Switch-mode Step-up 3-Cell Li-ion Battery Charger IC

Features

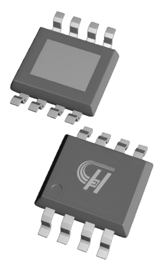
- Minimum Operating Voltage: 4.5V
- Fixed Charge Termination Voltage: 12.6V
- Self-adaptive to Input Supply
- Operating Current: 380μA@V_{IN}=5V
- Inductor Current Sensing
- Switching Frequency: up to 1MHz
- Quasi-CV Mode to Compensate for Voltage Loss on Parasitic Resistance
- Trickle, Constant Current and Quasi-CV Charge Mode
- Automatic Recharge
- JEITA-Compliant Battery Temperature Monitoring
- Battery Over-voltage Protection
- Over Junction-temperature Protection
- 2 Open-drain Indication Outputs
- Operating Temperature Range:−40°C to 85°C
- Available in SOP-8(EP) Package
- Lead-free, rohs-Compliant and Halogen Free

Applications

- Standalone 3-cell Battery Charger
- Electrical Appliance
- Audio Systems
- POS, etc.

General Description

HCR9733 is a PFM mode step-up 3-cell Li-ion battery charging controller IC with minimum operating voltage down to 4.5V. HCR9733 adopts trickle, constant current (CC) and quasi-constant voltage(Quasi-CV) mode to charge battery. On power up, HCR9733 enters charging mode, the external N-channel MOSFET is turned on first, inductor current rises. When inductor current reaches upper limit, the N-channel MOSFET is turned off, the energy stored in inductor is transferred to battery. When the inductor current is discharged to its lower limit, the N-channel MOSFET is turned on again, and so forth. When BAT pin voltage reaches 12.6V(Typ.) for the first time, HCR9733 enters quasi-CV mode, in which the charge current is reduced. The charge process will not be terminated until BAT voltage reaches 12.6V for the second time. In termination mode, the N-channel MOSFET is turned off. If BAT pin voltage falls below recharge threshold, HCR9733 enters charge mode again. HCR9733's switching frequency can be up to 1MHz, which makes a small-profile inductor usable. The other features include self-adaptive function to input supply, JEITA-compliant battery temperature monitoring, chip over temperature protection and status indication, etc. HCR9733 is available in thermally-enhanced SOP-8(EP) package.



SOP-8(EP)

Figure 1. Appearance Diagram of HCR9733

Pin Configuration

SOP-8(EP) (Top View)

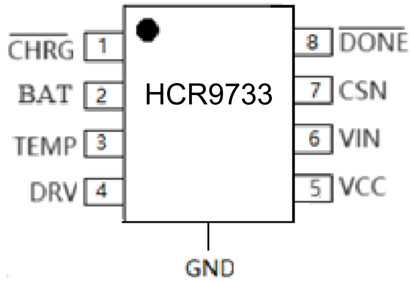


Figure 2. Pin Configuration

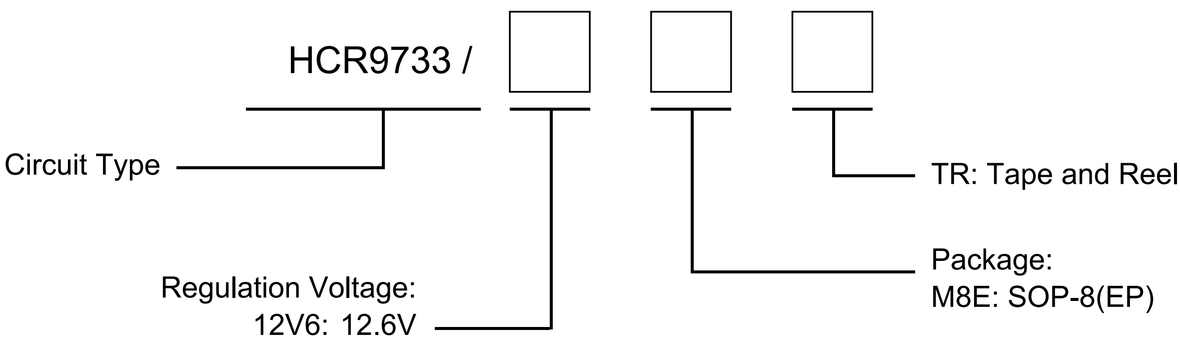
Pin Descriptions

Pin No.	Name	Description
1	$\overline{\text{CHRG}}$	Open Drain Charge Status Output. When the battery is being charged, the $\overline{\text{CHRG}}$ pin is pulled low by an internal switch, otherwise $\overline{\text{CHRG}}$ pin is in high impedance state.
2	BAT	Connection Pin for Positive Terminal of Battery. BAT pin can be connected to positive terminal of battery directly or via a resistor as shown in Figure 1. If BAT pin is directly connected to positive terminal of battery, charge termination voltage is 12.6V typical; If BAT pin is connected to positive terminal of battery via a resistor, charge termination voltage will be: $V_{term}= 12.6+10.5\times10^{-6}\times R_x$ (V)
3	TEMP	Battery Temperature Monitoring Input. Connecting a 10KΩ NTC thermistor between TEMP pin and GND. • If TEMP pin's voltage is below 0.1V or above 0.85V, which means battery is too hot or too cold, charging is suspended. • If TEMP's voltage is between 0.1V and 0.135V, which means battery is warm, charge current is reduced to 50% of full-scale current and termination voltage is reduced to 97.91%*V_{term} • If TEMP's voltage is between 0.135V and 0.55V, HCR9733 functions normally. • If TEMP's voltage is between 0.55V and 0.85V, which means battery is cool, charge current is reduced to 33% of constant current. If battery temperature monitoring function is not needed, connect a fixed 10K ohm resistor from TEMP pin to GND.
4	DRV	Gate Drive Output. Connect this pin to the gate of external N-channel MOSFET.
5	VCC	5V Voltage Regulator (LDO) Output. Connect a 10µF capacitor from V_{CC} to GND, the maximum output current is 15mA. The 5V voltage can be used to power the external circuitry. If input supply is less than 5.35V, V_{CC} may not be regulated at 5V, V_{CC} voltage may be a bit less than input supply.

