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MIC28303

50V, 3A Power Module

Features

- · Easy to Use
 - Stable with low-Equivalent Series Resistance (ESR) ceramic output capacitor
 - No Inductor and No Compensation to Choose
- 4.5V to 50V Input Voltage
- Single-Supply Operation
- · Power Good (PG) Output
- · Low Radiated Emission (EMI) per EN55022, Class B
- Adjustable Current Limit
- Adjustable Output Voltage from 0.9V to 24V (Also Limited by Duty Cycle)
- 200 kHz to 600 kHz, Programmable Switching Frequency
- · Supports Safe Start-Up into a Prebiased Output
- –40°C to +125°C Junction Temperature Range
- Available in 64-pin, 12 mm × 12 mm × 3 mm QFN Package

Applications

- Distributed Power Systems
- Industrial
- Medical
- Telecom
- Automotive

Typical Application Circuit

General Description

MIC28303 is synchronous step-down regulator module, featuring a unique adaptive ON-time control architecture. The module incorporates a DC/DC controller, power MOSFETs, bootstrap diode, bootstrap capacitor and an inductor in a single package. The MIC28303 operates over an input supply range from 4.5V to 50V and can be used to supply up to 3A of output current. The output voltage is adjustable down to 0.8V with an accuracy of $\pm 1\%$. The device operates with programmable switching frequency from 200 kHz to 600 kHz.

The MIC28303-1 uses HyperLight Load[®] architecture for improved efficiency at light loads. The MIC28303-2 uses Hyper Speed Control[®] for ultra-fast transient response.

The MIC28303 offers a full suite of protection features. These include undervoltage lockout, internal soft-start, foldback current limit, "hiccup" mode short-circuit protection, and thermal shutdown.



Functional Block Diagram



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

PV _{IN} , V _{IN} to P _{GND}	
P _{VDD} , V _{ANODE} to P _{GND}	
V _{SW} , V _{FREQ} , V _{ILIM} , V _{EN}	
V _{BSTC/BSTR} to V _{SW}	
V _{BSTC/BSTR} to P _{GND}	
V _{FB} , V _{PG} to P _{GND}	
P _{GND} to A _{GND}	-0.3V to +0.3V
ESD Rating ⁽¹⁾	ESD Sensitive

Operating Ratings ‡

Supply Voltage (PV _{IN} , V _{IN})	
Enable Input (V _{EN})	0V to V _{IN}
V _{SW} , V _{FREQ} , V _{ILIM} , V _{EN}	
Power Good (V _{PGOOD})	0V to P _{VDD}

† Notice: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational sections of this specification is not intended. Exposure to maximum rating conditions for extended periods may affect device reliability.

‡ Notice: The device is not guaranteed to function outside its operating ratings.

Note 1: Devices are ESD sensitive. Handling precautions are recommended. Human body model, 1.5 k Ω in series with 100 pF.

TABLE 1-1: ELECTRICAL CHARACTERISTICS

1100000000000000000000000000000000000	Note I).				
Parameters	Min.	Тур.	Max.	Units	Conditions
Power Supply Input		-1			
Input Voltage Range (PV _{IN} , V _{IN})	4.5	—	50	V	_
Controller Supply Current	—	0.4	0.75	mA	Current into Pin 60; V _{FB} = 1.5V (MIC28303-1)
	_	2.1	3.0		Current into Pin 60; V _{FB} = 1.5V (MIC28303-2)
	_	0.1	10	μA	Current into Pin 60; V _{EN} = 0V
Operating Current		0.7	—	mA	I _{OUT} = 0A (MIC28303-1)
	_	27	_		I _{OUT} = 0A (MIC28303-2)
Shutdown Supply Current	_	4.0	_	μA	PV _{IN} = V _{IN} = 12V, V _{EN} = 0V
P _{VDD} Supply					
P _{VDD} Output Voltage	4.8	5.2	5.4	V	V_{IN} = 7V to 50V, I_{PVDD} = 10mA
P _{VDD} UVLO Threshold	3.8	4.2	4.7		P _{VDD} rising
P _{VDD} UVLO Hysteresis	_	400	_	mV	—
Load Regulation	0.6	2.0	3.6	%	$I_{PVDD} = 0$ to 40mA
Reference					
Feedback Reference Voltage	0.792	0.8	0.808	V	T _J = 25°C (±1.0%)
	0.784	0.8	0.816		$-40^{\circ}C \le T_{J} \le 125^{\circ}C (\pm 2\%)$
FB Bias Current		5	500	nA	V _{FB} = 0.8V
Enable Control					
EN Logic Level High	1.8		_	V	—
EN Logic Level Low			0.6		—
EN Hysteresis		200		mV	_
EN Bias Current	_	5	20	μA	V _{EN} = 12V
Oscillator					
Switching Frequency	400	600	750	kHz	FREQ pin = open
	_	300	—		R_{FREQ} =100k Ω (FREQpin-to-GND)
Maximum Duty Cycle	_	85	—	%	_
Minimum Duty Cycle	_	0	_		V _{FB} > 0.8V
Minimum Off-Time	140	200	260	ns	_
Soft-Start					
Soft-Start Time	_	5	_	ms	<u> </u>
Short-Circuit Protection					
Current Limit Protection (V _{CL})	-30	-14	0	mV	V _{FB} = 0.79V
Short-Circuit Threshold	-23	-7	9	mV	V _{FB} = 0V

