1 Cell Linear Lithium-Ion Battery Charger

FEATURES

- Complete Linear Charger for 1 Cell Lithium-Ion Battery
- Ideal for Low-Dropout Designs for Single-Cell Li-ion or Li-Pol Packs in Space Limited Applications
- No External MOSFET, Sense Resistor or Blocking Diode Required
- Up to 1000mA Charge Current
- Reverse Leakage Protection Prevents Battery Drainage
- Integrated Current and Voltage Regulation
- Charge Termination by 1/10 Full Charge Current
- Precharge With Safety Timer
- Status Outputs for LED or System Interface Indicates Charge and Fault Conditions
- Battery Insertion and Removal Detection
- Available in Tiny Thermally Enhanced MSOP-10 Exposed Pad, SOP-8 Exposed Pad and DFN-10 (3x3x0.75-0.5) Package

APPLICATIONS

- Cellular Phones
- Handheld Devices
- Digital Still Cameras
- MP3 Players
- PDAs
- Charging Docks and Cradles
- USB Chargers

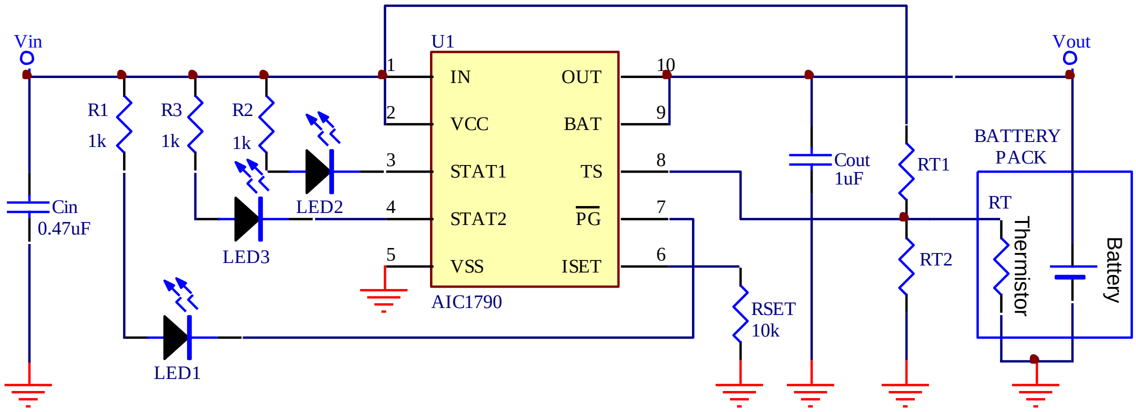
GENERAL DESCRIPTION

The AIC1790 is highly integrated Li-ion and Li-Pol linear charge devices targeted at space limited portable applications. It offers integrated power MOSFET and current sensor, reverse blocking protection, high accuracy current and voltage regulation, charge status, and charge termination, in a small package.

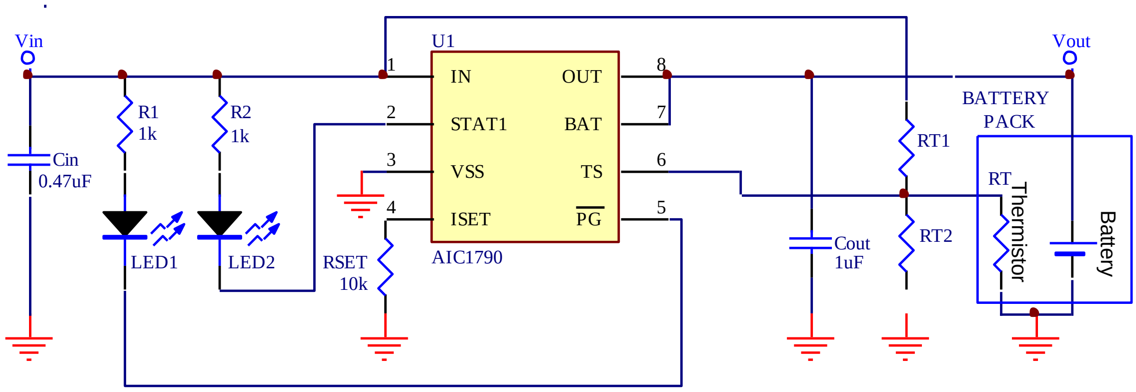
The AIC1790 charges the battery in three phases, precharge, constant current and constant voltage. Charge is terminated based on 1/10 full charge current. An internal charge timer provides a backup safety feature for charge termination. AIC1790 automatically restarts the charge if the battery voltage falls below an internal threshold. AIC1790 automatically enters sleep mode when VCC supply is removed.

In addition to the standard features, AIC1790 offers a multitude of additional features. These include temperature-sensing input for detecting hot or cold battery packs; power good ($\overline{PG}$) output indicating the presence of input power.

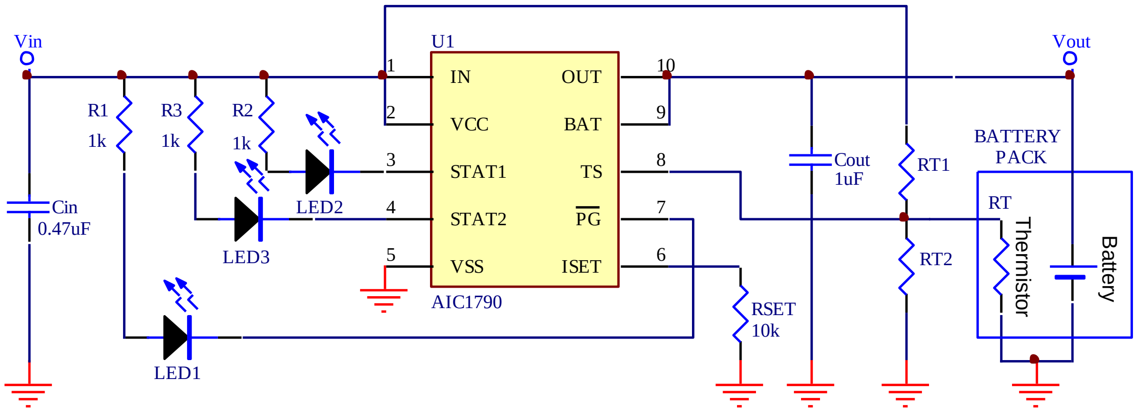
TYPICAL APPLICATION CIRCUIT



Typical Application Circuit for MSOP-10



Typical Application Circuit for SOP-8



Typical Application Circuit for DFN-10

ORDERING INFORMATION

AIC1790-XXXXX XX

PACKING TYPE
TR: TAPE & REEL
TB: TUBE
BG: BAG
(For DFN-10 (3x3x0.75-0.5))

PACKAGING TYPE
OW: MSOP10 Exposed Pad
R8: SOP-8 Exposed Pad
DC: DFN-10 (3x3x0.75-0.5)

G: Green Package

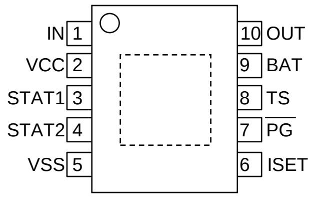
OUTPUT VOLTAGE
DEFAULT: 4.2V
35: 4.35V

Example: AIC1790GOWTR
→ in MSOP-10 Exposed Pad Green Package and Tape & Reel Packing Type

AIC1790-35GDCBG
→ 4.35V Output Version, in DFN-10 (3x3x0.75-0.5) Green Package and BAG Packing Type

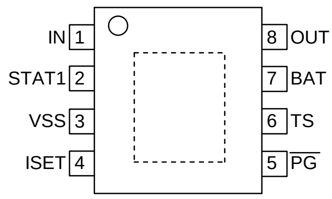
PIN CONFIGURATION

MSOP-10 Exposed Pad
TOP VIEW



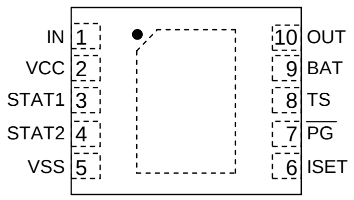
Note:
The exposed pad should be connected with VSS pin.