Pin Descriptions (Continued)

Pin No.	Name	Description
6	VIN	The Positive Terminal of Input Supply. In addition to power the internal circuits, V_{IN} pin also serves as the positive terminal of current sense.
7	CSN	Negative Terminal of Inductor Current Sensing. A current sense resistor R_{CS} between V_{IN} pin and CSN pin is used to sense inductor current, also the input current.
8	$\overline{\text{DONE}}$	Open Drain Termination Output. When charging is terminated, the $\overline{\text{DONE}}$ pin is pulled low by an internal switch, otherwise $\overline{\text{DONE}}$ pin is in high impedance state.
9	Exposed PAD	Ground(GND). The ground of HCR9733, and need to connected to negative terminal of input supply and battery.

Ordering Information



Ordering Code

Part Number	Marking ID (Note 2)	Temperature Range	Package	Quantity per Reel
HCR9733/12V6M8ETR	HCR9733xx	−40 to +85°C	SOP-8(EP)	4000

Note 2: ”HCR9733” is the product type and ”xx” is the date code.

Typical Application Circuit

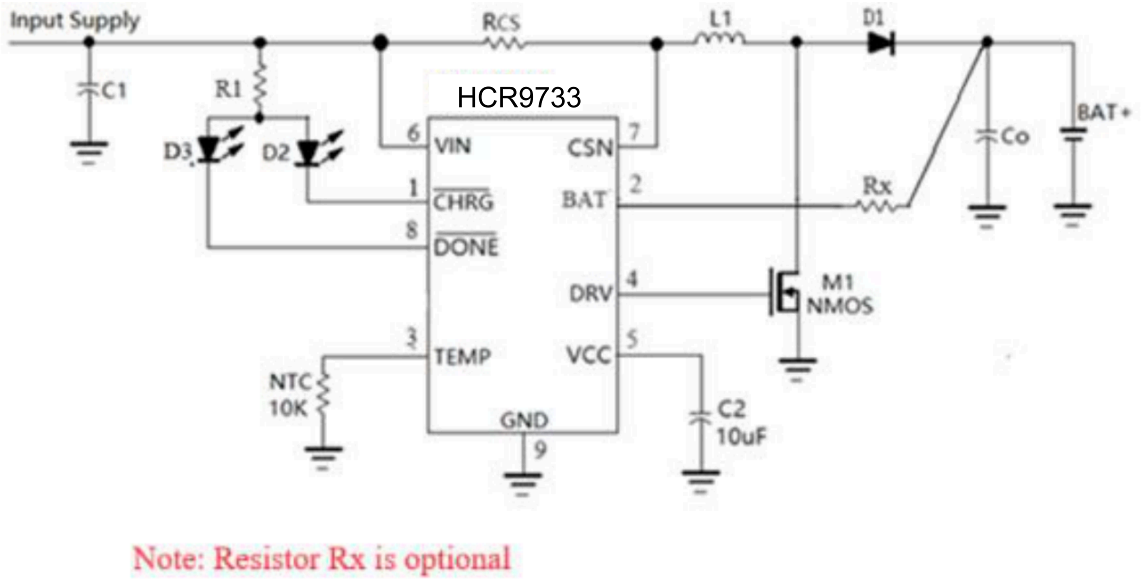


Figure 3. Typical Application Circuit

Block Diagram

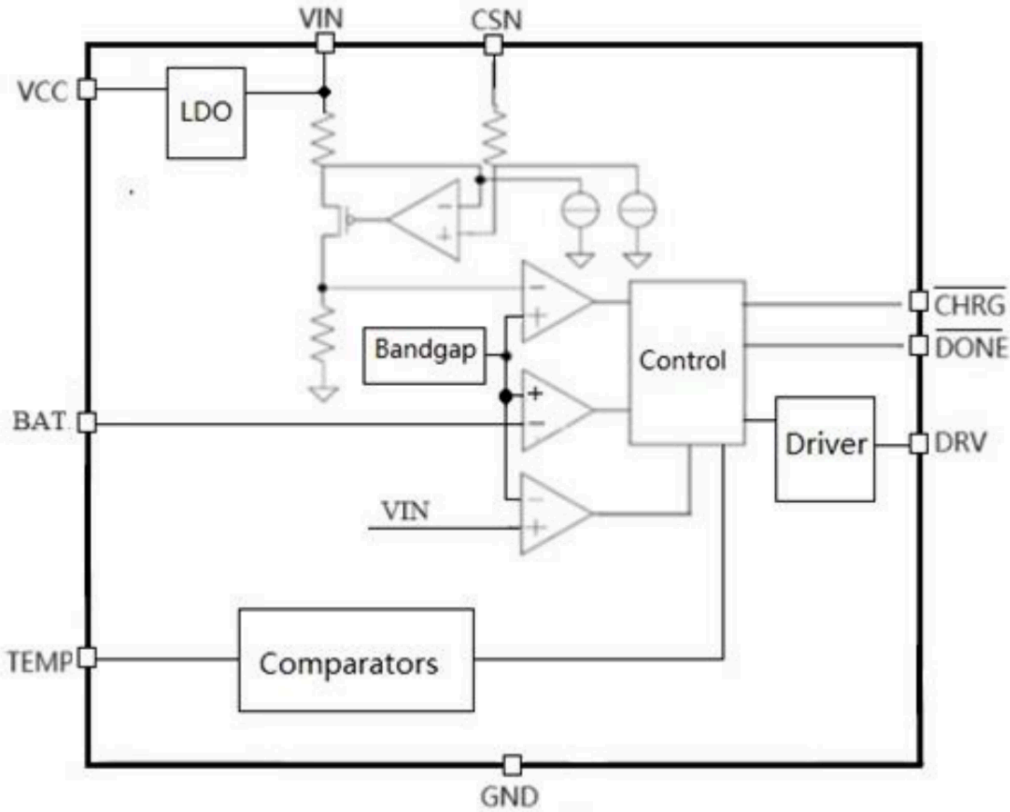


Figure 4. Block Diagram

Absolute Maximum Ratings

Parameter	Min.	Max.	Unit
V_{IN} and BAT Voltage	−0.3	36	V
DRV Voltage	−0.3	V_{CC}	V
V_{IN}-V_{CSN} Voltage	−0.3	0.3	V
TEMP, V_{CC} Voltage	−0.3	6.5	V
$\overline{CHRG}$, $\overline{DONE}$ Voltage	−0.3	V_{IN}	V
Maximum Junction Temperature		150	°C
Operating Temperature Range	−40	85	°C
Storage Temperature	−65	150	°C
Lead Temperature (Soldering, 10s)		260	°C

