Li-ion/Li-Polymer Battery Charger

Description

The FP6900 is a single-cell Li-ion/Li-polymer battery charger IC which can be operated with an input voltage as low as 2.65V. The FP6900 can work with various types of AC adapters.

The FP6900 can also be operated as a linear charger when the AC adapter is a voltage source. The battery is charged in a CC/CV (constant current/constant voltage) profile. The charge current is programmable with an external resistor up to 1.5A. The FP6900 can also work with a current-limited adapter to minimize the thermal dissipation.

The FP6900 is designed with charge current thermal foldback function to guarantee safe operation when the printed circuit board is space limited for thermal dissipation. A negative temperature coefficient (NTC) thermister is connected between the TEMP and GND to monitor the battery or ambient temperature.

Features

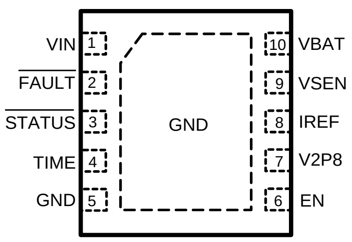
- Integrated Pass Element and Current Sensor
- No External Blocking Diode Required
- Complete Charger for Single-Cell Li-ion Batteries
- 1% Voltage Accuracy
- Very Low Thermal Dissipation
- Programmable Current Limit up to 1.5A
- Charge Current Thermal Foldback
- Accepts Multiple Types of Adapters
- Can Operate at 2.65V After Start Up
- Ambient Temperature Range: -20°C to 85°C
- NTC Interface (FP6900D)
- Less than 3μA Leakage Current off the Battery when No Input Power Attached or Charger Disabled
- Thermally-Enhanced thin DFN Package

Applications

- Handheld Devices including Medical Handhelds
- PDAs, Cell Phones and Smart Phones
- Portable Instruments, MP3 Players
- Self-Charging Battery Packs
- Stand-Alone Chargers
- USB Bus-Powered Chargers

Pin Assignment

WD Package TDFN-10 (3mmx3mm) for FP6900B/C



WD Package TDFN-10 (3mmx3mm) for FP6900D

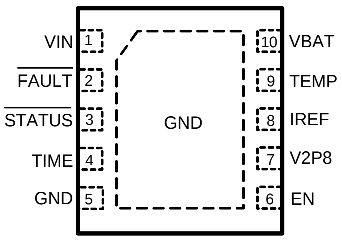
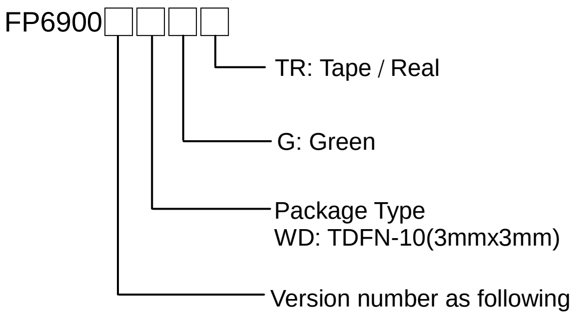