SOP-8 Exposed Pad
TOP VIEW



Note:
The exposed pad should be connected with VSS pin.

DFN-10 (3x3x0.75-0.5)
TOP VIEW



Note:
The exposed pad should be connected with VSS pin.

ABSOLUTE MAXIMUM RATINGS

Input Supply Voltage (VCC to VSS) 6V

BAT, OUT, ISET to VSS 6V

IN, STAT1, STAT2, TS, $\overline{PG}$ to VSS VCC

VCC - IN .... ±0.5V

Output Sink/Source Current (STAT1, STAT2, $\overline{PG}$) 15mA

Operating Ambient Temperature Range T_A .... -40ºC~85ºC

Operating Maximum Junction Temperature T_J 150ºC

Storage Temperature Range T_{STG} .... -65ºC~150ºC

Lead Temperature (Soldering 10 Sec.) 260ºC

Thermal Resistance Junction to Case	MSOP-10 Exposed Pad	45°C/W
	SOP-8 Exposed Pad*	15ºC /W
	DFN-10 (3x3x0.75-0.5)	20ºC /W
Thermal Resistance Junction to Ambient	MSOP10 Exposed Pad	120°C/W
	SOP-8 Exposed Pad*	60ºC /W
	DFN-10 (3x3x0.75-0.5)	50ºC /W

(Assume no Ambient Airflow, no Heat sink)

Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

*The package is place on a two layers PCB with 2 ounces copper and 2 square inch, connected by 8 vias.

ELECTRICAL CHARACTERISTICS

(V_{CC}=5V, T_A=25°C, Unless otherwise specified.) (Note1)

PARAMETER	TEST CONDITIONS	SYMBOL	MIN.	TYP.	MAX.	UNIT
Input Current						
Operation Voltage		V_{CC}	4.5		5.5	V
V_{CC} Current	V_{CC} > $V_{CC(MIN)}$, STATx pins in OFF state	I_{CC}	0	3.5	5	mA
Sleep Current	Sum of currents into OUT and BAT pins, V_{CC} < $V_{(SLP)}$				5	μA
Input Bias Current on BAT pin	V_{CC}=0V, V_{IN}=0V				500	nA
Input Current on TS pin					1	μA
Voltage Regulation						
Output Voltage	For AIC1790GOW	$V_{O(REG)}$		4.2		V
	For AIC1790-35GOW			4.35		
Voltage Regulation Accuracy	T_A= -40 ~ 85℃, R_{SET}=10KΩ		-1%		1%	
Dropout Voltage	$V_{O(REG)}$ + $V_{DO(MAX)}$ ≦ V_{CC}, $I_{O(OUT)}$ = 1000mA	V_{DO}		650	790	mV
Current Regulation						
Output Current Range	$V_{(BAT)}$ > $V_{(LOWV)}$, V_{IN} – $V_{(BAT)}$ > $V_{DO(MAX)}$, t < $t_{(CHG)}$	$I_{O(OUT)}$	200		1000	mA
Output Current Set Voltage	V_O=$V_{(BAT)}$=3.8V, R_{SET}=10KΩ	$V_{(CHG)}$	2.45	2.50	2.55	V
Output Current Set Factor	V_O=$V_{(BAT)}$=3.8V, R_{SET}=10KΩ	$K_{(SET)}$	900	1000	1100	

■ ELECTRICAL CHARACTERISTICS (Continued)

PARAMETER	TEST CONDITIONS	SYMBOL	MIN.	TYP.	MAX.	UNIT
Precharge and Short-circuit Current Regulation						
Precharge to Fast-Charge Transition Threshold		$V_{(LOWV)}$	2.80	2.95	3.10	V
Precharge to Short-Circuit Transition Threshold		$V_{(SC)}$	1.0	1.4	1.8	V
Precharge Current Range	$V_{(SC)} < V_{(BAT)} < V_{(LOWV)}$, $t < t_{(PRECHG)}$	$I_{O(PRECHG)}$	20		100	mA
Precharge Set Voltage	$V_O=V_{(BAT)}=2.5V$, $R_{SET}=10K\Omega$	$V_{(PRECHG)}$	225	250	280	mV
Short-Circuit Current	$V_{(SC)} > V_{(BAT)}$	I_{SC}	660	900	1200	μA
CHARGE TAPER AND TERMINATION DETECTION						
Charge Taper Detection Range	$V_{(BAT)} = V_{O(REG)}$, $t < t_{(TAPER)}$	$I_{O(TAPER)}$	40		200	mA
Charge Taper Detection Set Voltage	$V_{(BAT)} = V_{O(REG)}$, $t < t_{(TAPER)}$	$V_{(TAPER)}$		500mV		V
Charge Termination Detection Set Voltage	$V_{(BAT)} = V_{O(REG)}$, $t < t_{(TAPER)}$	$V_{(TERM)}$		250		mV
TEMPERATURE COMPARATOR						
Low Threshold		$V_{(TS1)}$	29	30	31	$\%V_{CC}$
Upper Threshold		$V_{(TS2)}$	59	60	61	$\%V_{CC}$
Hysteresis				1		$\%V_{CC}$
BATTERY RECHARGE THRESHOLD						
Recharge Threshold		$V_{(RCH)}$	$V_{O(REG)}$ - 0.150	$V_{O(REG)}$ - 0.1	$V_{O(REG)}$ - 0.050	V
STAT1, STAT2, and PG OUTPUTS						
Output (low) Saturation Voltage	I_O = 10mA				0.5	V

■ ELECTRICAL CHARACTERISTICS (Continued)

PARAMETER	TEST CONDITIONS	SYMBOL	MIN.	TYP.	MAX.	UNIT
TIMERS						
Precharge Time		$t_{(PRECHG)}$	1548	2065	2581	s
Taper Time		$t_{(TAPER)}$	1548	2065	2581	s
Charge Time		$t_{(CHG)}$	15480	20650	25810	s
SLEEP COMPARATOR						
Sleep Mode Entry Threshold Voltage	$V_{(BAT)} \leqq V_{O(REG)}$	$V_{(SLP)}$			$V_{CC} \leqq V_{(BAT)}$ + 10mV	V
Sleep Mode Exit Threshold Voltage	$V_{(BAT)} \leqq V_{O(REG)}$		$V_{CC} \geqq V_{(BAT)}$ + 50mV			V
BATTERY DETECTION THRESHOLDS						
Battery Detection Current	$0V \leqq V_{(BAT)} \leqq V_{O(REG)}$	$I_{(DETECT)}$	-660	-900	-1200	μA
Battery Detection Time	$0V \leqq V_{(BAT)} \leqq V_{O(REG)}$	$t_{(DETECT)}$	100	125	150	ms
Fault Current	$V_{(BAT)} < V_{(RCH)}$	$I_{(FAULT)}$	660	900	1200	μA
Under Voltage Lockout Protection						
Under Voltage Lockout Protection	V_{CC} rising		3.8	4.1	4.3	V
UVLO Hysteresis				100		mV

Note 1: Specifications are production tested at T_A=25°C. Specifications over the -40°C to 85°C operating temperature range are assured by design, characterization and correlation with Statistical Quality Controls (SQC).