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

Recommend Operating Conditions

Parameter	Symbol	Min.	Max.	Unit
Input Voltage	V_{IN}	4.5		V
Operating Ambient Temperature	T_A	−40	+85	°C

Electrical Characteristics

(V_{IN} = 5V, T_A=−40°C to +85°C, Typical values are at T_A=+25°C, unless otherwise noted)

Parameter	Symbol	Test Conditions	Min.	Typ.	Max.	Unit
Operating Voltage	V_{IN}		4.5	5		V
Operating Current	I_{VIN}	$V_{IN}=V_{CSN}$	300	380	500	μA
Switching Frequency	f_{SW}		200		1000	kHz
BAT Pin Bias Current	I_{BAT}	V_{BAT}=12V	6.5	10.5	14.5	μA
Inductor Current (Input Current) Sensing						
Upper Limit of Inductor Current Measure (V_{IN}-V_{CSN})	V_{CSHI}	CC mode	90	100	110	mV
Upper Limit of Inductor Current Measure (V_{IN}-V_{CSN})	V_{CSHI}	CC mode, Battery warm	43	50	57	mV
Upper Limit of Inductor Current Measure (V_{IN}-V_{CSN})	V_{CSHI}	Trickle, Quasi-CV, Battery cold	28	33	38	mV
Lower Limit of Inductor Current Measure (V_{IN}-V_{CSN})	V_{CSLO}	CC mode	67	75	83	mV
Lower Limit of Inductor Current Measure (V_{IN}-V_{CSN})	V_{CSLO}	CC mode, Battery warm	30	37	44	mV
Lower Limit of Inductor Current Measure (V_{IN}-V_{CSN})	V_{CSLO}	Trickle, Quasi-CV, Battery cold	20	25	30	mV
Propagation Delay For DRV Assertion	t_{DPDH}	($V_{IN}−V_{CSN}$):0.13V to 0.065V		95		ns
Propagation Delay for DRV De-assertion	t_{DPDL}	($V_{IN}−V_{CSN}$):0.07V to 0.13V		91		ns
V_{CC} Pin						
Output Voltage	V_{CC}	I_{VCC}=0.1mA to 15mA, V_{IN}=5.5V to 30V	4.7		5.3	V
Load Regulation		I_{VCC}=0.1mA to 10mA,		5		Ohm
Line Regulation		V_{IN}=6V to 32V, I_{VCC}=3mA		6		mV
Power Supply Rejection Ratio	PSRR	I_{VCC}=3mA, f_{IN}=10kHz		−35		dB
Start Time	t_{START}	V_{CC}=0 to 4.5V		1		ms

Electrical Characteristics (Continued)

(V_{IN} = 5V, T_A=−40°C to +85°C, Typical values are at T_A=+25°C, unless otherwise noted)

Parameter	Symbol	Test Conditions	Min.	Typ.	Max.	Unit
Charge Termination(BAT Pin)						
Charge Termination Threshold	V_{term}	BAT voltage rises	12.474	12.6	12.726	V
Charge Termination Threshold	V_{term}	BAT voltage rises, Battery warm	12.215	12.338	12.461	V
Recharge (BAT Pin)						
Recharge Threshold	V_{rech}	BAT voltage falls	11.835	12.075	12.315	V
Recharge Threshold	V_{rech}	BAT voltage falls, Battery warm	11.32	11.55	11.78	V
Trickle Charge (BAT Pin)						
Trickle to CC Threshold	$V_{trickleH}$	BAT rises, V_{IN}<=V_{BAT}+V_D	7.08	7.35	7.62	V
CC to Trickle Threshold	$V_{trikleL}$	BAT falls, V_{IN}<=V_{BAT}+V_D	6.84	7.16	7.48	V
Battery Over-voltage Protection (BAT Pin)						
Over-voltage Protection Threshold	V_{OVP}	BAT voltage rises	13.168	13.437	13.706	V
Over-voltage Protection Release Threshold	V_{OVRLS}	BAT voltage falls	12.65	12.91	13.17	V
Over Junction-Temperature Protection (OTP)						
OTP Threshold	T_{OTP}	Junction temperature rises		145		°C
OTP Release Threshold	T_{RLS}	Junction temperature falls		128		°C
DRV Pin						
DRV Source Current	I_{SRC}	V_{CSN}=V_{IN}, V_{DRV}=0.5×V_{CC}		0.65		A
DRV Sink Current	I_{SINK}	V_{CSN}=V_{IN}−0.2V, V_{DRV}=0.5×V_{CC}		0.65		A
DRV Output High	V_{OH}	I_{DRV}=5mA	V_{CC}−0.3			V
DRV Output Low	V_{OL}	I_{DRV}=−5mA			0.3	V
$\overline{\text{CHRG}}$ Pin						
$\overline{\text{CHRG}}$ Sink Current	I_{CHRG}	V_{CHRG}=1V, Charge mode	7	12	18	mA
$\overline{\text{CHRG}}$ Leakage Current	I_{LK1}	V_{CHRG}=30V, Termination mode			1	μA

Electrical Characteristics (Continued)

(V_{IN} = 5V, T_A=−40°C to +85°C, Typical values are at T_A=+25°C, unless otherwise noted)

Parameter	Symbol	Test Conditions	Min.	Typ.	Max.	Unit
$\overline{\text{DONE}}$ Pin						
$\overline{\text{DONE}}$ Sink Current	I_{DONE}	V_{DONE}=1V, Termination mode	7	12	18	mA
$\overline{\text{DONE}}$ Leakage Current	I_{LK2}	V_{DONE}=30V, Charge mode			1	μA
TEMP Pin						
TEMP Pin Current	I_{TEMP}		27	30	33	μA
Cold Threshold	V_{COLD}	V_{TEMP} rises, cool to cold	800	850	900	mV
Cold Release Threshold	V_{COLDR}	V_{TENP} falls, cold to cool	755	805	855	mV
Cool Threshold	V_{COOL}	V_{TEMP} rises, normal to cool	510	550	590	mV
Cool Release Threshold	V_{COOLR}	V_{TENP} falls, cool to normal	465	505	545	mV
Warm Threshold	V_{WARM}	V_{TENP} falls, normal to warm	120	135	150	mV
Warm Release Threshold	V_{WARMR}	V_{TEMP} rises, warm to normal	138	155	172	mV
Hot Threshold	V_{HOT}	V_{TENP} falls, warm to hot	85	100	115	mV
Hot Release Threshold	V_{HOTR}	V_{TEMP} rises, hot to warm	105	120	135	mV

Note: V_D is the forward voltage drop of diode D1 in Figure 3.

