

## 23V, 2A, 380KHz Synchronous Step-Down DC/DC Converter

### Description

The FR9886 is a synchronous step-down DC/DC converter that provides wide 4.5V to 23V input voltage range and 2A continuous load current capability.

Fault protection includes cycle-by-cycle current limit, input UVLO, output over voltage protection and thermal shutdown. Besides, adjustable soft-start function prevents inrush current at turn-on. This device uses current mode control scheme that provides fast transient response. In shutdown mode, the supply current is less than 1uA.

The FR9886 is available in an 8-pin SOIC package, provides a very compact system solution and good thermal conductance.

### Features

- Wide Input Voltage from 4.5V to 23V
- 2A Output Current
- Low Rds(on) Integrated Power MOSFET
- High Efficiency Up to 96%
- Fixed 380KHz Switching Frequency
- Current Mode Operation
- Adjustable Soft-Start
- Cycle-by-Cycle Current Limit
- Input Under Voltage Lockout
- Over-Temperature Protection with Auto Recovery
- <1uA Shutdown Current
- Internal Compensation Function
- SOP-8 and Thermal Enhanced SOP-8P Packages
- RoHS Compliant

### Applications

- Set-Top-Box
- DVD, LCD Displays
- OLPC, Netbook
- Datacom, XDSL

### Pin Assignments

SO Package (SOP- 8)

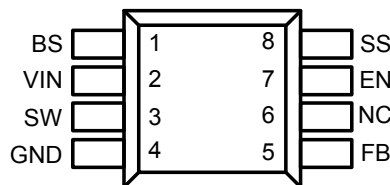
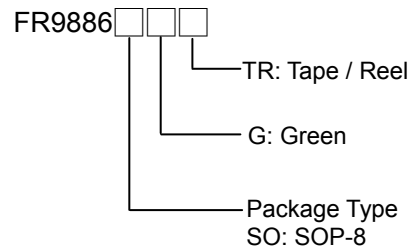


Figure 1. Pin Assignment of FR9886

### Ordering Information



**Typical Application Circuit**

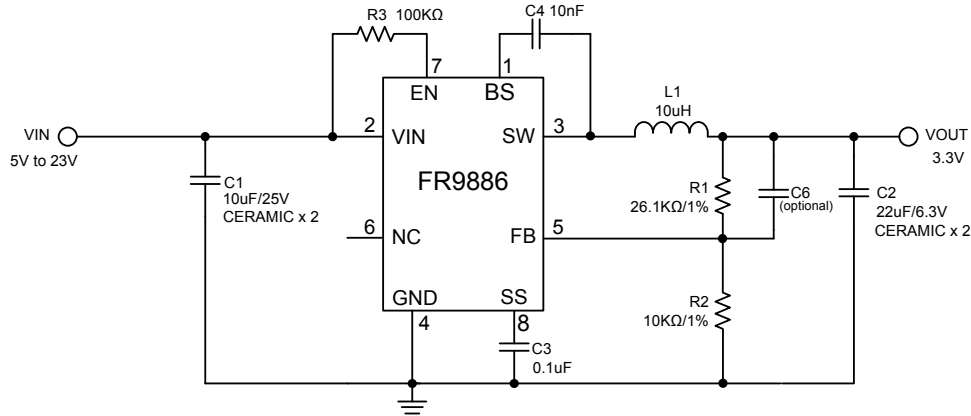


Figure 2. C<sub>IN</sub>/C<sub>OUT</sub> use Ceramic Capacitors Application Circuit

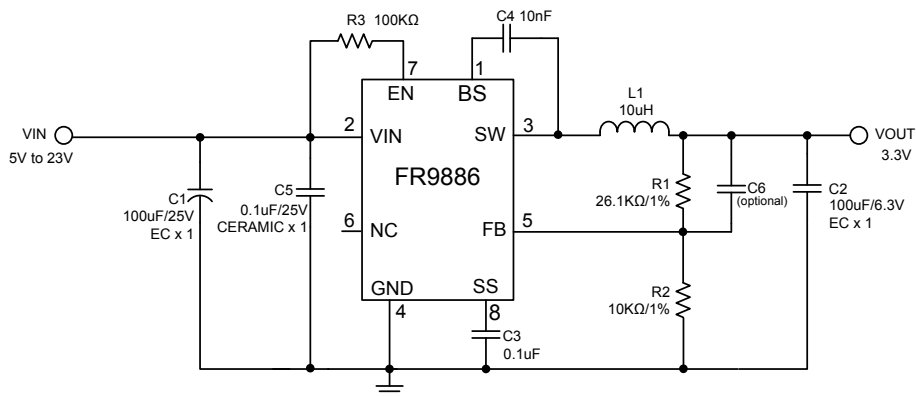


Figure 3. C<sub>IN</sub>/C<sub>OUT</sub> use Electrolytic Capacitors Application Circuit

