Standalone Linear Li-Ion Battery Charger

Features

- Constant-Current/Constant-Voltage Operation with Thermal Regulation to Maximize Charge Rate Without Risk of Overheating
- No MOSFET, Sense Resistor or Blocking Diode Required
- Complete Linear Charger in SOT Package for Single Cell Lithium-Ion Batteries
- Charges Single Cell Li-Ion Batteries Directly from USB Port
- Charge Current Monitor Output for Gas Gauging
- Automatic Recharge

- Charge Status Output Pin
- C/10 Charge Termination
- Programmable Charge Current Up to 500mA
- Preset 4.2V Charge Voltage with ±1% Accuracy
- 6.4V Input Over Voltage Protection
- 25µA Supply Current in Shutdown
- 2.9V Trickle Charge Threshold
- Soft-Start Limits Inrush Current
- Available in SOT23 Package
- RoHS Compliant and Lead (Pb) Free

Applications

- Cellular Telephones
- Charging Docks and Cradles

- Bluetooth Application
- Wearable Application

General Description

The RY4064 is a complete constant-current/constant-voltage linear charger for single cell lithium-ion batteries. Its SOT package and low external component count make the RY4064 ideally suited for portable applications. Furthermore, the RY4064 is specifically designed to work within USB power specifications.

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 RY4064 automatically terminates the charge cycle when the charge current drops to 1/10th the programmed value after the final float voltage is reached.

When the input supply (wall adapter or USB supply) is removed, the RY4064 automatically enters a low current state, dropping the battery drain current to less than 2µA. The RY4064 can be put into shutdown mode, reducing the supply current to 25µA. Other features include charge current monitor, undervoltage lockout, automatic recharge, and a status pin to indicate charge termination and the presence of an input voltage.
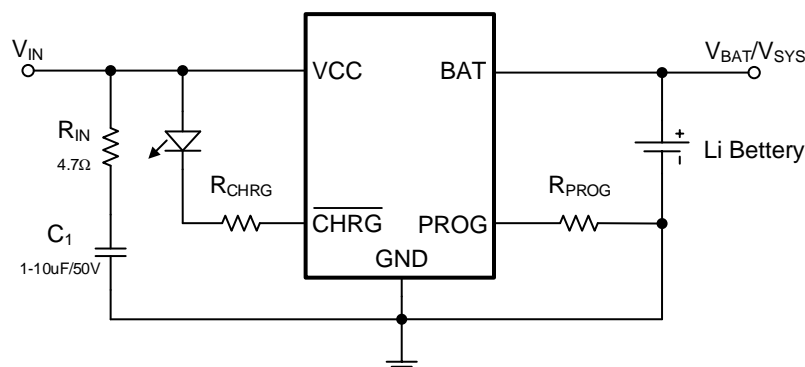
Typical Application Circuit

Figure 1. Typical Application Circuit

Standalone Linear Li-Ion Battery Charger

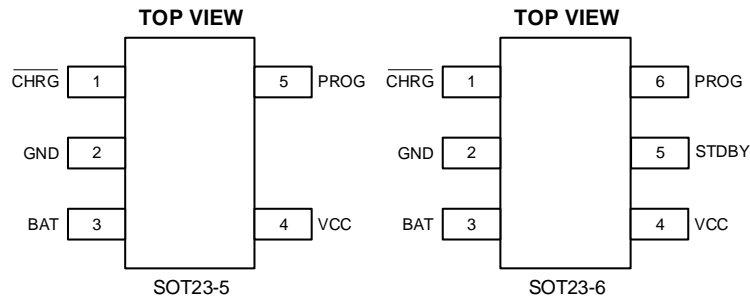## Pin Description

Pin Configuration

Figure 2. Pin Configuration

RY4064AT5 Top Marking: NG<u>YLL</u> (device code: NG, Y=year code, LL= lot number code)

RY4064AT6 Top Marking: NH<u>YLL</u> (device code: NH, Y=year code, LL= lot number code)

Pin Description

Pin	SOT23-5	SOT23-6	Function
CHRG	1	1	Open-Drain Charge Status Output Pin.
GND	2	2	Ground.
BAT	3	3	Charge Current Output Pin.
VCC	4	4	Positive Input Supply Voltage Pin.
STDBY	--	5	Charge terminated status output.
PROG	5	6	Charge Current Program, Charge Current Monitor and Shutdown Pin.