Detailed Description

HCR9733 is a PFM mode step-up 3-cell Li-ion battery charge controller IC with minimum operating voltage down to 4.5V. HCR9733 consists of circuit blocks such as voltage reference, inductor current sensing, over voltage protection, over junction-temperature protection, circuit for self-adaptive to input supply, control and gate driver, etc., and adopts trickle, constant current (CC) and quasi-constant voltage (Quasi-CV) modes to charge battery with fewer external components.

On power up, HCR9733 enters charging mode, the external N-channel MOSFET is turned on first, inductor current rises. When inductor current reaches upper limit, the N-channel MOSFET is turned off, inductor is discharged, the energy stored in inductor is transferred to battery. When the inductor current is discharged to its lower limit, the N-channel MOSFET is turned on again, and so forth.

In charging mode, if the voltage at BAT pin is below 7.35V(Typical), HCR9733 is in trickle charge mode, in which the charge current is 33% of that in constant current mode; If BAT voltage is between 7.35V and 12.6V, HCR9733 is in constant current mode. When BAT voltage reaches 12.6V(Typ.) for the first time, HCR9733 enters quasi-CV mode, in which the charge current is reduced. The charge process will not be terminated until BAT voltage reaches 12.6V for the second time.

In termination mode, the N-channel MOSFET is turned off, no current flows to battery. If BAT voltage falls below recharge threshold (12.075V typical), the HCR9733 enters charge mode again.

HCR9733's switching frequency can be up to 1MHz, which makes a small-profile inductor usable.

The HCR9733 has 2 open-drain status outputs: $\overline{\text{CHRG}}$ and $\overline{\text{DONE}}$. $\overline{\text{CHRG}}$ pin is pulled low when the charger is in charging mode, otherwise $\overline{\text{CHRG}}$ becomes high impedance. $\overline{\text{DONE}}$ pin is pulled low if the charger is in termination mode, otherwise $\overline{\text{DONE}}$ becomes high impedance.

The other features include JEITA-compliant battery temperature monitoring, chip over temperature protection and battery over voltage protection, etc.

Charging profile is shown in Figure 5.

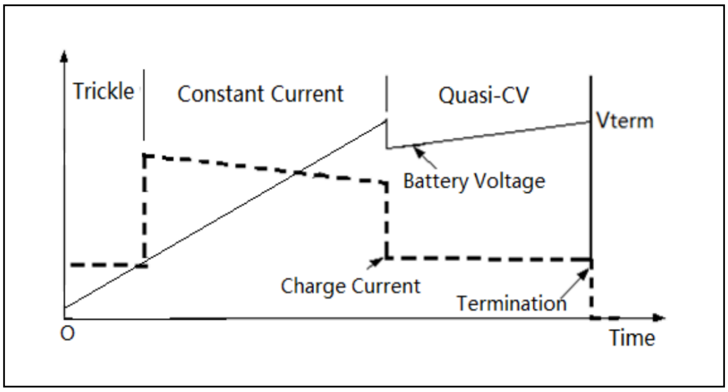


Figure 5. Charging Profile

Application Information

Minimum Operating Voltage

The HCR9733 functions well when the input voltage is down to 4.5V. If input voltage is below 4.5V, DRV pin outputs low. On-chip UVLO circuit will shut down the HCR9733 if input voltage falls below UVLO threshold (4.3V Max.).

+5V Voltage Regulator (V_{CC} Pin)

V_{CC} is the output of an on-chip 5V voltage regulator (LDO) capable of sourcing 15mA, which can be used to power external circuitry. Always bypass V_{CC} to GND with a 10µF ceramic capacitor.

If input supply is less than 5.35V, V_{CC} may not be regulated at 5V, the voltage at V_{CC} pin is a bit less than input supply.

The 5V voltage regulator will be shut down in junction over temperature protection mode.

About Quasi-CV Mode

If the voltage at BAT pin is lower than 12.6V (Typical), HCR9733 charges the battery in constant current mode.

When BAT voltage reaches 12.6V for the first time, HCR9733 enters quasi-CV mode, the charge current is reduced to 33% of that in constant current mode. When BAT voltage reaches 12.6V in quasi-CV mode, HCR9733 terminates the charging after deglitching. The quasi-CV mode can compensate for the voltage drop across the battery internal resistance to some extent, which is similar to constant voltage mode, this is why the quasi-CV is named.

Trickle Charge and Constant Current Charge Mode

On the condition that input voltage is less than battery voltage plus forward voltage of diode D1 in Figure 3:

If the voltage at BAT pin rises above 7.35V, HCR9733 enters constant current mode; If the voltage at BAT pin falls below 7.16V, HCR9733 enters trickle charge mode, in which the charge current is 33% of the current in constant current mode.

If the BAT voltage is between 7.35V and 12.6V, HCR9733 is in constant current mode.

Charge Termination

In quasi-CV charge mode, if the voltage at BAT pin reaches charge termination threshold V_{term} (12.6V typical), charging is terminated, HCR9733 is in termination mode, the external N-channel MOSFET is turned off, no current flows to battery.

If battery temperature is in warm range, the charge termination threshold V_{term} is 12.338V(Typical).

Recharge

In charge termination mode, if the voltage at BAT pin falls below recharge threshold V_{rech} (12.075V typical), HCR9733 enters charge mode again.

