

## DIO6099

# Synchronous Boost Converter with Ultra-Low Quiescent Current

### Features

- Operating Input Voltage Range: 0.7V to 5.5V
- Adjustable Output Voltage Range: 1.8V to 5.5V
- Ultra-Low Quiescent Current ( $V_{OUT}$  Pin): 600nA
- Ultra-Low Quiescent Current ( $V_{IN}$  Pin): 400nA
- Switch Peak Current Limit
- Regulated Output Voltage in Down Mode
- True Disconnection During Shutdown
- Up to 93% Efficiency from 10mA to 300mA Load
- Package: WLCSP-6, DFN2\*2-6 and SOT23-6

### Applications

- Portable Products
- Battery Powered Systems
- Low Power Wireless Applications
- Wearable Applications
- Memory LCD Bias
- Optical Heart Rate Monitor LED Bias

### Descriptions

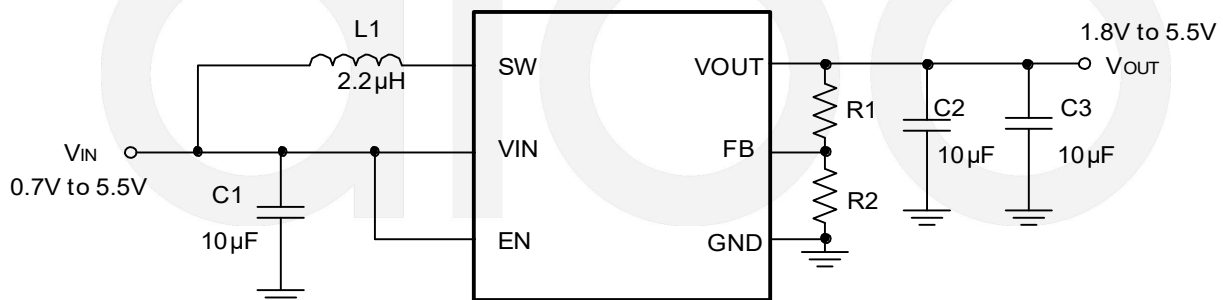
DIO6099 is a synchronous boost converter with 1 $\mu$ A ultra-low quiescent current. It can operate efficiently under light load conditions, which is essential to prolong the service life of batteries.

DIO6099 boost converter adopts hysteresis control topology, which can achieve the highest efficiency with the lowest quiescent current. The device consumes only 1 $\mu$ A quiescent current under light load.

DIO6099 can also provide Down mode and Pass-through mode for different applications. In Down mode, even if the input voltage is higher than the output voltage, the output voltage can be adjusted as the target value. In Pass-through mode, the output voltage varies with the input voltage. When  $V_{IN} > V_{OUT} + 0.5V$ , DIO6099 exits the Down mode and transfers to Pass-through mode.

DIO6099 can disconnect the load from the input power supply when it is disabled, thus realizing the real shutdown, thus reducing the current consumption. The device is packaged in WLCSP-6, DFN2\*2-6 and SOT23-6.

### Typical Application



## Ordering Information

Order Part Number	Top Marking		T <sub>A</sub>	Package	
DIO6099WL6	FV9	Green	-40 to 85°C	WLCSP-6	Tape & Reel, 3000
DIO6099DN6	DFV9	Green	-40 to 85°C	DFN2*2-6	Tape & Reel, 3000
DIO6099ST6	WV9	Green	-40 to 85°C	SOT23-6	Tape & Reel, 3000

