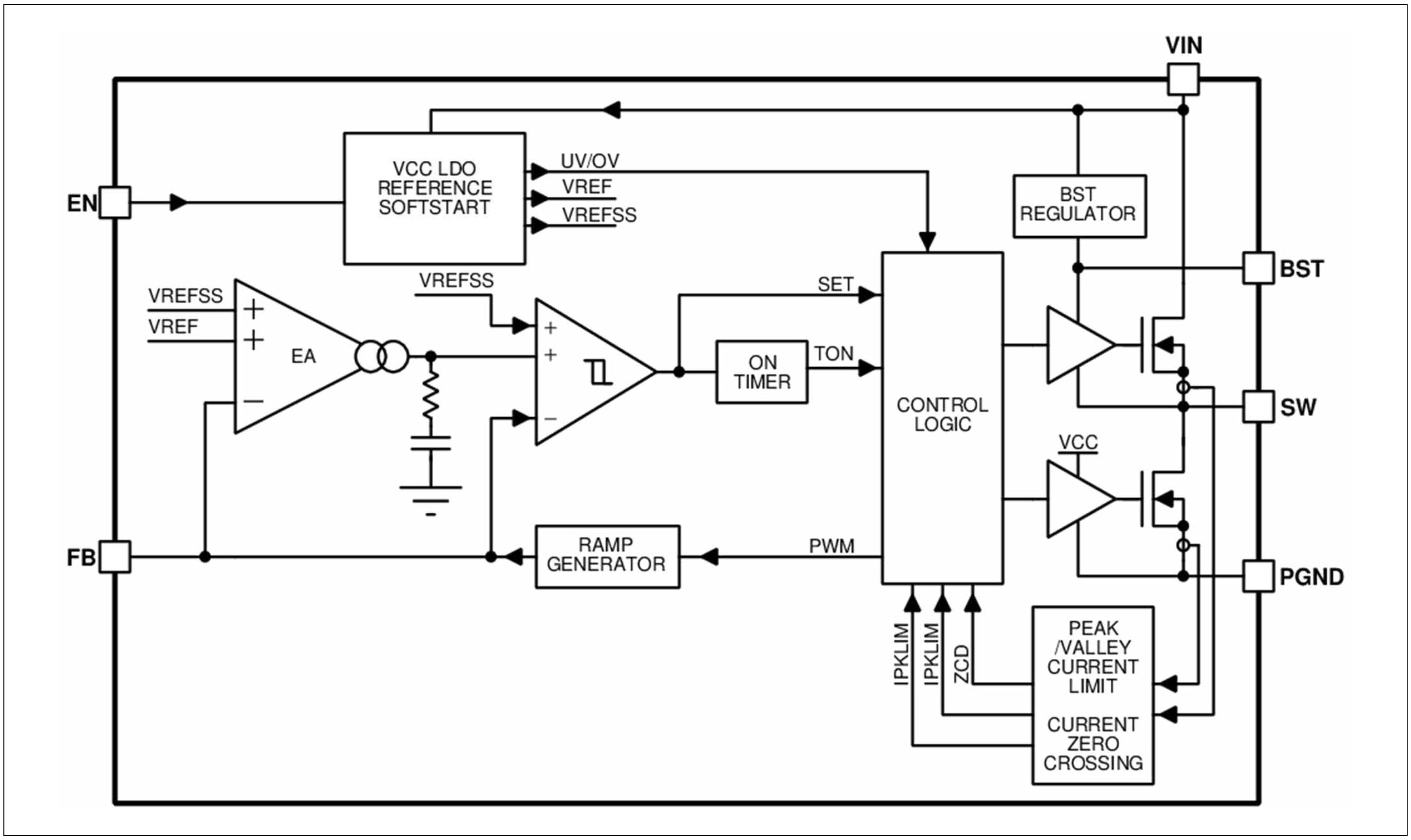


Figure 5: Functional Block Diagram

Typical Application Circuit

The following figure shows a typical application of the MxL76503.