If battery temperature is in warm range, the recharge threshold V_{rech} is 11.55V (Typical)

Self-adaptive Function to Input Supply

HCR9733 can automatically adjust inductor current to adapt to input supply with different driving capability. If the driving capability of input supply is less than the inductor current requirement set by current sense resistor (R_{CS} in Figure 3), HCR9733 regulates the voltage at V_{IN} pin at 4.5V by reducing inductor current.

Inductor Current (Input Current)

In the application circuit shown in Figure 3, HCR9733 sets the inductor current through a current sense resistor R_{CS} connected between V_{IN} and CSN pin.

When the external N-channel MOSFET is turned on, inductor current rises, when inductor current rises above the upper limit decided by the following 3 equations (The propagation delay is already considered):

$I_{Lhigh} = 0.108V / R_{CS}$ (Constant current mode)

$I_{Lhigh} = 0.58V / R_{CS}$ (Constant current mode, Battery warm)

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I_{Lhigh} = 0.039V / R_{CS} (Trickle mode, Quasi-CV mode and Battery cool)

The external N-channel MOSFET is turned off, inductor current falls, the energy stored in inductor is transferred to battery and output capacitor. When inductor current falls below the lower limit decided by the following 3 equations (The propagation delay is already considered):

I_{Llow} = 0.07V / R_{CS} (Constant current mode)

I_{Llow} = 0.033V / R_{CS} (Constant current mode, Battery warm)

I_{Llow} = 0.02V / R_{CS} (Trickle mode, Quasi-CV mode and Battery cool)

The external N-channel MOSFET is turned on again, a new switching cycle is started.

So the average inductor current is:

I_L = 0.089V / R_{CS} (Constant current mode)

I_L = 0.046V / R_{CS} (Constant current mode, Battery warm)

I_L = 0.03V / R_{CS} (Trickle mode, Quasi-CV mode and Battery cool)

In the above equations, I_{Lhigh} is the upper limit of inductor current in Ampere I_{Llow} is the lower limit of inductor current in Ampere R_{CS} is the inductor current sense resistor in ohm

Calculate Switching Frequency and Inductor

In the application circuit shown in Figure 3, the on-time of external N-channel MOSFET is:

$$t_{on} = \frac{0.04 \times L}{VIN \times R_{CS}} \quad \text{------------} \quad (1)$$

The off-time of the N-channel MOSFET is:

$$t_{off} = \frac{0.04 \times L}{(V_{BAT} + V_D - VIN) \times R_{CS}} \quad \text{--------} \quad (2)$$

So the switching frequency is:

$$f_{sw} = \frac{1}{t_{on} + t_{off}} = \frac{1}{\frac{0.04 \times L}{VIN \times R_{CS}} + \frac{0.04 \times L}{(V_{BAT} + V_D - VIN) \times R_{CS}}}$$

HCR9733 requires that the minimum switching frequency is no less than 200kHz. A frequency between 300kHz and 600kHz can achieve a good balance between efficiency and inductor size.

The switching frequency varies with input voltage and battery voltage, so when determining the switching frequency, the nominal battery voltage should be used.

The duty cycle of pulse at HCR9733 DRV pin:

$$D = \frac{t_{on}}{t_{on} + t_{off}} = \frac{V_{BAT} + V_D - VIN}{V_{BAT} + V_D}$$

In the above equations:

L is the inductor value in Henry(H) V_{IN} is the input voltage in Volt V_{BAT} is battery voltage in Volt V_D is the forward voltage drop of diode in Volt R_{CS} is the total current sense resistance in ohm(Ω), R_{CS}=REXT+RINT

Estimate Charge Current in Constant Current Mode

HCR9733 controls charge current by monitoring inductor current, so the charge current in constant current mode may vary with the input voltage and battery voltage.

Normally the following equation can be used to estimate the charge current:

$$I_{CH} = \frac{VIN \times I_L \times \eta}{V_{BAT}}$$

Where, I_{CH} is charge current in Ampere V_{IN} is input voltage in Volts I_L is the average inductor current in Ampere, and decided by 0.089 / R_{CS} η is the

Application Information

conversion efficiency varying between 85% and 92%, generally 88% can be used.

V_{BAT} is battery voltage in Volt

Battery Temperature Monitoring

To prevent the damage caused by the very high or very low temperature done to the battery, the HCR9733 continuously monitor battery temperature by measuring the voltage at TEMP pin which is determined by TEMP pin's source current (30μA typical) and a 10KΩ negative temperature coefficient (NTC) thermistor connected between TEMP pin and GND as shown in Figure 3.

If battery temperature monitoring function is not needed, connect a fixed 10KΩ resistor from TEMP to GND.

The battery temperature monitoring function for HCR9733 is designed to follow the JEITA standard; charge current or charge termination voltage is reduced based on battery temperature ranges.

There are totally five battery temperature ranges for HCR9733:

• Hot: Above 55°C,

• Warm: 45°C to 55°C,

• Normal: 10°C to 45°C

• Cool: 0°C to 10°C,

• Cold: Below 0°C.

Normal operation occurs when battery temperature is between 10°C and 45°C, charge current and voltage will be the normal values.

When battery is in the Cool temperature range, which is between 0°C and 10°C, the charge current is 33% of full-scale charge current and charge termination voltage is not changed.

When the battery is in the Warm temperature range, which is between 45°C and 55°C, the charge current is reduced to 50% of full-scale charge current and charge termination voltage is reduced to 97.91% of nominal value.

Charging is suspended if battery temperature is below Cold temp of 0°C or above Hot temp of 55°C. When charging is suspended, both $\overline{\text{CHRG}}$ and $\overline{\text{DONE}}$ pin becomes high impedance state.

Once battery temperature is not in hot range and cold range, charging resumes automatically.

TEMP pin voltage is the product of its source current and NTC's resistance, so the selection of NTC should make sure TEMP pin voltage meet the requirements of hot, warm, cool and cold threshold. An NTC of nominal resistance 10KΩ at room temperature may be suitable for HCR9733.

A resistor of small resistance in series with NTC thermistor and a resistor of large resistance in parallel with NTC thermistor can fine tune HCR9733's temperature range.

The following table lists TEMP pin voltage, charge current and termination voltage in the above-mentioned 5 battery temperature range.

