WS4538Q

Linear Li-Ion Battery Charger with PCM function **www.sh-willsemi.com**

Descriptions

The WS4538Q is a fully integrated high input voltage single-cell Li-ion Battery charger with PCM protection. The charger uses a CC/CV charge profile required by Li-ion battery. The charger input voltage can be up to 28V. The 28V rating eliminates the over-voltage protection circuit required in a low input voltage charger.

The WS4538Q is a complete constant-current, constant voltage linear charger for single cell Li-Ion batteries. No external sense resistor is needed, and no blocking diode is required due to the internal MOSFET architecture. Thermal feedback regulates the charge current to limit the die temperature during high power operation or under high ambient temperature. The charge termination voltage is fixed at 4.2V or 4.35V, and the charge current can be programmed externally with a single resistor.

The WS4538Q includes a Li-Ion battery PCM function for over charge protection, over discharge protection, over current protection and short circuit protection. The quiescent current of the Li-Ion battery protector is lower than 1uA when the input is not connected which can prolong the work time of the battery.

The WS4538Q support 5mA charge current at minimum with high accuracy. This is very suited for ultra small capacity Li-ion battery applications like wearable and smart card system.

The WS4538Q is available in ultra-thin QFN1616-12L (1.6x1.6x0.37mm) package. All products are Pb-Free and halogen-Free.

Features

- Maximum Input Voltage Up to 28V
- 4.2V/4.35V Floating Voltage with ±1% Accuracy
- 5mA to 300mA High Precision Programmable Charge Current for Tiny Cell Li-Ion or Polymer Batteries
- 2.9V Trickle Charge Threshold
- 2.5V Over Discharge Voltage Threshold with ±3% Accuracy
- 0.75uA Battery Leakage Current While No Input Power Attached
- 0.45uA Battery Leakage Current While Over Discharge
- Programmable Current Limit Threshold with External Resistor for PCM
- CC/CV Operation with Thermal Regulation to Maximize Charge Rate without Risk of Overheating
- Charge Status Output Pin

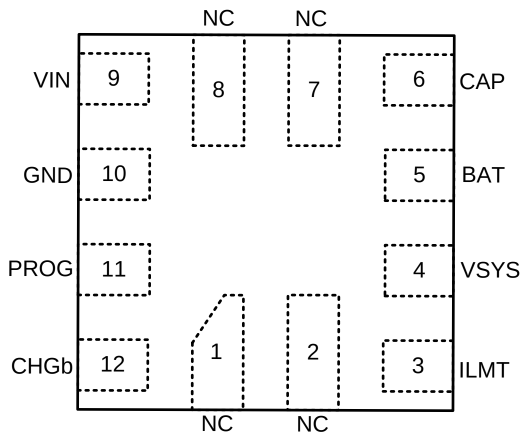
Applications

- Smart Card
- Wearable Devices
- Credential Keys
- Wireless Remote

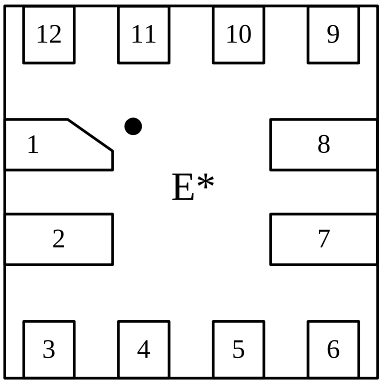
Order Information

Device	Package	Shipping
WS4538Q-12/TR	QFN1616-12L	3000/Reel&Tape
WS4538QB-12/TR	QFN1616-12L	3000/Reel&Tape

Pin Configuration (Top View)



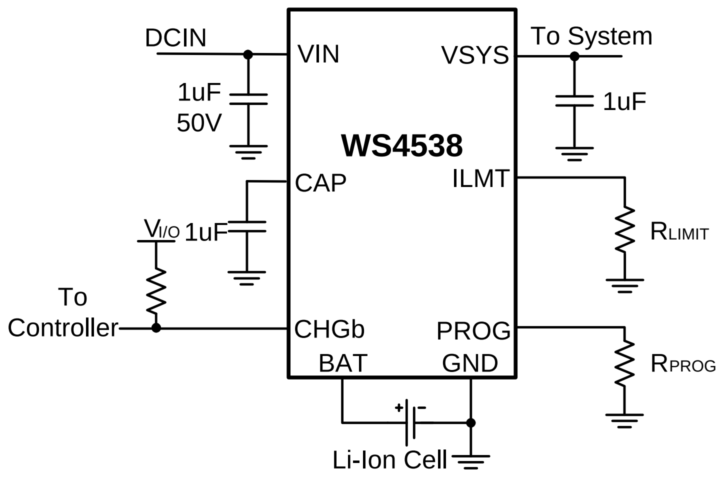
Marking (Top View)