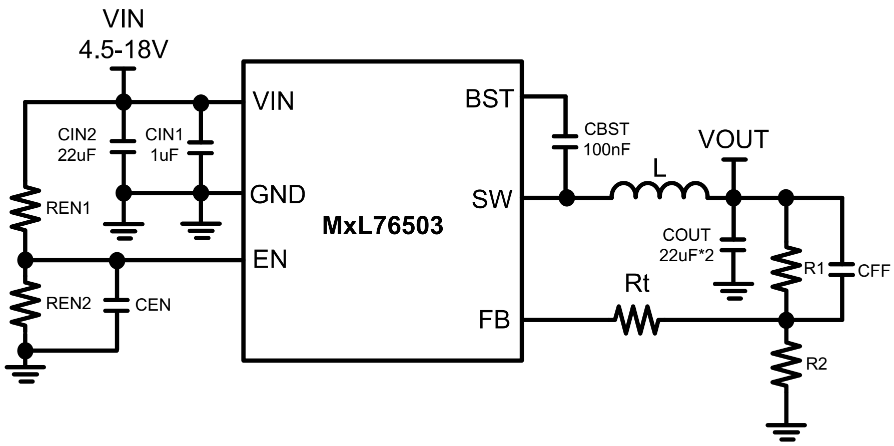


Figure 6: MxL76503 Typical Application

Typical Performance Characteristics

V_{IN} = 12V, V_{OUT} = 5V/1V, L= 4.7µH/1.5µH, T_J = 25°C, unless otherwise specified.

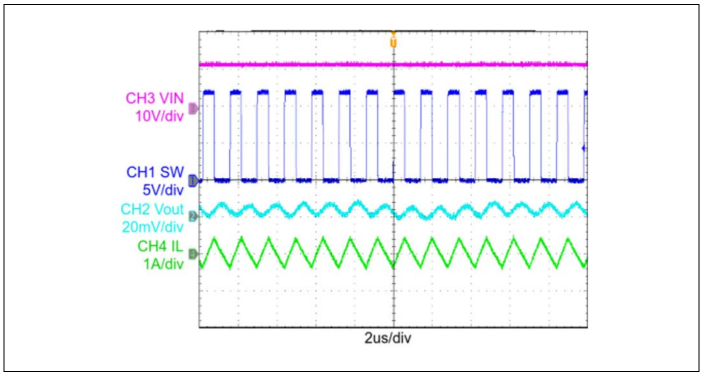


Figure 7: Steady State Test—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 0A

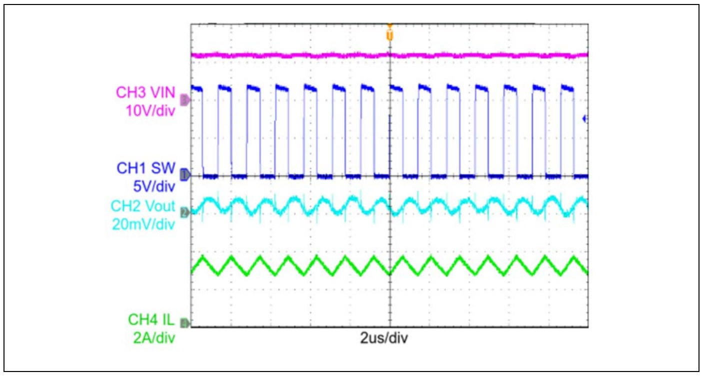


Figure 8: Steady State Test—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 3A

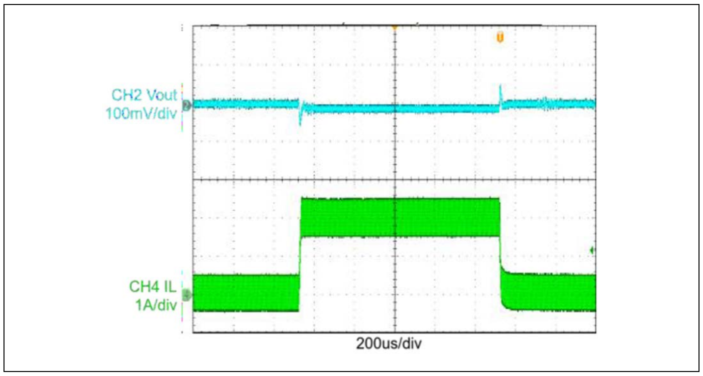


Figure 9: Load Transient Response—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 0A–2A