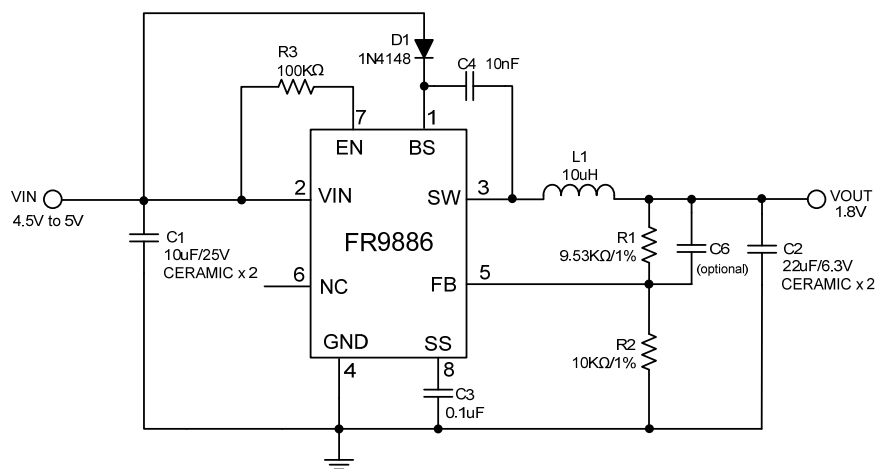


Figure 4. Low Input Voltage Application Circuit

## Functional Pin Description

Pin No.	Pin Name	Pin Function
1	<b>BS</b>	High Side Gate Drive Boost Input. A 10nF or greater capacitor must be connected from this pin to SW. It can boost the gate drive to fully turn on the internal high side NMOS.
2	<b>VIN</b>	Power Supply Input Pin. Drive 4.5V to 23V voltage to this pin to power on this chip.
3	<b>SW</b>	Power Switching Output. It is the output pin that internal high side NMOS switching to supply power.
4	<b>GND</b>	Ground Pin.
5	<b>FB</b>	Voltage Feedback Input Pin. Connecting FB and VOUT with a resistive voltage divider. This IC senses feedback voltage via FB and regulate it at 0.925V.
6	<b>NC</b>	No connection. Keeping this pin floating.
7	<b>EN</b>	Enable Input Pin. This pin provides a digital control to turn the converter on or off. Connect to VIN with a 100KΩ resistor for self-startup.
8	<b>SS</b>	Soft-Start Input Pin. This pin controls the soft-start period. Connect a capacitor from SS to GND to set the soft start period.

## Block Diagram

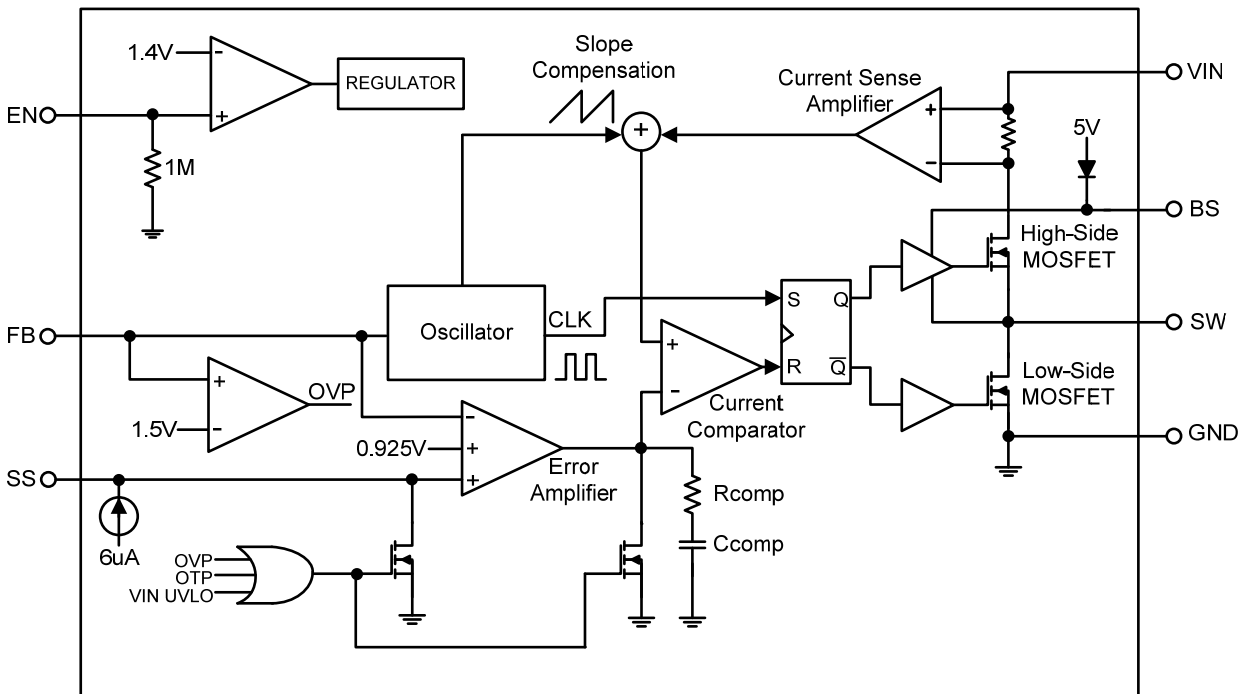


Figure 5. Block Diagram of FR9886

## Absolute Maximum Ratings

- Supply Voltage  $V_{IN}$ ----- -0.3V to +25V
- SW Voltage  $V_{SW}$ ----- -1V to  $V_{IN} + 0.3V$
- Boost Trap Voltage  $V_{BS}$ -----  $V_{sw} - 0.3V$  to  $V_{sw} + 6V$
- All Other Pins Voltage ----- -0.3V to +6V
- Maximum Junction Temperature ( $T_J$ )----- +150°C
- Storage Temperature ( $T_S$ )----- -65°C to +150°C
- Lead Temperature (Soldering, 10sec.) ----- +260°C
- Power Dissipation @ $T_A=25^\circ C$ , ( $P_D$ )
  - SOP-8 ----- 0.63W
- Package Thermal Resistance, ( $\theta_{JA}$ ):
  - SOP-8----- 90°C/W
- Package Thermal Resistance, ( $\theta_{JC}$ ):
  - SOP-8----- 39°C/W

Note1 : Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device.