Figure1. Pin Assignment of FP6900

Ordering Information



PART NUMBER	VBAT(V)	VSEN	TEMP	TIMEOUT
FP6900B	4.2	YES	NO	YES
FP6900C	4.256	YES	NO	YES
FP6900D	4.2	NO	YES	YES

Typical Application Circuit

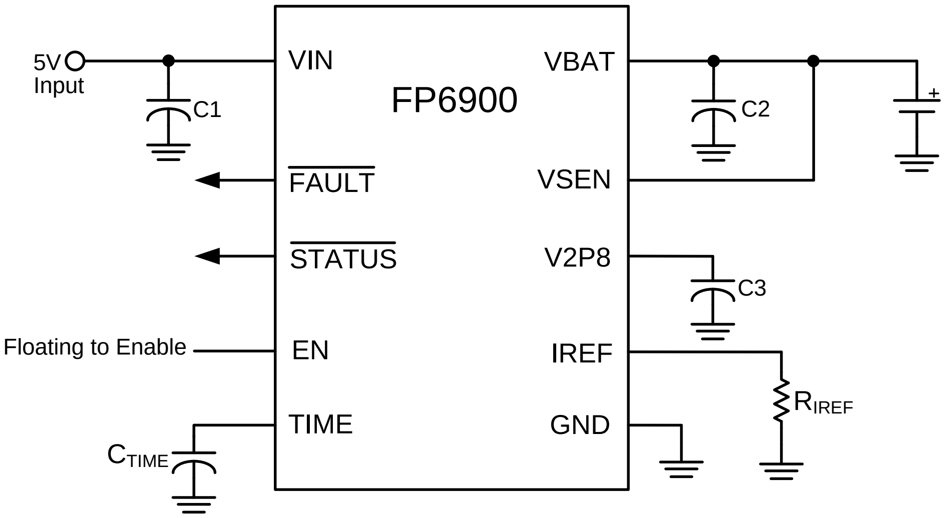


Figure 2. Typical Application Circuit of FP6900

Functional Pin Description

Pin Name	NO.	Pin Function
VIN	**1**	VIN is the input power source. Connect to a wall adapter.
/FAULT	**2**	It is an open-drain output indicating fault status. This pin is pulled to LOW under any fault conditions. Any time a FAULT condition happens, it will reset the counter of the charger.
/STATUS	**3**	It is an open-drain output indicating charging and inhibits states. The /STATUS pin is pulled LOW when the charger is charging a battery. It will be forced to high impedance when the charge current drops to IMIN. This high impedance mode will be latched until a recharge cycle or a new charge cycle starts.
TIME	**4**	The TIME pin determines the oscillation period by connecting a timing capacitor between this pin and GND. The oscillator also provides a time reference for the charger.
GND	**5**	GND is the connection to system ground.
EN	**6**	EN is the enable logic input. Connect the EN pin to LOW to disable the charger or leave it floating to enable the charger.
V2P8	**7**	This is a 2.8V reference voltage output. This pin outputs a 2.8V voltage source when the input voltage is above POR threshold, otherwise it outputs zero. The V2P8 pin can be used as an indication for adapter presence.
IREF	**8**	This is the programming input for the constant charging current. It maintains at 0.8V when the charger is in normal operation.
VSEN/TEMP	**9**	VSEN is the remote voltage sense pin in FP6900B/C. Connect this pin as close as possible to the battery pack positive connection. If the VSEN pin is floating, its voltage drops to zero volt and the charger operates in the Trickle mode. TEMP is the input for an external NTC thermister in FP6900D. The TEMP pin is also used for battery removal detection.
VBAT	**10**	VBAT is the connection to the battery. Typically a 10µF Tantalum capacitor is needed for stability when there is no battery attached. When a battery is attached, only a 0.1µF ceramic capacitor is required.