Note 1: Specification for packaged product only.

TABLE 1-1: ELECTRICAL CHARACTERISTICS (CONTINUED)

Electrical Characteristics: PV indicate $-40^{\circ}C \le T_{J} \le +125^{\circ}C$. (_{IN} = V _{IN} = 12' (Note 1).	V, V _{OUT} = {	5V, V _{BST} – V _S	_{SW} = 5V; T _A :	= 25°C, unless noted. Bold values
Parameters	Min.	Тур.	Max.	Units	Conditions
Current-Limit Source Current	60	80	100	μA	V _{FB} = 0.79V
Short-Circuit Source Current	27	36	47		V _{FB} = 0V
Leakage					
SW, BSTR Leakage Current	_	_	50	μA	_
Power Good					
Power Good Threshold Voltage	85	90	95	%V _{OUT}	Sweep V_{FB} from low-to-high
Power Good Hysteresis	_	6	_		Sweep V _{FB} from high-to-low
Power Good Delay Time	_	100	_	μs	Sweep V _{FB} from low-to-high
Power Good Low Voltage	_	70	200	mV	V _{FB} < 90% x V _{NOM} , I _{PG} = 1 mA
Thermal Protection					
Overtemperature Shutdown	—	160	—	°C	T _J rising
Overtemperature Shutdown Hysteresis	—	4	—		—
Output Characteristic					
Output Voltage Ripple	—	16	—	mV	I _{OUT} = 3A
Line Regulation	—	0.36	—	%	$PV_{IN} = V_{IN} = 7V$ to 50V, $I_{OUT} = 3A$
Load Regulation	—	0.75	—	%	I _{OUT} = 0A to 3A PV _{IN} = V _{IN} =12V (MIC28303-1)
	—	0.05	—		I _{OUT} = 0A to 3A PV _{IN} = V _{IN} =12V (MIC28303-2)
Output Voltage Deviation from Load Step	—	400	—	mV	I _{OUT} from 0A to 3A at 5 A/μs (MIC28303-1)
	—	500	—		I _{OUT} from 3A to 0A at 5 A/μs (MIC28303-1)
		400	—		I _{OUT} from 0A to 3A at 5 A/μs (MIC28303-2)
	—	500	—		I _{OUT} from 3A to 0A at 5 A/μs (MIC28303-2)

Note 1: Specification for packaged product only.

TEMPERATURE SPECIFICATIONS

Parameters	Sym.	Min.	Тур.	Max.	Units	Conditions
Temperature Ranges						
Junction Operating Temperature	TJ	-40	—	+125	°C	Note 1
Storage Temperature Range	Τ _S	-65	—	+150	°C	—
Junction Temperature	TJ	-	—	+150	°C	—
Lead Temperature	_	-	—	+260	°C	Soldering, 10s
Package Thermal Resistances						
Thermal Resistance 12 mm x 12 mm	θ_{JA}	-	20	—	°C/W	—
QFN-64LD	θ_{JC}	-	5	—	°C/W	—

Note 1: The maximum allowable power dissipation is a function of ambient temperature, the maximum allowable junction temperature and the thermal resistance from junction to air (i.e., T_A, T_J, θ_{JA}). Exceeding the maximum allowable power dissipation will cause the device operating junction temperature to exceed the maximum +125°C rating. Sustained junction temperatures above +125°C can impact the device reliability.

2.0 TYPICAL PERFORMANCE CURVES

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore outside the warranted range.