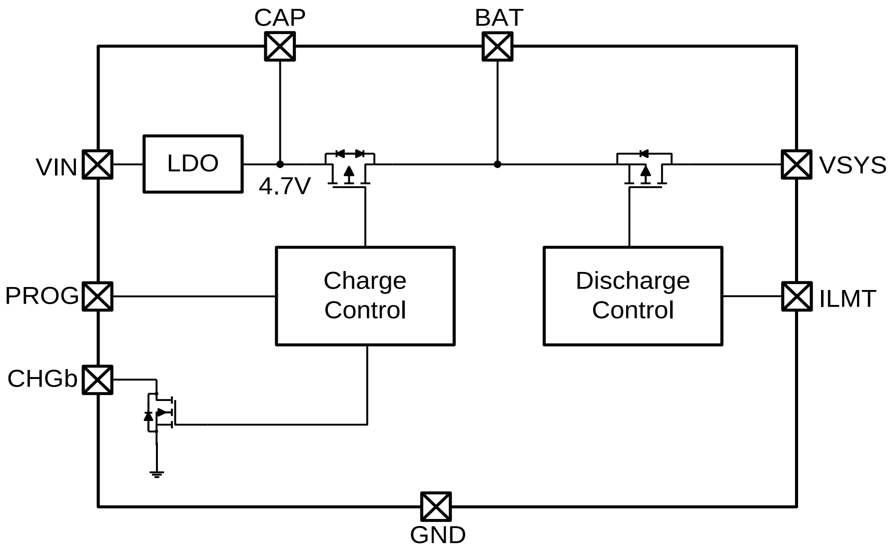
E = Device code

*** = Month code (A~Z)**

Typical Applications



Block Diagram



Pin Descriptions

Pin No.	Symbol	Function
3	ILMT	Output over current and short circuit threshold program pin. The OCP and short circuit threshold is programmed by connecting a high precision resistor R_{LIMIT} to ground. The OCP and short circuit threshold can be set using the following formula: $I_{OC}=(0.5V/R_{LIMIT}) \times 10^6$ $I_{SHORT}=3 \times I_{OC}$ The R_{LIMIT} must be close to the ILMT pin for stability.
4	VSYS	System power supply. If the over current or short circuit of the following system happen, the VSYS pin will output a pulse between 0 and VBAT with a very small duty cycle. The capacitor connected in this pin must not larger than 4.7uF.
5	BAT	Charge current output. Provides charge current to the battery and regulates the final float voltage to 4.2V/4.35V. An internal precision resistor divider from this pin sets the float voltage which is disconnected in shutdown mode.
6	CAP	Internal regulator output pin. 1uF capacitor must be connected as close as possible to this pin.
9	VIN	Input supply voltage. Provides power to the charger. VIN can range from 4.25V to 28V and should be bypassed with at least a 1uF capacitor. Although 28V can be put in VIN pin, the Charger may be in the thermal regulation condition depending on the power dissipation of WS4538Q.
10	GND	Ground
11	PROG	Charge current program pin. The charge current is programmed by connecting a high precision resistor, R_{PROG}, to ground. When charging in constant-current mode, this pin servos to 1V. The charge current can be set by following formula: $I_{BAT} = (1V/R_{PROG}) \times 100$
12	CHGb	Open-Drain charge status output. When the battery is charging, the CHGb pin is pulled low by an internal N-channel MOSFET. When the charge cycle is completed or the WS4538Q detects an under-voltage lockout condition, CHGb is forced high impedance.
1, 2, 7, 8	NC	Not connected

Absolute Maximum Ratings

Parameter	Symbol	Rating	Unit
Supply Voltage	V_{IN}	-0.3~28	V
PROG Voltage	V_{PROG}	-0.3~6.5	V
PROG Pin Current	I_{PROG}	3	mA
BAT Voltage	V_{BAT}	-0.3~6.5	V
BAT Pin Current	I_{BAT}	300	mA
CHGb Voltage	V_{CHGb}	-0.3~6.5	V
CAP Pin Voltage	V_{CAP}	-0.3~6.5	V
ILMT Pin Voltage	V_{ILMT}	-0.3~6.5	V
VSYS Pin Voltage	V_{VSYS}	-0.3~6.5	V
Junction Temperature	T_J	150	^oC
Operation Temperature	T_{OPR}	-40~85	^oC
Storage Temperature	T_{STG}	-65~125	^oC
Lead Temperature (Soldering 10s)		260	^oC
ESD Ratings	HBM	±8000	V
	MM	±300	V
	CDM	±2000	V
Latch-Up		±800	mA

These are stress ratings only. Stresses exceeding the range specified under “Absolute Maximum Ratings” may cause substantial damage to the device. Functional operation of this device at other conditions beyond those listed in the specification is not implied and prolonged exposure to extreme conditions may affect device reliability.

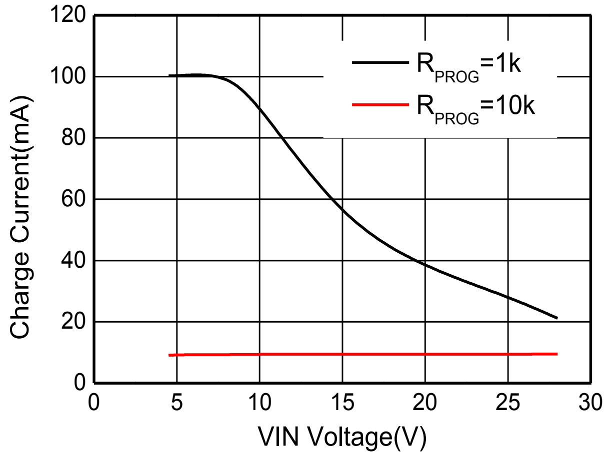
Recommend Operation Ratings

Parameter	Symbol	Rating	Unit
Supply Voltage	V_{IN}	4.5~24	V
Charge Current	I_{CC}	5~100	mA
Maximum System Load Current	I_{SYS}	100	mA
Maximum System Load Capacitance	C_{LOAD}	4.7	uF
Thermal Resistance	$R_{\theta JA}$	180	$^oC/W$

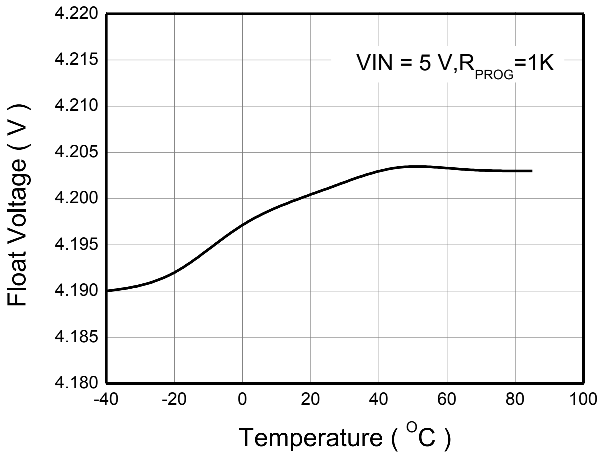
Electronics Characteristics (V_{IN}=5V, T_A=25°C, unless otherwise noted)