Order Information

Marking	Part No.	Model	Description	Package	T/R Qty
NG<u>YLL</u>	70705101	RY4064AT5	RY4064AT5 Linear Li-Ion Battery Charger, 4.3-30V, 500mA, Preset 4.2V, IQ 25μA, 1 Charge Status, SOT23-5	SOT23-5	3000 PCS
NH<u>YLL</u>	70705102	RY4064AT6	RY4064AT6 Linear Li-Ion Battery Charger, 4.3-30V, 500mA, Preset 4.2V, IQ 25μA, 1 Charge Status, SOT23-6	SOT23-6	3000 PCS

Note (1): All RYCHIP parts are Pb-Free and adhere to the RoHS directive.

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Specifications

Absolute Maximum Ratings [1] [2]

Item	Min	Max	Unit
VCC Input Voltage	-0.3	32	V
PROG Voltage	-0.3	VCC+0.3	V
BAT Voltage	-0.3	7	V
$\overline{CHRG}, \overline{STDBY}$ Voltage	-0.3	10	V
Power dissipation	Internally Limited		
Operating Junction Temperature, T_J	-40	150	°C
Storage Temperature, T_{stg}	–65	125	°C
Operating Temperature Range	-40	85	°C
Lead Temperature (Soldering, 10sec.)		260	°C

Note (1): Exceeding these ratings may damage the device.

Note (2): The device is not guaranteed to function outside of its operating conditions.

ESD Ratings

Item	Description	Value	Unit
$V_{(ESD-HBM)}$	Human Body Model (HBM) ANSI/ESDA/JEDEC JS-001-2014 Classification, Class: 2	±2000	V
$V_{(ESD-CDM)}$	Charged Device Model (CDM) ANSI/ESDA/JEDEC JS-002-2014 Classification, Class: C0b	±200	V
$I_{LATCH-UP}$	JEDEC STANDARD NO.78E APRIL 2016 Temperature Classification, Class: I	±150	mA

Recommended Operating Conditions

Item	Min	Max	Unit
Operating junction temperature [1]	–40	125	°C
Operating temperature range	-40	85	°C

Note (1): All limits specified at room temperature (TA = 25°C) unless otherwise specified. All room temperature limits are 100% production tested. All limits at temperature extremes are ensured through correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).

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Thermal Information

Item	Description	SOT23-5	SOT23-6	Unit
$R_{\theta JA}$	Junction-to-ambient thermal resistance [1][2]	180	105	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	130	55	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	45	17.5	°C/W
ψ_{JT}	Junction-to-top characterization parameter	35	3.5	°C/W
ψ_{JB}	Junction-to-board characterization parameter	45	17.5	°C/W

Note (1): The package thermal impedance is calculated in accordance to JESD 51-7.

Note (2): Thermal Resistances were simulated on a 4-layer, JEDEC board.

Electrical Characteristics [1] [2] [3]

$V_{CC} = 5$, TA = 25°C, unless otherwise noted.

Parameter	Symbol	Test Conditions	Min	Typ.	Max	Unit
Input Supply Voltage	V_{CC}		4.25		30	V
Input Over Voltage Protection				6.4		V
Input Supply Current	I_{CC}	Charge Mode (Note 4), R_{PROG} = 10k		300	2000	µA
		Standby Mode (Charge Terminated)		200	500	µA
		Shutdown Mode (R_{PROG} Not Connected, $V_{CC} < V_{BAT}$, or $V_{CC} < V_{UV}$)		25	50	µA
Regulated Output (Float) Voltage	V_{FLOAT}	0°C ≤ TA ≤ 85°C, I_{BAT} = 40mA	4.158	4.2	4.242	V
BAT Pin Current	I_{BAT}	R_{PROG} = 10k, Current Mode	93	100	107	mA
		R_{PROG} = 2k, Current Mode	465	500	535	mA
		Standby Mode, V_{BAT} = 4.2V	0	-2.5	-6	µA
		Shutdown Mode (R_{PROG} Not Connected)		±1	±2	µA
		Sleep Mode, V_{CC} = 0V		±1	±2	µA
Trickle Charge Current	I_{TRIKL}	$V_{BAT} < V_{TRIKL}$, R_{PROG} = 2k	20	45	70	mA
Trickle Charge Threshold Voltage	V_{TRIKL}	R_{PROG} = 10k, VBAT Rising	2.8	2.9	3.0	V
Trickle Charge Hysteresis Voltage	V_{TRHYS}	R_{PROG} = 10k	60	80	110	mV
V_{CC} Undervoltage Lockout Threshold	V_{UV}	From V_{CC} Low to High	3.7	3.8	3.92	V
V_{CC} Undervoltage Lockout Hysteresis	V_{UVHYS}		150	200	300	mV
Manual Shutdown Threshold Voltage	V_{MSD}	PROG Pin Rising	1.15	1.21	1.30	V
		PROG Pin Falling	0.9	1.0	1.1	V
$V_{CC} - V_{BAT}$ Lockout Threshold Voltage	V_{ASD}	V_{CC} from Low to High	70	100	140	mV
		V_{CC} from High to Low	5	30	50	mV