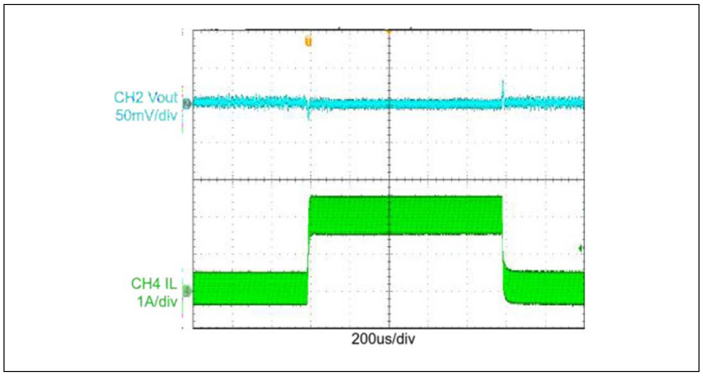


Figure 10: Load Transient Response—V_{IN} = 12V, V_{OUT} = 1V, I_{OUT} = 0A–2A

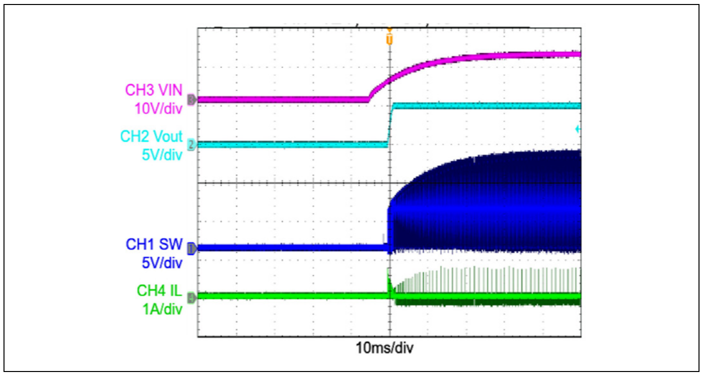


Figure 11: V_{IN} Power On—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 0A

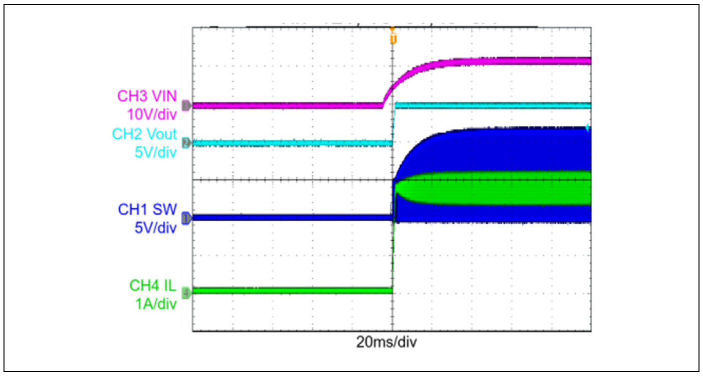


Figure 12: V_{IN} Power On—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 3A

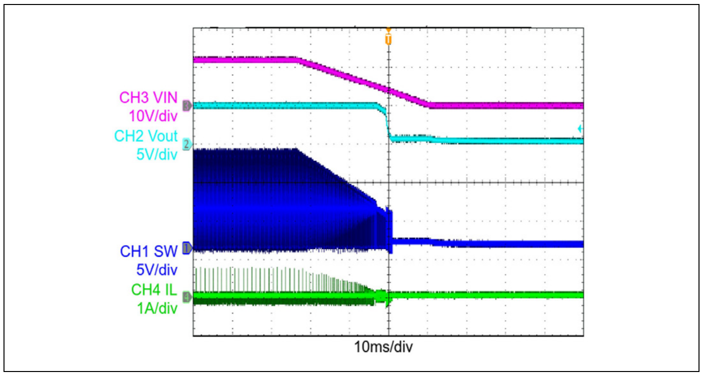


Figure 13: **V_{IN} Power Off—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 0A**