## Pin Assignment

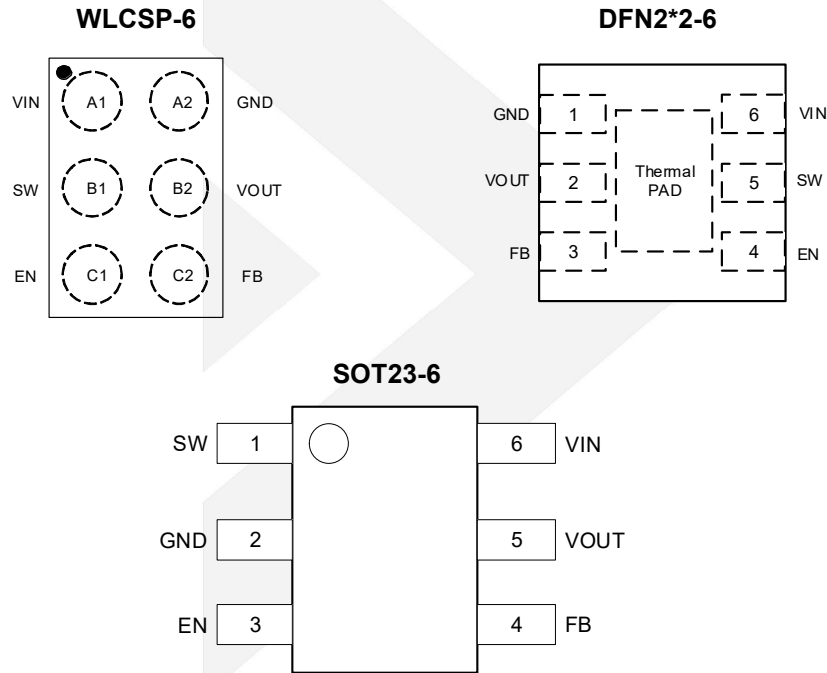


Figure 1 Top View

## Pin Descriptions

Pin Name	Type	Description
VIN	I	IC power supply input.
SW	PWR	Switch pin of the converter. It is connected to the inductor.
EN	I	Enable logic input. Logic high voltage enables the device; logic low voltage disables the device. Do not leave it floating.
GND	PWR	Ground.
VOUT	PWR	Boost converter output.
FB	I	Voltage feedback of adjustable output voltage. Connect to the center tap of a resistor divider to program the output voltage.
Thermal PAD	NC	Not connected internally. Can be connected to GND.

### Absolute Maximum Ratings

Stresses beyond those listed under “Absolute Maximum Rating” may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other condition beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Symbol	Parameter	Rating	Unit	
	Voltage range at terminals <sup>(1)</sup> (VIN, SW, VOUT, FB, EN)	-0.3 to 6.0	V	
T <sub>J</sub>	Operating junction temperature	-40 to 150	°C	
T <sub>STG</sub>	Storage Temperature	-65 to 150	°C	
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	WLCSP-6	134.4	°C/W
		DFN2*2-6	71.7	°C/W
ESD	Human Body Model (HBM)	±2000	V	
	Charged Device Model (CDM)	±500	V	

Note: 1. All voltage values are with respect to network ground terminal.

### Recommend Operating Conditions

The Recommended Operating Conditions table defines the conditions for actual device operation. Recommended Operating conditions are specified to ensure optimal performance to the datasheet specifications. DIOO does not Recommend exceeding them or designing to Absolute Maximum Ratings.

Symbol	Parameter	Min.	Typ.	Max.	Unit
V <sub>IN</sub>	Input voltage range	0.7		5.5	V
V <sub>OUT</sub>	Output voltage range	1.8		5.5	V
L	Inductor	0.7	2.2	2.86	μH
C <sub>IN</sub>	Input capacitor	1.0	10		μF
C <sub>OUT</sub>	Output capacitor	10	20	100	μF
T <sub>J</sub>	Operating virtual junction temperature	-40		125	°C