FIGURE 2-1: Efficiency vs. Output Current (MIC28303-1).



FIGURE 2-2: Efficiency vs. Output Current (MIC28303-2).



V _{OUT}	V _{IN}	R3 (R _{inj})	R19	R15	R1 (Top Feedback Resistor)	R11 (Bottom Feedback Resistor)	C10 (C _{inj})	C12 (C _{ff})	С _{оит}
5V	7V to 18V	16.5 kΩ	75 kΩ	3.57 kΩ	10 kΩ	1.9 kΩ	0.1 µF	2.2 nF	2 x 47 µF/6.3V
5V	18V to 50V	39.2 kΩ	75 kΩ	3.57 kΩ	10 kΩ	1.9 kΩ	0.1 µF	2.2 nF	2 x 47 µF/6.3V
3.3V	5V to 18V	16.5 kΩ	75 kΩ	3.57 kΩ	10 kΩ	3.24 kΩ	0.1 µF	2.2 nF	2 x 47 µF/6.3V
3.3V	18V to 50V	39.2 kΩ	75 kΩ	3.57 kΩ	10 kΩ	3.24 kΩ	0.1 µF	2.2 nF	2 x 47 µF/6.3V



FIGURE 2-3: (MIC28303-2).

Thermal Derating



FIGURE 2-4: V_{IN} Operating Supply vs. Input Voltage (MIC28303-1).



FIGURE 2-5: Output Regulation vs. Input Voltage (MIC28303-1).



FIGURE 2-6: Output Voltage vs. Input Voltage (MIC28303-1).



FIGURE 2-7: V_{IN} Operating Supply Current vs. Temperature (MIC28303-1).



FIGURE 2-8: Load Regulation vs. Temperature (MIC28303-1).



FIGURE 2-9: Line Regulation vs. Temperature (MIC28303-1).



FIGURE 2-10: Line Regulation vs. Temperature (MIC28303-1).



FIGURE 2-11: Line Regulation vs. Output Current (MIC28303-1).



FIGURE 2-12: Efficiency $(V_{IN} = 12V)$ vs. Output Current (MIC28303-1).



FIGURE 2-13: Efficiency $(V_{IN} = 24V)$ vs. Output Current (MIC28303-1).



FIGURE 2-14: Efficiency vs. Output Current (MIC28303-1).



FIGURE 2-15: V_{IN} Operating Supply Current vs. Input Voltage (MIC28303-2).



FIGURE 2-16: Output Regulation vs. Input Voltage (MIC28303-2).



FIGURE 2-17: V_{IN} Shutdown Current vs. Input Voltage.



FIGURE 2-18: vs. Input Voltage.



FIGURE 2-19: Switching Frequency vs. Input Voltage.



FIGURE 2-20: Enable Threshold vs. Input Voltage.



FIGURE 2-21: Temperature.

V_{IN} Shutdown Current vs.



FIGURE 2-22: Output Peak Current Limit vs. Temperature.



FIGURE 2-23: Temperature.





FIGURE 2-24: Temperature.



FIGURE 2-25: V_{IN} Operating Supply Current vs. Temperature (MIC28303-2).



FIGURE 2-26: Load Regulation vs. Temperature (MIC28303-2).



FIGURE 2-27: Line Regulation vs. Temperature (MIC28303-2).



FIGURE 2-28: Line Regulation vs. Temperature (MIC28303-2).



FIGURE 2-29: Switching Frequency vs. Temperature (MIC28303-2).



FIGURE 2-30: Line Regulation vs. Output Current (MIC28303-2).



FIGURE 2-31: Efficiency $(V_{IN} = 12V)$ vs. Output Current (MIC28303-2).



FIGURE 2-32: Efficiency $(V_{IN} = 24V)$ vs. Output Current (MIC28303-2).



FIGURE 2-33: Efficiency ($V_{IN} = 38V$) vs. Output Current (MIC28303-2).



FIGURE 2-34:

Switching Frequency.



FIGURE 2-35: Thermal Derating (MIC28303-2).



FIGURE 2-36: Thermal Derating (MIC28303-2).



FIGURE 2-37: Thermal Derating (MIC28303-2).