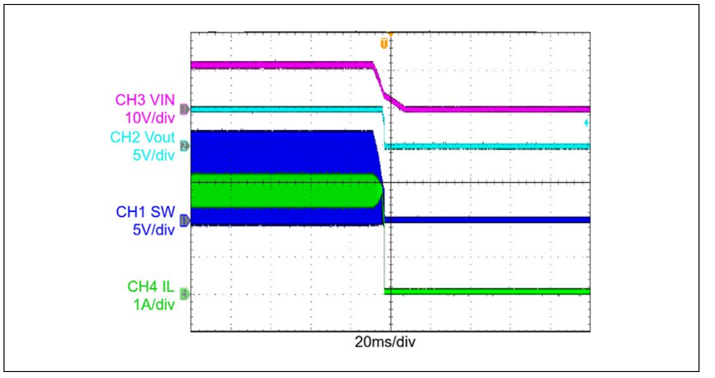


Figure 14: **V_{IN} Power Off—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 3A**

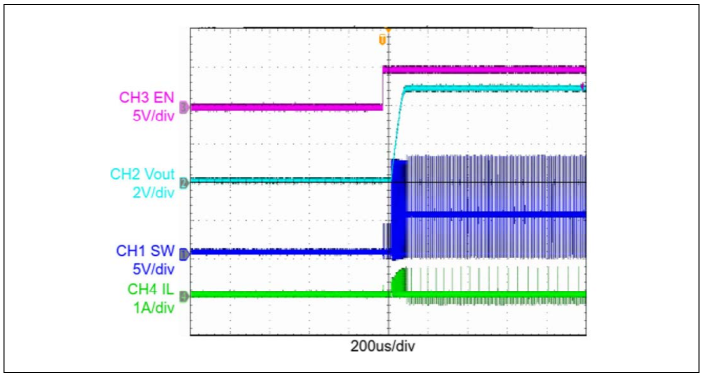


Figure 15: **EN Power On—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 0A**

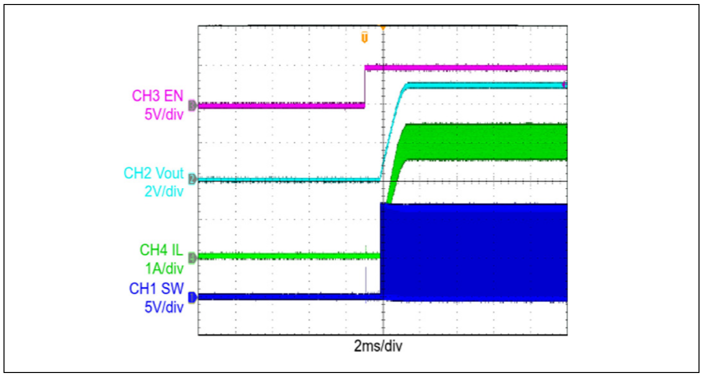


Figure 16: **EN Power On—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 3A**

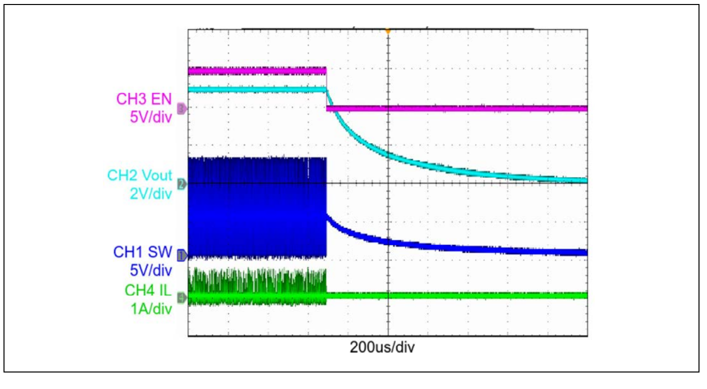


Figure 17: **EN Power Off—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 0A**