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C/10 Termination Current Threshold	I_{TERM}	R_{PROG} = 10k (Note 5)	0.085	0.10	0.115	mA/mA
		R_{PROG} = 2k	0.085	0.10	0.115	mA/mA
PROG Pin Voltage	V_{PROG}	R_{PROG} = 10k, Current Mode	0.93	1.0	1.07	V
$\overline{CHRG}$ Pin Weak Pull-Down Current	I_{CHRG}	V_{CHRG} = 5V	8	20	35	μA
$\overline{CHRG}$ Pin Output Low Voltage	V_{CHRG}	I_{CHRG} = 5mA		0.35	0.6	V
Recharge Battery Threshold Voltage Protection	ΔV_{RECHRG}	V_{FLOAT} - V_{RECHRG}	100	150	200	mV
Junction Temperature in Constant Temperature Mode	T_{LIM}			120		°C
Power FET "ON" Resistance (Between V_{CC} and BAT)	R_{ON}			600		mΩ
Soft-Start Time	T_{SS}	I_{BAT} = 0 to I_{BAT} =1000V/R_{PROG}		100		μS
Recharge Comparator Filter Time	$t_{RECHARGE}$	V_{BAT} High to Low	0.75	2	4.5	mS
Termination Comparator Filter Time	t_{TERM}	I_{BAT} Falling Below I_{CHG}/10	400	1000	2500	μS
PROG Pin Pull-Up Current	I_{PROG}			3		μA

Note (1): Absolute Maximum Ratings are those values beyond which the life of the device may be impaired.

Note (2): The RY4064 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.

Note (3): See Thermal Considerations.

Note (4): Supply current includes PROG pin current (approximately 100μA) but does not include any current delivered to the battery through the BAT pin (approximately 100mA).

Note (5): I_{TERM} is expressed as a fraction of measured full charge current with indicated PROG resistor.