Note 2: It is recommended to use PCB as heat sink to add the IC's power dissipation ability. Otherwise, IC may thermal shutdown at 1000mA charge current and low battery voltage condition.

TYPICAL PERFORMANCE CHARACTERISTICS

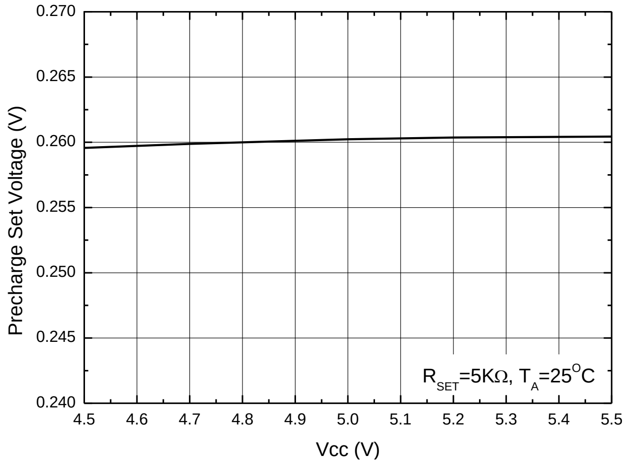


Fig. 1 Precharge Set Voltage vs. V_{CC}

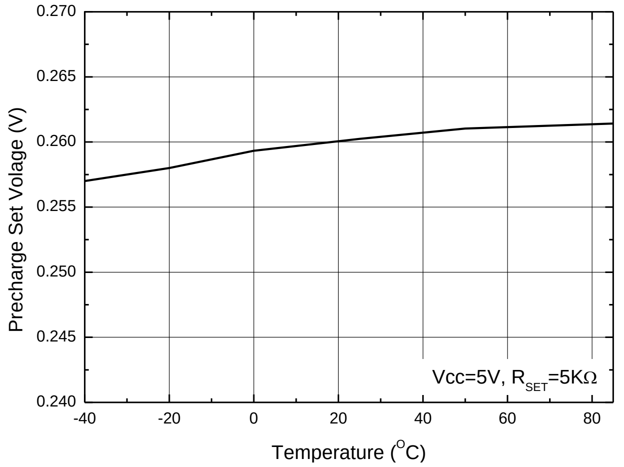


Fig. 2 Precharge Set Voltage vs. Temperature

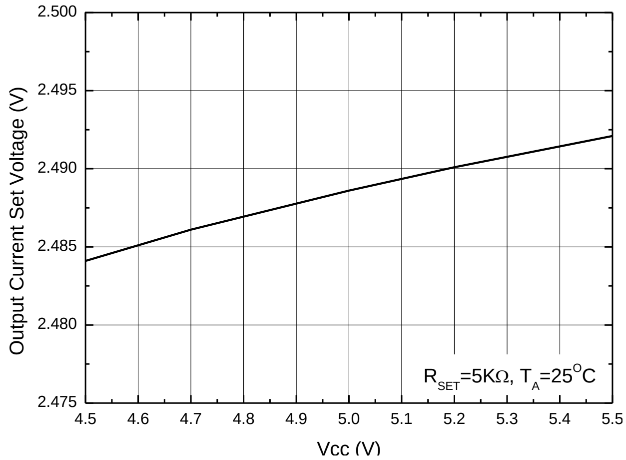


Fig. 3 Output Current Set Voltage vs. V_{CC}

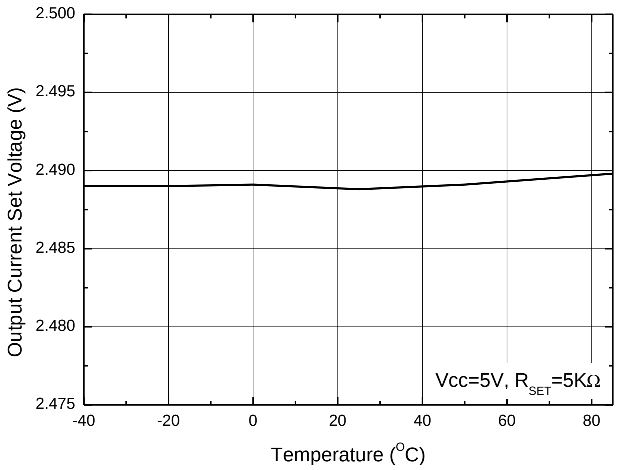


Fig. 4 Output Current Set Voltage vs. Temperature

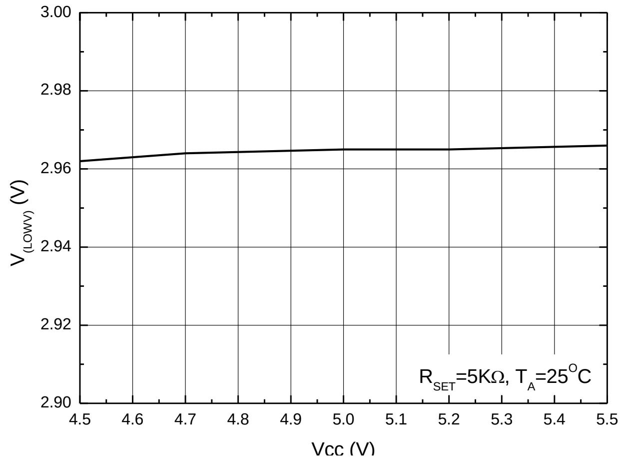