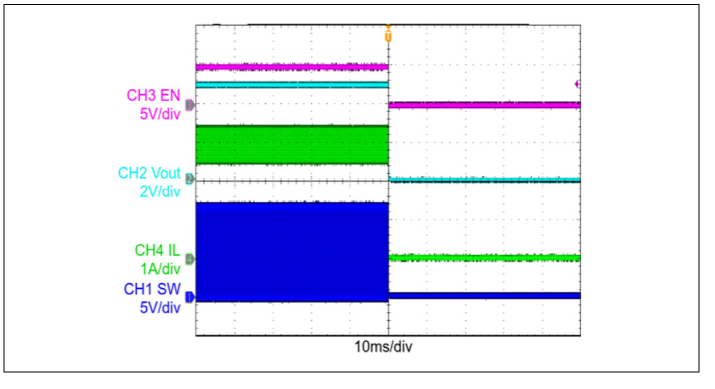


Figure 18: **EN Power Off—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 3A**

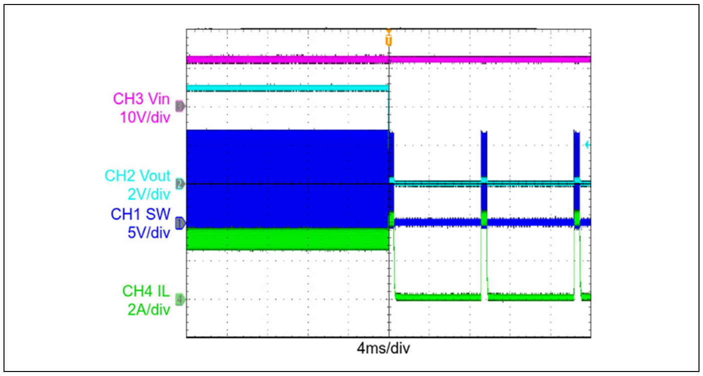


Figure 19: **Short Circuit Protection—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = 3A–Short**

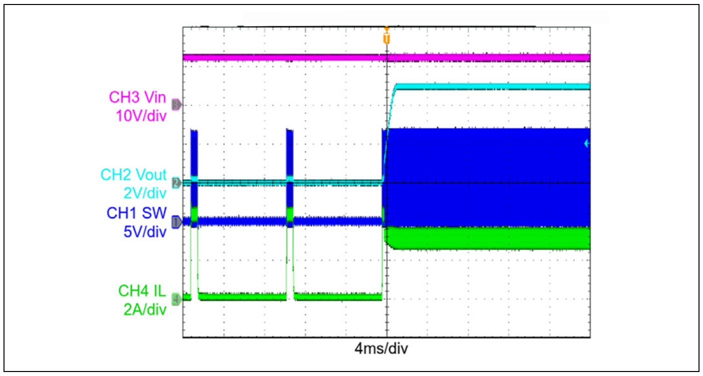


Figure 20: **Short Circuit Protection Recovery—V_{IN} = 12V, V_{OUT} = 5V, I_{OUT} = Short–3A**

Operation

The MxL76503 device is a fully integrated synchronous step-down converter that uses a constant on-time (COT) control scheme to achieve superior transient performance. With adjustable external ramp compensation, it can achieve stable operation with lower equivalent series resistance (ESR) ceramic output capacitors and excellent transient response.

Constant On-Time Control

The constant on-time control (COT) operates by comparing the feedback voltage V_{FB} with the reference voltage (V_{FBREG}). When FB drops below the reference, the control circuit immediately turns on the high-side (HS) switch for a predetermined period of time (on-time) to ramp up the inductor current. When this on-time times out, the low-side (LS) switch is then turned on to ramp down the inductor current. The LS switch is turned off when the inductor current reaches zero I_{ZX} (or triggers the negative current limit I_{NEG} MxL76503) or the HS switch is turned on again for the next cycle. This operation repeats if FB drops below the reference again.

The MxL76503 uses a proprietary algorithm to calculate the on-time based on the input voltage and output voltage to achieve a nearly constant switching frequency over the entire continuous conduction load current range. The on-time can be estimated as:

$$T_{ON} = \frac{V_{OUT}}{V_{IN}} \times \frac{1}{F_{SW}}$$

Due to its immediate response to the FB voltage drop and simplified loop compensation, the MxL76503 offers superior transient response compared to traditional fixed-frequency pulse-width modulation (PWM) control converters.