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
DC Characteristics						
V_{UVLO}	V_{IN} UVLO Voltage Threshold	V_{IN} From Low to High	3.6	3.8	4.0	V
V_{UVLO_HYS}	V_{IN} UVLO Voltage Hysteresis	V_{IN} From High to Low	100	250	400	mV
RON1	HV LDO FET ON Resistance		0.55	0.7	0.86	Ω
RON2	Charge FET ON Resistance			0.6		Ω
RON3	Discharge FET ON Resistance		0.7	1	1.3	Ω
$I_{VINCHRG}$	Charge Mode V_{IN} Quiescent Current	R_{PROG}=1kΩ	100	250	500	uA
		R_{PROG}=10kΩ	100	150	400	uA
$I_{VINSTBY}$	Standby Mode V_{IN} Quiescent Current	Charge Terminated	40	120	310	uA
$I_{BATSTBY}$	Standby Mode V_{BAT} Quiescent Current	Charge Terminated	0.5	2.5	5.5	uA
$I_{BATSLEEP}$	Sleep Mode V_{BAT} Leakage Current	VIN disconnected V_{BAT}>V_{ODCH}	0.2	0.75	1	uA
V_{PROG}	PROG Pin Voltage	R_{PROG}=1kΩ	0.93	1	1.07	V
V_{CHGb}	CHGb Pin Output Low Voltage	I_{CHGb}=5mA		0.3	0.6	V
Charging and PCM Characteristics						
V_{FLOAT}	Charge Termination Voltage and Over Charge Voltage	WS4538Q	4.158	4.200	4.242	V
		WS4538QB	4.307	4.350	4.394	V
V_{RECHRG}	Auto Recharge Voltage Hysteresis	R_{PROG}=10kΩ	100	150	200	mV
$I_{BATCHRG}$	Charge Mode Battery Current	R_{PROG}=1kΩ	90	100	110	mA
		R_{PROG}=10kΩ	8.3	9.2	10.1	mA
V_{TRIKL}	Trickle Charge Voltage Threshold	R_{PROG}=10kΩ	2.8	2.9	3	V
$V_{TRIKL,\_HYS}$	Trickle Charge Voltage Hysteresis	R_{PROG}=10kΩ		100		mV
I_{TRIKL}	Trickle Charge Current	R_{PROG}=1kΩ	7.8	9.6	11.4	mA
V_{ODCH}	Over Discharge Voltage Threshold	V_{BAT} Falling	2.4	2.5	2.6	V
V_{ODCH_HYS}	Over Discharge Voltage Hysteresis	V_{BAT} Rising		0.7		V
t_{ODCH}	Over Discharge Response Time	V_{BAT} Falling		75		ms
I_{ODCH}	Over Discharge State VBAT Leakage Current	V_{BAT}<V_{ODCH}		0.45		uA
I_{OCP}	V_{SYS} Load Over Current Threshold	R_{LIMIT}=5MΩ		100		mA
t_{OCP}	V_{SYS} Load OCP Response Time			150		ms
t_{oc_retry}				8		s
I_{SHORT}	V_{SYS} Load Short Current Threshold	R_{LIMIT}=5MΩ, V_{SYS}=0	240	300	360	mA
t_{SHORT}	V_{SYS} Load Short Response Time			50		us
Thermal and Soft Start Protection						
T_{LIM}	Thermal Regulation Temperature	Guaranteed by design		140		°C
T_{OTP}	Over Temperature Protect threshold	Guaranteed by design		160		°C
T_{OTP_HYS}	Over Temperature Protect Hysteresis	Guaranteed by design		20		°C
T_{SS}	Soft-Start Time	R_{PROG}=1kΩ		200		us

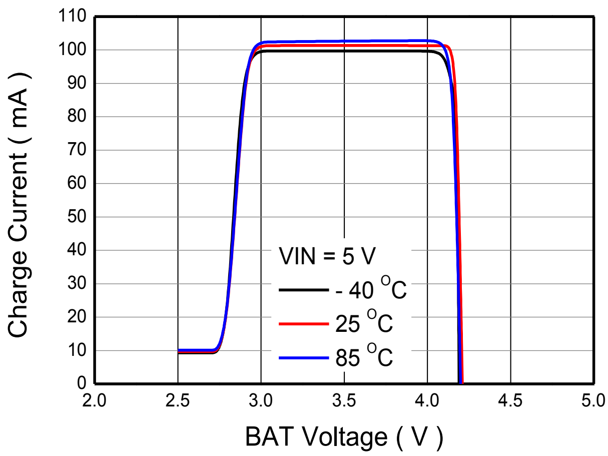
Typical Characteristics (T_A=25°C, unless otherwise noted)