## Recommended Operating Conditions

- Supply Voltage  $V_{IN}$ ----- 4.5V to 23V
- Enable Voltage  $V_{EN}$ ----- 0V to  $V_{IN}$
- Operation Temperature Range----- - 40°C to + 85°C

## Electrical Characteristics

( $V_{IN}=12V$ ,  $T_A=25^{\circ}C$ , unless otherwise specified.)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
$V_{IN}$ Input Supply Voltage	$V_{IN}$		4.5		23	V
$V_{IN}$ Quiescent Current	$I_{DDQ}$	$V_{EN}=1.8V$ , $V_{FB}=1.0V$		2.5		mA
$V_{IN}$ Shutdown Supply Current	$I_{SD}$	$V_{EN}=0V$			1	$\mu A$
Feedback Voltage	$V_{FB}$	$4.5V \leq V_{IN} \leq 23V$	0.9	0.925	0.95	V
Feedback OVP Threshold Voltage	$V_{OVP}$			1.5		V
High-Side MOSFET $R_{DS(ON)}$ (Note2)	$R_{DS(ON)}$			120		m $\Omega$
Low-Side MOSFET $R_{DS(ON)}$ (Note2)	$R_{DS(ON)}$			120		m $\Omega$
High-Side MOSFET Leakage Current	$I_{SW(leak)}$	$V_{EN}=0V$ , $V_{SW}=0V$			10	$\mu A$
High-Side MOSFET Current Limit (Note2)	$I_{LIMIT(HS)}$	Minimum Duty	3.5	4.5		A
Low-Side MOSFET Current Limit (Note2)	$I_{LIMIT(LS)}$			1.5		A
Error Amplifier Voltage Gain (Note2)				400		V/V
Oscillation frequency	$F_{OSC}$		340	380	420	KHz
Short Circuit Oscillation Frequency	$F_{OSC(short)}$	$V_{FB}=0V$		120		KHz
Maximum Duty Cycle	$D_{MAX}$	$V_{FB}=0.8V$		90		%
Minimum On Time (Note2)	$T_{MIN}$			220		ns
Input UVLO Threshold	$V_{UVLO(Vth)}$	$V_{IN}$ Rising		4.4		V
Under Voltage Lockout Threshold Hysteresis	$V_{UVLO(HYS)}$			300		mV
Soft-Start Current	$I_{SS}$			6		$\mu A$
Soft-Start Period	$T_{SS}$	$C_{SS}=0.1\mu F$		15		ms
EN Input Low Voltage	$V_{EN(L)}$				0.4	V
EN Input High Voltage	$V_{EN(H)}$		2			V
EN Input Current	$I_{EN}$	$V_{EN}=2V$		2		$\mu A$
Thermal Shutdown Threshold (Note2)	$T_{SD}$			150		$^{\circ}C$

Note2 : Not production tested.

### Typical Performance Curves

$V_{IN} = 12V$ ,  $V_{OUT} = 3.3V$ ,  $C1 = 10\mu F \times 2$ ,  $C2 = 22\mu F \times 2$ ,  $L1 = 10\mu H$ ,  $T_A = +25^\circ C$ , unless otherwise noted.