## Electrical Characteristics

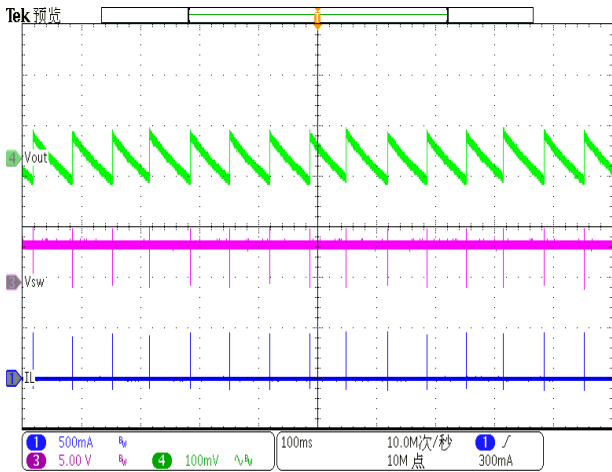
$T_J = -40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$  and  $V_{IN} = 0.7\text{V}$  to  $5.5\text{V}$ . Typical values are at  $V_{IN} = 3.7\text{V}$ ,  $T_J = 25^{\circ}\text{C}$ , unless otherwise noted.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
<b>Power Supply</b>						
$V_{IN}$	Input voltage range		0.7		5.5	V
$V_{UVLO}$	Input under voltage lockout threshold	$V_{IN}$ rising		0.6	0.7	V
	UVLO hysteresis			200		mV
$I_Q$	Quiescent current into $V_{IN}$ pin	IC enabled, no Load, no Switching $T_J = -40^{\circ}\text{C}$ to $85^{\circ}\text{C}$		0.4	1.1	$\mu\text{A}$
	Quiescent current into $V_{OUT}$ pin	IC enabled, no Load, no Switching, Boost or Down Mode $T_J = -40^{\circ}\text{C}$ to $85^{\circ}\text{C}$		0.6	1.5	$\mu\text{A}$
$I_{SD}$	Shutdown current into $V_{IN}$ pin	IC disabled, $V_{IN} = 3.7\text{V}$ , $V_{OUT} = 0\text{V}$ $T_J = -40^{\circ}\text{C}$ to $85^{\circ}\text{C}$		0.5	1.6	$\mu\text{A}$
<b>Output</b>						
$V_{OUT}$	Output voltage range		1.8		5.5	V
$V_{REF}$	Feedback reference voltage	$V_{IN} < V_{OUT}$ , PWM mode	0.98	1.00	1.02	V
		$V_{IN} < V_{OUT}$ , PFM mode		1.03		V
$V_{OVP}$	Output overvoltage protection threshold	$V_{OUT}$ rising	5.6	5.8	6.0	V
	OVP hysteresis			100	200	mV
$I_{FB\_LKG}$	Leakage current into FB pin	$V_{FB} = 1.0\text{V}$		10	50	nA
<b>Power Switch</b>						
$R_{DS(on)\_LS}$	Low side switch on resistance	$V_{OUT} = 5.0\text{V}$		250		m $\Omega$
		$V_{OUT} = 3.3\text{V}$		300		m $\Omega$
		$V_{OUT} = 1.8\text{V}$		400		m $\Omega$
$R_{DS(on)\_HS}$	Rectifier on resistance	$V_{OUT} = 5.0\text{V}$		300	350	m $\Omega$
		$V_{OUT} = 3.3\text{V}$		350	450	m $\Omega$
		$V_{OUT} = 1.8\text{V}$		500	750	m $\Omega$
$F_{SW}$	Operation frequency			1		MHz
$I_{LIM}$	Current limit threshold	$V_{OUT} \geq 2.5\text{V}$ , boost operation	0.8	1.0	1.25	A
		$V_{OUT} < 2.5\text{V}$ , boost operation	0.5	0.75		A
$I_{SW\_LKG}$	Leakage current into SW pin (from SW pin to GND)	$V_{SW} = 5.0\text{V}$ , no switch, $T_J = -40^{\circ}\text{C}$ to $85^{\circ}\text{C}$			200	nA
<b>Control logic</b>						
$V_{IL}$	EN input low voltage threshold	$V_{IN} \leq 1.5\text{V}$			$0.2 \times V_{IN}$	V