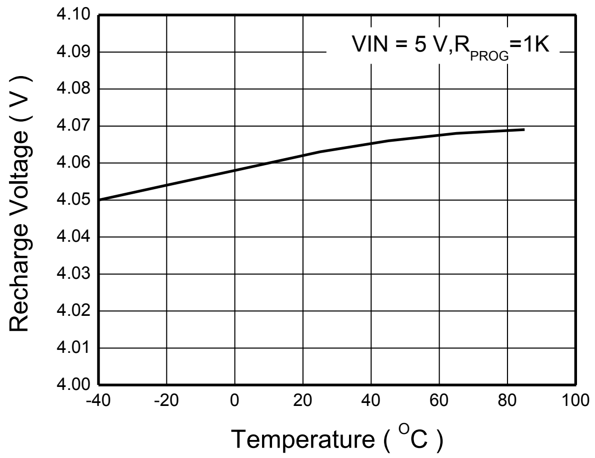
Charge Current vs. VIN Voltage



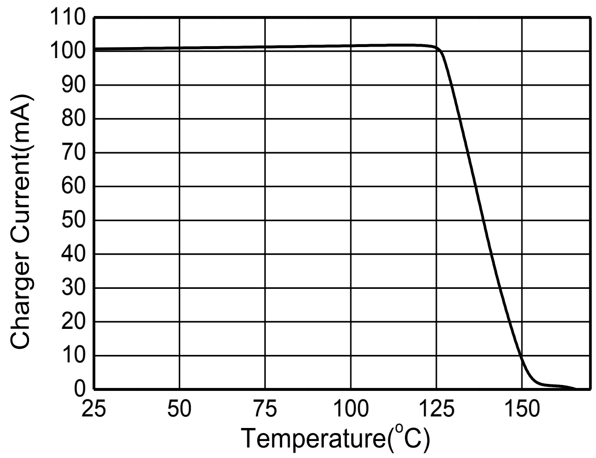
Float Voltage vs. Temperature



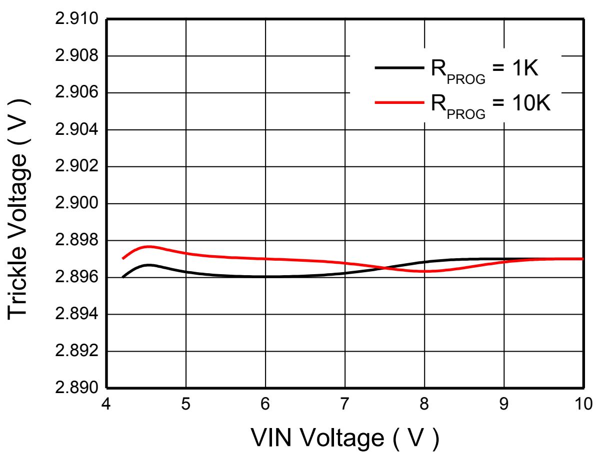
Charge Current vs. BAT Voltage



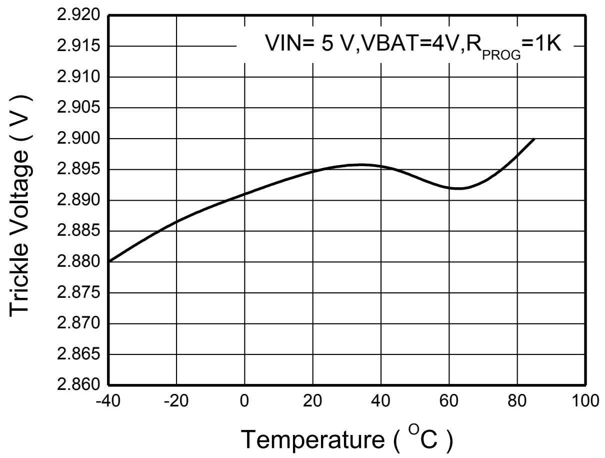
Recharge Voltage vs. Temperature



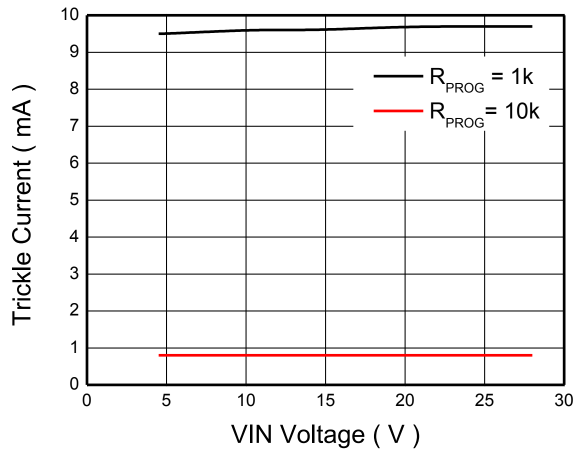
Charger Current vs. Temperature



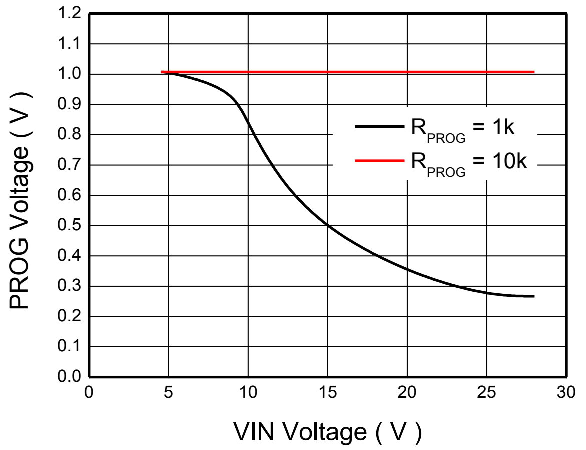
Trickle Voltage vs. VIN Voltage



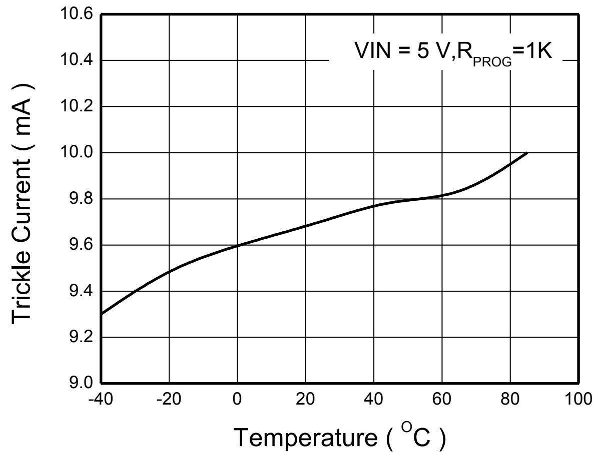
Trickle Voltage vs. Temperature



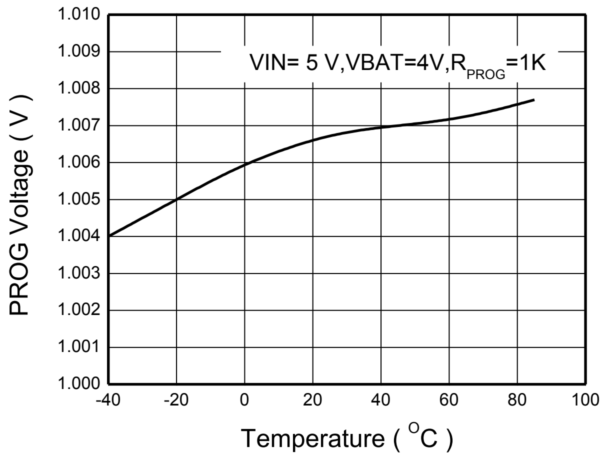
Trickle Current vs. VIN Voltage



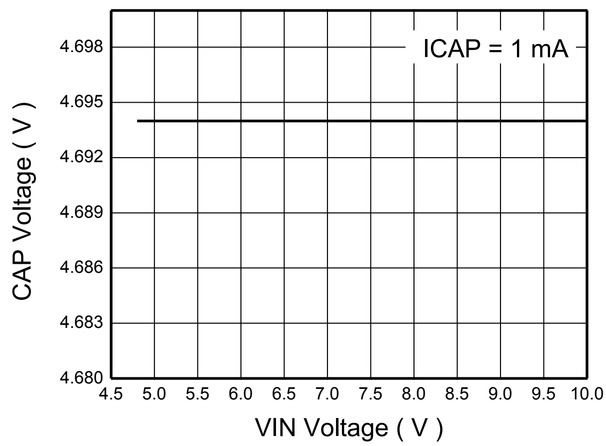
PROG Voltage vs. VIN Voltage



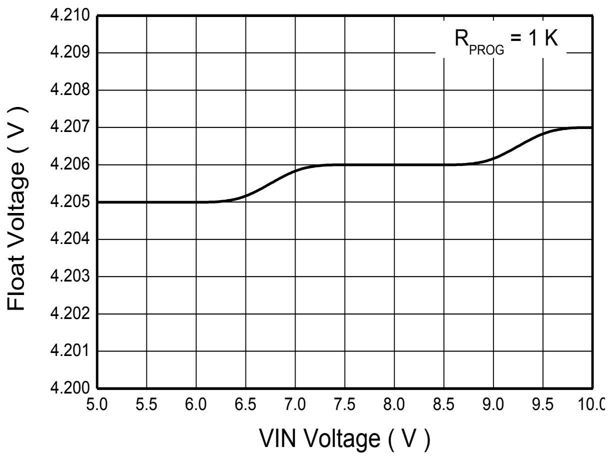
Trickle Current vs. Temperature



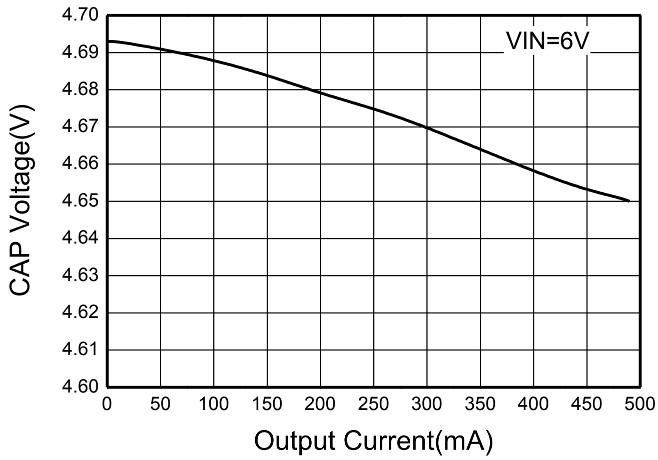
PROG Voltage vs. Temperature



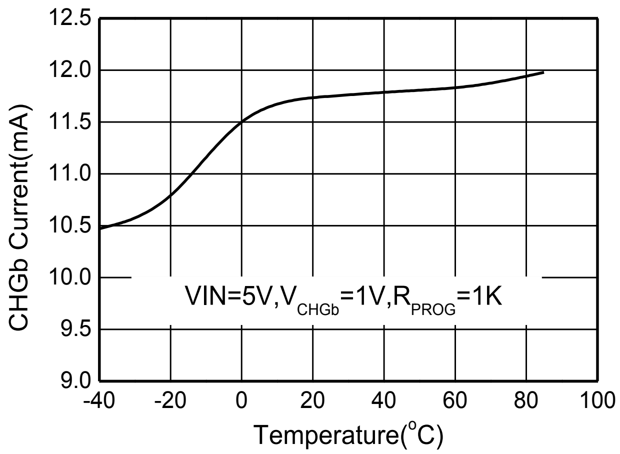
CAP Voltage vs. VIN Voltage



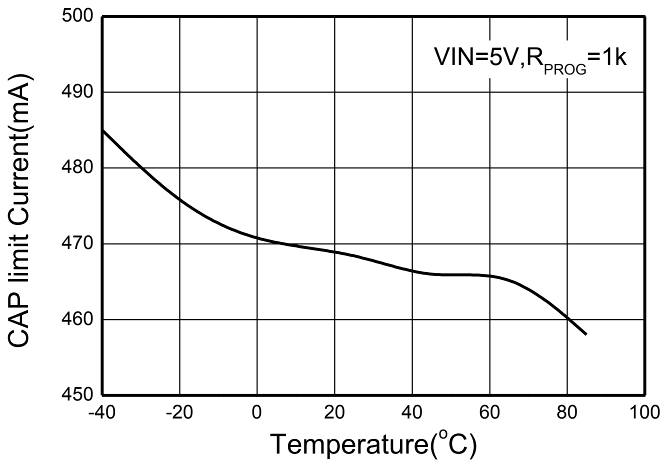
Float Voltage vs. VIN Voltage



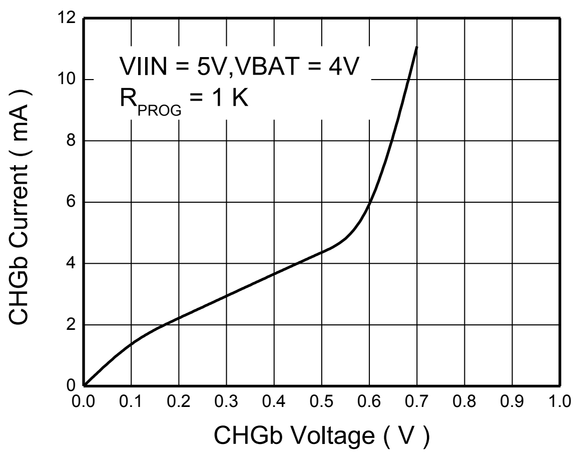
CAP Voltage vs. Output Current



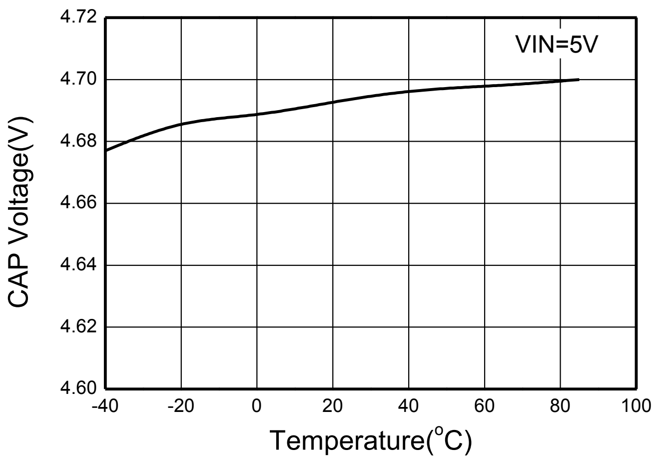
CHGb Current vs. Temperature



CAP limit Current vs. Temperature



CHGb Current vs. CHGb Voltage



CAP Voltage vs. Temperature

Operation Information

The WS4538Q is a single cell Lithium-Ion battery charger using a constant-current/constant-voltage algorithm. It can deliver up to 0.3A of charge current (using a good thermal PCB layout) with a final float voltage accuracy of ±1%. The WS4538Q includes an internal P-channel power MOSFET and thermal regulation circuitry. No blocking diode or external current sense resistor is required. The charger input voltage can be up to 28V. The 28V rating eliminates the over-voltage protection circuit required in a low input voltage charger. The WS4538Q also includes a Li-Ion battery protector for over current and output shorted protection and the over-discharge protection is also included when the voltage of the Li-Ion battery is lower than 2.5V.