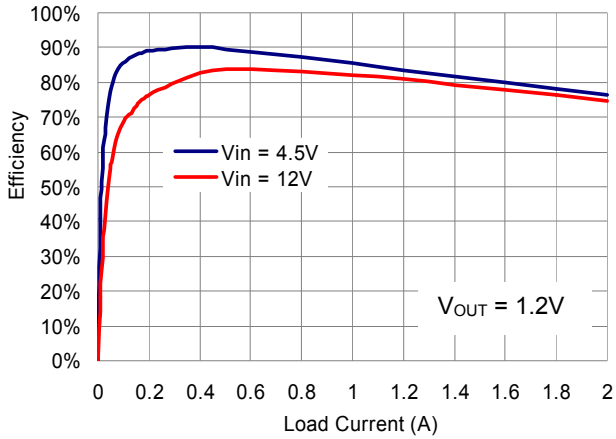


Figure 6. Efficiency vs. Loading

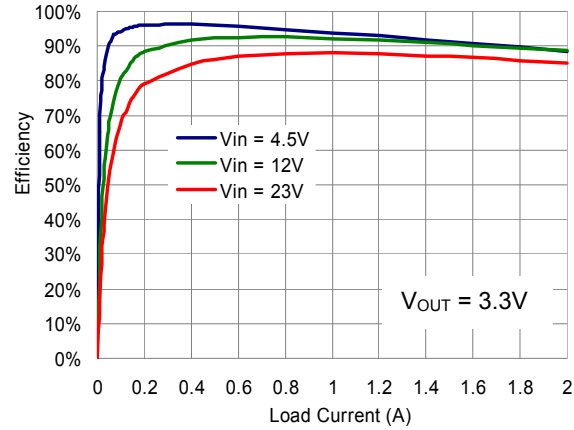


Figure 7. Efficiency vs. Loading

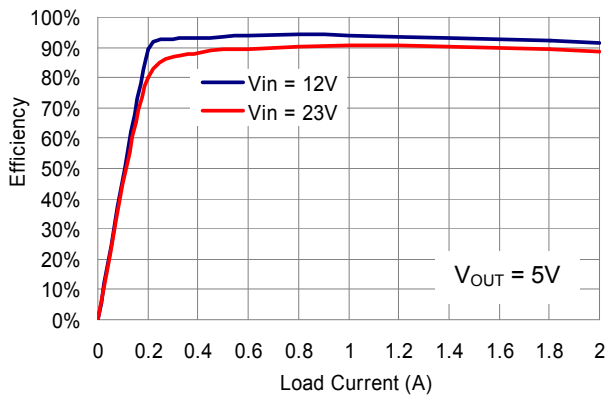


Figure 8. Efficiency vs. Loading

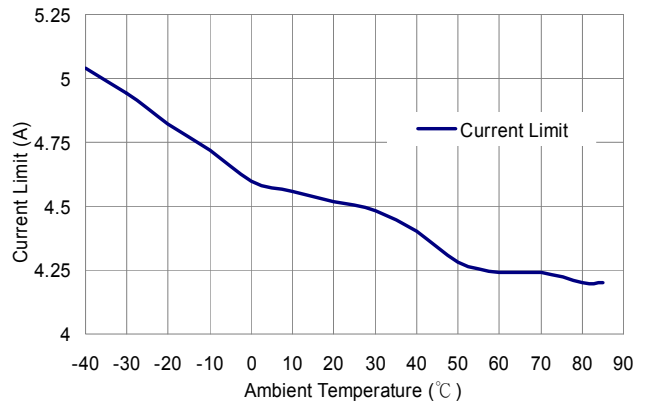


Figure 9. Current Limit vs. Temperature

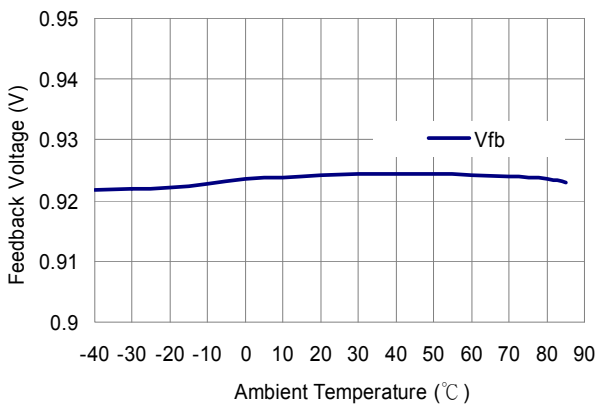


Figure 10. Feedback Voltage vs. Temperature

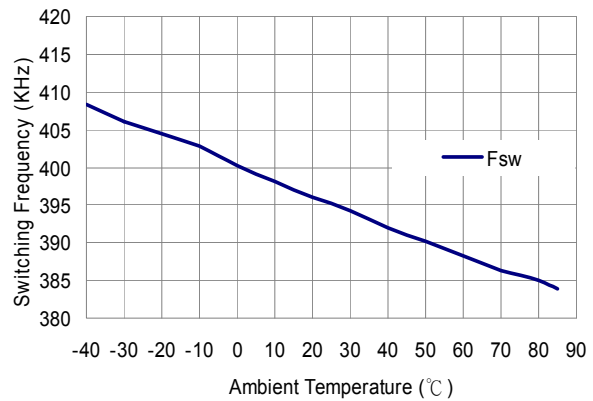


Figure 11. Switching Frequency vs. Temperature

### Typical Performance Curves (Continued)

$V_{IN} = 12V$ ,  $V_{OUT} = 3.3V$ ,  $C1 = 10\mu F \times 2$ ,  $C2 = 22\mu F \times 2$ ,  $L1 = 10\mu H$ ,  $T_A = +25^\circ C$ , unless otherwise noted.