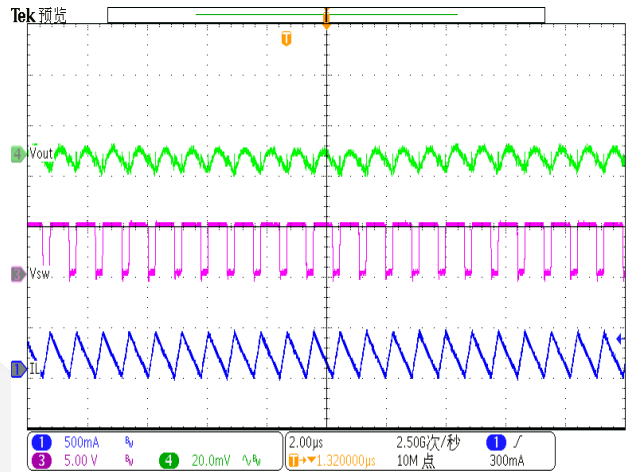
$V_{IH}$	EN input high voltage threshold	$V_{IN} \leq 1.5V$	$0.8 \times V_{IN}$			V
$V_{IL}$	EN input low voltage threshold	$V_{IN} > 1.5V$			0.4	V
$V_{IH}$	EN input high voltage threshold	$V_{IN} > 1.5V$	1.2			V
$I_{EN\_LKG}$	Leakage current into EN pin	$V_{EN} = 5.0V$			50	nA
	Over temperature protection			150		°C
	Over temperature hysteresis			25		°C



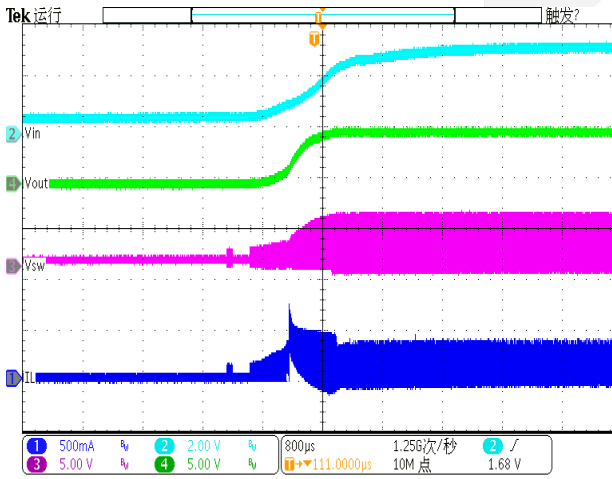
Typical Characteristic



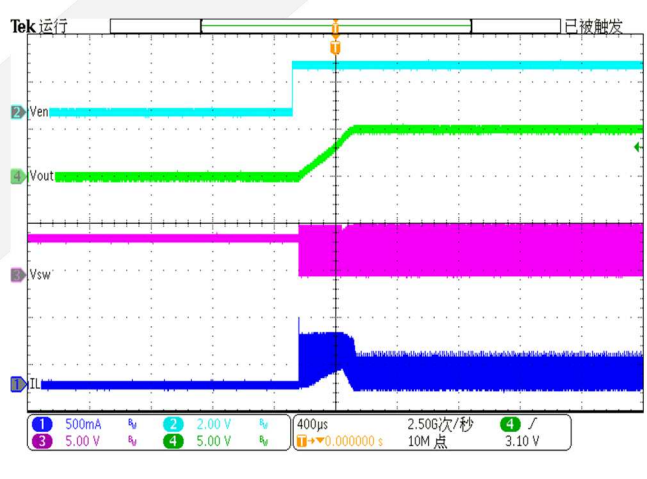
Vin=3.7V, No Load at Light Load  
Figure 2. Switching Waveform at Light Load



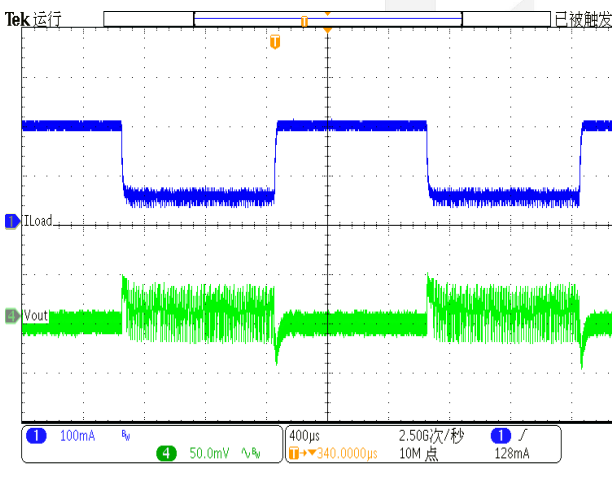
Vin=3.7V, Load=100mA at Heavy Load  
Figure 3. Switching Waveform at Heavy Load