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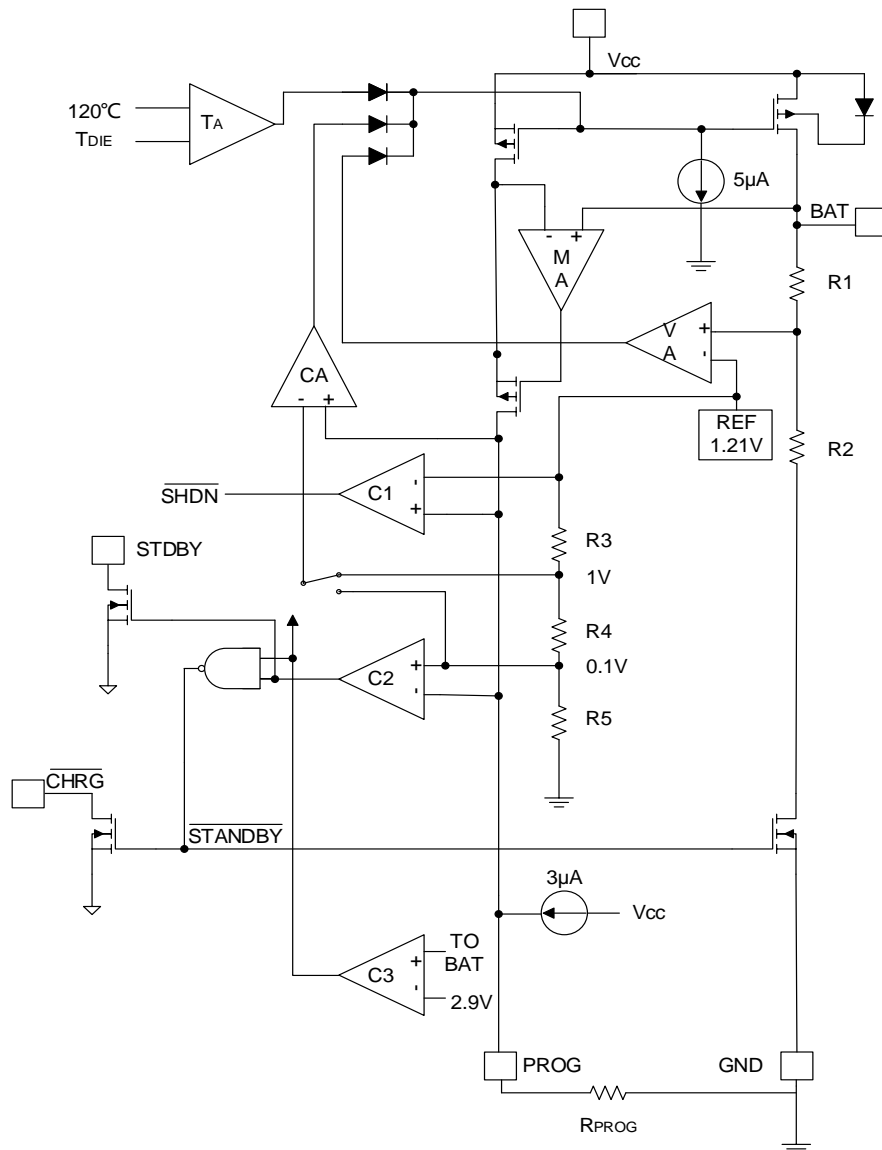
Functional Block Diagram

Figure 3. Functional Block Diagram

Functions Description

The RY4064 is a single cell lithium-ion battery charger using a constant-current/constant-voltage algorithm. It can deliver up to 500mA of charge current (using a good thermal PCB layout) with a final float voltage accuracy of ±1%. The RY4064 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 RY4064 can operate from a USB power source.

Normal Charge Cycle

A charge cycle begins when the voltage at the VCC 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 RY4064 supplies approximately 1/10 the programmed charge current to bring the battery voltage up to a safe level for full current charging.

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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 (4.2V), the RY4064 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:

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

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

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

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

Charge Termination

A charge cycle is terminated when the charge current falls to 1/10th 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 100mV1 for longer than t_{TERM} (typically 1ms), charging is terminated. The charge current is latched off and the RY4064 enters standby mode, where the input supply current drops to 200µA. (Note: C/10 termination is disabled in trickle charging and thermal limiting modes).

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 1/10th 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 1/10th the programmed value, the RY4064 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.

The RY4064 constantly monitors the BAT pin voltage in standby mode. If this voltage drops below the 4.05V recharge threshold (V_{RECHRG}), another charge cycle begins and current is once again supplied to the battery. To manually restart a charge cycle when in standby mode, the input voltage must be removed and reapplied, or the charger must be shut down and restarted using the PROG pin. Figure 4 shows the state diagram of a typical charge cycle.

Charge Status Indicator

RY4064 has two open-drain status indicator output $\overline{CHRG}$ pin and $\overline{STDBY}$ pin. $\overline{CHRG}$ pin is pull-down in a charge cycle. In other status, $\overline{CHRG}$ pin in high impedance. Both $\overline{CHRG}$ and $\overline{STDBY}$ are all in high impedance when the battery out of the normal temperature. $\overline{STDBY}$ bright after charge terminal, and is in high impedance state at other times. The $\overline{CHRG}$ pin has three different states: strong pull-down (~10mA), weak pull-down (~20µA)