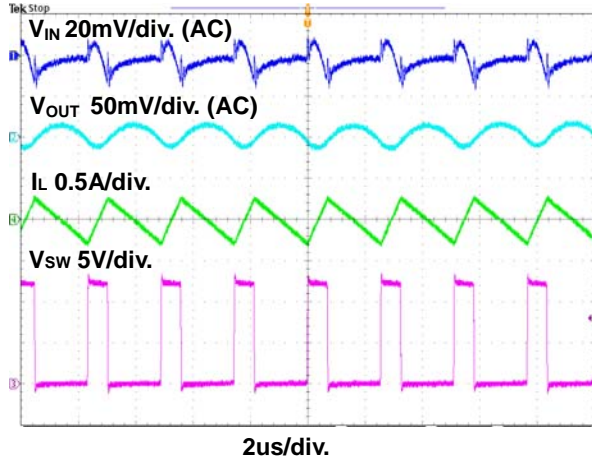


Figure 12. 0A Steady State Waveform

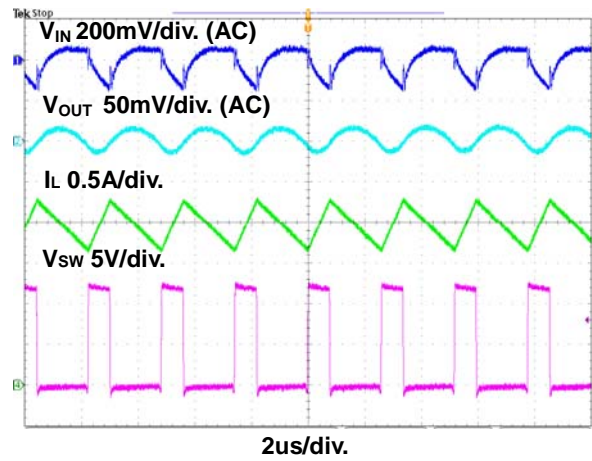


Figure 13. 2A Steady State Waveform

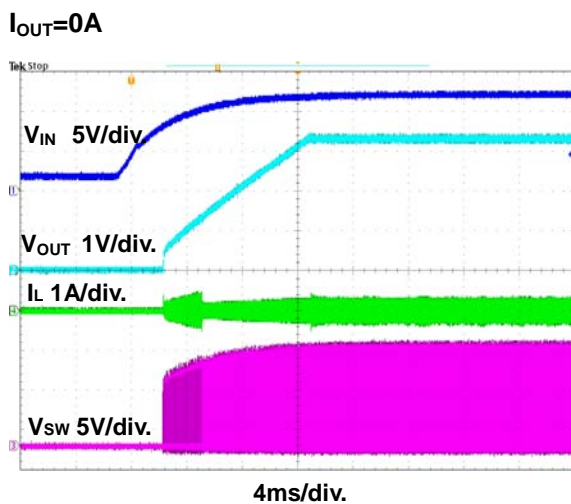


Figure 14. Power On through VIN Waveform

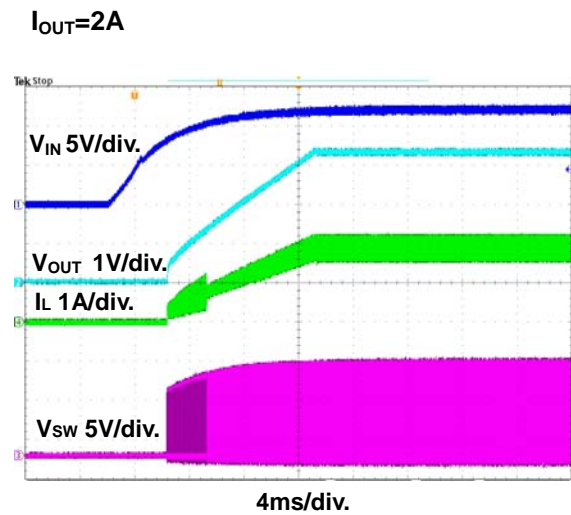


Figure 15. Power On through VIN Waveform

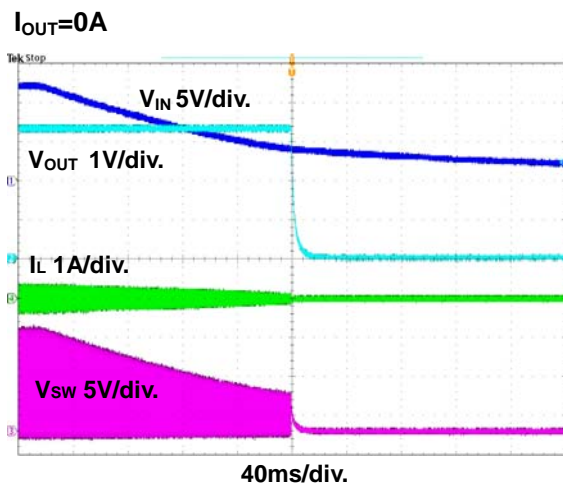


Figure 16. Power Off through VIN Waveform

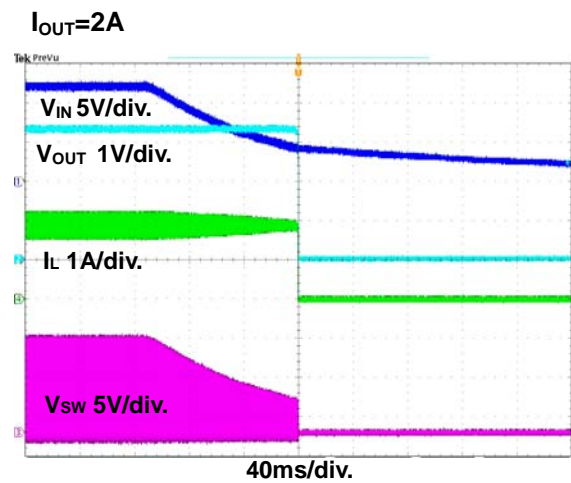


Figure 17. Power Off through VIN Waveform

**Typical Performance Curves (Continued)**

$V_{IN} = 12V$ ,  $V_{OUT} = 3.3V$ ,  $C1 = 10\mu F \times 1$ ,  $C6 = 100\mu F \times 1$ ,  $C2 = 22\mu F \times 2$ ,  $L1 = 10\mu H$ ,  $T_A = +25^\circ C$ , unless otherwise noted.