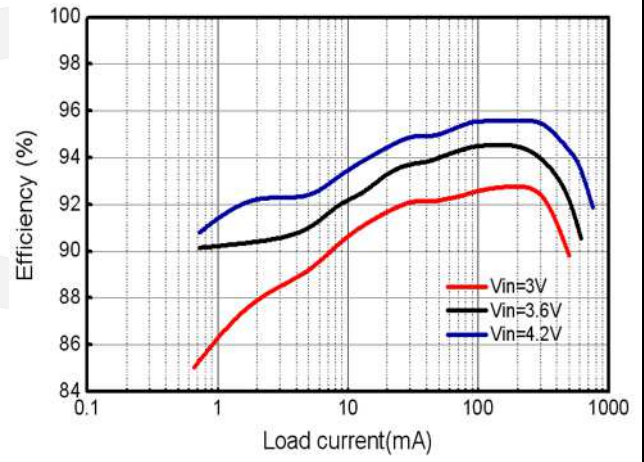
Vin=3.7V, Load=50mA  
Figure 4. Startup by VIN



Vin=3.7V, Load=50mA  
Figure 5. Startup by EN

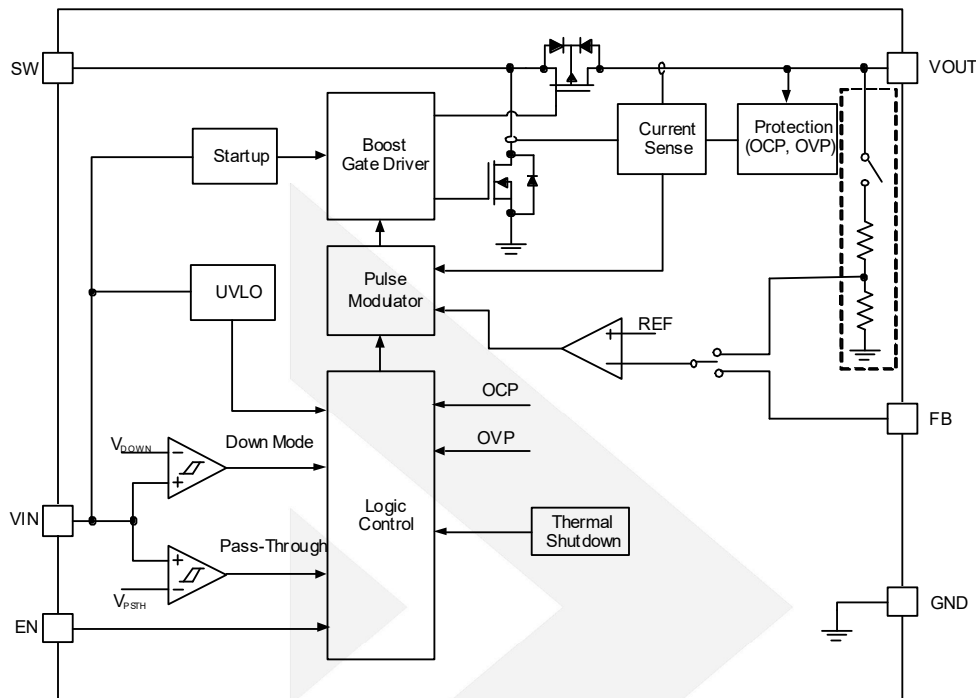


Vin=3.7V, Vou t=5V, Load=50mA to 200mA  
Figure 6. Load Transient



Vin=3V/3.6V/4.2V, Vout=5V  
Figure 7. Efficiency vs. Load Current

## Block Diagram



## Detailed Description

### Overview

The DIO6099 synchronous step-up converter is designed for alkaline battery, coin-cell battery, Li-ion or Li-polymer battery powered systems, which requires long battery running time and tiny solution size. The DIO6099 can operate with a wide input voltage from 0.7V to 5.5V. It only consumes 1 $\mu$ A quiescent current and can achieve high efficiency under light load condition.