High Voltage Low Dropout Regulator

The input voltage of the LDO can be up to 28V and the output voltage of the LDO is 4.7V which prevents the damage from the high voltage surge. The output current of the LDO can up to 300mA. The current limit protection and over temperature protection can protect the high voltage LDO from damage.

Normal Charge Cycle

A charge cycle begins when the voltage at the VIN pin rises above the UVLO threshold level and a high precision program resistor is connected from the PROG pin to ground. If the BAT pin is less than 2.9V, the charger enters trickle charge mode. In this mode, the WS4538Q supplies approximately 1/10 the programmed charge current to bring the battery voltage up to a safe level for full current charging.

When the BAT pin voltage rises above 2.9V, the charger enters constant-current mode, where the programmed charge current is supplied to the battery. When the BAT pin approaches the final float voltage, the WS4538Q enters constant-voltage mode and the charge current begins to decrease. The charge cycle ends when the PROG voltage is less than 100mV.

Programming Charge Current

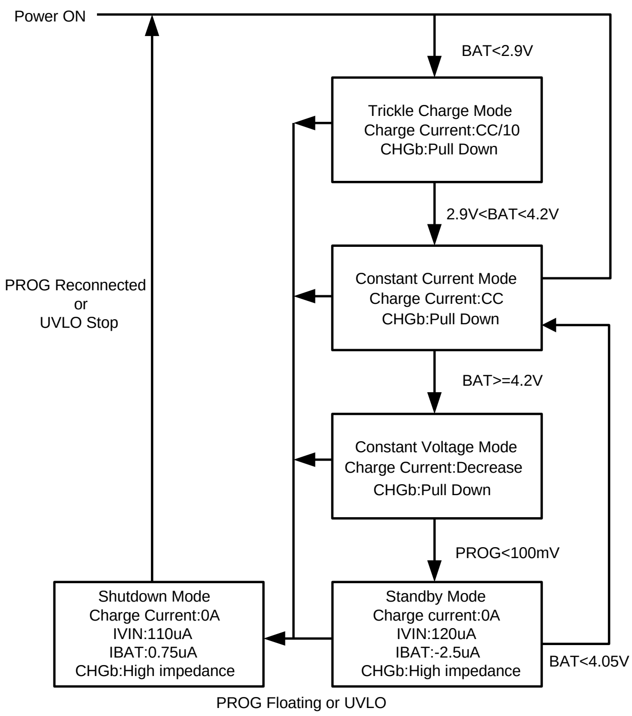
The charge current is programmed using a single resistor from the PROG pin to ground. The battery charge current of constant current mode is 100 times the current out of the PROG pin. The program resistor and the charge current of constant current are calculated using the following equations:

$$I_{CHG} = (1V/R_{PROG}) \times 100$$