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and high impedance. The strong pull-down state indicates that the RY4064 is in a charge cycle. Once the charge cycle has terminated, the pin state is determined by undervoltage lockout conditions. A weak pull-down indicates that VCC meets the UVLO conditions and the RY4064 is ready to charge. High impedance indicates that the RY4064 is in undervoltage lockout mode: either VCC is less than 100mV above the BAT pin voltage or insufficient voltage is applied to the VCC pin. A microprocessor can be used to distinguish between these three states—this method is discussed in the Applications Information section.
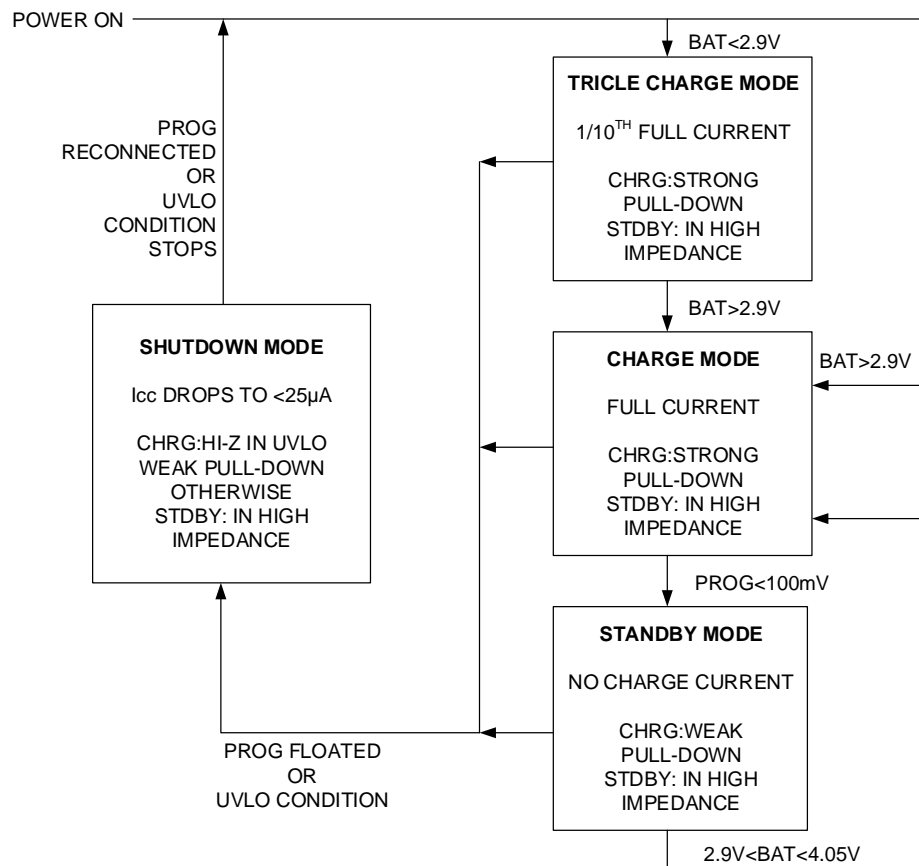
Figure 4. State Diagram of a Typical Charge Cycle

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 RY4064 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 RY4064. 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.

Undervoltage Lockout (UVLO)

An internal undervoltage lockout circuit monitors the input voltage and keeps the charger in shutdown mode until VCC rises above the undervoltage lockout threshold. The UVLO circuit has a built-in hysteresis of 200mV. Furthermore, to protect against reverse current in the power MOSFET, the UVLO circuit keeps the charger in shutdown mode if VCC falls to within 30mV of the battery voltage. If the UVLO comparator is tripped, the charger will not come out of shutdown mode until VCC rises 100mV above the battery voltage.

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Manual Shutdown

At any point in the charge cycle, the RY4064 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 $\overline{CHRG}$ pin is in a weak pull-down state if VCC is high enough to exceed the UVLO conditions. The $\overline{CHRG}$ pin is in a high impedance state if the RY4064 is in undervoltage lockout mode: either VCC is within 100mV of the BAT pin voltage or insufficient voltage is applied to the VCC pin.

Automatic Recharge

Once the charge cycle is terminated, the RY4064 continuously monitors the voltage on the BAT pin using a comparator with a 2ms filter time ($t_{RECHARGE}$). 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. $\overline{CHRG}$ output enters a strong pulldown state during recharge cycles.