The DIO6099 operates in a hysteretic control scheme with typical 1A peak switch current limit. The DIO6099 provides the true shutdown function and the load is completely disconnected from the input so as to minimize the leakage current. It also adopts Down Mode and Pass-Through operation when input voltage is close to or higher than the regulated output voltage.

## Feature Description

### Boost Controller Operation

The DIO6099 boost converter is controlled by a Constant Off Time (COT) controller. This controller regulates the output voltage by keeping the off time constant according to input an output voltage, and adjusting the peak inductor current depending on the output load. Since COT is a PFM control mode, the switching frequency is not fixed and is determined by the operation condition. If the required current is lower than the minimum CCM inductor current, the inductor current goes discontinuously to keep the efficiency high under light load condition.

To achieve high efficiency, the power stage is realized as a synchronous boost topology. The output voltage  $V_{OUT}$  is monitored via an external or internal feedback network which is connected to the voltage error amplifier. To regulate the output voltage, the voltage error amplifier compares this feedback voltage to the internal voltage reference and adjusts the required offset of the inductor current accordingly.

### Under-Voltage Lockout

An under-voltage lockout (UVLO) circuit stops the operation of the converter when the input voltage drops below the typical UVLO threshold of 0.4V. A hysteresis of 200mV is added so that the device cannot be enabled again until the input voltage goes up to 0.6V. This function is implemented in order to prevent malfunctioning of the device when the input voltage is between 0.4V and 0.6V.

### Enable and Disable

When the input voltage is above UVLO rising threshold and the EN pin is pulled to high voltage, the DIO6099 is enabled. When the EN pin is pulled to low voltage, the DIO6099 goes into shutdown mode. In shutdown mode, the device stops switching and the rectifying PMOS fully turns off, providing the completed disconnection between input and output. Less than 0.5 $\mu$ A input current is consumed in shutdown mode.

### Soft Start

After the EN pin is tied to high voltage, the DIO6099 begins to startup. At the beginning, if input voltage is lower than approximately 1.6V, the device operates at the boundary of Discontinuous Conduction Mode (DCM) and Continuous Conduction Mode (CCM), and the inductor peak current is limited to around 200mA during this stage. When the output voltage is charged above approximately 1.6V, the device starts the Constant Off Time (COT) Mode. If input voltage is higher than approximately 1.6V, the device starts the Constant Off Time (COT) Mode directly. The current limit threshold in cot mode is  $0.7 \times I_{LIM}$  within 500 $\mu$ s. In this way, the soft start function reduces the inrush current during startup. After  $V_{OUT}$  reaches the target value, soft start stage ends and the peak current is now determined by the output of an internal error amplifier which compares the feedback of the output voltage and the internal reference voltage.

### Current Limit Operation

The DIO6099 employs cycle-by-cycle over-current protection (OCP) function. If the inductor peak current reaches the current limit threshold  $I_{LIM}$ , the main switch turns off so as to stop further increase of the input current. In this case the output voltage will decrease until the power balance between input and output is achieved. If the output drops below the input voltage, the DIO6099 enters into Down Mode. The peak current is still limited by  $I_{LIM}$  cycle-by-cycle in Down Mode. If the output drops below 1.6V, the DIO6099 enters into startup process again. In Pass-Through operation, current limit function is not enabled.



### Output Short-to-Ground Protection

If input voltage is below 1.6V, the DIO6099 starts to limit the switch current to 200mA when the output voltage is below 1.6V. If input voltage is higher than 1.6V, the DIO6099 starts to limit the switch current to  $0.7 \times I_{LIM}$  when the output voltage is below  $0.1 \times V_{OUT}$ . Once the short circuit is released, the DIO6099 goes back to soft start again and regulates the output voltage.

### Over Voltage Protection

DIO6099 has an output over-voltage protection (OVP) to protect the device in case that the external feedback resistor divider is wrongly populated. When the output voltage of the DIO6099 exceeds the OVP threshold of 5.8V, the device stops switching. Once the output voltage falls 0.1V below the OVP threshold, the device starts operating again.