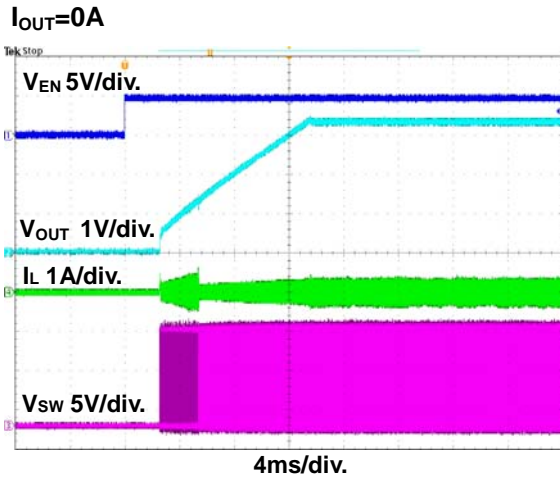


Figure 18. Power On through EN Waveform

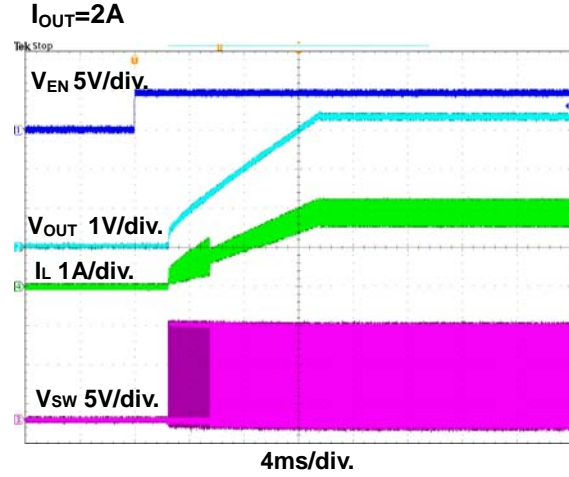


Figure 19. Power On through EN Waveform

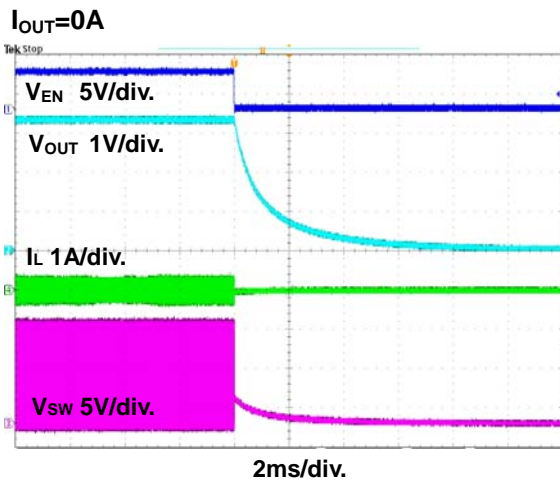


Figure 20. Power Off through EN Waveform

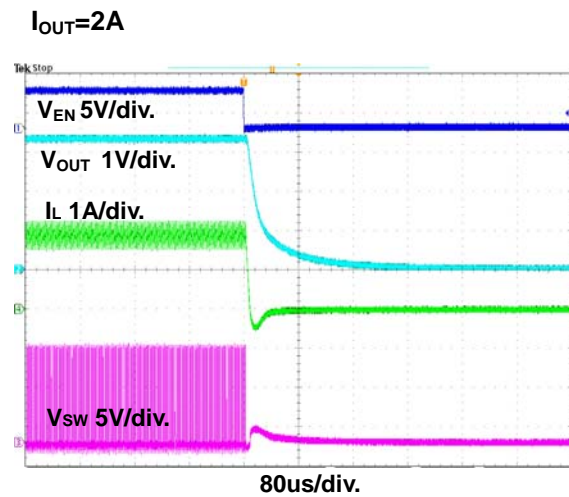


Figure 21. Power Off through EN Waveform

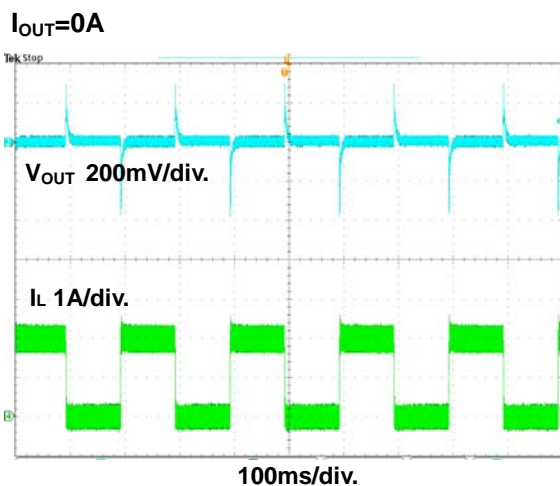


Figure 22. Load Transient Waveform

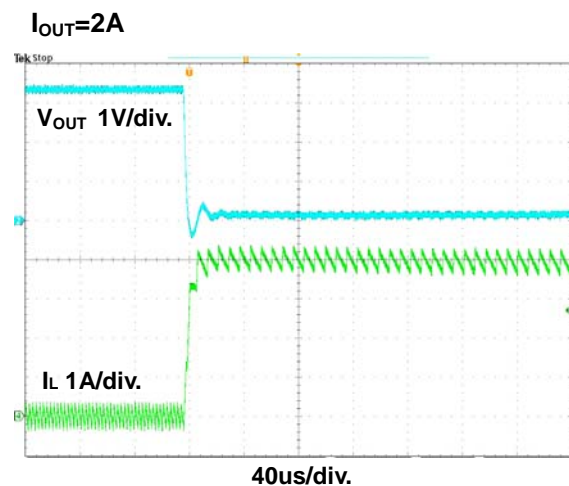


Figure 23. Short Circuit Test



## Function Description

The FR9886 is a constant frequency current mode step-down synchronous DC/DC converter. It regulates input voltage from 4.5V to 23V, down to an output voltage as low as 0.925V, and can provide 2A of continuous load current.