FIGURE 2-38: (MIC28303-2)

Thermal Derating

V _{OUT}	V _{IN}	R3 (R _{inj})	R1 (Top Feedback Resistor)	R11 (Bottom Feedback Resistor)	R19	C10 (C _{inj})	C12 (C _{ff})	С _{оит}
0.9V	5V to 50V	16.5 kΩ	10 kΩ	80.6 kΩ	DNP	0.1 µF	2.2 nF	47 μF/6.3V or 2 x 22 μF
1.2V	5V to 50V	16.5 kΩ	10 kΩ	20 kΩ	DNP	0.1 µF	2.2 nF	47 μF/6.3V or 2 x 22 μF
1.8V	5V to 50V	16.5 kΩ	10 kΩ	8.06 kΩ	DNP	0.1 µF	2.2 nF	47 μF/6.3V or 2 x 22 μF
2.5V	5V to 50V	16.5 kΩ	10 kΩ	4.75 kΩ	DNP	0.1 µF	2.2 nF	47 μF/6.3V or 2 x 22 μF
3.3V	5V to 50V	16.5 kΩ	10 kΩ	3.24 kΩ	DNP	0.1 µF	2.2 nF	47 μF/6.3V or 2 x 22 μF
5V	7V to 50V	16.5 kΩ	10 kΩ	1.9 kΩ	DNP	0.1 µF	2.2 nF	47 μF/6.3V or 2 x 22 μF
12V	18V to 50V	23.2 kΩ	10 kΩ	715 kΩ	DNP	0.1 µF	2.2 nF	47 μF/16V or 2 x 22 μF

TABLE 2-2: RECOMMENDED COMPONENT VALUES FOR 600 KHZ SWITCHING FREQUENCY



FIGURE 2-39: Enable Turn-On Delay and Rise Time.



Fall Time.







FIGURE 2-42: MIC28303-1 VIN Start-Up with Pre-Biased Output.









FIGURE 2-50: Output Recovery from Thermal Shutdown.



FIGURE 2-51: MIC28303-2 Switching Waveforms ($I_{OUT} = 3A$).



FIGURE 2-52: MIC28303-2 Transient Response.



FIGURE 2-53: MIC28303-2 Transient Response.



FIGURE 2-54: MIC28303-1 Transient Response.



MIC28303-2 Transient FIGURE 2-55: Response.



FIGURE 2-56: Response.



Response.



MIC28303-1 Transient FIGURE 2-58: Response.



FIGURE 2-59: Power Good at V_{IN} Soft Turn-On.



Turn-Off.

Power Good at V_{IN} Soft



FIGURE 2-61: Radiated Emissions – 30 MHz to 1000 MHz (V_{IN} = 12V/I_{OUT} = 2A).



30 MHz to 1000 MHz ($V_{IN} = 36V/I_{OUT} = 2A$).



FIGURE 2-63: Radiated Emissions – 30 MHz to 1000 MHz (V_{IN} = 12V/I_{OUT} = 3A).

3.0 PIN DESCRIPTIONS

Package Type



The descriptions of the pins are listed in Table 3-1.

TABLE 3-1: PIN FUNCTION TABLE

Pin Number	Symbol	Description
1, 2, 3, 54, 64	GND	Analog Ground. Ground for internal controller and feedback resistor network. The analog ground return path should be separate from the power ground (P_{GND}) return path.
4	I _{LIM}	Current Limit Setting. Connect a resistor from SW (Pin 6) to I_{LIM} to set the overcurrent threshold for the converter.
5, 60	V _{IN}	Supply Voltage for Controller. The V _{IN} operating voltage range is from 4.5V to 50V. A 0.47 μ F ceramic capacitor from V _{IN} (pin 60) to GND is required for decoupling. Pin 5 should be externally connected to either PV _{IN} or Pin 60 on PCB.
6, 40 to 48, 51	SW	Switch Node and Current-Sense Input. High current output driver return. The SW pin connects directly to the switch node. Due to the high-speed switching on this pin, the SW pin should be routed away from sensitive nodes. The SW pin also senses the current by monitoring the voltage across the low-side MOSFET during OFF time.
7, 8	FREQ	Switching Frequency Adjust Input. Leaving this pin open will set the switching frequency to 600 kHz. Alternatively, a resistor from this pin to ground can be used to lower the switching frequency.
9 to 13	P _{GND}	Power Ground. P_{GND} is the return path for the buck converter power stage. The P_{GND} pin connects to the sources of low-side N-Channel external MOSFET, the negative terminals of input capacitors, and the negative terminals of output capacitors. The return path for the power ground should be as small as possible and separate from the analog ground (GND) return path.
14 to 22	PV _{IN}	Power Input Voltage. Connection to the drain of the internal high-side power MOSFET.
23 to 38	V _{OUT}	Output Voltage. Connection with the internal inductor, the output capacitor should be connected from this pin to P_{GND} as close to the module as possible.
39	NC	No Connection. Leave it floating.