### Down Mode Regulation and Pass-Through Operation

The DIO6099 features Down Mode and Pass-Through operation when input voltage is close to or higher than output voltage.

In the Down Mode, output voltage is regulated at target value even when  $V_{IN} > V_{OUT}$ . The control circuit changes the behavior of the rectifying PMOS by pulling its gate to input voltage instead of to ground. In this way, the voltage drop across the PMOS is increasing as high as to regulate the output voltage. The power loss also increases in this mode, which needs to be taken into account for thermal consideration.

In the Pass-Through operation, the boost converter stops switching. The rectifying PMOS constantly turns on and low side switch constantly turns off. The output voltage is the input voltage minus the voltage drop across the dc resistance (DCR) of the inductor and the on-resistance of the rectifying PMOS.

With  $V_{IN}$  ramping up, the DIO6099 goes into Down Mode first when  $V_{IN} > V_{OUT} - 50mV$ . It stays in Down Mode until  $V_{IN} > V_{OUT} + 0.5V$  and then goes automatically into Pass-Through operation. In the Pass-Through operation, output voltage follows input voltage. The DIO6099 exits Pass-Through Mode and goes back to Down Mode when  $V_{IN}$  ramps down to 103% of the target output voltage. It stays in Down Mode until input voltage falls 100mV below the output voltage, returning to Boost operation.

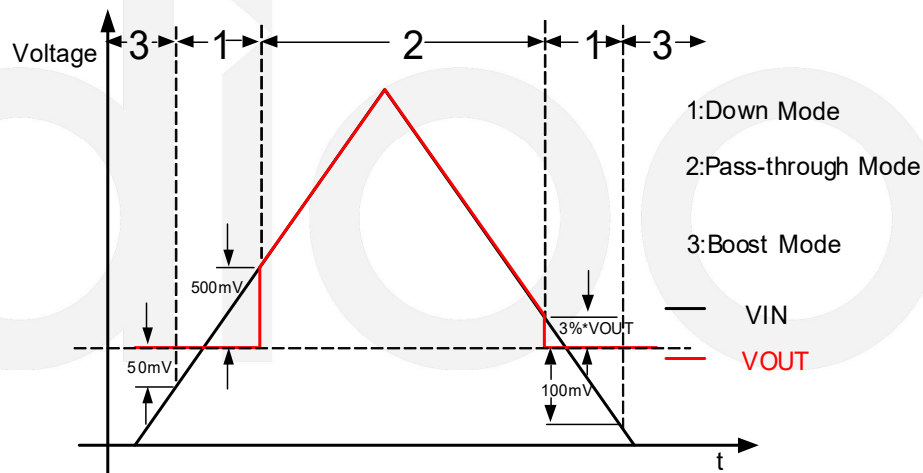


Figure 8. Down Mode and Pass-Through Operation

**Thermal Shutdown**

The DIO6099 has a built-in temperature sensor which monitors the internal junction temperature in boost mode operation. If the junction temperature exceeds the threshold 150°C, the device stops operating. As soon as the junction temperature drops below the shutdown temperature minus the hysteresis, typically 125°C, it starts operating again.

**Adjustable Output Voltage**

An external resistor divider is used to set the output voltage. The output voltage of the switching regulator ( $V_{OUT}$ ) is determined by the following equation:

$$V_{OUT} = V_{FB} \times \left( 1 + \frac{R_1}{R_2} \right)$$

**Device Functional Modes****Burst Mode Operation under Light Load Condition**

The boost converter of DIO6099 enters into Burst Mode operation under light load condition. Refer to Boost Controller Operation for details.

**Down Mode Regulation and Pass-Through Mode Operation**

The boost converter of DIO6099 automatically enters into Down Mode or pass-through mode operation when input voltage is higher than the target output voltage. Refer to Down Mode Regulation and Pass-Through Operation for details.



## CONTACT US

Dioo is a professional design and sales corporation for high-quality and performance analog semiconductors. The company focuses on industry markets, such as, cell phone, handheld products, laptop, and medical equipment and so on. Dioo's product families include analog signal processing and amplifying, LED drivers and charger IC. Go to <http://www.dioo.com> for a complete list of Dioo product families.

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