Application Information

Battery Temperature Range	TEMP Pin Voltage	Charge Current	Termination Voltage
Hot: above 55°C	$V_{TEMP}<V_{HOT}$	Charge Suspended	Charge Suspended
Warm: 45°C to 55°C	$V_{HOTR}<V_{TEMP}<V_{WARM}$	50%*I_{CC}	97.91%*V_{TERM}
Normal: 10°C to 45°C	$V_{WARMR}<V_{TEMP}<V_{COOLR}$	Normal Value	Normal Value
Cool: 0°C to 10°C	$V_{COOL}<V_{TEMP}<V_{COLDR}$	33%*I_{CC}	Normal Value
Cold: below 0°C	$V_{TEMP}>V_{COLD}$	Charge Suspended	Charge Suspended

Selection of N-Channel MOSFET

The HCR9733's gate driver is capable of sourcing 0.65A and sinking 0.65A of current. MOSFET selection is based on the maximum battery voltage, inductor current and operating switching frequency. Choose an N-channel MOSFET that has a higher breakdown voltage than the maximum battery voltage, low R_{ds} (ON), and low total gate charge (Q_g) for better efficiency. MOSFET threshold voltage must be adequate if operated at the low end (4.5V) of the input-voltage operating range.

Selection of Free-Wheeling Diode

The forward voltage of the freewheeling diode (D1 in Figure. 3) should be as low as possible for better efficiency. A Schottky diode is a good choice as long as the breakdown voltage is high enough to withstand the maximum battery voltage. The current rating of the diode must be greater than the maximum charge current.

Input Capacitor

In most applications, a bypass capacitor at V_{IN} is needed. An at least 10μF ceramic capacitor, placed in close proximity to V_{IN} and GND pins, works well. In some applications depending on input current, the power supply characteristics and cable length, it may be necessary to increase the capacitor's value. The capacitor's breakdown voltage should be higher than the maximum input voltage.

Generally a capacitor between 10μF and 47μF works well, ceramic capacitor of X5R or X7R is highly recommended.

Output Capacitor

A filter capacitor (Co in Figure 3) is needed between battery positive terminal and ground, the capacitor also supply energy to battery when the N-channel MOSFET is turned on.

The output capacitance is determined by the requirement of output ripple voltage. The ripple voltage is decided by the following equation:

$$\Delta V_{BAT} = \frac{I_{CH} \bullet t_{off}}{C_o} + \frac{0.04 \bullet r_{esr}}{R_{cs}}$$

Where, I_{CH} is the charge current flowing into battery t_{off} is the off time of N-channel MOSFET Co is the output capacitance r_{esr} is the equivalent series resistance of output capacitor R_{cs} is the inductor current sense resistor shown in Figure 3 So ESR of output capacitor should be as small as possible, X5R or X7R ceramic capacitors are recommended.

Application Information

Status Indication

The HCR9733 has 2 open-drain status outputs: $\overline{\text{CHRG}}$ and $\overline{\text{DONE}}$. $\overline{\text{CHRG}}$ pin is pulled low when the charger is in charging mode, otherwise $\overline{\text{CHRG}}$ becomes high impedance. $\overline{\text{DONE}}$ pin is pulled low if the charger is in termination mode, otherwise $\overline{\text{DONE}}$ becomes high impedance.

When the battery is not present, the charger charges the output capacitor to the over-voltage protection threshold quickly, HCR9733 enters over-voltage protection mode, both $\overline{\text{CHRG}}$ and $\overline{\text{DONE}}$ becomes high impedance, then battery voltage decays slowly to over-voltage release threshold because of discharge by the feedback resistors, HCR9733 enters charge mode, and the output capacitor is charged to over-voltage protection threshold again, and so forth. Then a ripple waveform is formed at charger's output, namely battery positive terminal, in the meantime, $\overline{\text{CHRG}}$ and $\overline{\text{DONE}}$ pin outputs pulse to indicate the battery's absence.

The open drain status output that is not used should be tied to ground.

The table 1 lists the two indicators' status and its corresponding charging status. It is supposed that red LED is connected to $\overline{\text{CHRG}}$ pin and green LED is connected to $\overline{\text{DONE}}$ pin.

$\overline{\text{CHRG}}$ pin	$\overline{\text{DONE}}$ pin	State Description
Low (the red LED on)	High impedance (the green LED off)	Charging
High impedance (the red LED off)	Low (the green LED on)	Termination
Pulse (the red LED blinking)	Pulse (the green LED blinking)	Battery not present
High impedance (the red LED off)	High impedance (the green LED off)	There are 4 possible reasons: • the voltage at V_{IN} pin below the UVLO level or • Over-voltage protection, or • HCR9733 over junction temperature, or • Battery hot or cold

Table 1. Indication Status

Adjusts Charge Termination Voltage Upwards

The charge termination voltage can be adjusted upwards by connecting a resistor between BAT pin and positive terminal of battery, R_x in Figure 1 serves this purpose. When battery is connected to inductive loading such as motors or step-up DC-DC converters, the resistor R_x also serves the purpose of protecting HCR9733.

Due to different characteristics and temperature coefficient between R_x and on-chip resistors, the adjusting amplitude by R_x should be limited within 0.45V.

The amplitude of adjusted charge termination voltage is calculated by the following equation:

$V_x=10.5\times10^{-6}\times R_x$ (V_x is in Volt, R_x is in ohm) So the charge termination voltage is: $V_{term}=12.6+V_x$ (V)

Application Information

About Short Battery or Battery's Voltage being lower than Input Supply Voltage

In some certain cases of short battery or battery voltage being lower than input supply voltage, the current may flow to battery from input supply via inductor and diode, which is out of HCR9733's control. In this case, battery protection circuit or limiting driving capability of input supply is needed.

Design Procedures

The following design procedures can be followed to design the parameters of HCR9733 application circuit:

(1) To determine the charge current based on the battery capacity and the requirement of charge time.

(2) To estimate the input current based on the input voltage range, battery voltage range and charge current.

The input current is also the inductor current.

(3) To decide the input bypassing capacitor based on the input supply's characteristics, input supply's cable length and input current.

(4) To select diode and N-channel MOSFET based on input voltage, inductor current, charge current and the battery's highest voltage.

(5) To calculate the current sense resistor R_{CS} based on the average inductor current.