	1	
Pin Number	Symbol	Description
49, 50	ANODE	Anode Bootstrap Diode Input. Anode connection of internal bootstrap diode. This pin should be connected to the P_{VDD} pin.
52, 53	BSTC	Bootstrap Capacitor. Connection to the internal bootstrap capacitor. Leave floating, no connect.
55, 56	BSTR	Bootstrap Resistor. Connection to the internal bootstrap resistor and high-side power MOSFET drive circuitry. Leave floating, no connect.
57	FB	Feedback Input. Input to the transconductance amplifier of the control loop. The FB pin is regulated to 0.8V. A resistor divider connecting the feedback to the output is used to set the desired output voltage.
58	P _{GOOD}	Power Good Output. Open-drain output. An external pull-up resistor to external power rails is required.
59	EN	Enable Input. A logic signal to enable or disable the buck converter operation. The EN pin is CMOS compatible. Logic high enables the device, logic low shuts down the regulator. In the disable mode, the input supply current for the device is minimized to 4 μ A typically. Do not pull EN to P _{VDD} .
61, 62	P _{VDD}	Internal +5V Linear Regulator Output. P _{VDD} is the internal supply bus for the device. In the applications with V _{IN} < +5.5V, P _{VDD} should be tied to V _{IN} to bypass the linear regulator.
63	NC	No Connection. Leave it floating.

TABLE 3-1: PIN FUNCTION TABLE (CONTINUED)

4.0 FUNCTIONAL DESCRIPTION

The MIC28303 is an adaptive on-time synchronous buck regulator module built for high-input voltage to low-output voltage conversion applications. The MIC28303 is designed to operate over a wide input voltage range, from 4.5V to 50V, and the output is adjustable with an external resistor divider. An adaptive on-time control scheme is employed to obtain a constant switching frequency and to simplify the control compensation. Hiccup mode over-current protection is implemented by sensing low-side MOSFET's R_{DS(ON)}. The device features internal soft-start, enable, UVLO, and thermal shutdown. The module has integrated switching FETs, inductor, bootstrap diode, resistor and capacitor.

4.1 Theory of Operation

Per the Functional Diagram of the MIC28303 module, the output voltage is sensed by the MIC28303 feedback pin FB via the voltage divider R1 and R11, and compared to a 0.8V reference voltage V_{REF} at the error comparator through a low-gain transconductance (g_m) amplifier. If the feedback voltage decreases and the amplifier output is below 0.8V, then the error comparator will trigger the control logic and generate an ON-time period. The ON-time period length is predetermined by the "Fixed t_{ON} Estimator" circuitry:

EQUATION 4-1:

	$t_{ON(ESTIMATED)} = \frac{V_{OUT}}{V_{IN} \times f_{SW}}$
Where:	
V _{OUT}	Output Voltage
V _{IN}	Power Stage Input Voltage
f _{SW}	Switching Frequency

At the end of the ON-time period, the internal high-side driver turns off the high-side MOSFET and the low-side driver turns on the low-side MOSFET. The OFF-time period length depends upon the feedback voltage in most cases. When the feedback voltage decreases and the output of the gm amplifier is below 0.8V, the ON-time period is triggered and the OFF-time period ends. If the OFF-time period determined by the feedback voltage is less than the minimum OFF-time tooper(MIN), which is about 200 ns, the MIC28303 control logic will apply the toper(MIN) instead. toper(MIN) is required to maintain enough energy in the boost capacitor (C_{BST}) to drive the high-side MOSFET.

The maximum duty cycle is obtained from the 200 ns $t_{\mbox{OFF}(\mbox{MIN})}$:

EQUATION 4-2:

D_{MAX} = Where:	$\frac{t_S - t_{OFF(MIN)}}{t_S} = 1 - \frac{200ns}{t_S}$	
t _S	1/f _{SW}	

It is not recommended to use MIC28303 with an OFF-time close to $t_{\rm OFF(MIN)}$ during steady-state operation.