Charge Termination

A charge cycle is terminated when the charge current falls to 1/10 of the programmed value after the final float voltage is reached. This condition is detected by using an internal, filtered comparator to monitor the PROG pin. When the PROG pin voltage falls below 100mV for longer than T_{TERM} (typically 1ms), charging is terminated the charge current is latched off and the WS4538Q enters standby mode. When charging, transient loads on the BAT pin can cause the PROG pin to fall below 100mV for short periods of time before the DC charge current has dropped to 1/10 of the programmed value. The 1ms filter time (T_{TERM}) on the termination comparator ensures that transient loads of this nature do not result in premature charge cycle termination. Once the average charge current drops below 1/10 of the programmed value, the WS4538Q terminates the charge cycle and ceases to provide any current through the BAT pin, the chip will be put into standby mode. In this state, all loads on the BAT pin must be supplied by the battery.

The WS4538Q constantly monitors the BAT pin voltage in standby mode. If this voltage drops below the recharge threshold (V_{RECHRG}), another charge cycle begins and current is once again supplied to the battery. The state diagram of a typical charge cycle is as below:



Charge Status Indicator (CHGb)

The charge status output indicator is an open drain circuit. The indicator has two different states: pull-down (~10mA), and high impedance. The pull-down state indicates that the WS4538Q is in a charge cycle. High impedance indicates that the charge cycle is complete. The CHGb can also be used to detect the charge states by a microprocessor with a pull-up resistor.