Light Load Operation (MxL76503N)

Under medium and heavy load conditions, the MxL76503N operates in PWM mode with a typical switching frequency of 720KHz. When the load current reduces, the MxL76503N naturally transitions from PWM mode to PFM mode where the pulse width remains the calculated on-time but the switching frequency reduces to accommodate the low output current. The lower the output current, the lower the switching frequency. Once the switching frequency drops low enough, the device enters sleep mode to cut down its quiescent current to maintain high efficiency under light load.

The critical load current at the boundary of PWM mode and PFM mode is related to the inductor ripple current, which depends on the inductor value, input voltage, and output voltage. Typically, this critical load current level is estimated as:

$$I_{CRIT} = \frac{1}{2} \times \frac{(V_{IN} - V_{OUT}) \times V_{OUT}}{L \times F_{SW} \times V_{IN}}$$

Forced PWM Mode Operation (MxL76503A)

The MxL76503A operates in forced PWM (FPWM) operation. The main difference between FPWM mode and PFM mode is the inductor current at light load: the output load lower than the inductor current operates in boundary conduction mode. When the high-side FET (HSFET) turns off, the inductor current discharges and reaches zero and the low-side FET (LSFET) remains on for the FPWM part. This makes the inductor current become negative until the LSFET turns off and the inductor discharges to the input capacitor. In FPWM mode, the switching frequency remains constant at around 720kHz. The high switching frequency decreases the light load efficiency but provides high transient response and low output voltage ripple at light load.

100% Duty Cycle Low-Dropout Operation

When the input voltage approaches the output voltage, the MxL76503 device extends the on-time toward the maximum on-time to meet the duty cycle requirement to regulate the output voltage. If the input drops further to or below the output level, the MxL76503 forces the main HS switch to remain on for more than one cycle, eventually reaching 100% duty cycle. The 100% duty cycle operation enables the converter to efficiently pass through the input voltage directly to the output with minimum voltage drops on the HS switch and the inductor. In low-dropout operation mode, the MxL76503 turns on the HS switch for multiple switching cycles until it momentarily turns off the HS switch and turns on the LS switch (typically 140ns) to refresh the BST supply voltage. The LS switch is turned off after the BST refresh pulse, and then the HS switch resumes on for multiple switching cycles, which gives the effective 100% duty cycle. The BST refresh pulse is necessary to charge the BST capacitor and ensure correct operation of the HS switch driver circuits.

Enable

The MxL76503 offers an accurate EN pin enable threshold. The MxL76503 is enabled by pulling up the EN pin above 1.21V and it is disabled by pulling down the EN pin below 1.11V.

When using the EN pin threshold voltage to program the input startup voltage level, the following equation should be used:

$$V_{IN\_START} = 1.21V \times \frac{R_{UP} + R_{DOWN}//1M\Omega}{R_{DOWN}//1M\Omega}$$

Where 1MΩ is the internal pull-down resistor on the EN pin.

When EN is pulled high, the MxL76503 starts up if V_{IN} is higher than the under-voltage lockout (UVLO) threshold. When EN is pulled low, the MxL76503 shuts down. Connect the EN pin to V_{IN} if the shutdown feature is not used.

Soft-Start

The MxL76503 features a built-in internal soft-start of 1.2msec. During the soft-start period, the output voltage is ramped up linearly to the regulation level, independent of the load current and output capacitor value.

Current Limit and Hiccup Mode

The MxL76503 features a built-in cycle-by-cycle current-limit protection to prevent the inductor current from operating at an abnormally high or even saturated current in any fault condition. The MxL76503 continuously monitors the inductor valley current during its operation. Once the valley current exceeds the limit level, the MxL76503 turns on the LS switch and waits for the inductor current to drop down to a predetermined level before the HS switch can be turned on again. If this current-limit condition is repeated for a long, extended period of time, the MxL76503 enters hiccup mode, where it stops switching for a predetermined period of time before automatically trying to start up again. It always starts up with a soft-start to limit the inrush current and avoid output overshoot.