The adaptive ON-time control scheme results in a constant switching frequency in the MIC28303. The actual ON-time and resulting switching frequency will vary with the different rising and falling times of the external MOSFETs. Also, the minimum t_{ON} results in a lower switching frequency in high V_{IN} to V_{OUT} applications. During load transients, the switching frequency is changed due to the varying OFF-time.

To illustrate the control loop operation, both the steady-state and load transient scenarios were analyzed. For easy analysis, the gain of the g_m amplifier is assumed to be 1. With this assumption, the inverting input of the error comparator is the same as the feedback voltage.

Figure 4-1 shows the MIC28303 control loop timing during steady-state operation. During steady-state, the g_m amplifier senses the feedback voltage ripple, which is proportional to the output voltage ripple plus injected voltage ripple, to trigger the ON-time period. The ON-time is predetermined by the t_{ON} estimator. The termination of the OFF-time is controlled by the feedback voltage. At the valley of the feedback voltage ripple, which occurs when V_{FB} falls below V_{REF}, the OFF period ends and the next ON-time period is triggered through the control logic circuitry.



FIGURE 4-1: MIC28303 Control Loop Timing

Figure 4-2 shows the operation of the MIC28303 during a load transient. The output voltage drops due to the sudden load increase, which causes the V_{FB} to be less than V_{REF}. This will cause the error comparator to trigger an ON-time period. At the end of the ON-time period, a minimum OFF-time t_{OFF(MIN)} is generated to

charge the bootstrap capacitor (C_{BST}) because the feedback voltage is still below V_{REF}. Then, the next ON-time period is triggered due to the low feedback voltage. Therefore, the switching frequency changes during the load transient, but returns to the nominal fixed frequency once the output has stabilized at the new load current level. With the varying duty cycle and switching frequency, the output recovery time is fast and the output voltage deviation is small.



FIGURE 4-2: MIC28303 Load Transient Response

Unlike true current-mode control, the MIC28303 uses the output voltage ripple to trigger an ON-time period. The output voltage ripple is proportional to the inductor current ripple if the ESR of the output capacitor is large enough.

In order to meet the stability requirements, the MIC28303 feedback voltage ripple should be in phase with the inductor current ripple and are large enough to be sensed by the gm amplifier and the error comparator. The recommended feedback voltage ripple is 20 mV ~ 100 mV over the full input voltage range. If a low ESR output capacitor is selected, then the feedback voltage ripple may be too small to be sensed by the gm amplifier and the error comparator. Also, the output voltage ripple and the feedback voltage ripple are not necessarily in phase with the inductor current ripple if the ESR of the output capacitor is very low. In these cases, ripple injection is required to ensure proper operation. Please refer to "Section 5.6, Ripple Injection" for more details about the ripple injection technique.

4.2 Discontinuous Mode (MIC28303-1 Only)

In continuous mode, the inductor current is always greater than zero; however, at light loads, the MIC28303-1 is able to force the inductor current to operate in discontinuous mode. Discontinuous mode is where the inductor current falls to zero, as indicated by trace (I_L) shown in Figure 4-3. During this period, the efficiency is optimized by shutting down all the non-essential circuits and minimizing the supply current. The MIC28303-1 wakes up and turns on the high-side MOSFET when the feedback voltage V_{FB} drops below 0.8V.

The MIC28303-1 has a zero crossing comparator (ZC) that monitors the inductor current by sensing the voltage drop across the low-side MOSFET during its ON-time. If the $V_{FB} > 0.8V$ and the inductor current goes slightly negative, then the MIC28303-1 automatically powers down most of the IC's circuitry and goes into a low-power mode.

Once the MIC28303-1 goes into discontinuous mode, both DL and DH are low, which turns off the high-side and low-side MOSFETs. The load current is supplied by the output capacitors and V_{OUT} drops. If the drop of V_{OUT} causes V_{FB} to go below V_{REF}, then all the circuits will wake up into normal continuous mode. First, the bias currents of most circuits reduced during the discontinuous mode are restored, and then a t_{ON} pulse is triggered before the drivers are turned on to avoid any possible glitches. Finally, the high-side driver is turned on. Figure 4-3 shows the control loop timing in discontinuous mode.



FIGURE 4-3: MIC28303-1 Control Loop Timing (Discontinuous Mode)

During discontinuous mode, the bias current of most circuits is substantially reduced. As a result, the total power supply current during discontinuous mode is only about 400 μ A, allowing the MIC28303-1 to achieve high efficiency in light load applications.