(6) To determine the inductor value according to the switching frequency. The switching frequency can be from 200kHz to 1MHz. Generally speaking, a switching frequency between 300kHz and 600kHz can achieve a good balance between efficiency and inductor's profile.

(7) To select the output capacitor based on the switching frequency and charge current.

PCB Considerations

A good PCB design is very important to efficiency and performance. When laying out the printed circuit board, the following considerations should be taken to ensure proper operation of the IC.

• If possible, use multi-layer PCB for better performance.

• The high-current ground connections of output capacitor, source of N-channel MOSFET and battery negative terminal need to feed into same copper that connects to the input capacitor ground before tying back into system ground. This copper should be wide enough, and back to system ground separately.

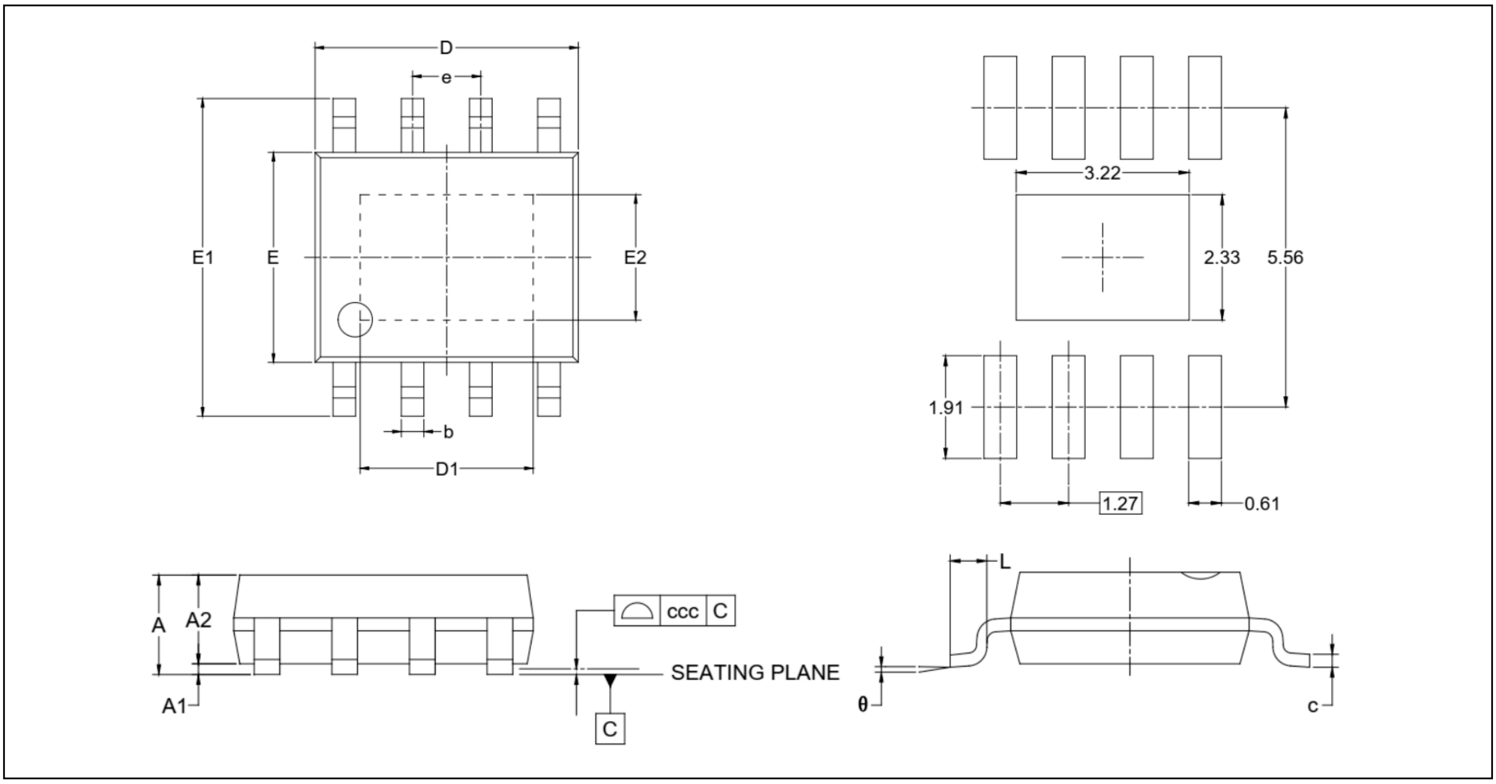
• The analog ground connections of HCR9733's exposed PAD, C_2 and NTC's grounding terminals as shown in Figure 3 should be back to system ground separately.

• To minimize radiation, the diode, MOSFET, inductor, the input bypass capacitor and the output capacitor traces should be kept as short as possible. The connection between the diode and the MOSFET should also be kept as short as possible.

• Place the inductor current sense resistor R_{CS} right next to the input capacitor and inductor but oriented such that the IC's CSN and V_{IN} traces going to R_{CS} are not long. The 2 traces need to be routed together as a single pair on the same layer at any given time with smallest trace spacing possible.