Fig. 5 $V_{(LOWV)}$ vs. V_{CC}

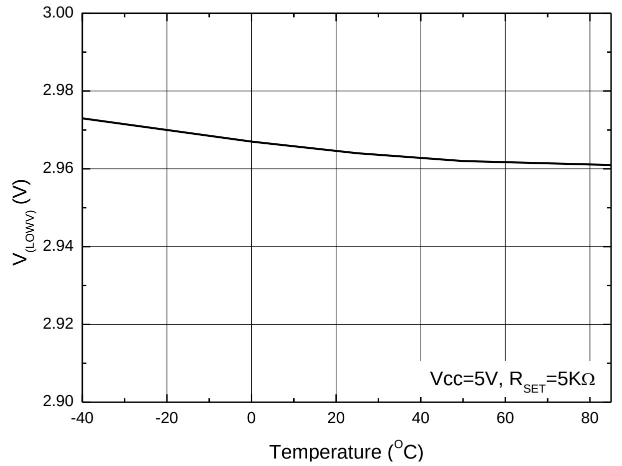


Fig. 6 $V_{(LOWV)}$ vs. Temperature

■ TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

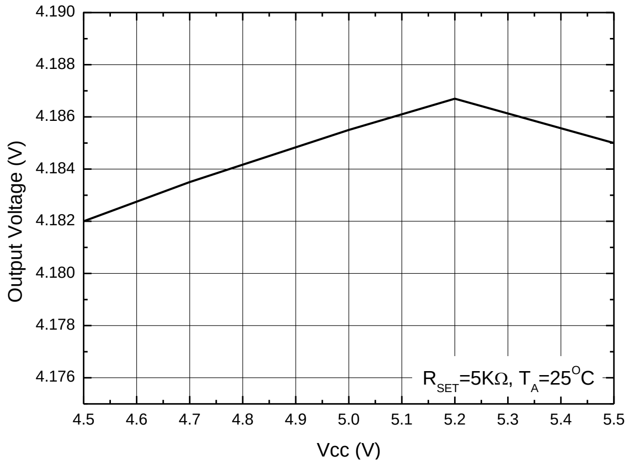


Fig. 7 Output Voltage vs. V_{CC}

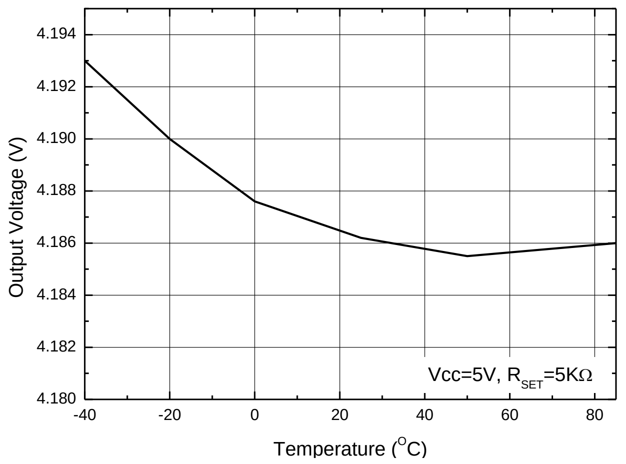


Fig. 8 Output Voltage vs. Temperature

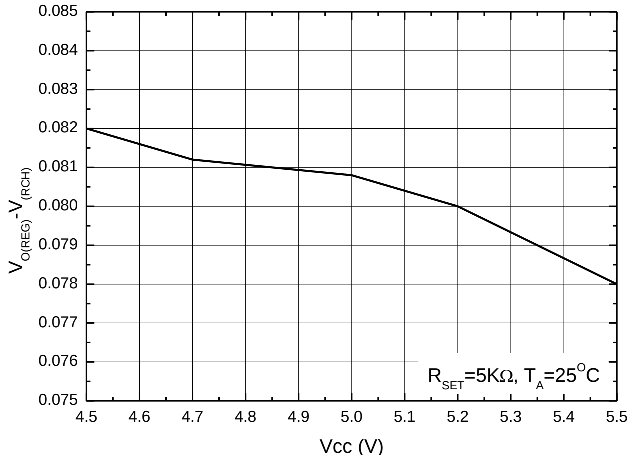


Fig. 9 $V_{O(REG)}$-$V_{(RCH)}$ vs Vcc

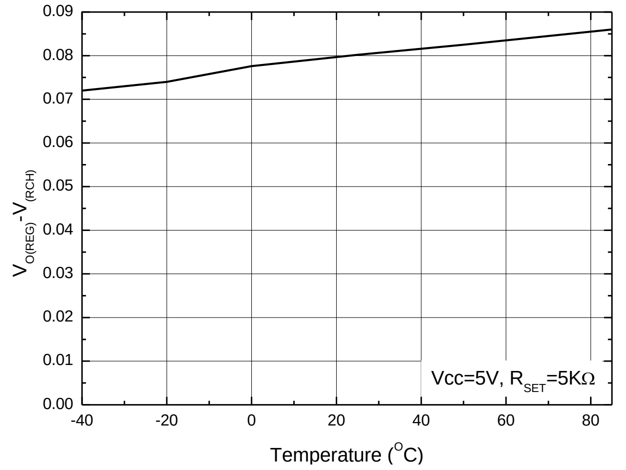


Fig. 10 $V_{O(REG)}$-$V_{(RCH)}$ vs Temperature

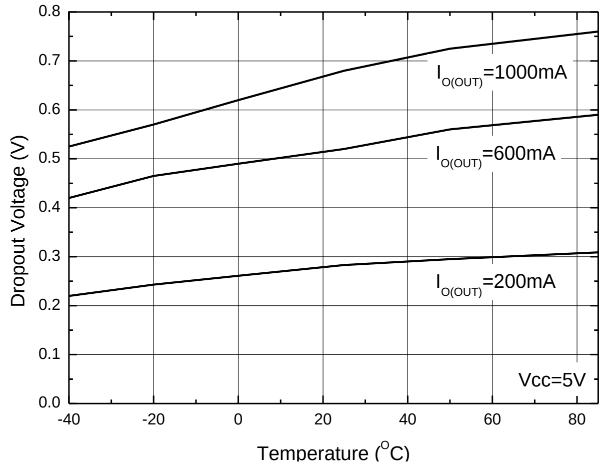
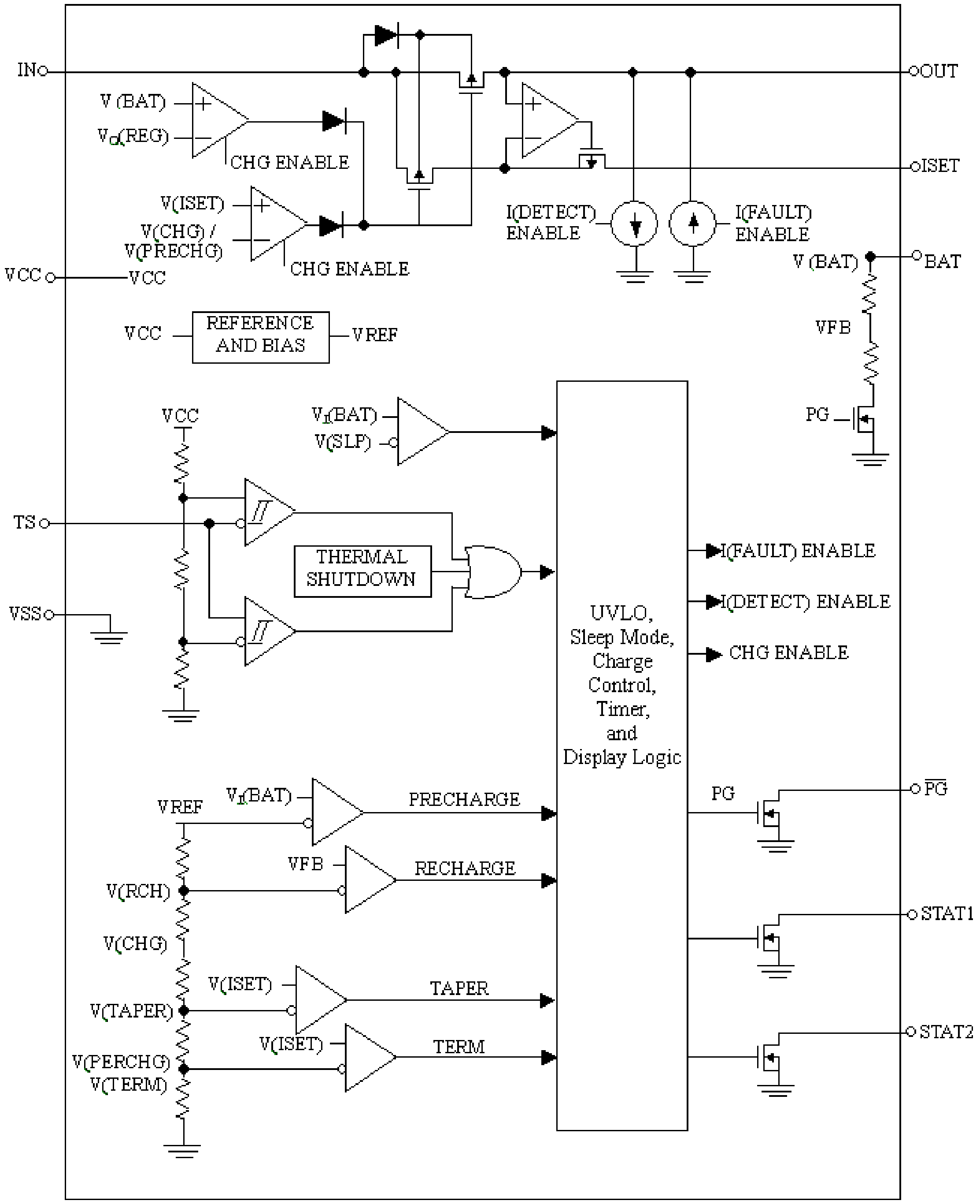