4.3 Soft-Start

Soft-start reduces the input power supply surge current at startup by controlling the output voltage rise time. The input surge appears while the output capacitor is charged up. A slower output rise time will draw a lower input surge current.

The MIC28303 implements an internal digital soft-start by making the 0.8V reference voltage V_{REF} ramp from 0 to 100% in about 5 ms with 9.7 mV steps. Therefore, the output voltage is controlled to increase slowly by a stair-case V_{FB} ramp. Once the soft-start cycle ends, the related circuitry is disabled to reduce current consumption. P_{VDD} must be powered up at the same time or after V_{IN} to make the soft-start function correctly.

4.4 Current Limit

The MIC28303 uses the ${\sf R}_{DS(ON)}$ of the low side MOSFET and external resistor connected from ${\sf I}_{LIM}$ pin to SW node to decide the current limit.



In each switching cycle of the MIC28303, the inductor current is sensed by monitoring the low-side MOSFET in the OFF period. The sensed voltage $V_{(ILIM)}$ is compared with the power ground (P_{GND}) after a blanking time of 150 ns. In this way the drop voltage over the resistor R15 (V_{CL}) is compared with the drop over the bottom FET generating the short current limit. The small capacitor (C6) connected from the I_{LIM} pin to P_{GND} filters the switching node ringing during the off-time allowing a better short limit measurement. The time constant created by R15 and C6 should be much less than the minimum off time.

The V_{CL} drop allows programming of short limit through the value of the resistor (R15), If the absolute value of the voltage drop on the bottom FET is greater than V_{CL}. In that case the V_(ILIM) is lower than P_{GND} and a short circuit event is triggered. A hiccup cycle to treat the short event is generated. The hiccup sequence including the soft start reduces the stress on the switching FETs and protects the load and supply for severe short conditions.

The short-circuit current limit can be programmed by using Equation 4-3.

EQUATION 4-3:

$R15 = \frac{(I_0)}{2}$ Where:	$\frac{CLIM - \Delta I_{L(PP)} \times 0.5) \times R_{DS(ON)} + V_{CL}}{I_{CL}}$
I _{CLIM}	Desired Current Limit
R _{DS(ON)}	On-Resistance of Low-Side Power MOSFET, 57 mΩ Typically
V_{CL}	Current-Limit Threshold (Typical Absolute Value is 14 mV per Table 1-1)
I _{CL}	Current-Limit Source Current (Typical Value is 80 µA, per Table 1-1)
$\Delta I_{L(PP)}$	Inductor Current Peak-to-Peak.

Because the inductor is integrated, use Equation 4-4 to calculate the peak-to-peak inductor ripple current.

EQUATION 4-4:

$$\Delta I_{L(PP)} = \frac{V_{OUT} \times (V_{IN(MAX)} - V_{OUT})}{V_{IN(MAX)} \times f_{SW} \times L}$$

The MIC28303 has 4.7 μ H inductor integrated into the module. The typical value of R_{WINDING(DCR)} of this particular inductor is in the range of 45 m Ω .

In case of hard short, the short limit is folded down to allow an indefinite hard short on the output without any destructive effect. It is mandatory to make sure that the inductor current used to charge the output capacitance during soft start is under the folded short limit; otherwise the supply will go in hiccup mode and may not be finishing the soft start successfully.

The MOSFET $R_{DS(ON)}$ varies 30% to 40% with temperature; therefore, it is recommended to add a 50% margin to I_{CLIM} in Equation 4-3 to avoid false current limiting due to increased MOSFET junction temperature rise. Table 4-1 shows typical output current limit value for a given R15 with C6 = 10 pF.

TABLE 4-1:TYPICAL OUTPUT
CURRENT-LIMIT VALUES

R15	Typical Output Current-Limit
1.81 kΩ	3A
2.7 kΩ	6.3A

5.0 APPLICATION INFORMATION

5.1 Simplified Input Transient Circuitry

The 56V absolute maximum rating of the MIC28303 allows simplifying the transient voltage suppressor on the input supply side which is very common in industrial applications. The input supply voltage V_{IN} (Figure 5-1) may be operating at 12V input rail most of the time, but can encounter noise spike of 50V for a short duration. By using MIC28303, which has 56V absolute maximum voltage rating, the input transient suppressor is not needed. This saves on component count, form factor, and ultimately the system becomes less expensive.



FIGURE 5-1: Simplified Input Transient Circuitry.