Typical Application

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. The pole frequency at the PROG pin should be kept above 100kHz. Therefore, if the PROG pin is loaded with a capacitance, C_{PROG}, the following equation can be used to calculate the maximum resistance value for R_{PROG}:

$$R_{PROG} \leq \frac{1}{2\pi \cdot 10^5 \cdot C_{PROG}}$$

Average, rather than instantaneous, charge current may be of interest to the user. For example, if a switching power supply operating 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 5. A 10k resistor has been added between the PROG pin and the filter capacitor to ensure stability.
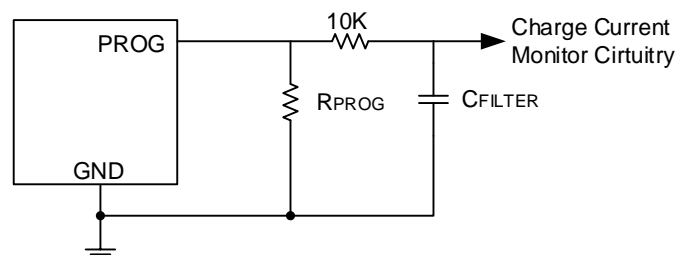
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Figure 5. Isolating Capacitive Load on PROG Pin and Filtering

Power Dissipation

The conditions that cause the RY4064 to reduce charge current through thermal feedback can be approximated by considering the power dissipated in the IC. Nearly all this power dissipation is generated by the internal MOSFET—this is calculated to be approximately:

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

where P$_D$ is the power dissipated, VCC is the input supply voltage, VBAT is the battery voltage and IBAT is the charge current. The approximate ambient temperature at which the thermal feedback begins to protect the IC is:

$$T_A = 120°C - P_D \theta_{JA}$$

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

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 RY4064 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.

Charge Current Soft-Start

The RY4064 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 100µs. This has the effect of minimizing the transient current load on the power supply during start-up.

$\overline{CHRG}$ Status Output Pin

The $\overline{CHRG}$ pin can provide an indication that the input voltage is greater than the undervoltage lockout threshold level. A weak pull-down current of approximately 20µA indicates that sufficient voltage is applied to VCC to begin charging. When a discharged battery is connected to the charger, the constant current portion of the charge cycle begins and the $\overline{CHRG}$ pin pulls to ground. The $\overline{CHRG}$ pin can sink up to 10mA to drive an LED that indicates that a charge cycle is in progress. When the battery is nearing full charge, the charger enters the constant-voltage portion of the charge cycle and the charge current begins to drop. When the charge current drops below 1/10 of the programmed current, the charge cycle ends and the strong pull-down is replaced by the 20µA pull-down, indicating that the charge cycle has ended. If the input voltage is removed or drops below the undervoltage lockout threshold, the $\overline{CHRG}$ pin becomes high impedance. Figure 6 shows that by using two different value pull-up resistors, a microprocessor can detect all three states from this pin. To detect when the RY4064 is in charge mode, force the digital output pin (OUT) high and measure the voltage at the $\overline{CHRG}$ pin. The N-channel MOSFET will pull the pin voltage low even with the 2k pull-up resistor. Once the charge cycle terminates, the N-channel MOSFET is turned off and a 20µA current source is connected to the $\overline{CHRG}$ pin. The IN pin will then be pulled high by the 2k pull-up resistor. To determine if there is a weak pull-down current, the OUT pin should be forced to a high impedance state. The weak current source will pull the IN-pin low through the 800k resistor; if $\overline{CHRG}$ is high impedance, the IN pin will be pulled high, indicating that the part is in a UVLO state.
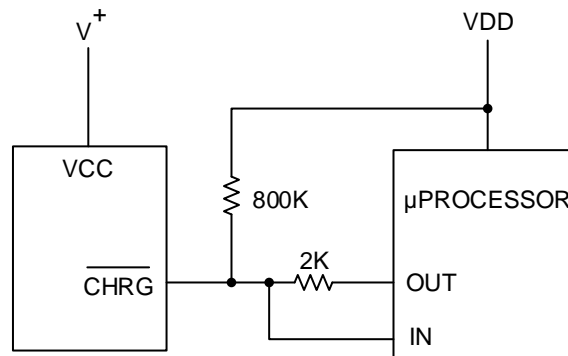
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Figure 6. Using a Microprocessor to Determine CHRG State