Fig. 11 Dropout Voltage vs Temperature

■ BLOCK DIAGRAM



Functional Block Diagram of AIC1790

PIN DESCRIPTIONS

IN Pin:	Charge input voltage. (For MSOP10 package, this input must be tied to the VCC pin.)
VCC Pin:	VCC supply input. (For MSOP10 package)
STAT1 Pin:	Charge status output 1 (open-drain).
STAT2 Pin:	Charge status output 2 (open-drain). (For MSOP10 package)
VSS Pin:	Ground input.
ISET Pin:	Charge current set point.
$\overline{PG}$ Pin:	Power good status output.
TS Pin:	Temperature sense input.
BAT Pin:	Battery voltage sense input.
OUT Pin:	Charge current output.

APPLICATION INFORMATIONS

The AIC1790 is a Li-ion and Li-Pol linear charge device. It supports a precision Li-Ion, Li-Pol charging system suitable for single-cells. The function flow chart and the typical charging profile are shown in figure 13 and figure 14, respectively.

Battery Precharge Current

During a charge cycle, the AIC1790 provides a precharge current to revive the deeply discharged battery if the battery voltage is lower than the $V_{(LOWV)}$. The precharge current can be determined by the resistor connected between the ISET pin and VSS pin, R_{SET}.

$$I_{O(PRECHG)} = \frac{V_{(PRECHG)} \times K_{(SET)}}{R_{SET}}$$

The $V_{(PRECHG)}$ and $K_{(SET)}$ parameters are specified in the specifications table. During the precharge period, the safety timer, $t_{(PRECHG)}$, can be activated. If the battery voltage cannot reach the $V_{(LOWV)}$ within the timer period, the AIC1790 can terminate the precharge action and indicates FAULT on the STAT1 and STAT2 pins.

Battery Charge Current

The AIC1790 provides a constant charge current to charge the battery when the battery voltage is between the $V_{(LOWV)}$ and $V_{O(REG)}$. The charge current can be determined by the resistor connected between the ISET pin and VSS pin, R_{SET}.

$$I_{O(OUT)} = \frac{V_{(CHG)} \times K_{(SET)}}{R_{SET}}$$

The $V_{(CHG)}$ and $K_{(SET)}$ parameters are specified in the specifications table.

Battery Voltage Regulation

The AIC1790 monitors the battery-pack voltage through the BAT pin. When the battery voltage rises to $V_{O(REG)}$, the AIC1790 will enter voltage regulation mode and the charge current will begin to decrease.

During the charge period, the safety timer, $t_{(CHG)}$, can be activated. If the taper threshold, $I_{O(TAPER)}$, is not detected within the timer period, the AIC1790 can terminate the charge action and indicates FAULT on the STAT1 and STAT2 pins.

Charge Taper Detection and Termination

Once the taper threshold is detected during the voltage regulation period, the AIC1790 initiates the taper timer, $t_{(TAPER)}$. The AIC1790 can terminate the charge action after the timer expires. The taper detection level can be determined by the resistor connected between the ISET pin and VSS pin, R_{SET}.

$$I_{O(TAPER)}=\frac{V_{(TAPER)}\times K_{(SET)}}{R_{SET}}$$

The $V_{(TAPER)}$ and $K_{(SET)}$ parameters are specified in the specifications table.

In addition to the taper timer detection, the AIC1790 can terminate the charge action when the charge current falls below the $I_{O(TERM)}$. This feature allows for quick decision of a battery removal condition or insertion of a fully charged battery. The termination detection level can be determined by the resistor connected between the ISET pin and VSS pin, R_{SET}.

$$I_{O(TERM)}=\frac{V_{(TERM)}\times K_{(SET)}}{R_{SET}}$$

The $V_{(TERM)}$ and $K_{(SET)}$ parameters are specified in the specifications table.

Recharge

The AIC1790 has recharge function to keep the battery at full capacity at all times. After the charge action is terminated, the AIC1790 can restart the charge action once the voltage on the BAT pin falls below the $V_{(RCH)}$.

Battery Temperature Detection

During the charge period, the AIC1790 continuously monitors the battery temperature by measuring the voltage on the TS pin. A negative temperature coefficient (NTC) thermistor and a resistor-divider, R_{T1} and R_{T2}, typical develop this voltage, as shown in figure 12. The AIC1790 compare the voltage on the TS pin against the $V_{(TS1)}$ and $V_{(TS2)}$ to determine whether charge action is allowed. Once the battery temperature outside the normal temperature range is detected, the AIC1790 immediately suspends charge action. The charge action is suspended by turning off the power MOSFETs and holding the timer value. The charge action is resumed when the battery temperature returns to the normal range.

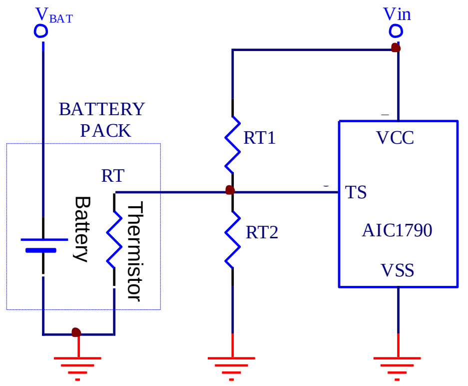


Fig. 12 Battery Temperature Sense Circuit

For R_{T1} and R_{T2} in the circuit, the below equations provide the calculations.

$$R_{T1}=\frac{5}{3}\times\frac{R_{TL}\times R_{TH}}{(R_{TL}-R_{TH})}$$

$$R_{T2}=2.5\times\frac{R_{TL}\times R_{TH}}{(R_{TL}-3.5\times R_{TH})}$$

Where R_{TL} is the resistance of thermistor at lower limit of temperature protection and R_{TH} is the resistance of thermistor at upper limit of temperature protection. If temperature characteristic of thermistor is like that of SEMITEC 103AT-2, the tables 1 and 2 show the resistance of R_{T1} and R_{T2} for different TL and TH. TL is the lower temperature limit and TH is the higher temperature limit.