Automatic Recharge

Once the charge cycle is terminated, the WS4538Q continuously monitors the voltage on the BAT pin using a comparator with a 2ms filter time (T_{RECHRG}). A charge cycle restarts when the battery voltage falls below V_{Float} minus V_{RECHRG} (which corresponds to approximately 80% to 90% battery capacity). This ensures that the battery is kept at or near a fully charged condition and eliminates the need for periodic charge cycle initiations. CHGb output enters a pull-down state during recharge cycles.

Programming Over-Current and Shorted-Current Protection Threshold

The battery discharge protector over-current and short circuit threshold are programmed using a single resistor R_{LIMIT} from the ILMT pin to ground. The program resistor and the threshold are calculated using the following equations:

$$I_{OC}=(0.5V/R_{LIMIT}) \times 10^{6}$$

$$I_{SHORT}=3 \times I_{OC}$$

When the OCP happens longer than t_{OC} (typ.150ms), the protector will shut down the integrated MOS and the VSYS pin voltage will fall to 0. After 8s, the protector will recheck the state of the system and the protector will enter normal state if the OCP do not exist otherwise shutdown the MOS after t_{OC}. The shorted-circuit protection is similar with the OCP except the delay time (typ.50us) is much shorter than t_{OC}.

Application Information

Stability Considerations

The constant-voltage mode feedback loop is stable without an output capacitor provided a battery is connected to the charger output. With no battery present, an output capacitor is recommended to reduce ripple voltage. When using high value, low ESR ceramic capacitors, it is recommended to add a 1Ω resistor in series with the capacitor. No series resistor is needed if tantalum capacitors are used.

In constant-current mode, the PROG pin is in the feedback loop, not the battery. The constant-current mode stability is affected by the impedance at the PROG pin. With no additional capacitance on the PROG pin, the charger is stable with program resistor values as high as 20KΩ. However, additional capacitance on this node reduces the maximum allowed program resistor thus it should be avoided.

The R_{LIMIT} must be closed to the ILMT pin for stability.

Thermal Limit

An internal thermal feedback loop reduces the programmed charge current if the die temperature attempts to rise above a preset value of approximately 140°C. This feature protects the WS4538Q from excessive temperature and allows the user to push the limits of the power handling capability of a given circuit board without risk of damaging the WS4538Q. The charge current can be set according to typical (not worst-case) ambient temperature with the assurance that the charger will automatically reduce the current in worst-case conditions.

Power Dissipation

The conditions that cause the WS4538Q to reduce charge current through thermal feed-back can be approximated by considering the power dissipated in the IC. Nearly all of this power dissipation is generated by the internal MOSFET. This is calculated to be approximately:

$$P_D = (V_{IN}-V_{BAT})*I_{BAT}$$

It is important to remember that WS4538Q applications do not be designed for worst-case thermal conditions since the IC will automatically reduce power dissipation when the junction temperature reaches approximately 140°C (Constant temperature mode).

VIN Bypass Capacitor

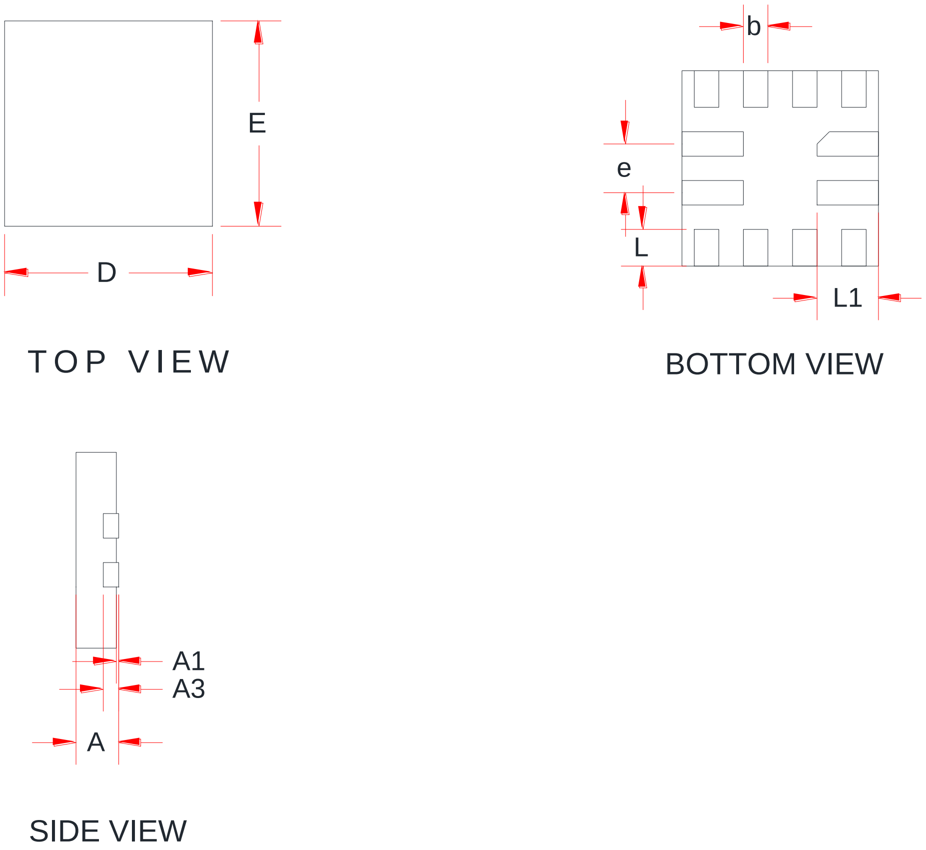
Many types of capacitors can be used for input bypass, however, caution must be exercised when using multilayer ceramic capacitors. Because of the self-resonant and high Q characteristics of some types of ceramic capacitors, a 1uF/50V ceramic capacitor is recommended for this bypass capacitor. A high voltage transient will be generated under some start-up conditions, such as connecting the charger input to a live power source.

Charge Current Soft-start

The WS4538Q includes a soft-start circuit to minimize the inrush current at the start of a charge cycle. When a charge cycle is initiated, the charge current ramps from zero to the full-scale current over a period of approximately 50us. This has the effect of minimizing the transient current load on the power supply during start-up.

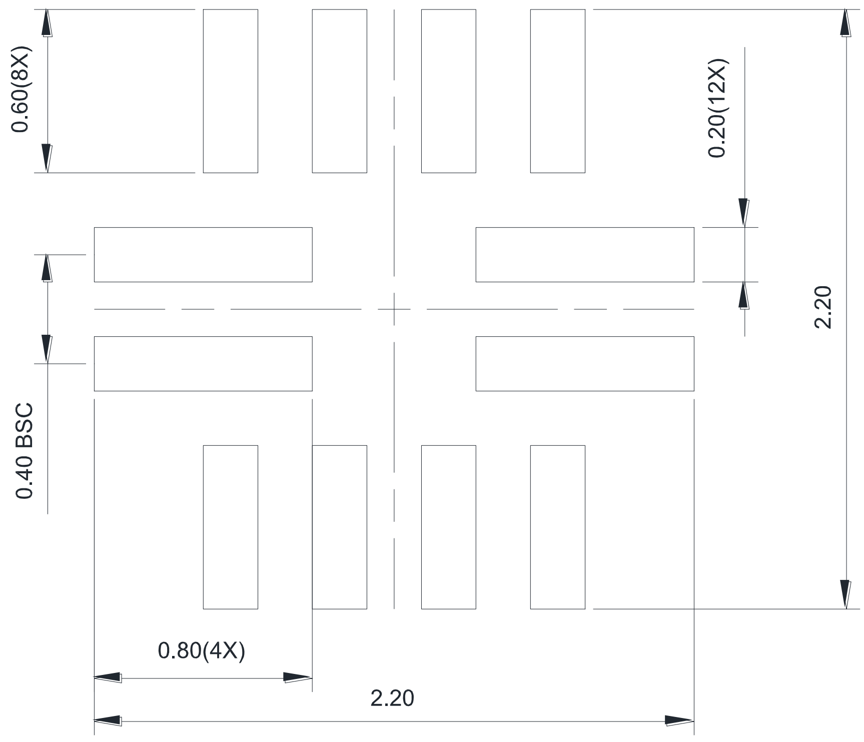
Package Outline Dimensions

QFN1616-12L



Symbol	Dimensions in Millimeters		
	Min.	Typ.	Max.
A	0.30	0.35	0.40
A1	0.00	0.02	0.05
A3	0.127 Ref.		
b	0.15	0.20	0.25
D	1.55	1.60	1.65
E	1.55	1.60	1.65
e	0.40 BSC		
L	0.25	0.30	0.35
L1	0.45	0.50	0.55

Recommend Land Pattern

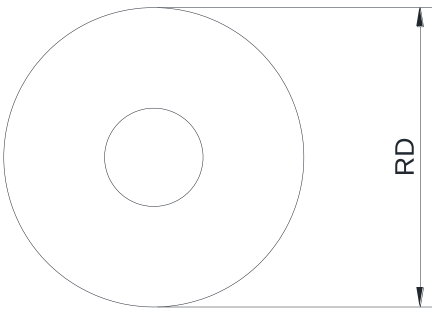


RECOMMENDED LAND PATTERN

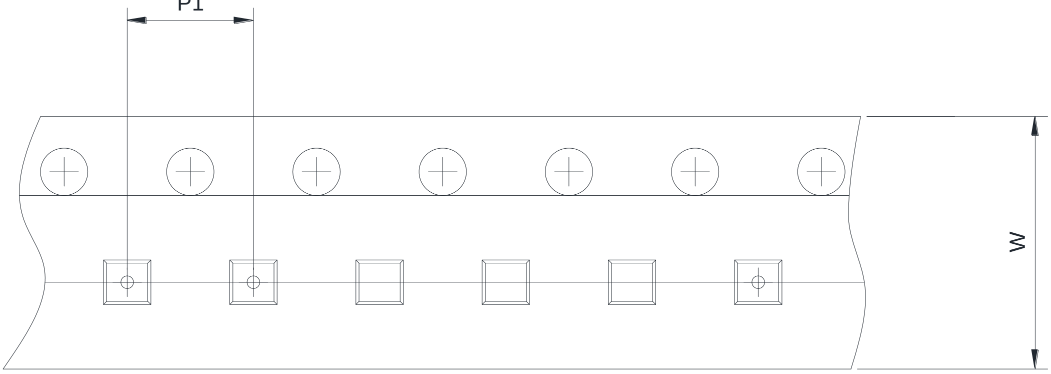
All dimensions are in millimeters

Tape and Reel Information

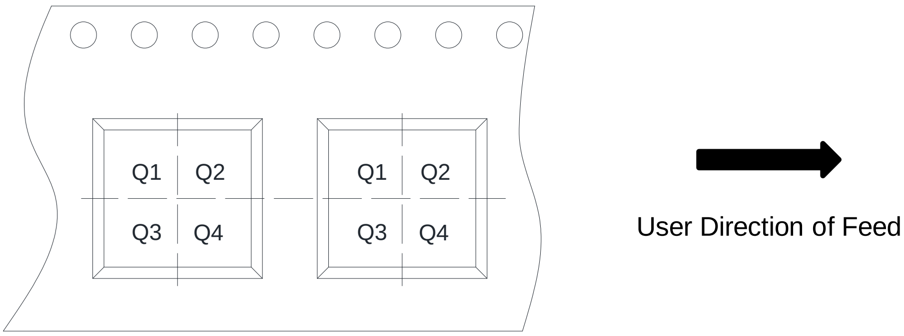
Reel Dimensions



Tape Dimensions



Quadrant Assignments For PIN1 Orientation In Tape



RD	Reel Dimension	☑ 7inch ☐ 13inch
W	Overall width of the carrier tape	☑ 8mm ☐ 12mm ☐ 16mm
P1	Pitch between successive cavity centers	☐ 2mm ☑ 4mm ☐ 8mm
Pin1	Pin1 Quadrant	☐ Q1 ☑ Q2 ☐ Q3 ☐ Q4