Reverse Polarity Input Voltage Protection

In some applications, protection from reverse polarity voltage on VCC is desired. If the supply voltage is high enough, a series blocking diode can be used. In other cases, where the voltage drop must be kept low a P-channel MOSFET can be used (as shown in Figure 7).
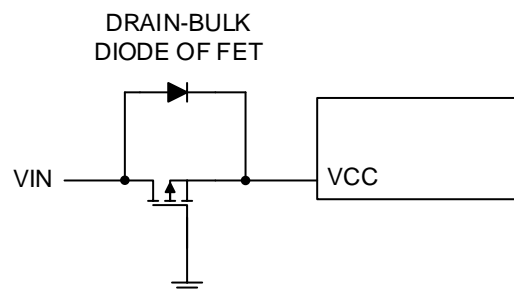

Figure 7. Low Loss Input Reverse Polarity Protection

USB and Wall Adapter Power

The RY4064 allows charging from both a wall adapter and a USB port. Figure 8 shows an example of how to combine wall adapter and USB power inputs. A P-channel MOSFET, MP1, is used to prevent back conducting into the USB port when a wall adapter is present and a Schottky diode, D1, is used to prevent USB power loss through the 2k pull-down resistor. Typically, a wall adapter can supply more current than the 500mA-limited USB port. Therefore, an N-channel MOSFET, MN1, and an extra 10k program resistor are used to increase the charge current to 600mA when the wall adapter is present.
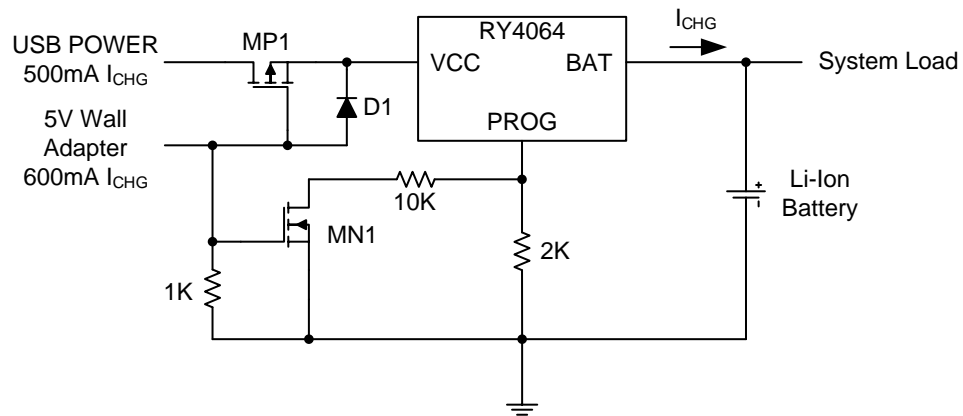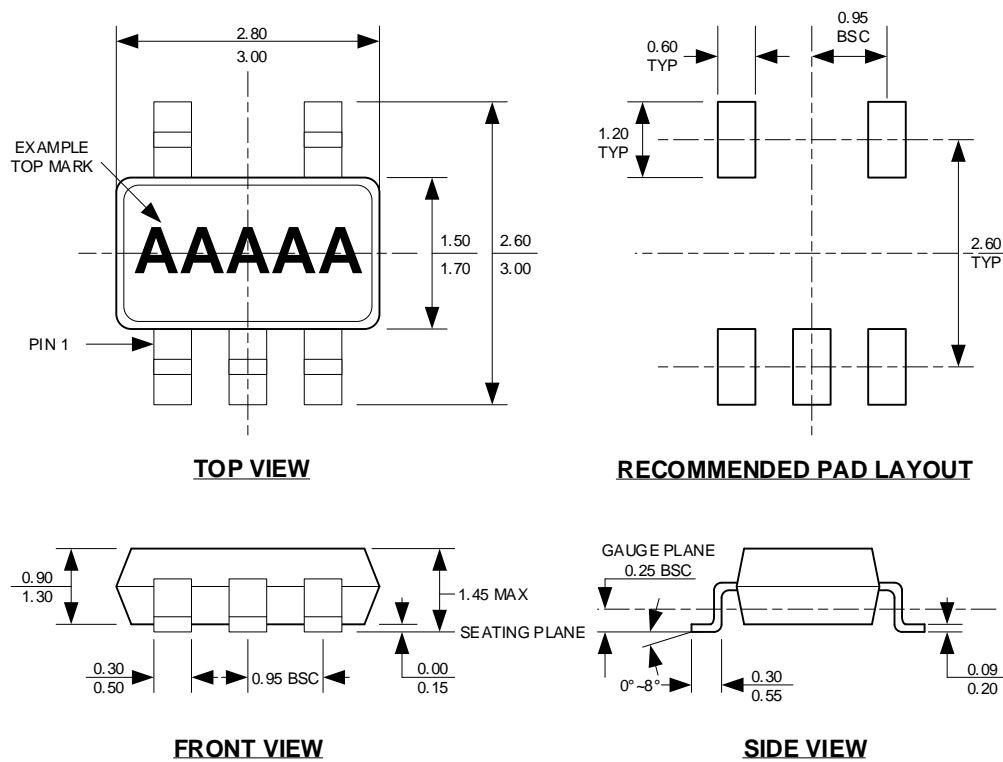
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Figure 8. USB and Wall Adapter Power