Table 1 Values of R_{T1} and R_{T2} at TL = 0℃

TH (℃)	R_{T1} (kΩ)	R_{T2} (kΩ)
50	8.2	22.3
55	6.8	16.2
60	5.7	12.3
65	4.8	9.7
70	4.0	7.8

Table 2 Values of R_{T1} and R_{T2} at TL = -10℃

TH (℃)	R_{T1} (kΩ)	R_{T2} (kΩ)
45	9.3	20.6
50	7.7	15.8
55	6.4	12.5
60	5.4	10.1
65	4.6	8.2

By applying a constant voltage between the $V_{(TS1)}$ and $V_{(TS2)}$ to TS pin, the battery temperature detection function can be disabled.

Under Voltage Lockout and Sleep Mode

The AIC1790 includes an under voltage lockout circuit, which monitors the input voltage and keep the charger in shutdown mode until V_{CC} rises above the under voltage lockout threshold. In addition, in order to prevent battery drainage, the AIC1790 can enter sleep mode if the V_{CC} falls below the sleep mode entry threshold.

Battery Absent Detection

The AIC1790 includes a battery absent detection circuit to detect insertion and/or removal of battery packs. At the battery absent condition, the voltage on the BAT pin rises and falls between ground and $V_{O(REG)}$ indefinitely.

Timer Fault Recovery

As shown in the figure 13, the AIC1790 provides a recovery manner to clear the timer fault. When the battery voltage is lower than $V_{(RCH)}$ and timer fault occurs, the AIC1790 applies the $I_{(FAULT)}$ current to charge the battery. If the battery voltage rises above the recharge threshold, the AIC1790 disables the $I_{(FAULT)}$ current and clears the timer fault.

Status Outputs

The AIC1790 provides three open-drained outputs: $\overline{PG}$, STAT1 and STAT2. The $\overline{PG}$ pin pulls low when a valid V_{CC} is detected and goes high when the input power source is removed or V_{CC} falls below the sleep mode entry threshold. The STAT1 and STAT2 work together to indicate the battery charging status, as shown in the following table. These status pins can be used to drive an LED or communicate to the host processor. If these status pins aren't used, it is suggested to connect the pull-high resistors with these status pins.

Table 3. Status Pins Summary

CHARGE STATE	STAT1	STAT2
Battery Absent	High	High
Charge-in-progress	Low	High
Charge Done	High	Low
Charge Suspend (temperature)	High	High
Timer Fault	High	High
Under Voltage Lockout (UVLO)	High	High
Sleep Mode	High	High

THERMAL PROTECTION

The AIC1790 includes a thermal-limiting circuit, which is designed to protect the device from excessive temperature. When the junction temperature exceeds T_J=150ºC, the thermal-limiting circuit suspends the charge action and allows the IC to cool. The charge action is resumed when the junction temperature falls below approximately T_J=115ºC.

INPUT CAPACITOR

The high-frequency decoupled capacitors make them ideal for AIC1790 applications. A 0.47μF ceramic input capacitor is sufficient for most AIC1790 applications. When choosing the input ceramic capacitors, X5R and X7R types are recommended because they retain their capacitance over wider ranges of voltage and temperature than other types.

When using the ceramic capacitor as the input capacitor, the high input voltage transient may be generated at some start-up conditions, such as connecting the input to a live power source. By adding a small resistor in series with the input ceramic capacitor, the high input voltage transient can be improved.

OUTPUT CAPACITOR

For application with removable battery packs, a 1μF ceramic output capacitor can ensure the battery absent detection circuit works well. When choosing the output ceramic capacitors, X5R and X7R types are recommended because they retain their capacitance over wider ranges of voltage and temperature than other types.

POWER DISSIPATION

The maximum power dissipation of AIC1790 depends on the thermal resistance of its case and circuit board, the temperature difference between the die junction and ambient air, and the rate of airflow. The rate of temperature rise is greatly affected by the mounting pad configuration on the PCB, the board material, and the ambient temperature. When the IC mounting with good thermal conductivity is used, the junction temperature will be low even when large power dissipation applies.

The power dissipation across the device is approximately:

$P = I_O (V_{CC}-V_{(BAT)})$

The maximum power dissipation is:

$$P_{MAX} = \frac{(T_{J\text{-}max} - T_A)}{R\theta_{JA}}$$

Where $T_{J\text{-}max}$ is the maximum allowable junction temperature (125°C), and T_A is the ambient temperature suitable in application.

As a general rule, the lower temperature is, the better reliability of the device is. So the PCB mounting pad should provide maximum thermal conductivity to maintain low device temperature.

Layout Consideration

In order to ensure a proper operation of AIC1790, the following points should be managed comprehensively.

1. The input capacitor and V_{CC} should be placed as close as possible to each other to reduce the input noise.
2. The BAT pin should be connected to the battery pack directly and the route should be as short as possible.
3. The routes with large current should be kept short and wide.
4. Logically the large current on the charger should flow at the same direction.
5. The ISET pin should be connected to the R_{SET} resistor directly and the route should be away from the noise sources.
6. The TS pin should be connected to the battery temperature measurement network directly and the route should be away from the noise sources.