When the MxL76503 enters valley current-limit mode, the peak current is also limited due to the fixed HS switch on-time, and this peak current can be estimated as:

$$I_{PEAK} = I_{VALLEY} + T_{ON} \times \frac{V_{IN} - V_{OUT}}{L}$$

Application Information

Output Voltage Setting

The external feedback resistor divider sets the output voltage (see Figure 1 on page i). MaxLinear recommends resistors of 1% to maintain output voltage accuracy. The feedback resistor R1 has an impact on the loop stability with the internal compensation capacitor. Choose a value for R1 and R2. The corresponding equation is as follows:

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

Note: MaxLinear recommends that R1 be 100kΩ.

Inductor

The inductor is necessary to supply a constant current to the output load while being driven by the switched input voltage. A higher-value inductor results in a lower ripple current, which results in a lower output ripple voltage. However, a higher-value inductor has a larger physical footprint, higher series resistance, and/or lower saturation current. To determine the inductance value, MaxLinear recommends designing the peak-to-peak ripple current in the inductor so that it ranges from 30% to 40% of the maximum output current, and the peak inductor current is below the maximum switching current limit. The inductance value can be calculated by:

$$L = \frac{V_{OUT}}{F_{SW} \times \Delta I_L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Where ΔI_L is the peak-to-peak inductor ripple current.

To avoid overheating and poor efficiency, you must choose an inductor with an RMS current rating greater than the maximum expected output load of the application. Additionally, the saturation current (typically referred to as *Isat*) rating of the inductor must be higher than the maximum load current plus half of the inductor's ripple current.

The peak inductor current can be calculated by:

$$I_{L-PEAK} = I_{OUT} + \frac{V_{OUT}}{2F_{SW} \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Input Capacitor

The input current to the step-down converter is discontinuous and therefore requires a capacitor to supply the AC current to the step-down converter while maintaining the DC input voltage. MaxLinear recommends using ceramic capacitors for best performance and placing them as close to the VIN pin as possible. MaxLinear recommends capacitors with X5R and X7R ceramic dielectrics because they are fairly stable with temperature fluctuations. The capacitors must also have a ripple current rating greater than the maximum input ripple current of the converter. The input ripple current can be estimated as follows:

$$I_{CIN} = I_{OUT} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)}$$

The worst-case condition occurs at $V_{IN} = 2*V_{OUT}$, where:

$$I_{CIN} = \frac{I_{OUT}}{2}$$

To simplify, choose the input capacitor with an RMS current rating greater than half of the maximum load current. The input capacitance value determines the input voltage ripple of the converter. If the system must meet an input voltage ripple, choose the input capacitor that meets the specification. The input voltage ripple can be estimated as follows:

$$\Delta V_{IN} = \frac{I_{OUT}}{F_{SW} \times C_{IN}} \times \frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Under worst-case conditions where $V_{IN} = 2*V_{OUT}$:

$$\Delta V_{IN} = \frac{1}{4} \times \frac{I_{OUT}}{F_{SW} \times C_{IN}}$$

Output Capacitor

The output capacitor has two essential functions:

- Together with the inductor, it filters the square wave generated by the MxL76503 to produce the DC output. In this role, it determines the output ripple, thus a low impedance at the switching frequency is important.
- It stores energy to satisfy transient loads and stabilize the MxL76503's control loop. X5R or X7R-type ceramic capacitors have very low ESR and provide low output ripple and good transient response. Transient performance can be improved with a higher value output capacitor and the addition of a feed-forward capacitor placed between V_{OUT} and FB.