### Control Loop

During normal operation, the output voltage is sensed at FB pin through a resistive voltage divider and amplified through the error amplifier. The voltage of error amplifier output is compared to the switch current to controls the RS latch. At each cycle, the high side NMOS would be turned on when the oscillator sets the RS latch and would be turned off when current comparator resets the RS latch. When the load current increases, the FB pin voltage drops below 0.925V, it causes the error amplifier output voltage increase until average inductor current arrive at new load current.

### Enable

The FR9886 EN pin provides digital control to turn on/turn off the regulator. When the voltage of EN exceeds the threshold voltage, the regulator starts the soft start function. If the EN pin voltage is below than the shutdown threshold voltage, the regulator will be disable and into the shutdown mode.

### Maximum Load Current

The maximum load current decreases at lower input voltage because of large IR drop on the high side switch and low side switch. The slope compensation signal reduces the peak inductor current as a function of the duty cycle to prevent sub-harmonic oscillations at duty cycles greater than 50%.

### Output Over Voltage Protection

When the FB pin voltage exceeds 1.5V, the output over voltage protection function will discharge the error amplifier output and the SS pin to GND, turning the high side MOSFET off.

### Input Under Voltage Lockout

When the FR9886 power on, the internal circuits are held inactive until  $V_{IN}$  exceeds the input UVLO threshold voltage. And the regulator will be disabled when  $V_{IN}$  below the input UVLO threshold voltage. The hysteric of the UVLO comparator is 300 mV.

### Short Circuit Protection

The FR9886 provides short circuit protection function to prevent the device damage from short condition. When the output short to ground, the oscillator frequency is reduced to prevent the inductor current increasing beyond the current limit. In the meantime, the current limit is also reduced to lower the short current. Once the short condition is removed, the frequency and current limit will return to normal.

### Over Temperature Protection

The FR9886 incorporates an over temperature protection circuit to protect itself from overheating. When the junction temperature exceeds the thermal shutdown threshold temperature, the regulator will be shutdown, and re-enables when the IC junction temperature drops by 50°C (typ).

### Internal Compensation Function

The stability of the feedback circuit is controlled through internal compensation circuits. This internal compensation function is optimized for most applications and this function can reduce external R, C components.

## Application Information

### Output Voltage Setting

The output voltage  $V_{OUT}$  is set using a resistive divider from the output to FB. The FB pin regulated voltage is 0.925V. Thus the output voltage is:

$$V_{OUT} = 0.925 \times \left( 1 + \frac{R1}{R2} \right) \text{ V}$$

R2 recommended value is 10k $\Omega$ , so R1 is determined by:

$$R1 = 10.81 \times (V_{OUT} - 0.925) \text{ k}\Omega$$

Table 1 lists recommended values of R1 and R2 for most used output voltage.

**Table 1 Recommended Resistance Values**

$V_{OUT}$	R1	R2
5V	44.2 k $\Omega$	10 k $\Omega$
3.3V	26.1 k $\Omega$	10 k $\Omega$
2.5V	16.9 k $\Omega$	10 k $\Omega$
1.8V	9.53 k $\Omega$	10 k $\Omega$
1.2 V	3 k $\Omega$	10 k $\Omega$

Place resistors R1 and R2 close to FB pin to prevent stray pickup.

### Input Capacitor Selection

The use of the input capacitor is controlling the input voltage ripple and the MOSFETS switching spike voltage. Because the input current to the step-down converter is discontinuous, the input capacitor is required to supply the current to the converter to keep the DC input voltage. The capacitor voltage rating should be 1.25 times to 1.5 times greater than the maximum input voltage. The input capacitor ripple current RMS value is calculated as:

$$I_{IN(RMS)} = I_{OUT} \times \sqrt{D \times (1 - D)}$$

Where D is the duty cycle of the power MOSFET.

A low ESR capacitor is required to keep the noise minimum. Ceramic capacitors are better, but tantalum or low ESR electrolytic capacitors may also suffice. When using tantalum or electrolytic capacitors, a 0.1 $\mu$ F ceramic capacitor should be placed as close to the IC as possible.

### Output Capacitor Selection

The output capacitor is used to keep the DC output voltage and supply the load transient current. Low ESR capacitors are preferred. Ceramic, tantalum or low ESR electrolytic capacitors can be used, depends on the output ripple requirement. The output ripple voltage  $\Delta V_{OUT}$  is described as:

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

$$\Delta V_{OUT} = \Delta I \times \left( R_{ESR} + \frac{1}{8 \times F_{OSC} \times C_{OUT}} \right)$$

Where  $\Delta I$  is the peak-to-peak inductor ripple current,  $F_{OSC}$  is the switching frequency, L is the inductance value,  $V_{IN}$  is the input voltage,  $V_{OUT}$  is the output voltage,  $R_{ESR}$  is the equivalent series resistance value of the output capacitor, and the  $C_{OUT}$  is the output capacitor. When using the ceramic capacitors, the RESR can be ignored and the output ripple voltage  $\Delta V_{OUT}$  is shown as:

$$\Delta V_{OUT} = \frac{\Delta I}{8 \times F_{OSC} \times C_{OUT}}$$

When using tantalum or electrolytic capacitors, typically 90% of the output voltage ripple is contributed by the ESR of output capacitors. the output ripple voltage  $\Delta V_{OUT}$  can be estimated as:

$$\Delta V_{OUT} = \Delta I \times R_{ESR}$$

### Output Inductor Selection

The output inductor is used for store energy and filter output ripple current. But the trade-off condition often happens between maximum energy storage and the physical size of the inductor. The first consideration for selecting the output inductor is to make sure that the inductance is large enough to keep the converter in the continuous current mode. That will lower ripple current and results in lower output ripple voltage. A good rule for determining the inductance is set the peak-to-peak inductor ripple current  $\Delta I$  almost equal to 30% of the maximum load current. Then the minimum inductance can be calculated with the following equation:

**Application Information (Continued)**

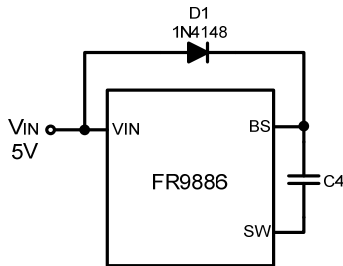
$$\Delta I = 0.3 \times I_{OUT(MAX)}$$

$$L \geq (V_{IN} - V_{OUT}) \times \left( \frac{V_{OUT}}{F_{OSC} \times \Delta I \times V_{IN}} \right)$$

Where  $V_{IN}$  is the maximum input voltage.

**External Boost Diode Selection**

For 5V input applications, it is recommended that an external boost diode be added. This helps improve the efficiency. The boost diode can be a low cost one such as 1N4148.



This diode is also recommended for high duty cycle operation (when duty cycle > 65%,  $V_{IN} < 15V$ ).

**PCB Layout Recommendation**

The device’s performance and stability is dramatically affected by PCB layout. It is recommended to follow these general guidelines show below:

1. Place the input capacitors, output capacitors as close to the device as possible. Trace to these capacitors should be as short and wide as possible to minimize parasitic inductance and resistance.
2. Place feedback resistors close to the FB pin.
3. Keep the sensitive signal (FB) away from the switching signal (SW).
4. Multi-layer PCB design is recommended.

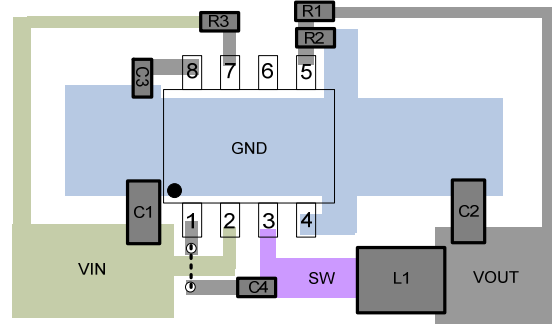
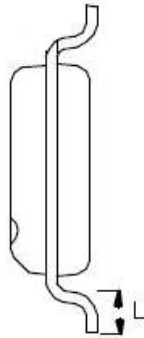
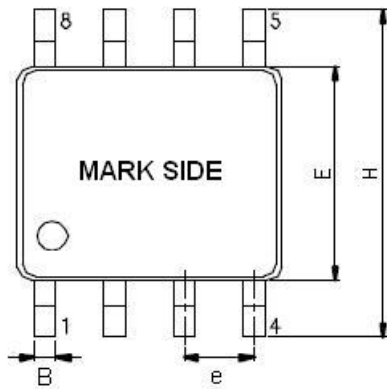


Figure 24. SOP-8 Recommended Layout Diagram

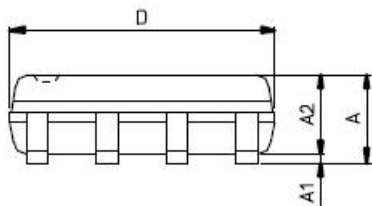
**Outline Information**

SOP- 8 Package (Unit: mm)

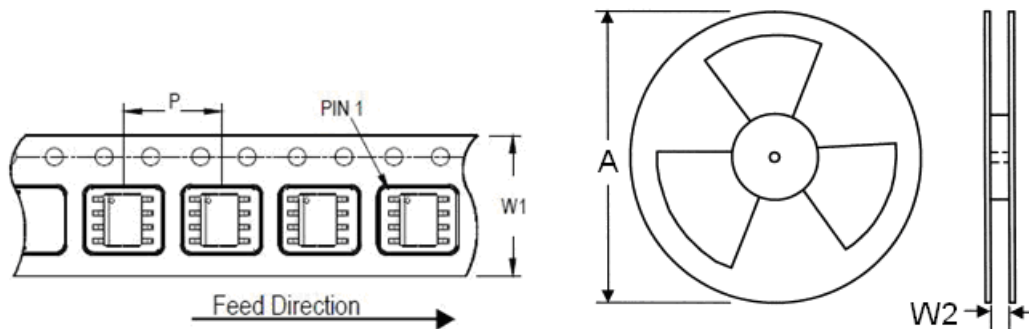


SYMBOLS UNIT	DIMENSION IN MILLIMETER	
	MIN	MAX
A	1.40	1.75
A1	0.10	0.25
A2	1.30	1.50
B	0.31	0.51
D	4.80	5.00
E	3.80	4.00
e	1.20	1.34
H	5.80	6.20
L	0.40	1.27

Note : Followed From JEDEC MO-012-E



**Carrier dimensions**



Tape Size (W1) mm	Pocket Pitch (P) mm	Reel Size (A)		Reel Width (W2) mm	Empty Cavity Length mm	Units per Reel
		in	mm			
12	8	13	330	12.4	400~1000	2,500

**Life Support Policy**

Fitipower's products are not authorized for use as critical components in life support devices or other medical systems.