Block Diagram

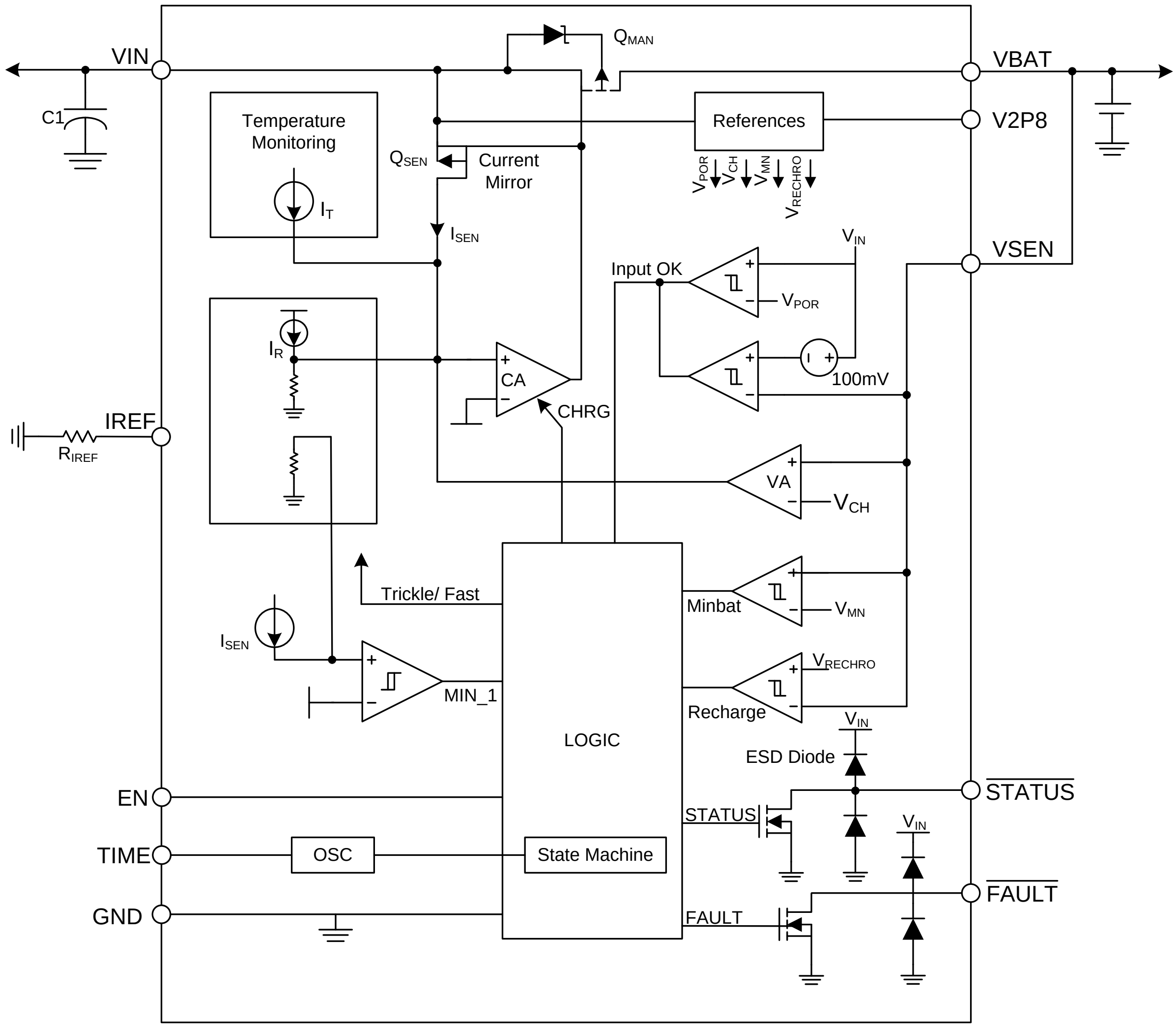


Figure 3. Block Diagram of FP6900

Absolute Maximum Ratings

- Supply Voltage (VIN) --- -0.3V to 7V
- Output Pin Voltage (VBAT, VSEN, V2P8) -- -0.3V to 5.5V
- Output Pin Voltage (/STATUS, /FAULT) --- -0.3V to 7V
- Signal Input Voltage (TIME, IREF) --- -0.3 to 3.2V
- Charge Current --- 1.6A
- Power Dissipation @ T_A=25°C,TDFN-10 (3mmX3mm) (P_D) -- 1.54W
- Package Thermal Resistance, TDFN-10 (3mmX3mm) (θ_{JA}) -- 65°C/W
- Lead Temperature (Soldering, 10sec.) --- 260°C
- Maximum Junction Temperature(T_J) -- 150°C
- Storage Temperature (T_{STG}) --- -65°C to 150°C

Note 1：Stresses beyond those listed under “Absolute Maximum Ratings" may cause permanent damage to the device.

Recommended Operating Conditions

- Supply Voltage (V_{IN}) --- 4.3V to 6.5V
- Operating Temperature Range -- -20°C to 85°C

Electrical Characteristics

(V_{IN} = 5V, T_A=25°C, maximum and minimum values are with a supply voltage in the range of 4.3V to 6.5V, unless otherwise specified.)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
POWER-ON RESET						
Rising VIN Threshold			3.0	3.5	3.95	V
Falling VIN Threshold			2.25	2.4	2.65	V
STANDBY CURRENT						
VBAT Pin Sink Current	$I_{STANDBY}$	V_{IN} floating or EN = LOW			3.0	µA
VIN Pin Supply Current	I_{VINL}	V_{BAT} floating and EN pulled low		30		µA
	I_{VINH}	V_{BAT} floating and EN floating		1		mA
VOLTAGE REGULATION						
Output Voltage(FP6900B/D)	V_{CH}		4.165	4.20	4.245	V
Output Voltage(FP6900C)	V_{CH}		4.20	4.256	4.30	V
Dropout Voltage	V_{DO}	V_{BAT} = 3.7V, 0.5A		360		mV
CHARGE CURRENT						
Constant Charge Current (Note2)	I_{CHARGE}	R_{IREF} = 80kΩ, V_{BAT} = 3.7V	0.9	1.0	1.1	A
Trickle Charge Current	$I_{TRICKLE}$	R_{IREF} = 80kΩ, V_{BAT} = 2.0V		100		mA
End-of-Charge Threshold	I_{MIN}	R_{IREF} = 80kΩ	85	100	135	mA
V2P8 PIN OUTPUT						
V2P8 Pin Output Voltage	V_{V2P8}	Load current less than 1mA	2.8	2.9	3.0	V
RECHARGE / TRICKLE CHARGE THRESHOLD						
Recharge Voltage Threshold	V_{RECHRG}		3.90	4.0	4.1	V
Trickle Charge Threshold Voltage	V_{MIN}		2.7	2.8	2.9	V
INTERNAL TEMPERATURE MONITORING						
Charge Current Foldback Threshold (Note3)	T_{FOLD}		85	100	115	°C
Current Foldback Gain (Note3)	G_{FOLD}			70		mA/°C
AMBIENT TEMPERATURE MONITORING (FP6900D)						
High Voltage Threshold		V2P8 = 3.0V	1.97	2.0	2.03	V
High Voltage Threshold Hysteresis		V2P8 = 3.0V		1.9		V
Low Voltage Threshold		V2P8 = 3.0V	0.985	1.0	1.015	V
Low Voltage Threshold Hysteresis		V2P8 = 3.0V		1.1		V
OSCILLATOR						
Oscillation Period	T_{OSC}	C_{TIME} = 15nF	2.4	3.0	3.6	ms
LOGIC INPUT AND OUTPUT						
EN Pin Logic Input High			1.3			V
EN Pin Logic Input Low					0.5	V
EN Pin Internal Pull-up Resistance			200	400	600	kΩ
STATUS/FAULT Sink Current		Pin Voltage = 0.8 V	10			mA

Note 2：The actual charge current may be affected by the thermal foldback function if the thermal dissipation capability is not enough or by the on resistance of the power MOSFET if the charger input voltage is too close to the output voltage.

Note 3：The specification is guaranteed by design, not production tested.