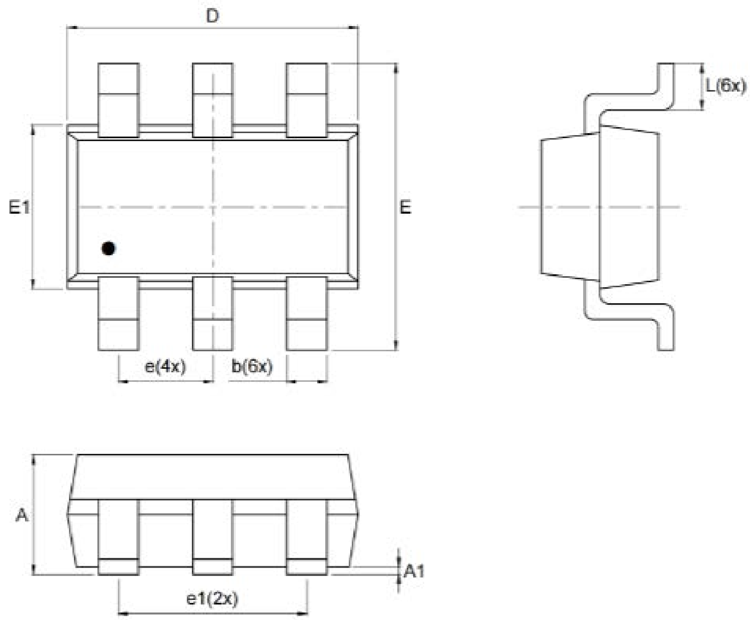
Increasing the output capacitance also decreases the output voltage ripple. You can use a lower value output capacitor to save space and cost, but transient performance suffers and can cause loop instability. When choosing a capacitor, particular attention should be paid to this data sheet to calculate the effective capacitance under the relevant operating conditions of voltage bias and temperature. A physically larger capacitor or one with a higher voltage rating may be required.

Mechanical Dimensions

SOT23-6L

SOT23_6L Outline Dimensions

Unit: inches/mm



SYMBOLS	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	0.89	1.45	0.035	0.057
A1	0.00	0.15	0.000	0.006
b	0.30	0.50	0.012	0.020
D	2.70	3.10	0.106	0.122
E1	1.40	1.80	0.055	0.071
e	0.95 BSC		0.037 BSC	
e1	1.90 BSC		0.075 BSC	
E	2.60	3.00	0.102	0.118
L	0.30	0.60	0.012	0.024

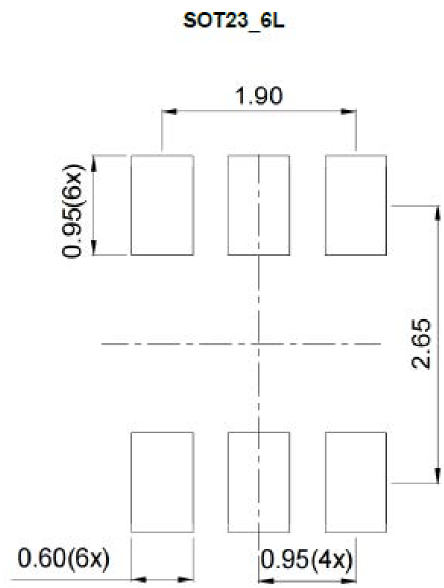
Drawing No.: POD-00000180
Revision: A.1

Figure 21: Mechanical Dimensions—SOT23-6L

Recommended Land Pattern and Stencil

SOT23-6L

LAND PATTERN INFORMATION



Note:

- **Dimensions in mm.**
- **For reference only.**

Drawing No.: POD-00000180
Revision: A.1

Figure 22: Recommended Land Pattern and Stencil—SOT23-6L

Ordering Information

Table 6: Ordering Information

Ordering Part Number	Operating Temperature Range	Remark	Package	Packaging
MXL76503N-ASA-R	–40°C to 85°C	MxL76503N: PFM mode (ASA)—Non-China OSAT	SOT23-6L	3000/Tape and Reel
MXL76503N-BSA-R	–40°C to 85°C	MxL76503N: PFM mode (BSA)—China OSAT	SOT23-6L	3000/Tape and Reel
MXL76503A-ASA-R	–40°C to 85°C	MxL76503A: FPWM mode (ASA)—Non-China OSAT	SOT23-6L	3000/Tape and Reel
MXL76503A-BSA-R	–40°C to 85°C	MxL76503A: FPWM mode (BSA)—China OSAT	SOT23-6L	3000/Tape and Reel

Note: For more information about part numbers, as well as the most up-to-date ordering information and additional information on environmental rating, go to www.maxlinear.com/MxL76503.

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