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Package Description

SOT23-5

TOP VIEW

EXAMPLE TOP MARK

AAAAA

PIN 1

2.80 / 3.00

1.50 / 1.70

2.60 / 3.00

RECOMMENDED PAD LAYOUT

0.60 TYP

0.95 BSC

1.20 TYP

2.60 TYP

FRONT VIEW

0.90 / 1.30

1.45 MAX

SEATING PLANE

0.30 / 0.50

0.95 BSC

0.00 / 0.15

SIDE VIEW

GAUGE PLANE
0.25 BSC

0°~8°

0.30 / 0.55

0.09 / 0.20

NOTE:
1. CONTROL DIMENSION IS IN INCHES. DIMENSION IN BRACKET IS IN MILLIMETERS.
2. PACKAGE LENGTH DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.
3. PACKAGE WIDTH DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.
4. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.004" INCHES MAX.
5. DRAWING CONFORMS TO JEDEC MS-012, VARIATION BA.
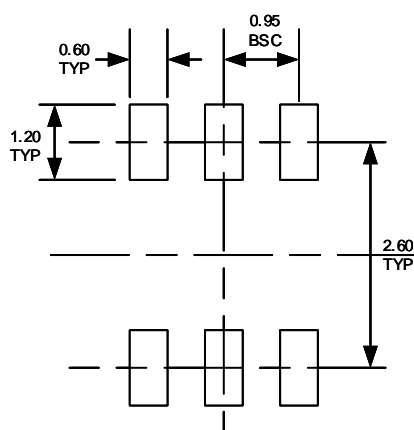6. DRAWING IS NOT TO SCALE.

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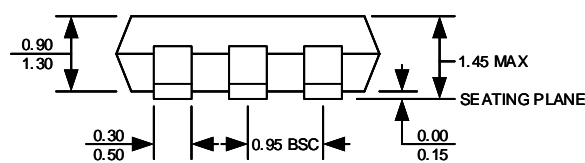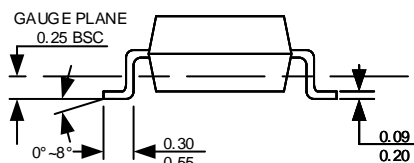
Package Description

SOT23-6
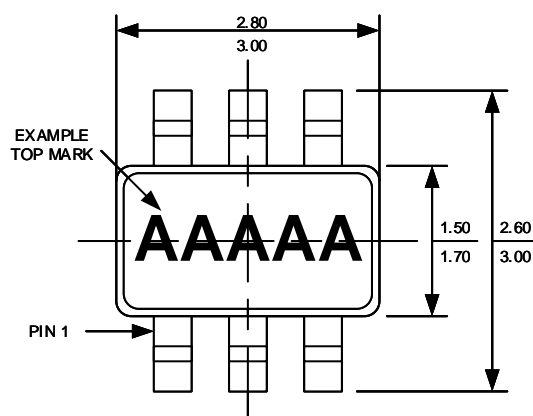
TOP VIEW

RECOMMENDED PAD LAYOUT

FRONT VIEW

SIDE VIEW

NOTE:
1. CONTROL DIMENSION IS IN INCHES. DIMENSION IN BRACKET IS IN MILLIMETERS.
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