Typical Performance Curves

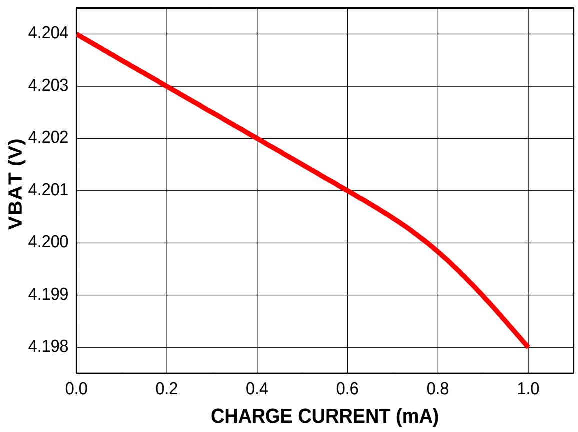


Figure 4. Charge Voltage vs. Charge Current

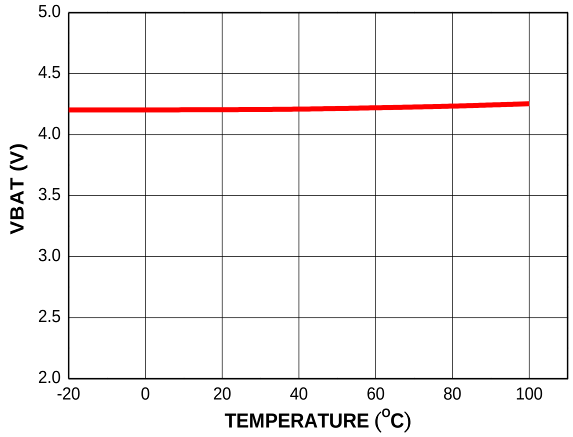


Figure 5. Charge Output Voltage vs. Temperature

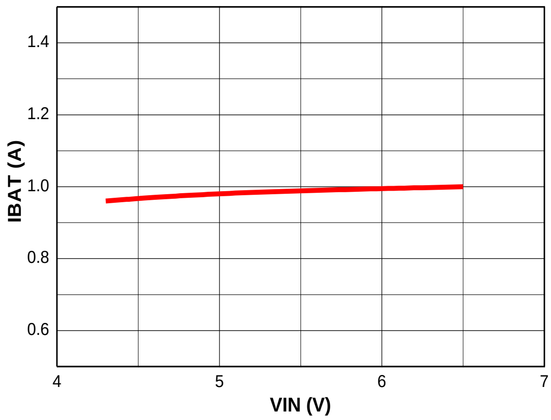


Figure 6. Charge Current vs. Input Voltage

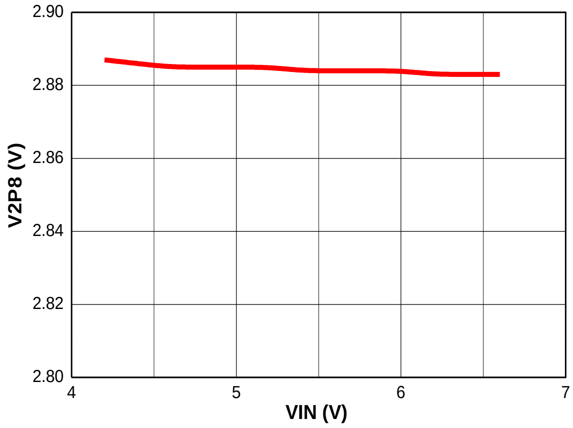


Figure 7. V2P8 Output vs. Input Voltage

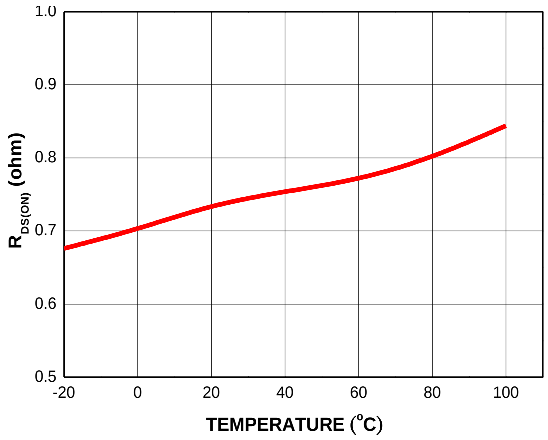


Figure 8. $R_{DS(ON)}$ vs. Temperature

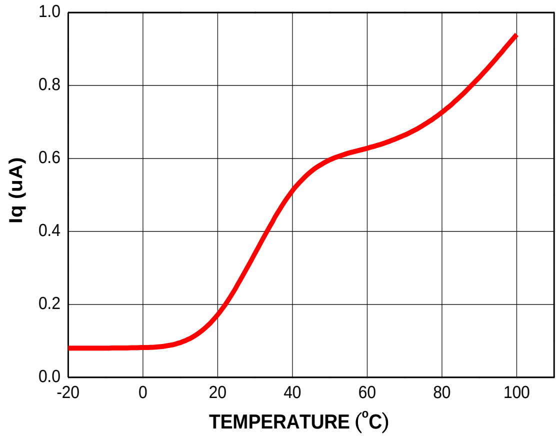


Figure 9. Input Quiescent Current vs. Temperature

Functional Description

Operation

The FP6900 is an integrated charger IC for single-cell Li-ion/Li-polymer batteries. The FP6900 functions as a traditional linear charger when powered with a voltage source adapter. When powered with a current-limited adapter, the charger minimizes the thermal dissipation commonly seen in traditional linear chargers.

When powered as a linear charger, the FP6900 charges a battery in the popular constant current (CC) and constant voltage (CV) profile. The constant charge current IREF is programmable up to 1.5A with an external resistor. The charge voltage VCH has 1% accuracy over the entire recommended operating condition range.

If the battery voltage is below the minimum fast charge voltage VMIN threshold, the charger always preconditions the battery with 10% of the programmed current at the beginning of a charge cycle, until the battery voltage is verified to be above the VMIN. This low current charge mode is named trickle mode. The verification takes 15 cycles of an internal oscillator whose period is programmable with the timing capacitor. A thermal-foldback feature is designed to throttle back the charge current to remove the thermal concern typically seen in linear chargers. The charger reduces the charge current automatically as the IC internal temperature rises above 100°C to prevent further temperature rise. The thermal-foldback feature guarantees safe operation when the printed circuit board (PCB) is space limited for thermal dissipation.

The charger provides a safety timer with external capacitor for setting the fast charge time (TIMEOUT) limit to prevent charging a dead battery for an extensively long time. The trickle mode is limited to 1/8 of TIMEOUT. When the battery voltage drops below a recharge threshold, the charger automatically re-charges the battery. When the wall adapter is not present, the FP6900 draws less than 1µA current from the battery.

Three pins are used to indicate the charge status. The V2P8 outputs a 2.8V dc voltage when the supply voltage is above the power-on reset (POR) level and can be used as the power-present indication. This pin is capable of sourcing a 2mA current, so it can also be used to bias external circuits.

The /STATUS pin is an open-drain logic output that turns LOW when FP6900 starts a charge cycle until the end-of-charge (EOC) condition is qualified. The EOC condition is: the battery voltage rises above the recharge threshold and the charge current falls below 1/10 of IREF.

Once the EOC condition is qualified, the /STATUS output rises to HIGH and is latched. The latch is released at the beginning of a charge or re-charges cycle. The open-drain /FAULT pin turns low when a charge time fault occurs or when the IREF pin is pulled below 0.35V or above 1.4V.

Figure.10 shows the typical charge curves in a traditional linear charger powered with a constant-voltage adapter. From the top to bottom, the curves represent the constant input voltage, the battery voltage, the charge current and the power dissipation in the charger. The power dissipation P_{CH} is given by the following equation:

$$P_{CH} = (V_{IN} - V_{BAT}) \times I_{CHARGE}$$

where I_{CHARGE} is the charge current.

The maximum power dissipation occurs during the beginning of the CC mode. The maximum power the IC is capable of dissipating is dependent on the thermal impedance of the printed-circuit board (PCB).

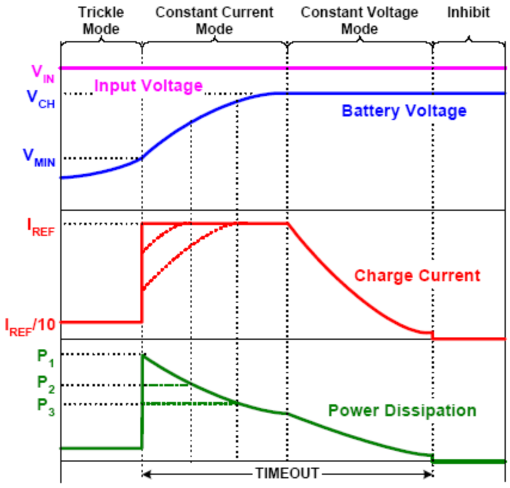


Figure 10. Typical charge curves using a Constant-Voltage adaptor

Figure10 shows, with dotted lines, two cases that the charge currents are limited by the maximum power dissipation capability due to the thermal foldback.

Functional Description (Continued)

When using a current-limited adapter, the thermal situation in the FP6900 is totally different. Figure11 shows the typical charge curves when a current-limited adapter is employed. The operation requires the IREF to be programmed higher than the limited current I_{LIM} of the adapter, as shown in Figure 6. The key difference of the charger operating under such conditions occurs during the CC mode.

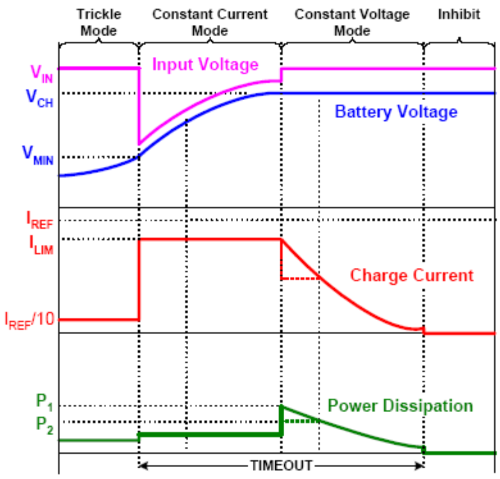


Figure 11. Typical charge curves using a current-limited adaptor

The power dissipation in the CC mode becomes:

$$P_{CH}= R_{DS(ON)} \times I_{CHARGE}^2$$

The worst power dissipation when using a current-limited adapter typically occurs at the beginning of the CV mode. When using a very small PCB whose thermal impedance is relatively large, it is possible that the internal temperature can still reach the thermal foldback threshold. In that case, the IC is thermally protected by lowering the charge current, as shown by the dotted lines in the charge current and power curves. Appropriate design of the adapter can further reduce the peak power dissipation of the FP6900.

Power on Reset (POR)

The FP6900 resets itself as the input voltage rises above the POR rising threshold. The V2P8 pin outputs a 2.8V voltage, the internal oscillator starts to oscillate, the internal timer is reset, and the charger begins to charge the battery. The two indication pins, /STATUS and /FAULT, indicate a LOW and a HIGH logic signal respectively. Figure 12 illustrates the start up of the charger between t0 to t2. The FP6900 has a typical rising POR threshold of 3.5V and a falling POR threshold of 2.4V. The 2.4V falling threshold guarantees charger operation with a current limited adapter to minimize the thermal dissipation.

Charge Cycle

There are 3 charge modes in a charge cycle: trickle mode, constant current (CC) mode, and constant voltage (CV) mode. The charge cycle always starts with the trickle mode until the battery voltage stays above V_{MIN} (2.8V typical) for 15 consecutive cycles of the internal oscillator. If the battery voltage drops below V_{MIN} during the 15 cycles, the 15-cycle counter is reset and the charger stays in the trickle mode. The charger proceeds to the CC mode after verifying the battery voltage. As the battery-pack terminal voltage rises to the final charge voltage VCH, the CV mode begins. The terminal voltage is regulated at the constant VCH in the CV mode and the charge current is expected to decline. When the charge current drops below I_{MIN} (1/10 of IREF, see End-of-Charge Current for more detail), the FP6900 indicates the end-of-charge (EOC) with the /STATUS pin. The charging actually does not terminate until the internal timer completes its length of TIMEOUT in order to bring the battery to its full capacity. Signals in a charge cycle are illustrated in Figure 12 between points t2 to t5:

The following events initiate a new charge cycle:

1. POR
2. The battery voltage drops below a recharge threshold after completing a charge cycle.
3. The EN pin is toggled from GND to floating.

Further descriptions of these events are given later in this data sheet.

Functional Description (Continued)

Recharge

After a charge cycle completes, charging is prohibited until the battery voltage drops to a recharge threshold, V_{RECHRG} (see Electrical specifications). Then a new charge cycle starts at point t6 and ends at point t8, as shown in Figure 12. The safety timer is reset at t6.

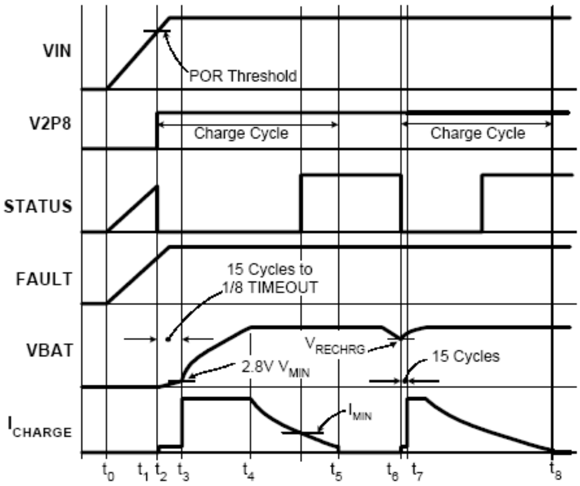


Figure 12. Operation waveform

Internal Oscillator

A timing reference generated by internal oscillator is used to calculate the charge cycles. The oscillation period is programmable with an external timing capacitor, CTIME, as shown in Typical Applications. The oscillator charges the timing capacitor to 1.5V and then discharges it to 0.5V in one period, both with 10 µA current. The period T_{OSC} is:

$$Tosc = 0.2 \times 10^6 \times C_{TIME} \text{ (seconds)}$$

A 1nF capacitor results in a 0.2ms oscillation period. The accuracy of the period is mainly dependent on the accuracy of the capacitance and the internal current source.

Total Charge Time and TIMEOUT

The total charge time for the CC mode and CV mode is limited to a length of TIMEOUT. A 22-stage binary counter increment each oscillation period of the internal oscillator to set the TIMEOUT. The TIMEOUT can be calculated as:

$$TIMEOUT = 2^{22} \times Tosc = 14 \times C_{TIME} / 1nF \text{ (minutes)}$$

A 1nF capacitor leads to 14 minutes of TIMEOUT. For example, a 15nF capacitor sets the TIMEOUT be 3.5 hours. The charger has to reach the end-of-charge condition before the TIMEOUT, otherwise, a TIMEOUT fault is issued. The TIMEOUT fault latches up the charger. There are two ways to release such a latch-up: either to recycle the input power, or toggle the EN pin to disable the charger and then enable it again.

The trickle mode charge has a time limit of 1/8 TIMEOUT. If the battery voltage does not reach VMIN within this limit, a TIMEOUT fault is issued and the charger latches up. The charger stays in trickle mode for at least 15 cycles of the internal oscillator and, at most, 1/8 of TIMEOUT, as shown in Figure 12. For the FP6900B, FP6900C and the FP6900D, the timeout function is always enforced.

Charge Current Programming

The charging current during the constant current mode is 100,000 times that of the current in the R_{IREF} resistor. The charge current in the CC mode is programmed by the IREF pin. The voltage of IREF is regulated to a 0.8V reference voltage. Hence, the charge current is:

$$I_{REF} = 0.8V \times 10^5 / R_{IREF} \text{ (A)}$$

R_{IREF} (kΩ)	CHARGE CURRENT (mA)		
	Min.	Typ	Max.
267	250	300	350
160	450	500	550
100	720	800	880
88.9	810	900	990
80	900	1000	1100

Table1. Charge current vs. R_{IREF} values

The FP6900 is designed to be safe when the IREF pin is accidentally short-circuited to an external source or to ground. If the IREF pin is driven by an external source to below 0.38V or above 1.5V for any reason, the charger is disabled and the /FAULT pin turns to LOW to indicate a fault condition.

Functional Description (Continued)

The charger will resume charging after the fault condition is removed. When the IREF is driven by a voltage between 0.38V to 0.5V (typical value), the charge current is limited to 100mA; or when driven to a voltage between 1.2V to 1.5V, the charge current is limited to 500mA. For any voltage between 0.5V to 1.2V, the charge current will drop to a very low value. This feature can protect the charger from a large charging current when IREF is accidentally shorted to ground or to a high voltage.

End-of-Charge (EOC) Current

The EOC current I_{MIN} sets the level at which the charger starts to indicate the end of the charge with the /STATUS pin, as shown in Figure 12. The charger actually does not terminate charging until the end of the TIMEOUT, as described in the Total Charge Time section. In the FP6900, the EOC current is internally set to 1/10 of the CC charge current that is:

$$I_{MIN} = 0.1 \times I_{REF}$$

At the EOC, the /STATUS signal rises to HIGH and is latched. The latch is not reset until a recharge cycle or a new charge cycle starts.

Temperature Monitoring and Thermal Foldback

In FP6900D version, there is an external temperature monitoring function. A negative temperature coefficient (NTC) thermistor can be connected between the TEMP pin and GND to monitor the battery temperature or ambient temperature. The hysteresis comparators internal to the FP6900D provide a valid temperature window centered at the voltage of the TEMP pin, which is programmed by the NTC and the pull-up resistor connected to the pin. When the measured temperature is outside this window, the charger is paused (both the charger and the timer are stopped) and a fault indication is issued. Over-heating is always a concern in a linear charger.

The maximum power dissipation usually occurs at the beginning of a charge cycle when the battery voltage is at its minimum but the charge current is at its maximum. The charge current thermal foldback function in the FP6900 frees users from the over-heating concern. Figure 13 shows the internal summing node current. I_R is the reference; I_T is the current from the Temperature Monitoring block. The I_T has no impact before internal temperature reaches ~100°C. I_{SEN} is equal to (I_R-I_T). Charge current is 100,000 times that of the sensed current and reduces at a rate of 100mA/°C. For a charger with the constant charge current set at 1A, the charge current is reduced to zero when the internal temperature rises to 110°C. The actual charge current settles between 100°C to 110°C. Usually the charge current should not drop below I_{MIN} because of the thermal foldback. For some extreme cases if that does happen, the charger does not indicate end-of-charge unless the battery voltage is already above the recharge threshold.

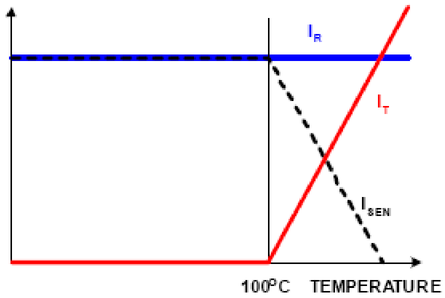


Figure 13. Current signals at internal charging loop

2.8V Bias Voltage

The FP6900 provides a 2.8V voltage for biasing the internal control and logic circuit. This voltage is also available for external circuits such as the NTC thermistor circuit. The maximum allowed external load is 2mA.

Shutdown

The FP6900 can be shutdown by pulling the EN pin to ground. When shut down, the charger draws typically less than 30µA current from the input power and the 2.8V output at the V2P8 pin is also turned off. The EN pin needs be driven with an open-drain or open-collector logic output, so that the EN pin is floating when the charger is enabled. If the EN pin is driven by an external source, the POR threshold voltage will be affected.

Functional Description (Continued)

Indication

The FP6900 has three indications: the input presence, the charge status, and the fault indication. The input presence is indicated by the V2P8 pin while the other two indications are presented by the /STATUS pin and /FAULT pin respectively. Figure 14 shows the V2P8 pin voltage vs. the input voltage. Table 2 summarizes the other two pins.

/FAULT	/STATUS	INDICATION
High	High	Charge completed with no fault (inhibit) or Standby
High	Low	Charging in one of the three modes
Low	High	Fault

Table2. State indications

NOTE: Both outputs are pulled up with external resistors

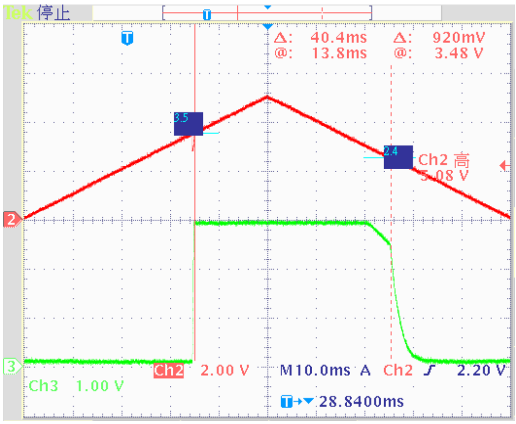


Figure 14. The V2P8 pin output vs. VIN voltage

Application Information

Input and Output Capacitor Selection

Typically any type of capacitors can be used for the input and the output. Use of a 0.47μF or higher value ceramic capacitor for the input is recommended. When the battery is attached to the charger, the output capacitor can be any ceramic type with the value higher than 0.1μF. However, if there is a chance the charger will be used as an LDO linear regulator, a 10μF tantalum capacitor is recommended.

Stability with Large Ceramic Output Capacitors

The FP6900 partially relies on the ESR (equivalent series resistance) of the output capacitor for the loop stability. When the system has a large ceramic capacitor or a number of ceramic capacitors in parallel, the ESR value can be too low for a stable operation. A low-value resistor should be inserted between the sensed feedback (VSEN pin) and the external large-value ceramic capacitor to improve the stability, as shown in Figure 15.

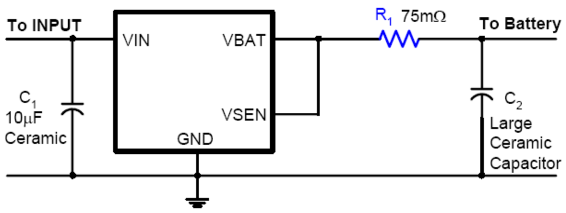


Figure 15. Inserting R1 to improve the stability of applications with large ceramic capacitor is used at the output

Board Layout Recommendations

The FP6900 internal thermal foldback function limits the charge current when the internal temperature reaches approximately 100°C. In order to maximize the current capability, it is very important that the exposed pad under the package is properly soldered to the board and is connected to other layers through thermal vias. More thermal vias and more copper attached to the exposed pad usually result in better thermal performance. On the other hand, the number of vias is limited by the size of the pad. The 3x3 TDFN package allows 8 vias be placed in two rows. Since the pins on the 3x3 TDFN package are on only two sides, as much top layer copper as possible should be connected to the exposed pad to minimize the thermal impedance.

In applications that have a sense resistor between the VBAT pin and the VSEN pin, such as the R1 shown in Figure 16, two small resistors can be used to create an equivalent low value resistor between the VSEN pin and the large capacitor, to avoid another more expensive low-value sense resistor. R2 and R3 in Figure 16 show how the two resistors are connected. The equivalent low-value resistance is,

$$R_{EQ} = \frac{R_3}{R_2 + R_3} \times R_1$$

The value of (R2 + R3) should be significantly larger than that of the sense resistor R1 to minimize the accuracy of the current sensing. The parallel value of R2 and R3 should be significantly smaller than 72kΩ (internal resistive divider value for setting the charger output voltage) to minimize the impact on the output voltage. Figure 16 shows two 20Ω resistor. The sum is 40Ω, much higher than the 150mΩ R1. The parallel value is 10Ω, negligible compared to the 72kΩ resistive divider. Such a selection is a good trade-off to result in 75mΩ equivalent low-value resistance between the VSEN pin and the large capacitor.

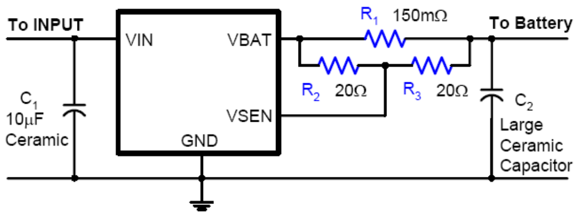
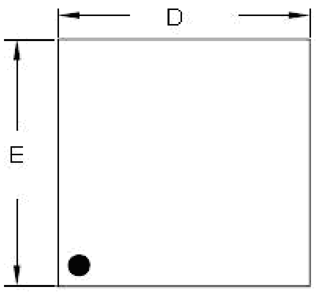
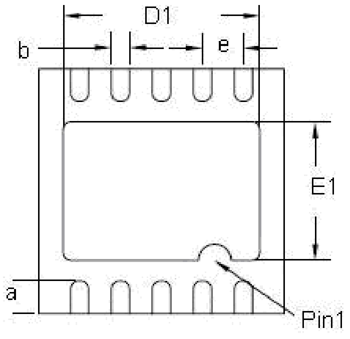


Figure 16. Generate the equivalent low-value resistor

Outline Information

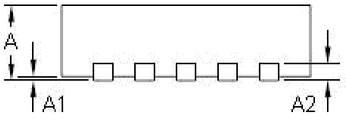
TDFN-10 Package (3mm x 3mm) (Unit: mm)





SYMBOLS UNIT	DIMENSION IN MILLIMETER	
	MIN	MAX
A	0.70	0.80
A1	0.00	0.05
A2	0.18	0.25
D	2.95	3.05
E	2.95	3.05
a	0.35	0.45
b	0.18	0.30
e	0.45	0.55
D1	2.25	2.65
E1	1.45	2.00

Note：Followed From JEDEC MO-220-J



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