Mechanical Dimensions

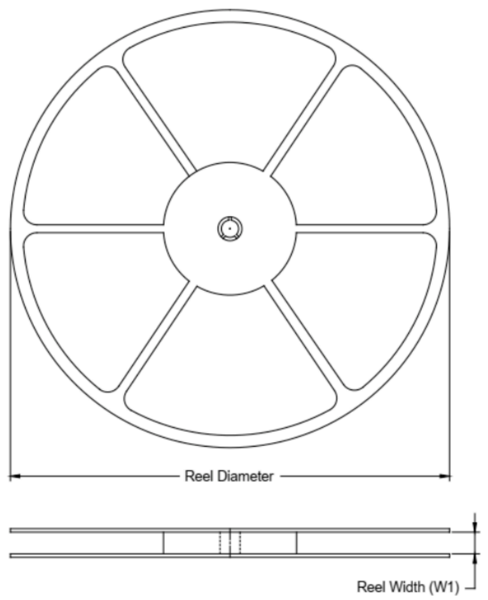
M8E PKG: SOP-8(EP) Unit: mm

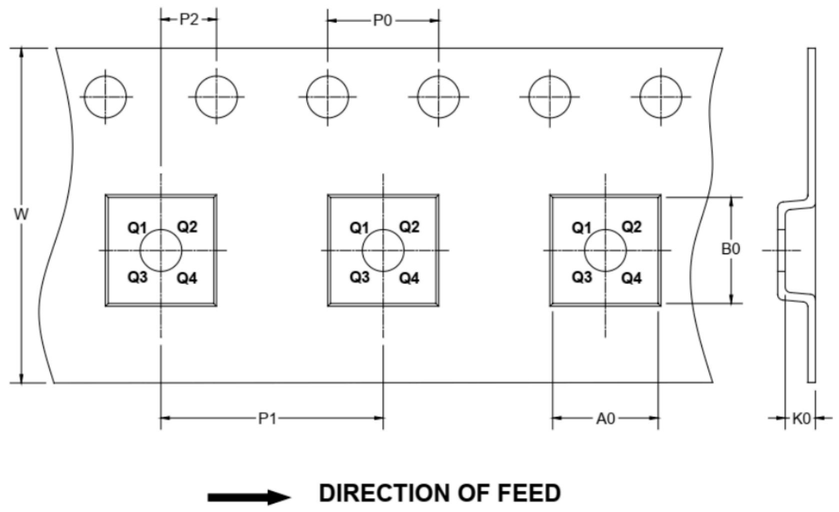


Symbol	Dimensions in Millimeters		
	MIN	MOD	MAX
A			1.700
A1	0.000	-	0.150
A2	1.250	-	1.650
b	0.330	-	0.510
c	0.170	-	0.250
D	4.700	-	5.100
D1	3.020	-	3.420
E	3.800	-	4.000
E1	5.800	-	6.200
E2	2.130	-	2.530
e	1.27 BSC		
L	0.400	-	1.270
θ	0°	-	8°
ccc	0.100		

NOTES:
1. This drawing is subject to change without notice.
2. The dimensions do not include mold flashes, protrusions or gate burrs.
3. Reference JEDEC MS-012.

Tape and Reel Information





NOTE: The picture is only for reference. Please make the object as the standard.

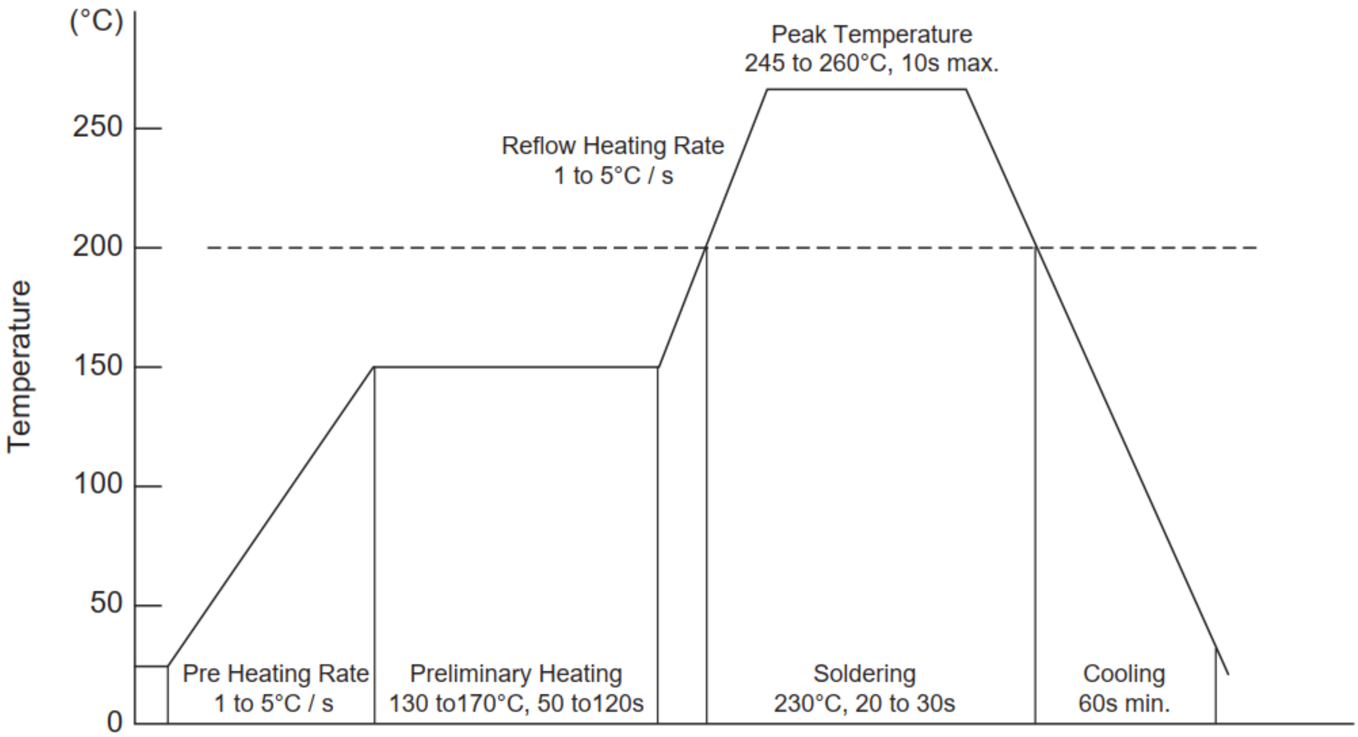
Key Parameter List of Tape and Reel

Package Type	Reel Diameter	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	P1 (mm)	P2 (mm)	W (mm)	Pin1 Quadrant
SOP-8(EP)	13″	12.4	6.40	5.40	2.10	4.0	8.0	2.0	12.0	Q1

Quantity per Reel: 4000

Conditions of Soldering and Storage

Recommended Condition of Reflow Soldering



Recommended peak temperature is over 245°C. If peak temperature is below 245°C, you may adjust the following parameters:

- Time length of peak temperature (longer)
- Time length of soldering (longer)
- Thickness of solder paste (thicker)

Conditions of Hand Soldering

- Temperature: 300°C
- Time: 3s max
- Times: one time

Storage Conditions

- Temperature: 5 to 40°C
- Humidity: 30 to 80% RH
- Recommended period: One year after manufacturing