5.2 Setting the Switching Frequency

The MIC28303 switching frequency can be adjusted by changing the value of resistor R19. The top resistor of 100 k Ω is internal to module and is connected between V_{IN} and FREQ pin, so the value of R19 sets the switching frequency. The switching frequency also depends upon V_{IN}, V_{OUT} , and load conditions.



Adjustment.

Equation 5-1 gives the estimated switching frequency:

EQUATION 5-1:

$$f_{SW(ADJ)} = f_O \times \frac{R19}{R19 + 100k\Omega}$$

Where:
$$f_O \qquad Switching Frequency When R19 is Open$$

For more precise setting, it is recommended to use Figure 5-3:



FIGURE 5-3: Switching Frequency vs. R19

5.3 Output Capacitor Selection

The type of the output capacitor is usually determined by the application and its equivalent series resistance (ESR). Voltage and RMS current capability are two other important factors for selecting the output capacitor. Recommended capacitor types are MLCC, tantalum, low-ESR aluminum electrolytic, OS-CON and POSCAP. The output capacitor's ESR is usually the main cause of the output ripple. The MIC28303 requires ripple injection and the output capacitor ESR effects the control loop from a stability point of view.

The maximum value of ESR is calculated as in Equation 5-2:

EQUATION 5-2:

$$ESR_{C_{OUT}} \leq \frac{\Delta V_{OUT(PP)}}{\Delta I_{L(PP)}}$$

Where:
$$\Delta V_{OUT(PP)} \qquad Peak-to-Peak Output Voltage Ripple$$

$$\Delta I_{L(PP)} \qquad Peak-to-Peak Inductor Current Ripple$$

The total output ripple is a combination of the ESR and output capacitance. The total ripple is calculated in Equation 5-3:

EQUATION 5-3:



As described in Section 4.1, Theory of Operation, the MIC28303 requires at least 20 mV peak-to-peak ripple at the FB pin to make the g_m amplifier and the error comparator behave properly. Also, the output voltage ripple should be in phase with the inductor current. Therefore, the output voltage ripple caused by the output capacitors value should be much smaller than the ripple caused by the output capacitors, such as ceramic capacitors, are selected as the output capacitors, a ripple injection method should be applied to provide enough feedback voltage ripple. Please refer to Section 5.6, Ripple Injection for more details.

The voltage rating of the capacitor should be twice the output voltage for a tantalum and 20% greater for aluminum electrolytic or OS-CON.

The output capacitor RMS current is calculated in Equation 5-4:

EQUATION 5-4:

$$I_{C_{OUT(RMS)}} = \frac{\Delta I_{L(PP)}}{\sqrt{12}}$$

The power dissipated in the output capacitor is:

EQUATION 5-5:

$$P_{DISS(C_{OUT})} = I_{C_{OUT(RMS)}}^{2} \times ESR_{C_{OUT}}$$

5.4 Input Capacitor Selection

The input capacitor for the power stage input PV_{IN} should be selected for ripple current rating and voltage rating. Tantalum input capacitors may fail when subjected to high inrush currents, caused by turning the input supply on. A tantalum input capacitor's voltage rating should be at least two times the maximum input voltage to maximize reliability. Aluminum electrolytic, OS-CON, and multilayer polymer film capacitors can handle the higher inrush currents without voltage

de-rating. The input voltage ripple will primarily depend on the input capacitor's ESR. The peak input current is equal to the peak inductor current, so:

EQUATION 5-6:

$$\Delta V_{IN} = I_{L(pk)} \times ESR_{CIN}$$

The input capacitor must be rated for the input current ripple. The RMS value of input capacitor current is determined at the maximum output current. Assuming the peak-to-peak inductor current ripple is low:

EQUATION 5-7:

$$I_{CIN(RMS)} \approx I_{OUT(MAX)} \times \sqrt{D \times (1-D)}$$

The power dissipated in the input capacitor is:

EQUATION 5-8:

$$P_{DISS(CIN)} = I_{CIN(RMS)}^{2} \times ESR_{CIN}$$

The general rule is to pick the capacitor with a ripple current rating equal to or greater than the calculated worst (V_{IN_MAX}) case RMS capacitor current. Its voltage rating should be 20% to 50% higher than the maximum input voltage. Typically the input ripple (d_V) needs to be kept down to less than ±10% of input voltage. The ESR also increases the input ripple.

Equation 5-9 should be used to calculate the input capacitor. Also it is recommended to keep some margin on the calculated value:

EQUATION 5-9:

