DESCRIPTION

The A4055 is a complete constant-current / constant-voltage linear charger for single cell lithium-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 high ambient temperature. The charge voltage is fixed at 4.2V, and the charge current can be programmed externally with a single resistor. The A4055 automatically terminates the charge cycle when the charge current drops to 1/10 the programmed value after the final float voltage is reached.

When the input supply (wall adapter or USB supply) is removed, the A4055 automatically enters a low current state, dropping the battery drain current to less than 2μA. The A4055 can be put into shutdown mode, reducing the supply current to 25μA. Other features include charge current monitor, under-voltage lockout, automatic recharge and a status pin to indicate charge termination and the presence of an input voltage.

The A4055 is available in SOT-25 Package

FEATURES

- Programmable Charge Current Up to 800mA
- No MOSFET, Sense Resistor or Blocking Diode Required
- Preset 4.2V Charge Voltage with ±1% Accuracy
- Charge Current Monitor Output for Gas Gauging
- Thermal Regulation Maximizes Charge Rate Without Risk of Overheating
- Charges Single Cell Li-Ion Batteries directly from USB Port
- Over-Voltage Protect
- Automatic Recharge
- Charge Status Output Pin
- C/10 Charge Termination
- 25μA Supply Current in Shutdown
- 2.9V Trickle Charge Threshold
- Soft-Start Limits Inrush Current
- Available in SOT-25 Package

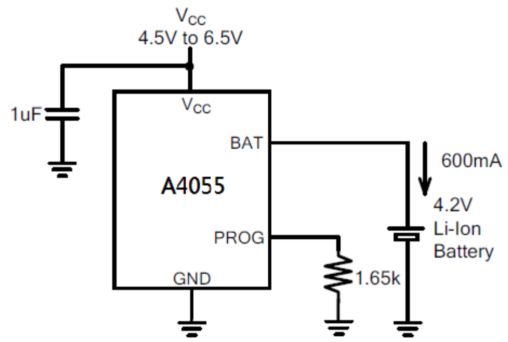
APPLICATION

- Cellular and Smart Phones
- Charging Docks and Cradles
- Blue Tooth Applications
- PDAs
- MP3/MP4/MP5 Players

ORDERING INFORMATION

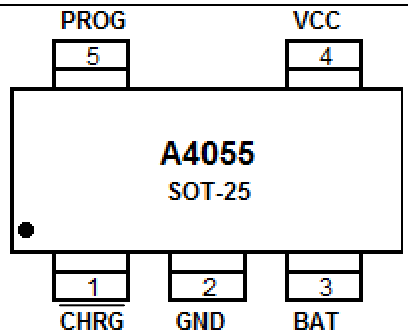
Package Type	Part Number	
SOT-25 SPQ: 3,000pcs/Reel	E5	A4055E5R
		A4055E5VR
Note	V: Halogen free package R: Tape & Reel	
AiT provides all RoHS products		

TYPICAL APPLICATION



600mA Application Circuit

PIN DESCRIPTION



Top View

Pin #	Symbol	Function
1	$\overline{CHRG}$	Open-Drain Charge Status Output. When the battery is charging, the $\overline{CHRG}$ pin is pulled low by an internal N-channel MOSFET. When the charge cycle is completed, a weak pull-down of approximately 12μA is connected to the $\overline{CHRG}$ pin, indicating an “AC present” condition. When the A4055 detects an under-voltage lockout condition, $\overline{CHRG}$ is forced high impedance.
2	GND	Ground.
3	BAT	Charge Current Output. Provides charge current to the battery and regulates the final float voltage to 4.2V. An internal precision resistor divider from this pin sets the float voltage which is disconnected in shutdown mode.
4	V_{CC}	Positive Input Supply Voltage. Provides power to the charger. V_{CC} can range from 4.25V to 6.5V and should be bypassed with at least a 1μF capacitor. When V_{CC} drops to within 30mV of the BAT pin voltage, the A4055 enters shutdown mode, dropping I_{BAT} to less than 2μA.
5	PROG	Charge Current Program, Charge Current Monitor and Shutdown Pin. The charge current is programmed by connecting a 1% resistor, R_{PROG}, to ground. When charging in constant-current mode, this pin servos to 1V. In all modes, the voltage on this pin can be used to measure the charge current using the following formula: $I_{BAT} = (V_{PROG}/R_{PROG}) \cdot 1000$ The PROG pin can also be used to shut down the charger. Disconnecting the program resistor from ground allows a 3μA current to pull the PROG pin high. When it reaches the 1.21V shutdown threshold voltage, the charger enters shutdown mode, charging stops and the input supply current drops to 25μA. This pin is also clamped to approximately 2.4V. Driving this pin to voltages beyond the clamp voltage will draw currents as high as 1.5mA. Reconnecting R_{PROG} to ground will return the charger to normal operation.

ABSOLUTE MAXIMUM RATINGS[NOTE1]

V_{CC} Input Supply Voltage	-0.3V to +10V
PROG Voltage	-0.3V to +V_{CC}
BAT Voltage	-0.3V to 7V
CHRG	-0.3V to 10V
BAT Short-Circuit Duration	Continuous
BAT Pin Current	800mA
PROG Pin Current	800μA
Maximum Junction Temperature	125°C
Operating Temperature Range [NOTE2]	-40°C to 85°C
Storage Temperature Range,	-65°C to 125°C
Lead Temperature (Soldering,10s)	300°C
Thermal Resistance [NOTE3]	
θ_{JA}, SOT-25	250°C/W
θ_{JC}, SOT-25	130°C/W

Stresses above 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 Electrical Characteristics are not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

NOTE1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

NOTE2: The A4055 is guaranteed to meet performance specifications from 0°C to 70°C. Specifications over the –40°C to 85°C operating temperature range are assured by design, characterization and correlation with statistical process controls.

NOTE3: Thermal Resistance is specified with approximately 1 square of 1 oz copper.

ELECTRICAL CHARACTERISTICS NOTE4

V_{CC}=5V, T_A= 25°C, unless otherwise noted

Parameter	Symbol	Conditions	Min	Typ.	Max	Unit
Charge Mode Supply Current NOTE5	$I_{SPLYCHRG}$	R_{PROG}=2kΩ	-	300	2000	µA
		R_{PROG}=10kΩ	-		2000	
Charge Mode Battery Current	$I_{BATCHRG}$	R_{PROG}=2kΩ	465	500	535	mA
		R_{PROG}=10kΩ	93	100	107	mA
PROG Pin Voltage	$V_{PROGCHRG}$	R_{PROG}=2kΩ	0.93	1	1.07	V
		R_{PROG}=10kΩ	0.93	1	1.07	V
Standby Mode Supply Current	$I_{SPLYSTBY}$		-	100	500	µA
Standby Mode Battery Current	$I_{BATSTBY}$		0	-2.5	-6	µA
Manual Shutdown Mode Supply Current	$I_{SPLYMSD}$		-	-	90	µA
Manual Shutdown Mode Battery Current	I_{BATMSD}		-2	0	2	µA
PROG Pin Clamp Voltage	$V_{PROGCLMP}$		2	-	3	V
Automatic Shutdown Mode Supply Current	$I_{SPLYASD}$		-	25	50	µA
Automatic Shutdown Mode Battery Current	I_{BATASD}		-2	0	2	µA
UVLO Mode Supply Current	$I_{SPLYUVLO}$		-	25	50	µA
UVLO Mode Battery Current	$I_{BATUVLO}$		-2	-	2	µA
Sleep Mode Battery Current	$I_{BATSLEEP}$		-1	-	1	µA
Float Voltage	V_{FLOAT}		4.158	4.2	4.242	V
Trickle Charge Current	I_{TRIKL}	R_{PROG}=2kΩ	20	50	70	mA
		R_{PROG}=10kΩ	5	10	15	mA
Trickle Charge Threshold	V_{TRIKL}		2.8	2.9	3	V
Trickle Charge Hysteresis	$V_{TRIKL, HYS}$		60	100	150	mV
UVLO Threshold	V_{UVLO}		3.7	3.9	4.1	V
UVLO Hysteresis	$V_{UVLO, HYS}$		150	200	300	mV
Input Over-Voltage Protect Threshold	V_{OVP}		6.8	7	7.2	V
Input Over-Voltage Protect Hysteresis	$V_{OVP, HYS}$		-	200	-	mV

Parameter	Symbol	Conditions	Min	Typ.	Max	Unit
Manual Shutdown Threshold, PROG rising	$V_{MSD, RISE}$		1.15	1.21	1.3	V
Manual Shutdown Threshold, PROG falling	$V_{MSD, FALL}$		0.95	1.0	1.05	V
Automatic Shutdown Threshold, BAT rising	$V_{ASD, RISE}$		5	30	50	mV
Automatic Shutdown Threshold, BAT falling	$V_{ASD, FALL}$		70	100	140	mV
C/10 Termination Current Threshold	I_{TERM}		85	100	115	mV
Auto Recharge Battery Voltage	V_{RECHRG}		4	4.05	4.1	V
CHRG Pin Weak Pull-down Current	I_{CHRG}		8	12	35	μA
CHRG Pin Output Low Voltage	V_{CHRG}		-	0.35	0.6	V
Junction Temperature In Constant Temperature Mode	T_{LIM}		-	120	-	°C
Power FET ON Resistance	R_{ON}		-	600	-	mΩ
Soft-Start Time	t_{SS}	R_{PROG}=2kΩ	-	50	-	μs
Recharge Comparator Filter Time	t_{RECHRG}		0.75	2	4.5	ms
Termination Comparator Filter Time	t_{TERM}		0.4	1	2.5	ms
PROG Pin Pull-up Current	I_{PROG}		-	3	-	μA

NOTE4: 100% production test at +25°C. Specifications over the temperature range are guaranteed by design and characterization.
NOTE5: Supply current includes PROG pin current (approximately 100μA) but does not include any current delivered to the battery through the BAT pin (approximately 100mA).

TYPICAL PERFORMANCE CHARACTERISTICS

Figure 1. PROG Pin Voltage vs. Supply Voltage (Constant Current Mode)

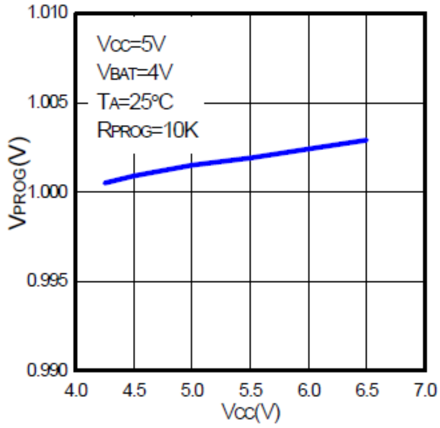


Figure 2. PROG Pin Voltage vs. Temperature

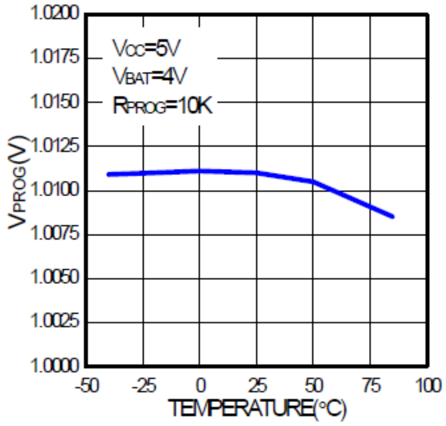


Figure 3. Charge Current vs. PROG Pin Voltage

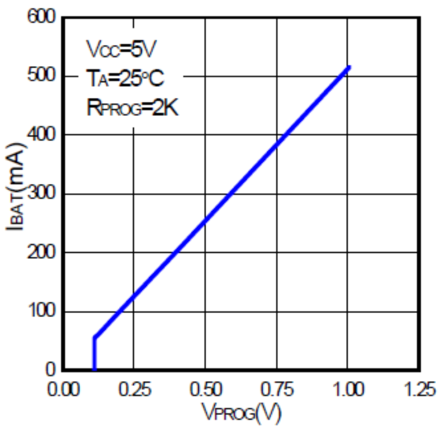


Figure 4. PROG Pin Pull-Up Current vs. Temperature and Supply Voltage

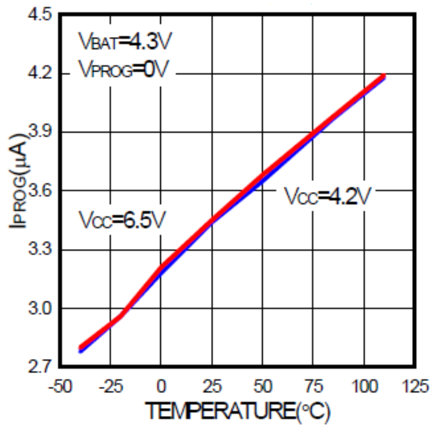


Figure 5. PROG Pin Current vs. PROG Pin Voltage (Pull-Up Current)

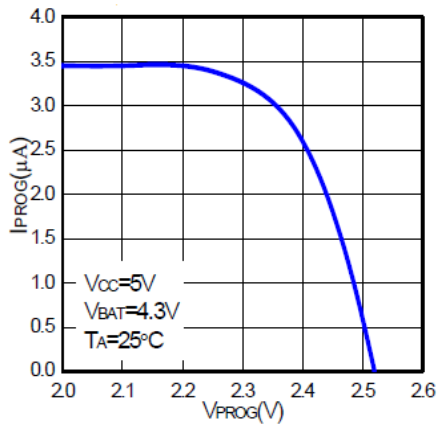


Figure 6. PROG Pin Current vs. PROG Pin Voltage (Clamp Current)

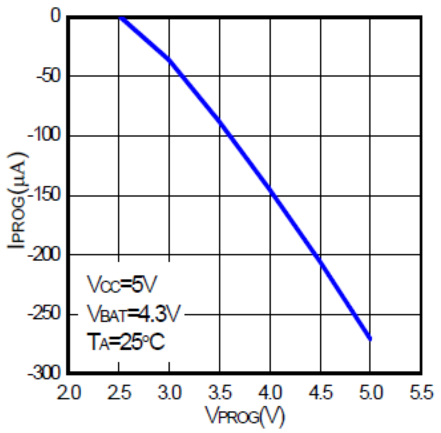


Figure 7. Regulated Output (Float) Voltage vs. Charge Current

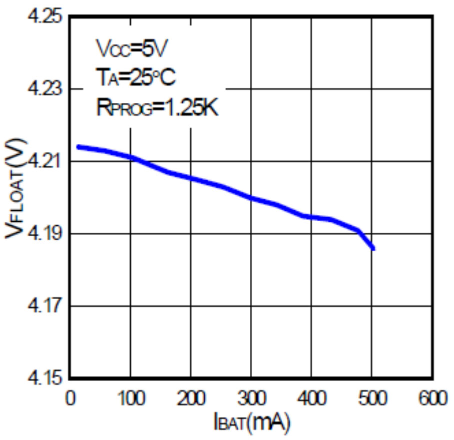


Figure 8. Regulated Output(Float) Voltage vs. Temperature

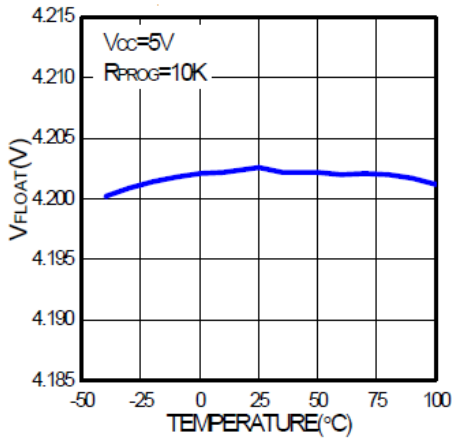


Figure 9. Regulated Output (Float) Voltage vs. Supply Voltage

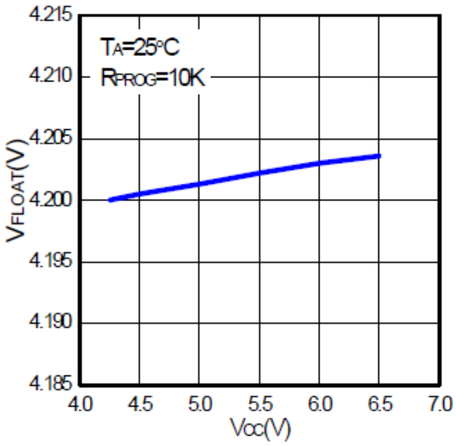


Figure 10. CHRG Pin I-V Curve (Strong Pull-Down State)

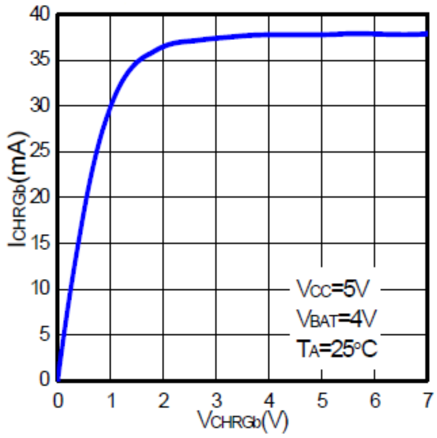


Figure 11. CHRG Pin Current vs. Temperature(Strong Pull-Down State)

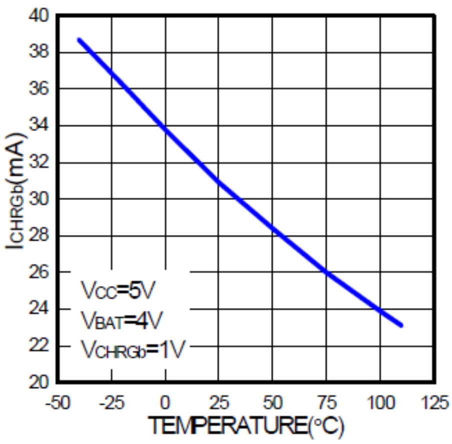


Figure 12. CHRG Pin I-V Curve (Weak Pull-Down State)

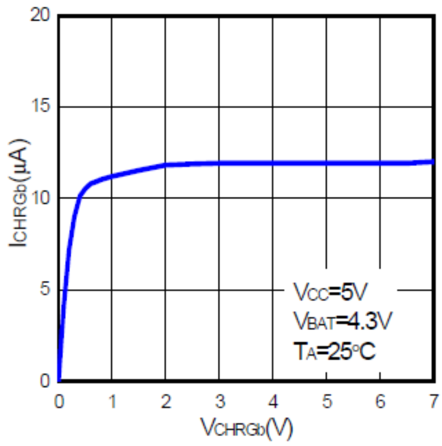


Figure 13. CHRG Pin Current vs. Temperature(Weak Pull-Down State)

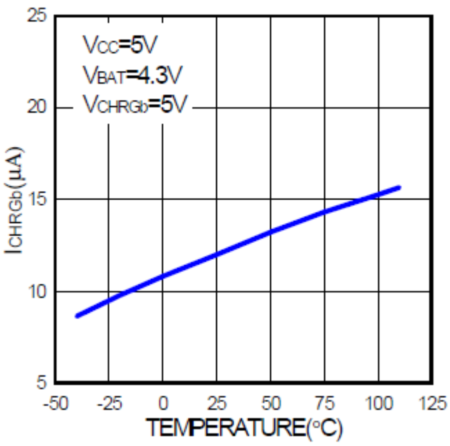


Figure 14. Trickle Charge Current vs. Temperature

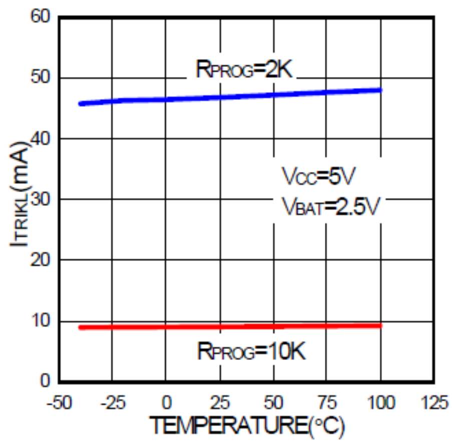


Figure 15. Trickle Charge Current vs. Supply Voltage

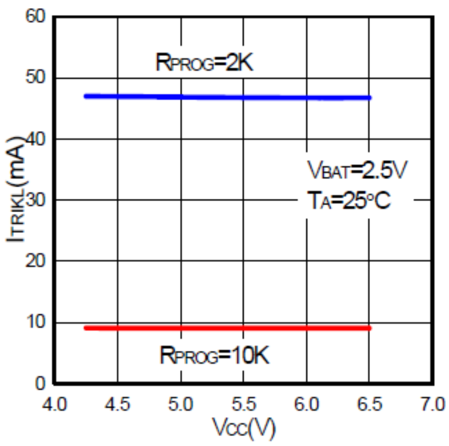


Figure 16. Trickle Charge Threshold vs. Temperature

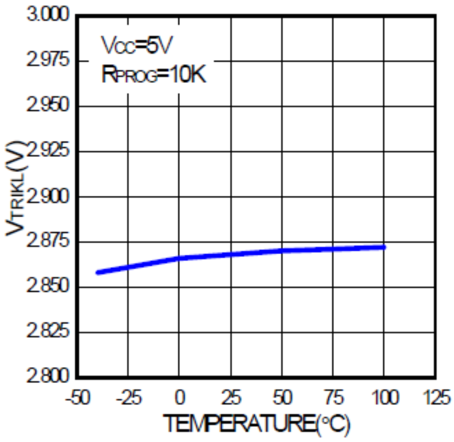


Figure 17. Charge Current vs. Battery Voltage

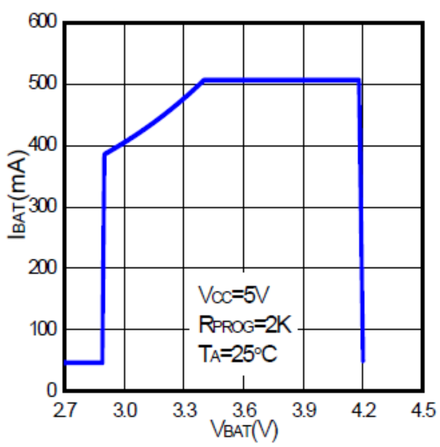


Figure 18. Charge Current vs. Supply Voltage

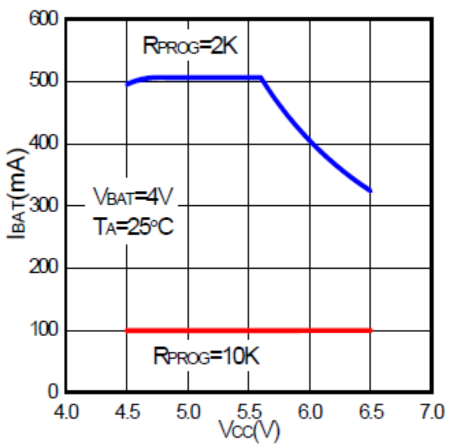


Figure 19. Charge Current vs. ambient Temperature

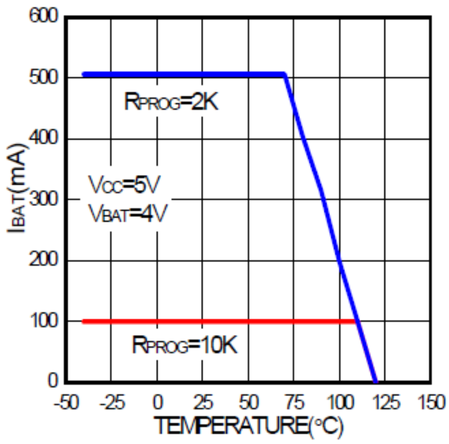


Figure 20. Recharge Voltage Threshold vs. Temperature

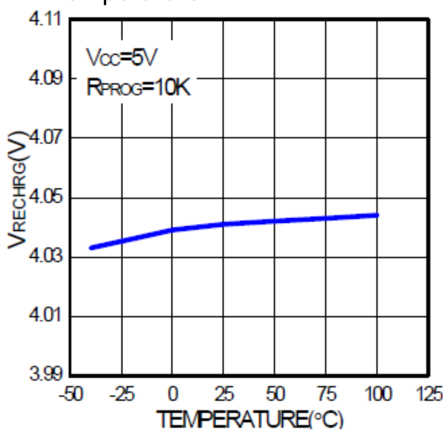
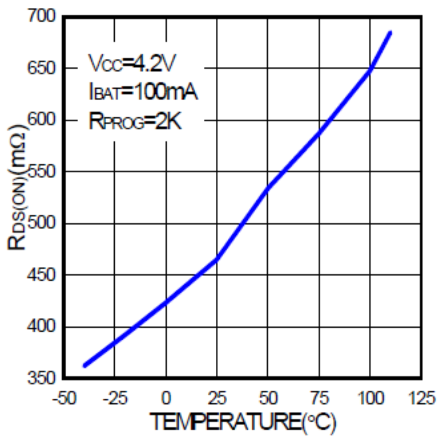
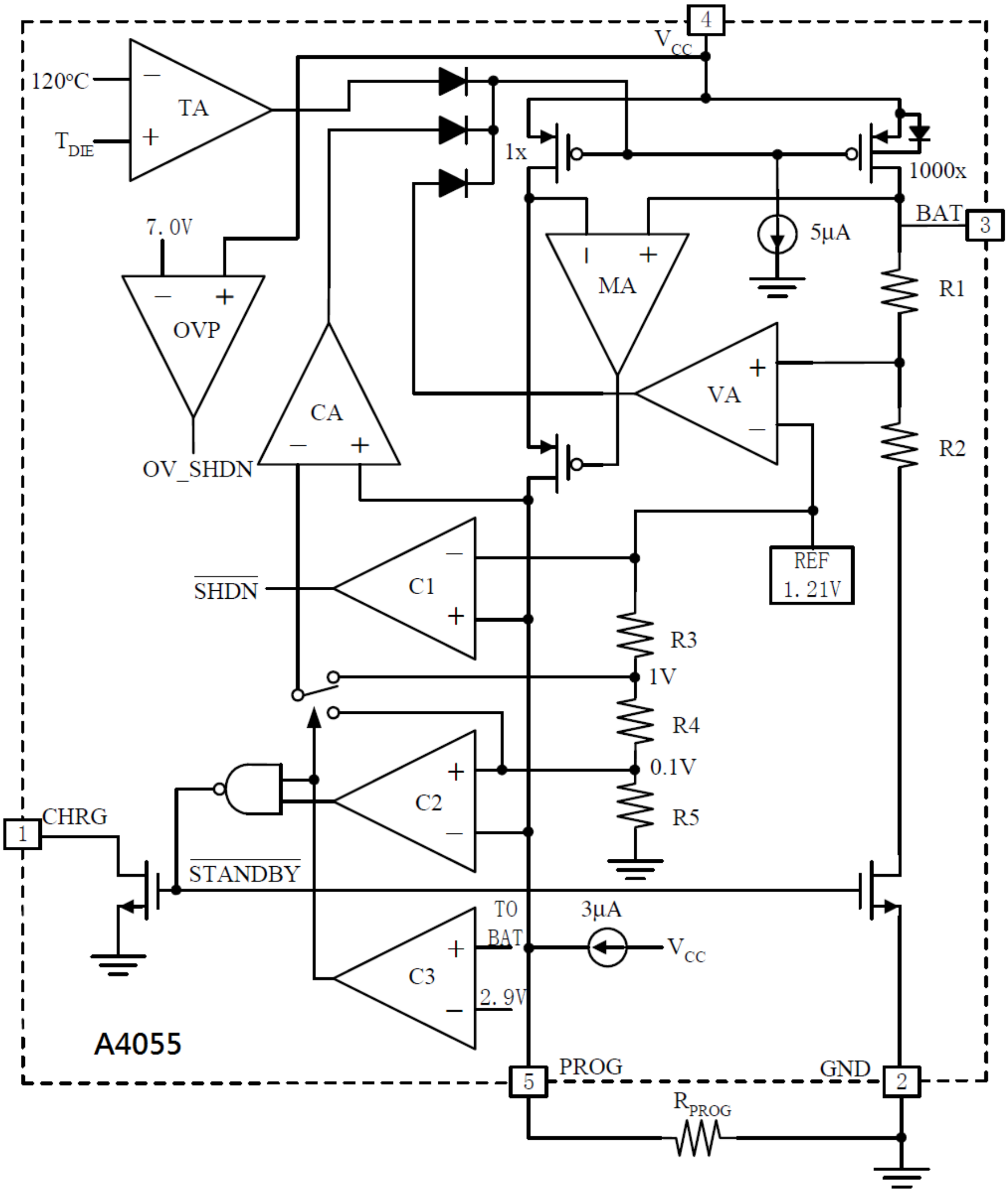


Figure 21. Power FET "ON" Resistance vs. Temperature

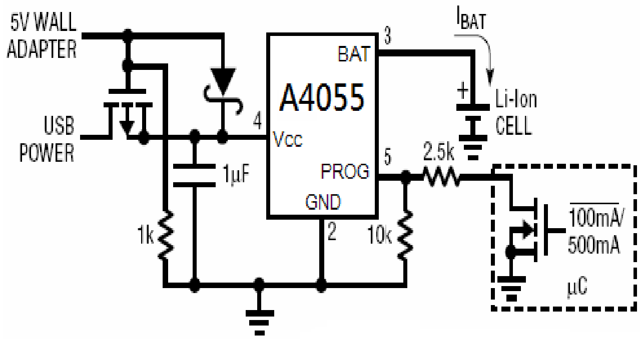


BLOCK DIAGRAM

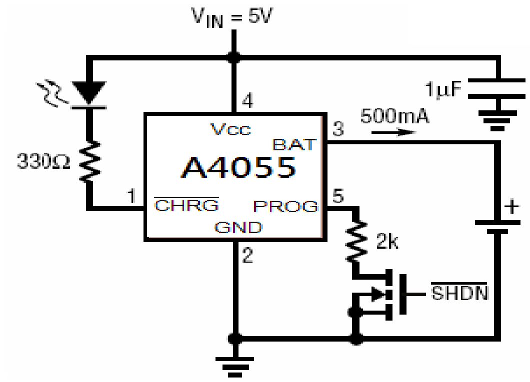


TYPICAL CIRCUIT

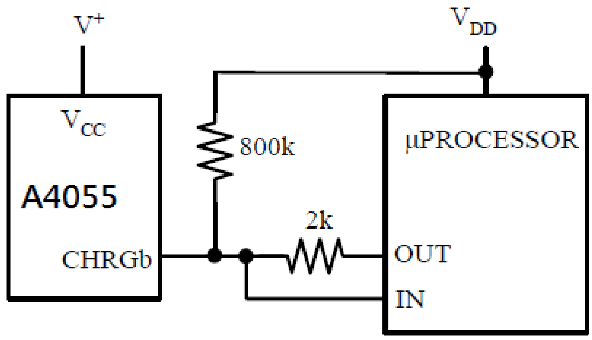
1. USB/Wall Adapter Power Li-Ion Charger



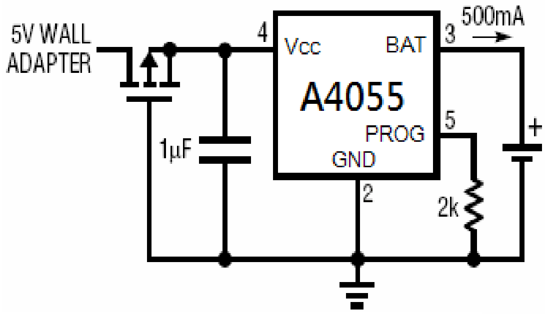
2. Full Featured Single Cell Li-Ion Charger



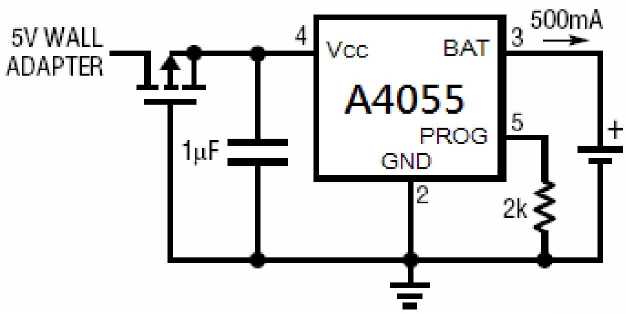
3. Using a Microprocessor to Determine CHRG State



4. Basic Li-Ion Charger with Reverse Polarity Input Protection



5. 800mA Li-Ion Charger with External Power Dissipation



DETAILED INFORMATION

The A4055 is a single cell Lithium-Ion battery charger using a constant-current / constant voltage algorithm. It can deliver up to 800mA of charge current (using a good thermal PCB layout) with a final float voltage accuracy of 1%. The A4055 includes an internal P-channel power MOSFET and thermal regulation circuitry. No blocking diode or external current sense resistor is required; thus, the basic charger circuit requires only two external components. Furthermore, the A4055 is capable of operating from a USB power source.

Normal Charge Cycle

A charge cycle begins when the voltage at the V_{CC} pin rises above the UVLO threshold level and a 1% program resistor is connected from the PROG pin to ground or when a battery is connected to the charger output. If the BAT pin is less than 2.9V, the charger enters trickle charge mode. In this mode, the A4055 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. If the battery voltage is above 2.9V at power-on, A4055 enters the constant-current mode immediately. Refer to Figure 1.

When the BAT pin approaches the final float voltage (4.2V), the A4055 enters constant-voltage mode and the charge current begins to decrease. When the charge current drops to 1/10 of the programmed value, the charge cycle ends.

Programming Charge Current

The charge current is programmed using a single resistor from the PROG pin to ground. The battery charge current is 1000 times the current out of the PROG pin. The program resistor and the charge current are calculated using the following equations:

$$R_{PROG} = \frac{1000V}{I_{CHG}} \qquad I_{CHG} = \frac{1000V}{R_{PROG}}$$

The charge current out of the BAT pin can be determined at any time by monitoring the PROG pin voltage using the following equation:

$$I_{BAT} = \frac{V_{PROG}}{R_{PROG}} \bullet 1000$$

Charge Termination

A charge cycle is terminated when the charge current falls to 1/10 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 A4055 enters standby mode, where the input supply current drops to 100µA. (Note: C/10 termination is disabled in trickle charging 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 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 the programmed value, the A4055 terminates the charge cycle and ceases to provide any current through the BAT pin. In this state, all loads on the BAT pin must be supplied by the battery.

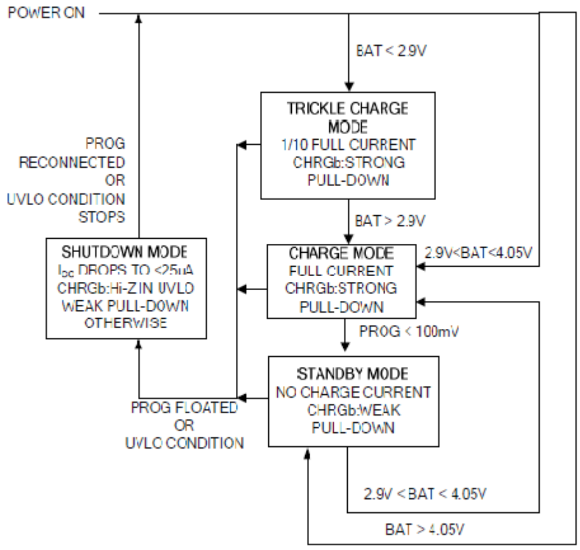


Figure1 State Diagram of A4055 Charge Cycle

Charge Status Indicator (CHRG)

The charge status output has three different states: strong pull-down (~10mA), weak pull-down (~12µA) and high impedance. The strong pull-down state indicates that the A4055 is in a charge cycle. Once the charge cycle has terminated, the pin state is deter-mined by under-voltage lockout conditions. A weak pull-down indicates that V_{CC} meets the UVLO conditions and the A4055 is ready to charge. High impedance indicates that the A4055 is in under-voltage lockout mode: either V_{CC} is less than 100mV above the BAT pin voltage or insufficient voltage is applied to the V_{CC} pin. A microprocessor can be used to distinguish between these three states—the application circuit of this method is shown in the Typical Applications section.

Manual Shutdown

At any point in the charge cycle, the A4055 can be put into shutdown mode by removing R_{PROG} thus floating the PROG pin. This reduces the battery drain current to less than 2μA and the supply current to less than 50μA. A new charge cycle can be initiated by reconnecting the program resistor.

In manual shutdown, the CHRG pin is in a weak pull-down state as long as V_{CC} is high enough to exceed the UVLO conditions. The CHRG pin is in a high impedance state if the A4055 is in under-voltage lockout mode: either V_{CC} is within 100mV of the BAT pin voltage or insufficient voltage is applied to the V_{CC} pin.

Over-Voltage Protect

The A4055 has an internal Over-Voltage Protect comparator, once the input voltage V_{CC} rises above 7V (V_{OVP}), this comparator will shut down the chip. This feature can pre-vent the A4055 from the over-voltage stress due to the input transient at hot plug in. In this state, the CHRG pin will be high impedance. Once the V_{CC} falls back to safe range (V_{OVP} - $V_{OVP,\ HYS}$), normal operation continues.

Automatic Recharge

Once the charge cycle is terminated, the A4055 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 4.05V (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. CHRG output enters a strong pull-down state during recharge cycles.

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 20k. However, additional capacitance on this node reduces the maximum allowed program resistor thus it should be avoided.

Average, rather than instantaneous, charge current may be of interest to the user. For example, if a switching power supply opera-ting in low current mode is connected in parallel with the battery, the average current being pulled out of the BAT pin is typically of more interest than the instantaneous current pulses. In such a case, a simple RC filter can be used on the PROG pin to measure the average battery current as shown in

Figure 2. A 10k resistor has been added between the PROG pin and the filter capacitor to ensure stability.

Thermal Limiting

An internal thermal feedback loop reduces the programmed charge current if the die temperature attempts to rise above a preset value of approximately 120°C. This feature protects the A4055 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 A4055. 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.

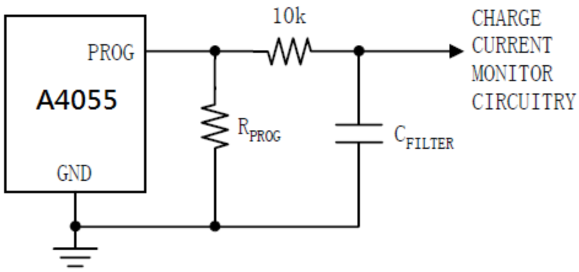


Figure 2. Isolating Capacitive Load on PROG Pin

Power Dissipation

The conditions that cause the A4055 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:

$$P_D = (V_{CC} - V_{BAT}) \bullet I_{BAT}$$

where PD is the power dissipated, V_{CC} is the input supply voltage, V_{BAT} is the battery voltage and I_{BAT} is the charge current. The approximate ambient temperature at which the thermal feedback begins to protect the IC is:

$$T_A = 120°C - P_D \bullet \theta_{JA}$$
$$T_A = 120°C - (V_{CC} - V_{BAT}) \bullet I_{BAT} \bullet \theta_{JA}$$

Example: An A4055 operating from a 5V USB supply is programmed to supply 400mA full-scale current to a discharged Li-Ion battery with a voltage of 3.75V. Assuming θ_{JA} is 150°C/W, the ambient temperature at which the A4055 will begin to reduce the charge current is approximately:

$$T_A = 120°C - (5V - 3.75V) \bullet 400mA \bullet 150°C / W$$

$$T_A = 45°C$$

The A4055 can be used above 45°C ambient, but the charge current will be reduced from 400mA. The approximate current at a given ambient temperature can be approximated by:

$$I_{BAT} = \frac{120°C - T_A}{(V_{CC} - V_{BAT}) \bullet \theta_{JA}}$$

Using the previous example with an ambient temperature of 60°C, the charge current will be reduced to approximately:

$$IBAT = \frac{120°C - 60°C}{(5V - 3.75V) \bullet 150°C / W} = 320mA$$

Moreover, when thermal feedback reduces the charge current, the voltage at the PROG pin is also reduced proportionally as discussed in the Operation section. It is important to remember that A4055 applications do not need to be designed for worst-case thermal conditions since the IC will automatically reduce power dissipation when the junction temperature reaches approximately 120°C.

Thermal Considerations

The small size of the SOT package, it is very important to use a good thermal PC board layout to maximize the available charge current. The thermal path for the heat generated by the IC is from the die to the copper lead frame, through the package leads, (especially the ground lead) to the PC board copper. The PC board copper is the heat sink. The footprint copper pads should be as wide as possible and expand out to larger copper areas to spread and dissipate the heat to the surrounding ambient. Feed-through vias to inner or backside copper layers are also useful in improving the overall thermal performance of the charger. Other heat sources on the board, not related to the charger, must also be considered when designing a PC board layout because they will affect overall temperature rise and the maximum charge current.

The following table lists thermal resistance for several different board sizes and copper areas.

All measurements were taken in still air on 3/32" FR-4 board with the device mounted on topside.

Table 1. Measured Thermal Resistance (2-Layer Board[NOTE6])

COPPER AREA		BOARD ARE	THERMAL RESISTANCE JUNCTION-TO-AMBIENT
TOPSIDE	BACKSIDE		
$2500mm^2$	$2500mm^2$	$2500mm^2$	125°C/W
$1000mm^2$	$2500mm^2$	$2500mm^2$	125°C/W
$225mm^2$	$2500mm^2$	$2500mm^2$	130°C/W
$100mm^2$	$2500mm^2$	$2500mm^2$	135°C/W
$50mm^2$	$2500mm^2$	$2500mm^2$	150°C/W

NOTE6: Each layer uses one ounce copper

Table 2. Measured Thermal Resistance (4-Layer Board[NOTE7])

COPPER AREA (EACH SIDE)	BOARD ARE	THERMAL RESISTANCE JUNCTION-TO-AMBIENT
$2500mm^2$ NOTE8	$2500mm^2$	80°C/W

NOTE7: Top and bottom layers use two ounce copper, inner layers use one ounce copper
NOTE8: $10,000mm^2$ total copper area

V_{CC} Bypass Capacitor

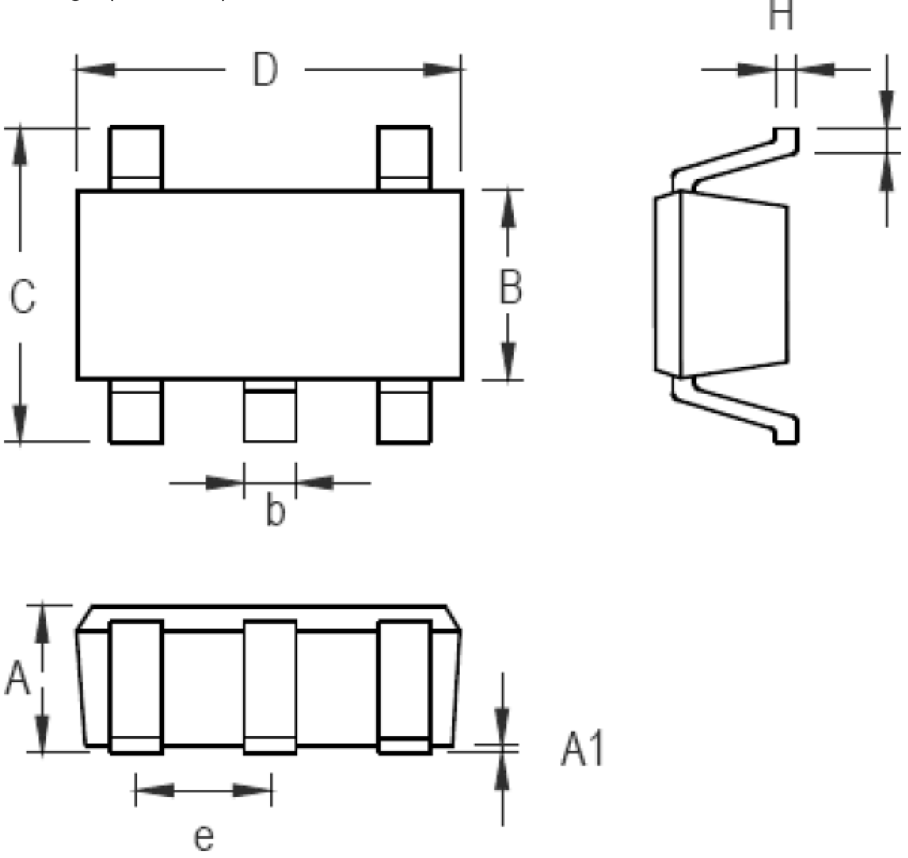
Many types of capacitors can be used for input bypassing, however, caution must be exercised when using multilayer ceramic capacitors. Because of the self-resonant and high Q characteristics of some types of ceramic capacitors, high voltage transients can be generated under some start-up conditions, such as connecting the charger input to a live power source. Adding a 1 Ω resistor in series with an X5R ceramic capacitor will minimize start-up voltage transients.

Charge Current Soft-Start

The A4055 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 50μs. This has the effect of minimizing the transient current load on the power supply during start-up.

PACKAGE INFORMATION

Dimension in SOT-25 Package (Unit: mm)



Symbol	Millimeters		Inches	
	Min	Max	Min	Max
A	0.889	1.295	0.035	0.051
A1	0.000	0.152	0.000	0.006
B	1.397	1.803	0.055	0.071
b	0.356	0.559	0.014	0.022
C	2.591	2.997	0.102	0.118
D	2.692	3.099	0.106	0.122
e	0.838	1.041	0.033	0.041
H	0.080	0.254	0.003	0.010
L	0.300	0.610	0.012	0.024

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