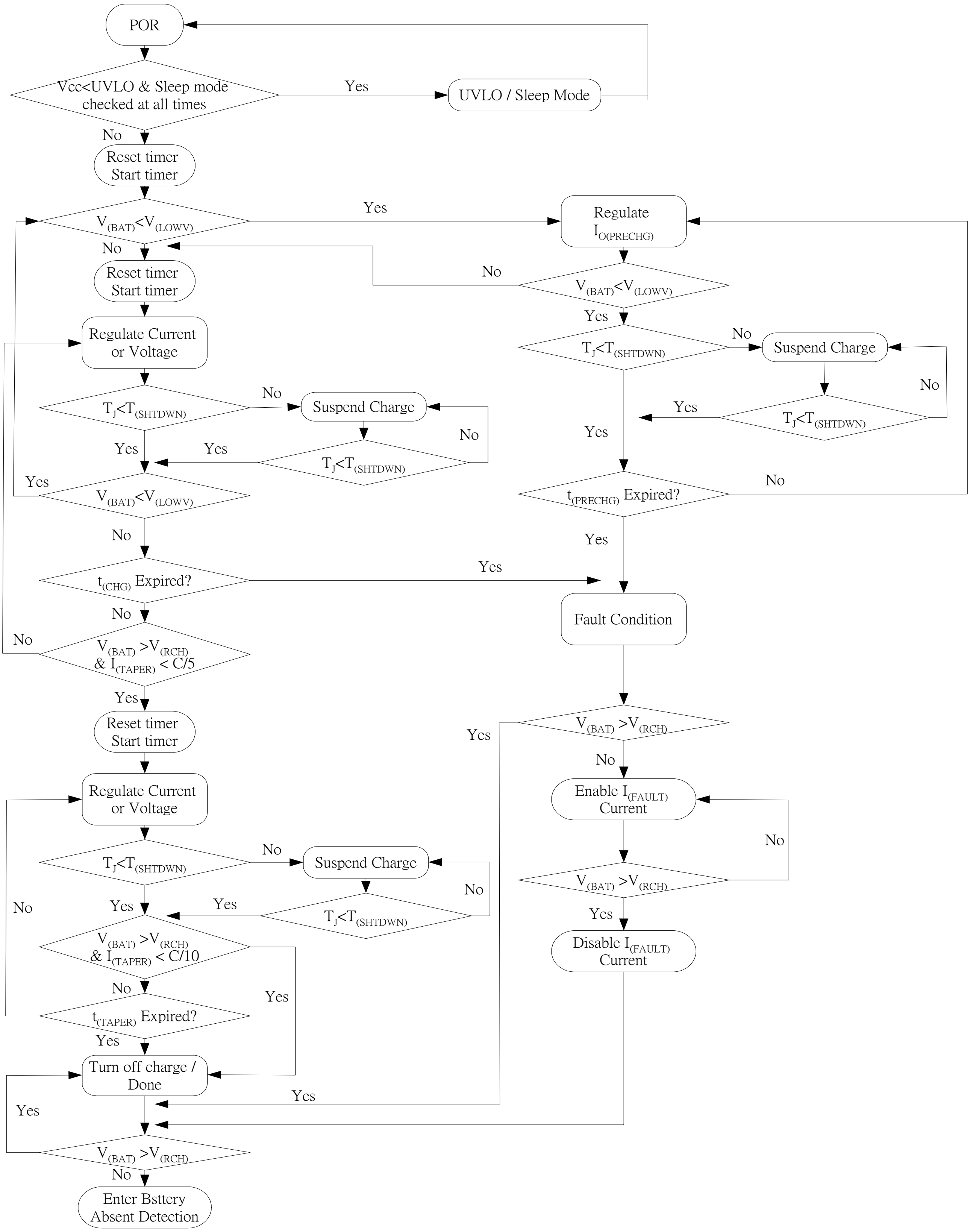


Fig. 13 Function Flow Chart of AIC1790

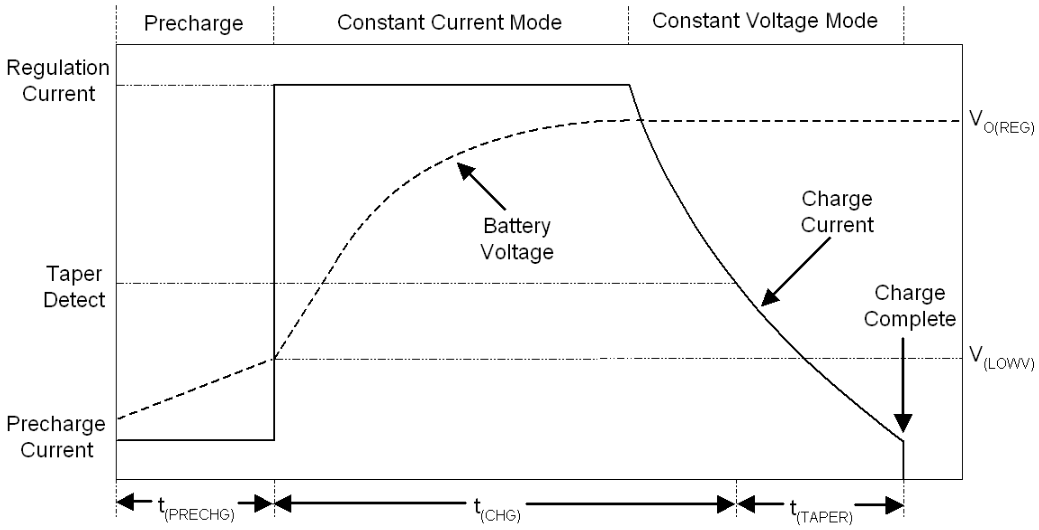
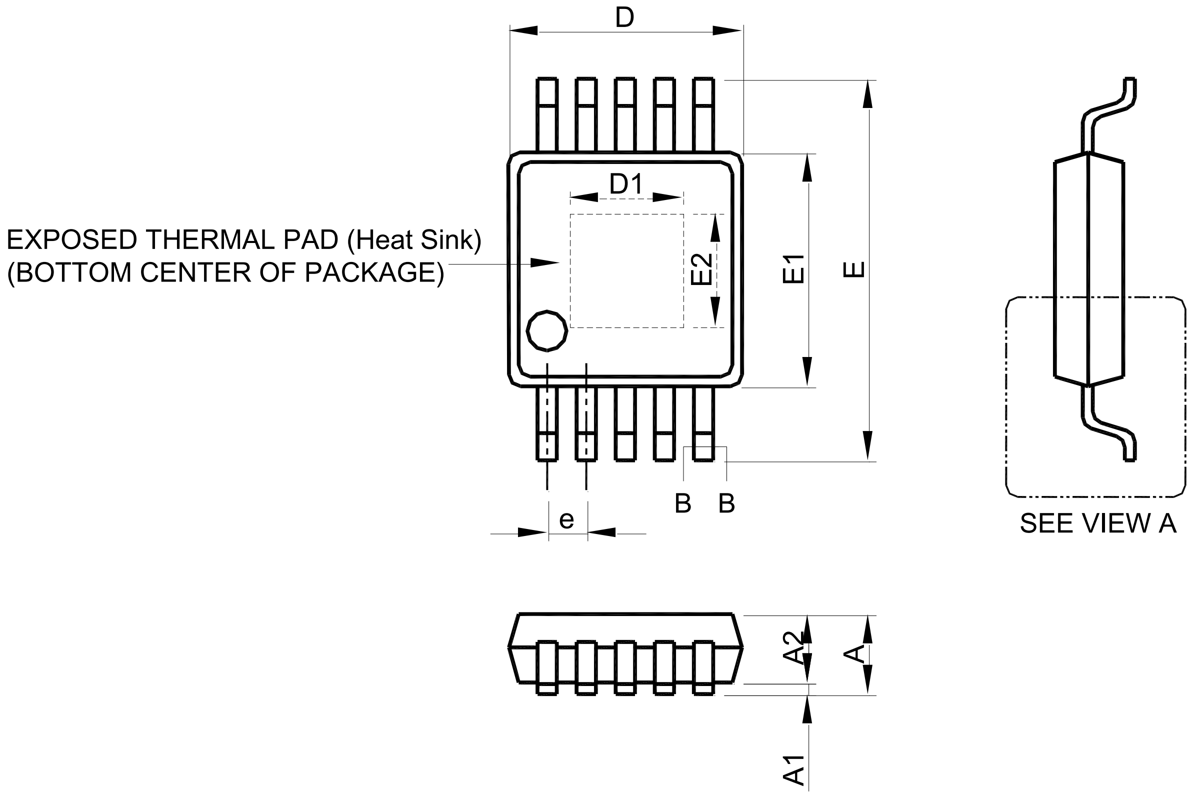


Fig. 14 Typical Charging Profile

PHYSICAL DIMENSIONS

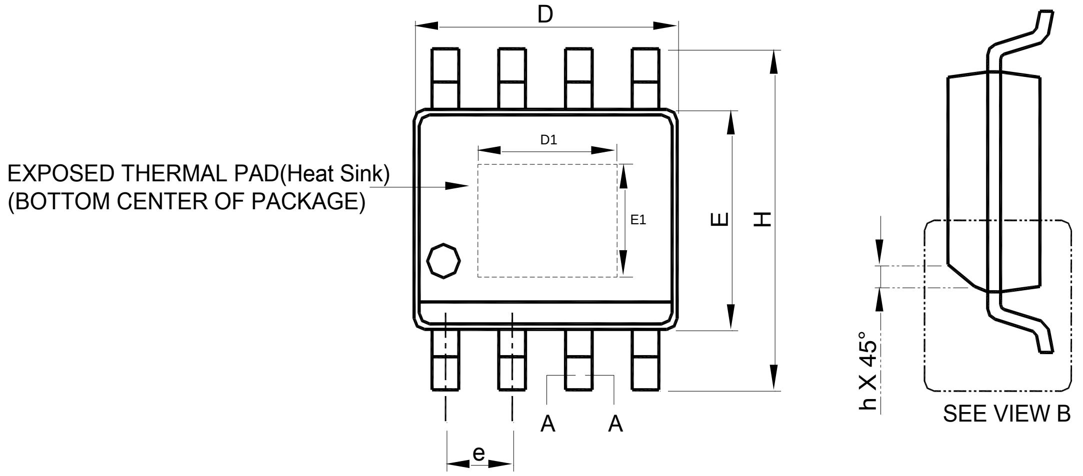
- **MSOP-10 Exposed Pad**

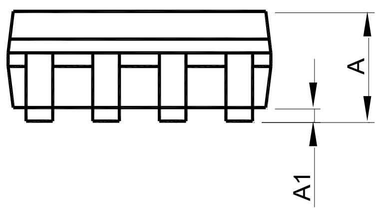


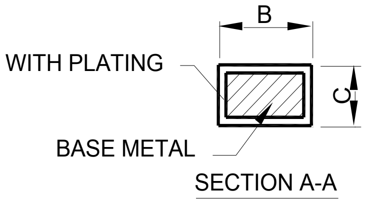
Note: 1. Refer to JEDEC MO-187E
2. Dimension "D" does not include mold flash, protrusions or gate burrs. Mold flash, protrusion or gate burrs shall not exceed 6 mil per side .
3. Dimension "E1" does not include inter-lead flash or protrusions.
4. Controlling dimension is millimeter, converted inch dimensions are not necessarily exact.

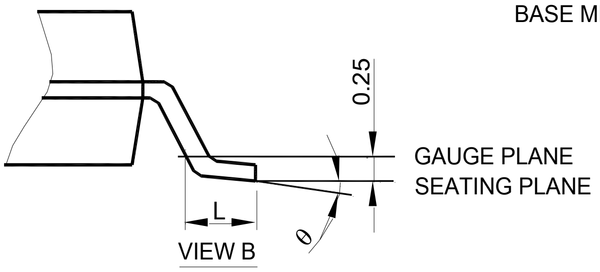
SYMBOL	MSOP-10 Exposed Pad	
	MILLIMETERS	
	MIN.	MAX.
A		1.10
A1	0	0.15
A2	0.75	0.95
b	0.17	0.33
c	0.08	0.23
D	3.00 BSC	
D1	0.75	2.50
E	4.90 BSC	
E1	3.00 BSC	
E2	0.75	2.50
e	0.50 BSC	
L	0.40	0.80
θ	0°	8°

- **SOP-8 Exposed Pad**





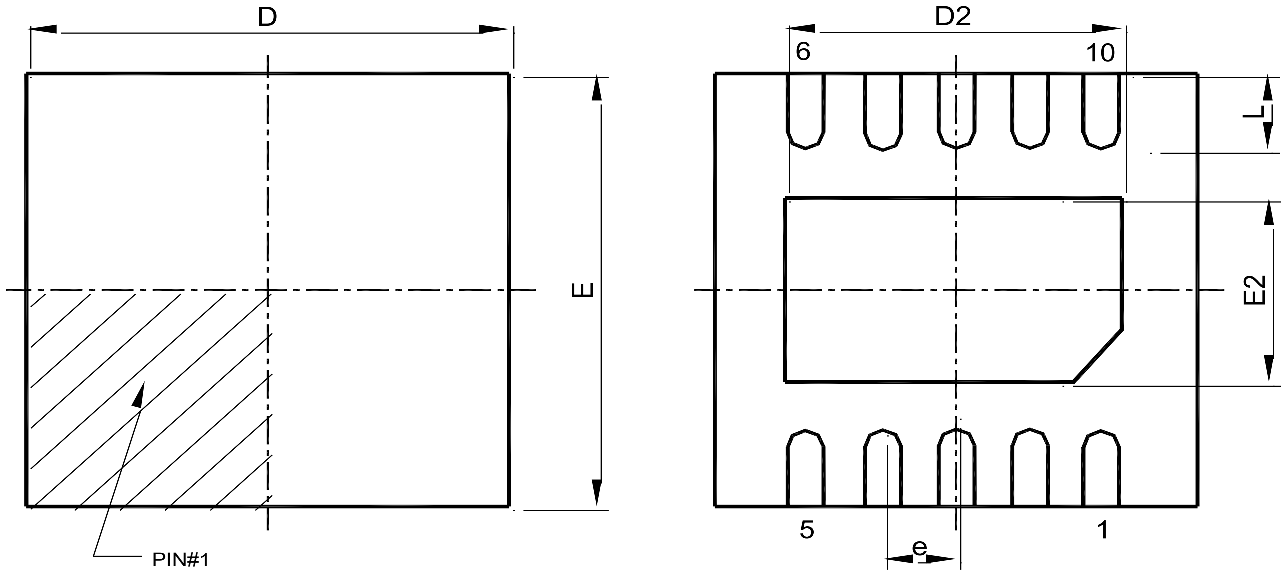


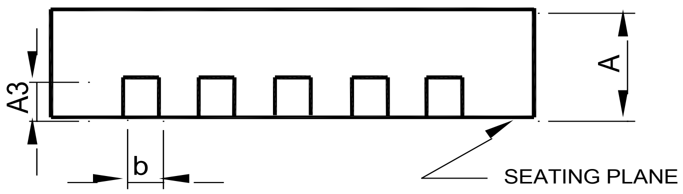


SYMBOL	SOP-8 Exposed Pad	
	MILLIMETERS	
	MIN.	MAX.
A	1.35	1.75
A1	0.00	0.15
B	0.31	0.51
C	0.17	0.25
D	4.80	5.00
D1	1.50	3.50
E	3.80	4.00
E1	1.0	2.55
e	1.27 BSC	
H	5.80	6.20
h	0.25	0.50
L	0.40	1.27
θ	0°	8°

Note : 1. Refer to JEDEC MS-012E.
2. Dimension "D" does not include mold flash, protrusions or gate burrs. Mold flash, protrusion or gate burrs shall not exceed 6 mil per side .
3. Dimension "E" does not include inter-lead flash or protrusions.
4. Controlling dimension is millimeter, converted inch dimensions are not necessarily exact.

- **DFN-10 (3x3x0.75-0.5)**





SYMBOL	DFN-10 (3x3x0.75-0.5)	
	MILLIMETERS	
	MIN.	MAX.
A	0.70	0.80
A3	0.20 BSC	
b	0.18	0.30
D	2.90	3.10
D2	2.20	2.70
E	2.90	3.10
E2	1.40	1.80
e	0.5 BSC	
L	0.30	0.50

Note : 1. DIMENSION AND TOLERANCING CONFORM TO ASME Y14.5M-1994.
2.CONTROLLING DIMENSIONS : MILLIMETER , CONVERTED INCH DIMENSION ARE NOT NECESSARILY EXACT.

Note: