

MAXIM

Advanced Lithium-Ion Battery-Pack Protector

MAX1666A/S/V/X

General Description

The MAX1666 provides complete protection against over-voltage, undervoltage, overcharge current, overdischarge current, and cell mismatch for 2-cell to 4-cell lithium-ion (Li+) battery packs. The voltage of each cell in the battery pack is checked and compared to the programmable threshold and to the other cells in the pack.

The MAX1666 protects the battery pack in an overcurrent condition by disconnecting the pack from the load at a programmable limit. On-chip power MOSFET drivers control external P-channel MOSFETs to disconnect the cells from external terminals when faults occur.

The MAX1666 employs a unique timing scheme that allows three modes of operation for optimal performance and battery power conservation. The MAX1666 can operate in a stand-alone configuration or in conjunction with a microcontroller. It is available in four versions: the S version monitors two Li+ cells, the A and V versions monitor three cells, and the X version monitors four cells. When the charge path is disabled by the charge control pin, the MAX1666A reduces current consumption compared to the MAX1666S/V/X.

Features

- ◆ **Overvoltage Protection**
Programmable Limits from +4.0V to +4.4V
Accurate to $\pm 0.5\%$
- ◆ **Undervoltage Protection**
Programmable Limits from +2.0V to +3.0V
Accurate to $\pm 2.5\%$
- ◆ **Cell Mismatch Protection**
Programmable Limits from 0 to 500mV
Accurate to $\pm 10\%$
- ◆ **Overcharge Current Protection**
- ◆ **Overdischarge Current Protection**
- ◆ **Low 30 μ A (typ) Operating Supply Current**
- ◆ **Low 1 μ A (max) Standby Current**
- ◆ **+28V (max) Input Voltage**
- ◆ **Available in Small 16-Pin QSOP (MAX1666S) and 20-Pin QSOP (MAX1666A/V/X) Packages**

Applications

2/3/4-Cell Lithium-Ion Battery Pack

Selector Guide

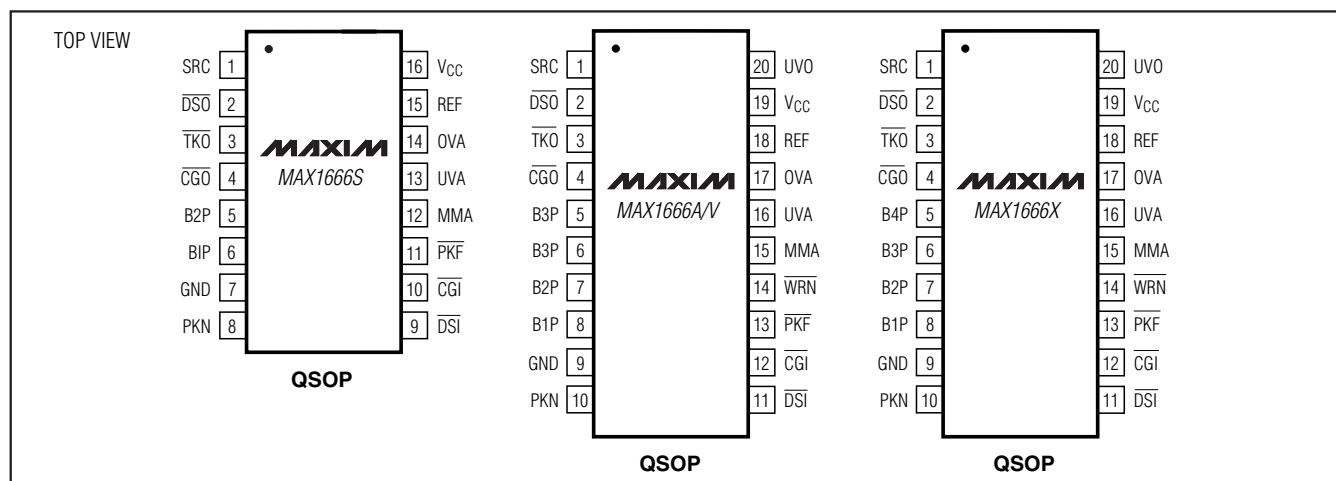
| PART | NUMBER OF Li+ CELLS |
|------------|---------------------|
| MAX1666S | 2 |
| MAX1666A/V | 3 |
| MAX1666X | 4 |

Typical Operating Circuits appear at end of data sheet.

Ordering Information

| PART | TEMP RANGE | PIN-PACKAGE |
|-------------|----------------|-------------|
| MAX1666SEEE | -40°C to +85°C | 16 QSOP |
| MAX1666AEPP | -40°C to +85°C | 20 QSOP |
| MAX1666VEEP | -40°C to +85°C | 20 QSOP |
| MAX1666XEEP | -40°C to +85°C | 20 QSOP |

Pin Configurations



MAXIM

Maxim Integrated Products 1

For pricing, delivery, and ordering information, please contact Maxim/Dallas Direct! at 1-888-629-4642, or visit Maxim's website at www.maxim-ic.com.

Advanced Lithium-Ion Battery-Pack Protector

ABSOLUTE MAXIMUM RATINGS

SRC, $\overline{\text{DSO}}$, $\overline{\text{TKO}}$, $\overline{\text{CGO}}$, UVO, PKF, $\overline{\text{WRN}}$ to GND ... -0.3V to +28V
 VCC, REF, OVA, UVA, MMA to GND -0.3V to +6V
 B4P to B3P -0.3V to +6V
 B3P to B2P -0.3V to +6V
 B2P to B1P -0.3V to +6V
 B1P to GND -0.3V to +6V
 PKN to GND $\pm 2\text{V}$

VCC, $\overline{\text{CGI}}$, $\overline{\text{DSI}}$ to PKN -0.3V to +6V
 Continuous Power Dissipation ($T_A = +70^\circ\text{C}$)
 16-Pin QSOP (derate 8.3mW/ $^\circ\text{C}$ above $+70^\circ\text{C}$) 667mW
 20-Pin QSOP (derate 9.1mW/ $^\circ\text{C}$ above $+70^\circ\text{C}$) 727mW
 Operating Temperature Range -40°C to $+85^\circ\text{C}$
 Storage Temperature Range -65°C to $+150^\circ\text{C}$
 Lead Temperature (soldering, 10s) $+300^\circ\text{C}$

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.

ELECTRICAL CHARACTERISTICS

($V_{\text{SRC}} = 16\text{V}$, each cell voltage $V_{\text{CELL}} = 3.6\text{V}$, 330k Ω load at REF, $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$, unless otherwise noted. Typical values are at $T_A = +25^\circ\text{C}$.)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|------------------------------------|-------------------|---|---------------------------------------|-------|-------|-------|---------------|
| Charge-Mode Detection Threshold | | $V_{\text{SRC}} - V_{\text{B_P}}$ | | 1 | | | V |
| SRC Supply Current | | $V_{\text{SRC}} - V_{\text{B_P}} = 1\text{V}$, $V_{\text{CGI}} = V_{\text{DSI}} = \text{GND}$ | | | 2 | 10 | μA |
| | | MAX1666A only, $V_{\text{SRC}} - V_{\text{B3P}} = 1\text{V}$, $V_{\text{CGI}} = 3\text{V}$, $V_{\text{DSI}} = \text{GND}$ | | | 2 | 5 | |
| | | MAX1666A only, $V_{\text{SRC}} - V_{\text{B3P}} = 1\text{V}$, $V_{\text{DSI}} = 3\text{V}$, $V_{\text{CGI}} = \text{GND}$ | | | 2 | 5 | |
| Supply Current | I_{SUP} | No faults, long-time average current from the top battery terminal B_P | | | 30 | 45 | μA |
| Shutdown Supply Current | I_{SHDN} | | | | | 1 | μA |
| VCC Output Voltage | VCC | $R_{\text{LOAD}} \geq 665\Omega$, $2\text{V} < V_{\text{CELL}} < 4.4\text{V}$ | | 3.09 | 3.25 | 3.41 | V |
| VCC Undervoltage-Lockout Threshold | | | | 2.7 | 2.85 | 3.0 | V |
| Reference Output Voltage | VREF | Pulse on | | | 1.221 | | V |
| Overvoltage Threshold | | Cell voltage rising | OVA = GND | 3.980 | 4.000 | 4.020 | V |
| | | | $V_{\text{OVA}} = V_{\text{REF}} / 2$ | | 4.2 | | |
| | | | OVA = REF | 4.378 | 4.400 | 4.422 | |
| Overvoltage-Threshold Hysteresis | | | | | 200 | | mV |
| Undervoltage Threshold | | Cell voltage falling | UVA = GND | 1.950 | 2.000 | 2.050 | V |
| | | | $V_{\text{UVA}} = V_{\text{REF}} / 2$ | | 2.500 | | |
| | | | UVA = REF | 2.925 | 3.000 | 3.075 | |
| Undervoltage-Threshold Hysteresis | | | | | 100 | | mV |

Advanced Lithium-Ion Battery-Pack Protector

MAX1666A/S/V/X

ELECTRICAL CHARACTERISTICS (continued)

($V_{SRC} = 16V$, each cell voltage $V_{CELL} = 3.6V$, 330k Ω load at REF, $T_A = 0^{\circ}C$ to $+85^{\circ}C$, unless otherwise noted. Typical values are at $T_A = +25^{\circ}C$.)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS | |
|--|--------------|---|-------------------------|-----------|-----------|-----------|------------|---|
| \overline{WRN} Early-Warning Threshold | | Above undervoltage threshold, cell voltage falling | | 100 | | | mV | |
| \overline{WRN} Early-Warning-Threshold Hysteresis | | | | 200 | | | mV | |
| OVA, UVA, MMA Input Current | | OVA, UVA, MMA = REF | | 0.1 | 20 | | nA | |
| Cell Mismatch Threshold | | All cells > 2V | MMA = GND | ± 0 | | | mV | |
| | | | $V_{MMA} = V_{REF} / 2$ | ± 250 | | | | |
| | | | MMA = REF | ± 450 | ± 500 | ± 550 | | |
| PKN to GND Overdischarge-Current Threshold | | | | 270 | 300 | 330 | mV | |
| PKN to GND Overcharge-Current Threshold | | | | -220 | -200 | -180 | mV | |
| Overcurrent Fault-Timer Delay | t_P -DELAY | | | 330 | 550 | 770 | ms | |
| Overdischarge/Overcharge-Current Fault-Blanking Time | t_I -DELAY | | | 1.6 | 2.4 | 3.2 | ms | |
| \overline{DSO} , \overline{CGO} , UVO Output Sink Current | | No faults, $V_{\overline{DSO}} = V_{\overline{CGO}} = V_{UVO} = 1V$ to 27V | | 20 | 30 | 40 | μA | |
| \overline{DSO} , \overline{CGO} Output Source Current | | $V_{\overline{DSO}} = V_{SRC} - 4V$ and $V_{\overline{CGO}} = V_{SRC} - 4V$, fault condition | | 2 | 10 | | mA | |
| \overline{DSO} , \overline{CGO} , UVO Leakage Current | | $V_{\overline{DSO}} = V_{\overline{CGO}} = V_{UVO} = 27V$, fault condition | | 0.2 | | | μA | |
| \overline{TKO} Pulldown Resistance, MAX1666S/V/X | | | | 100 | 200 | | k Ω | |
| \overline{TKO} Sink Current, MAX1666A Only | | $V_{\overline{TKO}} = 16V$ | | 1 | 2.5 | | mA | |
| \overline{TKO} Leakage Current, MAX1666A Only | | $V_{\overline{TKO}} = 16V$, $V_{CGI} = 3V$ | | 1 | | | μA | |
| Minimum B3P Voltage for \overline{TKO} Low, MAX1666A Only | | $V_{SRC} = V_{B3P} + 1V$, $I_{\overline{TKO}} = 0.5mA$ | | 2.4 | | | 3.6 | V |
| \overline{TKO} Source Current | | $\overline{TKO} = GND$ | | 1 | 8 | | mA | |
| \overline{DSI} , \overline{CGI} Input High Voltage | | Referenced to PKN | | 2 | | | | V |
| \overline{DSI} , \overline{CGI} Input Low Voltage | | Referenced to PKN | | 0.45 | | | V | |
| \overline{DSI} , \overline{CGI} Input Current | | V_{DSI} , $V_{CGI} = 5V$ | | 1 | | | μA | |
| \overline{WRN} Sink Current | | Fault condition, $V_{\overline{WRN}} = 0.4V$ | | 2 | 4 | | mA | |
| \overline{PKF} Sink Current | | Fault condition, $V_{\overline{PKF}} = 0.4V$ | | 4 | 8 | | mA | |
| \overline{PKF} , \overline{WRN} Leakage Current | | $V_{\overline{PKF}} = V_{\overline{WRN}} = 27V$ | | 0.2 | | | μA | |
| Undervoltage, Overvoltage, or Mismatch Fault, to \overline{DSO} , \overline{CGO} , \overline{TKO} Transition Delay | t_F -DELAY | Fault persistent for four consecutive sample periods | | 180 | 320 | 460 | ms | |

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ELECTRICAL CHARACTERISTICS

(V_{SRC} = 16V, each cell voltage V_{CELL} = 3.6V, 330k Ω load at REF, T_A = -40°C to +85°C, unless otherwise noted.) (Note 1)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|----------------------|--|-----------|-----|-----------|---------|
| Charge-Mode Detection Threshold | | V _{SRC} - V _{B_P} | 1 | | | V |
| SRC Supply Current | | V _{SRC} - V _{B_P} = 1V, V _{CGI} = V _{DSI} = GND | | | 10 | μ A |
| | | MAX1666A only, V _{SRC} - V _{B3P} = 1V, V _{CGI} = 3V, V _{DSI} = GND | | | 5 | |
| | | MAX1666A only, V _{SRC} - V _{B3P} = 1V, V _{DSI} = 3V, V _{CGI} = GND | | | 5 | |
| Supply Current | I _{SUP} | No faults, long-time average current from the top battery terminal B_P | | | 45 | μ A |
| Shutdown Supply Current | I _{SHDN} | | | | 1 | μ A |
| V _{CC} Output Voltage | V _{CC} | R _{LOAD} \geq 665 Ω , 2V < V _{CELL} < 4.4V | 3.09 | | 3.41 | V |
| V _{CC} Undervoltage-Lockout Threshold | | | 2.7 | | 3.0 | V |
| Overvoltage Threshold | | OVA = GND | 3.975 | | 4.025 | V |
| | | OVA = REF | 4.373 | | 4.427 | |
| Undervoltage Threshold | | UVA = GND | 1.950 | | 2.050 | V |
| | | UVA = REF | 2.925 | | 3.075 | |
| OVA, UVA, MMA Leakage | | OVA, UVA, MMA = REF | | | 20 | nA |
| Cell Mismatch Threshold | | All cells > 2V, MMA = REF | \pm 450 | | \pm 550 | mV |
| PKN to GND Overdischarge-Current Threshold | | | 270 | | 330 | mV |
| PKN to GND Overcharge-Current Threshold | | | -220 | | -180 | mV |
| Overcurrent Fault-Timer Delay | t _{P-DELAY} | | 330 | | 770 | ms |
| Overdischarge/Overcharge-Current Fault-Blanking Time | t _{I-DELAY} | | 1.6 | | 3.2 | ms |
| $\overline{\text{DSO}}$, $\overline{\text{CGO}}$, UVO Output Sink Current | | No faults; V $\overline{\text{DSO}}$, V $\overline{\text{CGO}}$, V _{UVO} = 1V to 27V | 20 | | 40 | μ A |
| $\overline{\text{DSO}}$, $\overline{\text{CGO}}$ Output Source Current | | V $\overline{\text{DSO}}$ = V _{SRC} - 4V and V $\overline{\text{CGO}}$ = V _{SRC} - 4V, fault condition | 2 | | | mA |
| $\overline{\text{DSO}}$, $\overline{\text{CGO}}$, UVO Leakage Current | | V $\overline{\text{DSO}}$ = V $\overline{\text{CGO}}$ = V _{UVO} = 27V, fault condition | | | 0.2 | μ A |

Advanced Lithium-Ion Battery-Pack Protector

MAX1666A/S/V/X

ELECTRICAL CHARACTERISTICS

(V_{SRC} = 16V, each cell voltage V_{CELL} = 3.6V, 330k Ω load at REF, T_A = -40°C to +85°C, unless otherwise noted.) (Note 1)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|----------------------|---|-----|-----|------|------------|
| $\overline{\text{TKO}}$ Pulldown Resistance, MAX1666S/V/X | | | 100 | | | k Ω |
| $\overline{\text{TKO}}$ Sink Current, MAX1666A Only | | V $\overline{\text{TKO}}$ = 16V | 1 | | | mA |
| Minimum B3P Voltage for $\overline{\text{TKO}}$ Low | | V _{SRC} = V _{B3P} + 1V, I $\overline{\text{TKO}}$ = 0.5mA | | | 3.6 | V |
| $\overline{\text{TKO}}$ Source Current | | $\overline{\text{TKO}}$ = GND | 1 | | | mA |
| $\overline{\text{DSI}}$, $\overline{\text{CGI}}$ Input High Voltage | | Referenced to PKN | 2 | | | V |
| $\overline{\text{DSI}}$, $\overline{\text{CGI}}$ Input Low Voltage | | Referenced to PKN | | | 0.45 | V |
| $\overline{\text{DSI}}$, $\overline{\text{CGI}}$ Input Current | | V _{DSI} = V _{CGI} = 5V | | | 1 | μ A |
| $\overline{\text{WRN}}$ Sink Current | | Fault condition, V $\overline{\text{WRN}}$ = 0.4V | 2 | | | mA |
| $\overline{\text{PKF}}$ Sink Current | | Fault condition, V $\overline{\text{PKF}}$ = 0.4V | 4 | | | mA |
| $\overline{\text{PKF}}$, $\overline{\text{WRN}}$ Leakage Current | | V $\overline{\text{PKF}}$ = V $\overline{\text{WRN}}$ = 27V | | | 0.2 | μ A |
| Undervoltage, Overvoltage, or Mismatch Fault, to $\overline{\text{DSO}}$, $\overline{\text{CGO}}$, $\overline{\text{TKO}}$ Transition Delay | t _{F-DELAY} | Fault persistent for four consecutive sample periods | 180 | | 460 | ms |

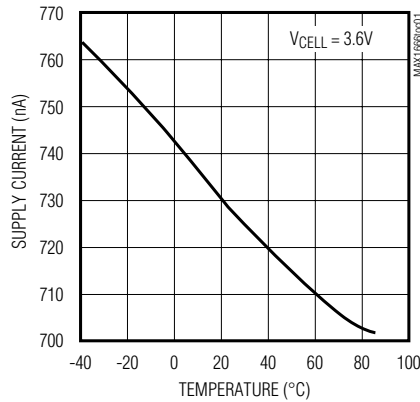
Note 1: Specifications to -40°C are guaranteed by design, not production tested.

Advanced Lithium-Ion Battery-Pack Protector

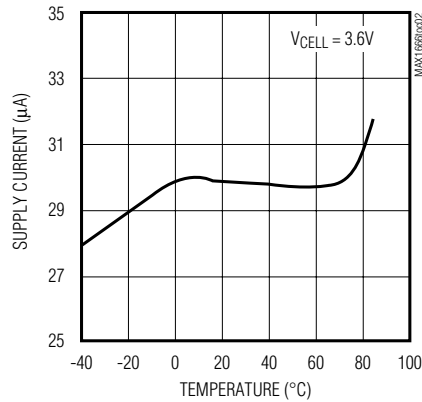
Typical Operating Characteristics

($T_A = +25^\circ\text{C}$, unless otherwise noted.)

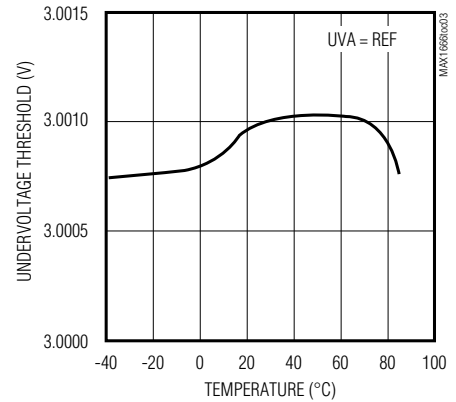
**SHUTDOWN SUPPLY CURRENT
vs. TEMPERATURE**



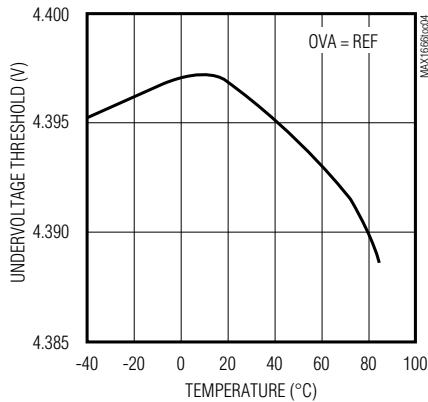
**SUPPLY CURRENT
vs. TEMPERATURE**



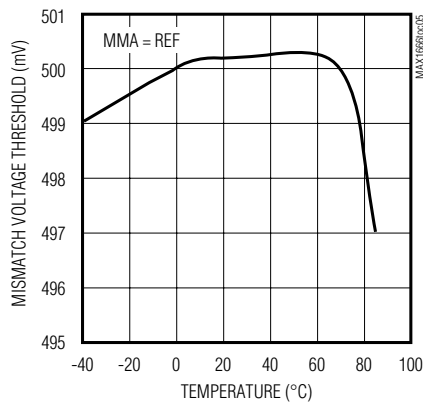
**UNDERVOLTAGE THRESHOLD
vs. TEMPERATURE**



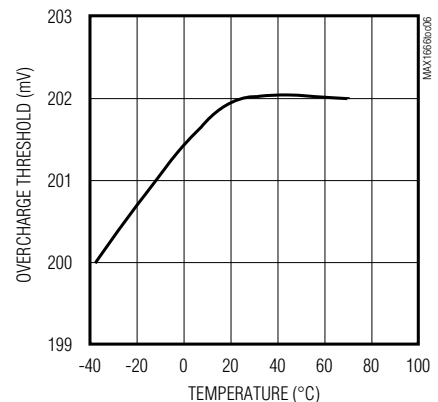
**OVERVOLTAGE THRESHOLD
vs. TEMPERATURE**



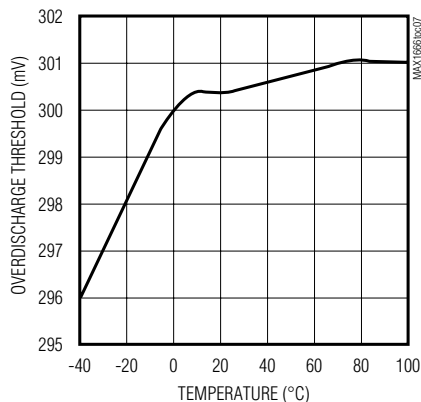
**MISMATCH VOLTAGE THRESHOLD
vs. TEMPERATURE**



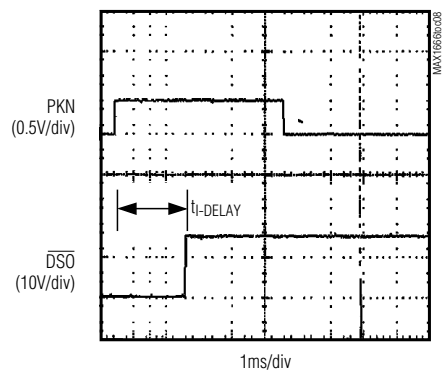
**OVERCHARGE THRESHOLD
vs. TEMPERATURE**



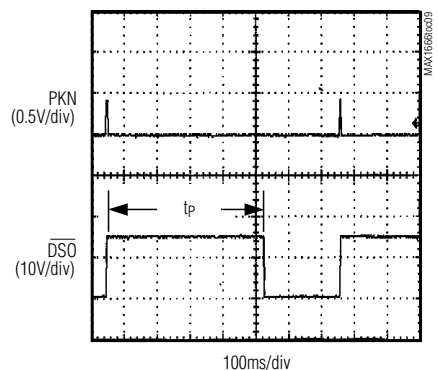
**OVERDISCHARGE THRESHOLD
vs. TEMPERATURE**



OVERDISCHARGE PROTECTION



OVERDISCHARGE RECOVERY TIME



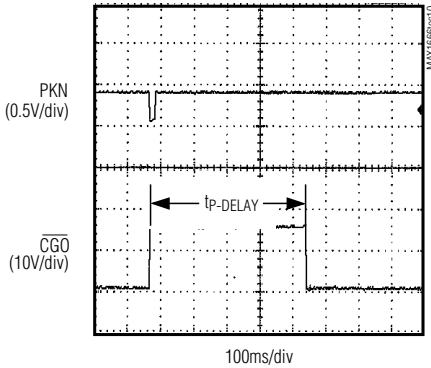
Advanced Lithium-Ion Battery-Pack Protector

Typical Operating Characteristics (continued)

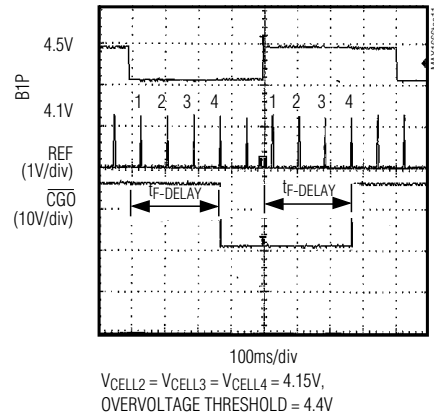
($T_A = +25^\circ\text{C}$, unless otherwise noted.)

MAX1666A/S/V/X

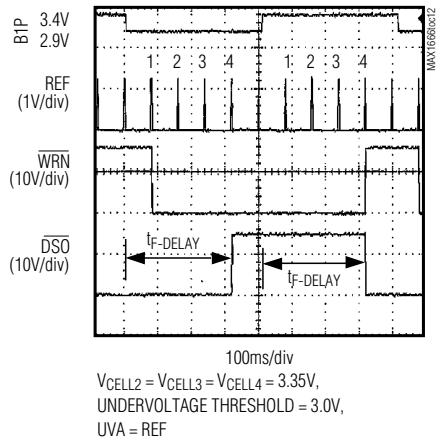
OVERCHARGE



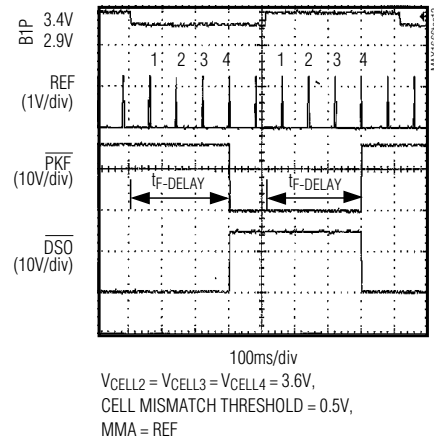
OVERVOLTAGE FAULT



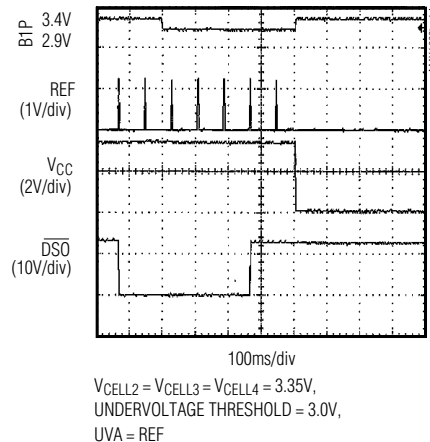
UNDERVOLTAGE FAULT



CELL MISMATCH FAULT



UNDERVOLTAGE FAULT WITHOUT CHARGE SOURCE ($V_{SRC} < V_{B4P} + 1\text{V}$)



Advanced Lithium-Ion Battery-Pack Protector

Pin Description

| | PIN | | NAME | FUNCTION |
|----------|-----------|----------|-------------------------|--|
| MAX1666X | MAX1666AV | MAX1666S | | |
| 1 | 1 | 1 | SRC | Charge Source Input. Provides current for gate drivers $\overline{\text{DSO}}$, $\overline{\text{TKO}}$, $\overline{\text{CGO}}$, and UVO. |
| 2 | 2 | 2 | $\overline{\text{DSO}}$ | Discharge Driver Output. Drives external P-channel MOSFET to control discharge. |
| 3 | 3 | 3 | $\overline{\text{TKO}}$ | Trickle-Charge Driver Output. Drives external P-channel MOSFET to control trickle-charge current. MAX1666A requires an external pullup resistor of 470k Ω . |
| 4 | 4 | 4 | $\overline{\text{CGO}}$ | Fast-Charge Driver Output. Drives external P-channel MOSFET to control fast charge. |
| 5 | — | — | B4P | Cell 4 Positive Input. Power supply input for MAX1666X. |
| 6 | 5, 6 | — | B3P | Cell 3 Positive Input. Power supply input for MAX1666A/V. |
| 7 | 7 | 5 | B2P | Cell 2 Positive Input. Power supply input for MAX1666S. |
| 8 | 8 | 6 | B1P | Cell 1 Positive Input |
| 9 | 9 | 7 | GND | Ground |
| 10 | 10 | 8 | PKN | Battery Pack Negative Terminal. Connect to bottom of current-sense resistor. Ground reference for logic inputs $\overline{\text{DSI}}$ and $\overline{\text{CGI}}$. |
| 11 | 11 | 9 | $\overline{\text{DSI}}$ | Discharge Control Input |
| 12 | 12 | 10 | $\overline{\text{CGI}}$ | Charge Control Input |
| 13 | 13 | 11 | $\overline{\text{PKF}}$ | Pack Fail Output. $\overline{\text{PKF}}$ goes low when any cell voltage exceeds the mismatch threshold or when a shorted cell is detected. |
| 14 | 14 | — | $\overline{\text{WRN}}$ | Undervoltage/Overvoltage Warning Output |
| 15 | 15 | 12 | MMA | Mismatch Adjust Input. Set the mismatch threshold by a resistor-divider from REF to GND. |
| 16 | 16 | 13 | UVA | Undervoltage Adjust Input. Set the undervoltage threshold with a resistor-divider from REF to GND. |
| 17 | 17 | 14 | OVA | Overvoltage Adjust Input. Set the overvoltage threshold with a resistor-divider from REF to GND. |
| 18 | 18 | 15 | REF | Reference Voltage Output. Minimize PC board stray capacitance on this node. |
| 19 | 19 | 16 | V _{CC} | 3.3V Linear Regulator Output. Bypass with a 0.47 μF min capacitor to GND. |
| 20 | 20 | — | UVO | Undervoltage Fault Output |

MAX1666A/S/V/X



Advanced Lithium-Ion Battery-Pack Protector

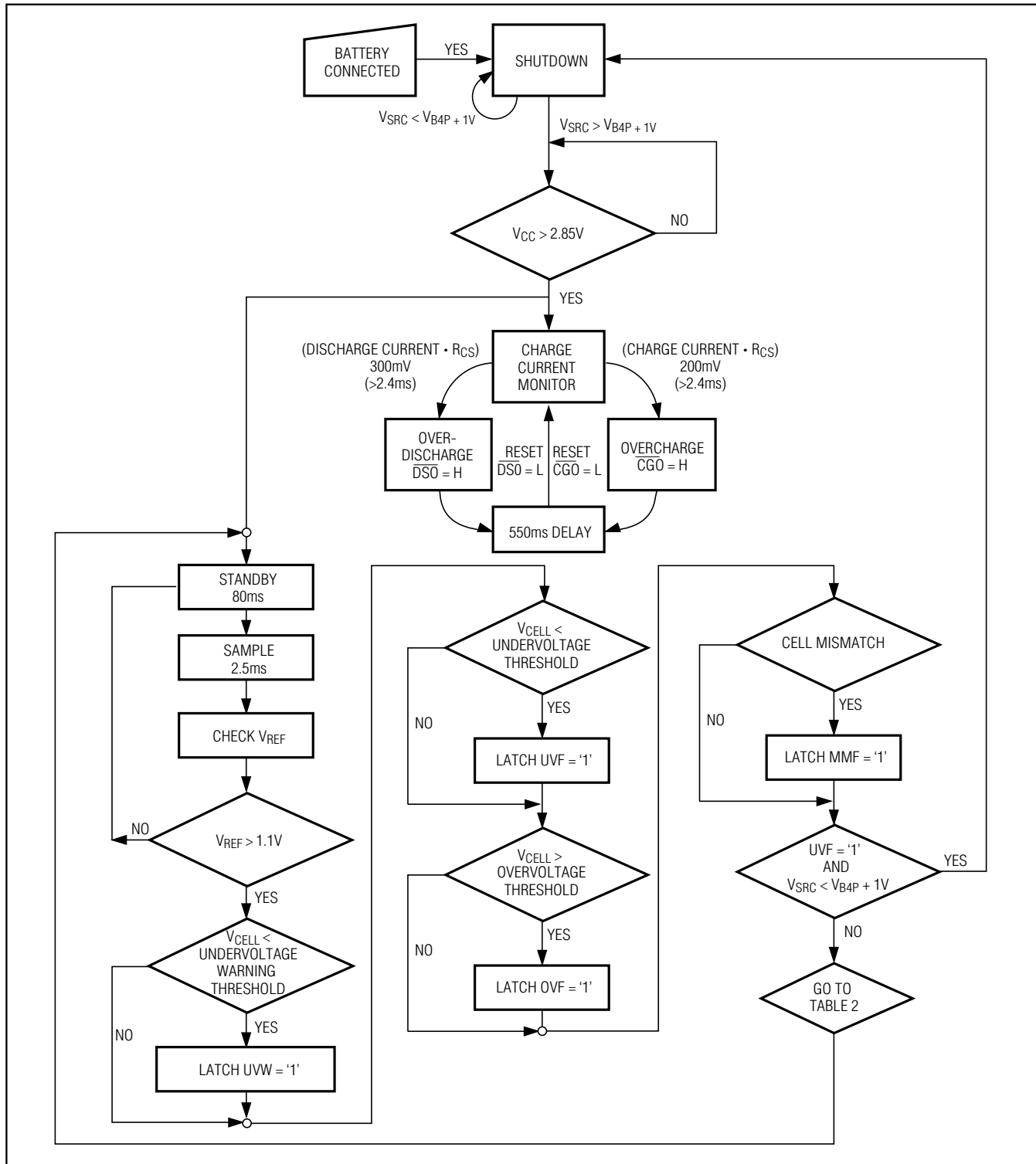


Figure 2. Cell Fault Monitor

Advanced Lithium-Ion Battery-Pack Protector

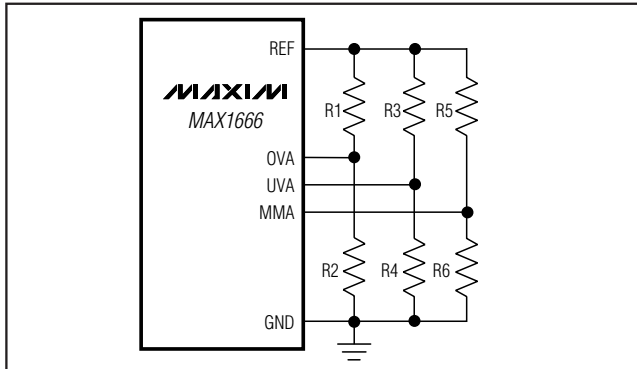


Figure 3. Using an External Resistor-Divider to Adjust Overvoltage Threshold

Detailed Description

The MAX1666 battery-pack protectors supervise the charging and discharging processes of Li+ battery cells. Designed for 2-, 3-, and 4-cell applications, these devices monitor the voltage across each cell to provide protection against undervoltage, overvoltage, and over-current damage.

Control pins $\overline{\text{CGO}}$, $\overline{\text{TKO}}$, and $\overline{\text{DSO}}$ allow control of external MOSFET gates. This allows fast charging, trickle charging, and discharging processes (see the *Typical Operating Circuits*). The voltage of each cell is measured individually. Also, each cell is measured differentially between every other cell of the pack.

The MAX1666 contains a state machine, a voltage regulator, an oscillator, and other logic functions to selectively drive $\overline{\text{CGO}}$, $\overline{\text{UVO}}$, $\overline{\text{TKO}}$, $\overline{\text{DSO}}$, $\overline{\text{WRN}}$, and $\overline{\text{PKF}}$ (Figure 1).

Modes of Operation

Shutdown Mode

The MAX1666 goes into shutdown mode when a battery pack is first connected. The quiescent current is less than 1 μA . All circuitry is inactive except the com-

parator monitoring V_{SRC} and the top-cell voltage. The MAX1666 remains in shutdown mode as long as V_{SRC} is less than the top-cell voltage. When SRC is connected to an external charger and V_{SRC} is 1V above the top-cell voltage, the device goes into standby mode.

The MAX1666 returns to shutdown mode under two conditions: the battery is disconnected and then re-connected, or the device detects an undervoltage fault and no charge source.

Normal Mode

The standby state activates the bias circuitry, overcurrent comparator, and timer. The standby state lasts 80ms, then the MAX1666 goes into the sample state for 2.5ms.

Within the 2.5ms, the MAX1666 checks for overvoltage, undervoltage, and mismatch between cells sequentially, and it stores the results in internal latches. The MAX1666 drives the outputs according to the faults (if any) detected by reading the latches (Figure 2) at the end of the sample state. Then the MAX1666 returns to the standby state.

Overvoltage Protection

The MAX1666 provides overvoltage protection to avoid overcharging of any cell. When any cell is at overvoltage, $\overline{\text{CGO}}$ and $\overline{\text{TKO}}$ go high, turning off the external MOSFETs and stopping the charging process (see the *Typical Operating Circuits*). $\overline{\text{WRN}}$ goes low. Overvoltage is set when any cell voltage exceeds the overvoltage threshold.

Overvoltage threshold is linearly adjustable through an external 1% resistor-divider (Figure 3) from REF. Determine the overvoltage threshold (V_{OVT}) required. V_{OVT} must be between 4V and 4.4V. Set $\text{R}_{\text{TOTAL}} = \text{R1} + \text{R2} = 1\text{M}\Omega$. Calculate R1 and R2 as follows:

$$\text{R2} = [(\text{V}_{\text{OVT}} - 4\text{V}) / (4.4\text{V} - 4\text{V})] \cdot \text{R}_{\text{TOTAL}}$$

$$\text{R1} = \text{R}_{\text{TOTAL}} - \text{R2}$$

Table 1. Operating Modes

| MODE | STATE | TIME (ms) | TYPICAL QUIESCENT CURRENT (μA) | CONDITION |
|----------|---------|-----------|---|---|
| Normal | Standby | 80 | 24 | Only bias circuitry, overcurrent comparator, and timer are active. |
| | Sample | 2.5 | 250 | All circuitry active. |
| Shutdown | — | — | 0.7 | All circuitry inactive. Device enters shutdown when it detects an undervoltage fault and $\text{V}_{\text{SRC}} < \text{V}_{\text{TOP-CELL}} + 1\text{V}$ (no charge source). |

Advanced Lithium-Ion Battery-Pack Protector

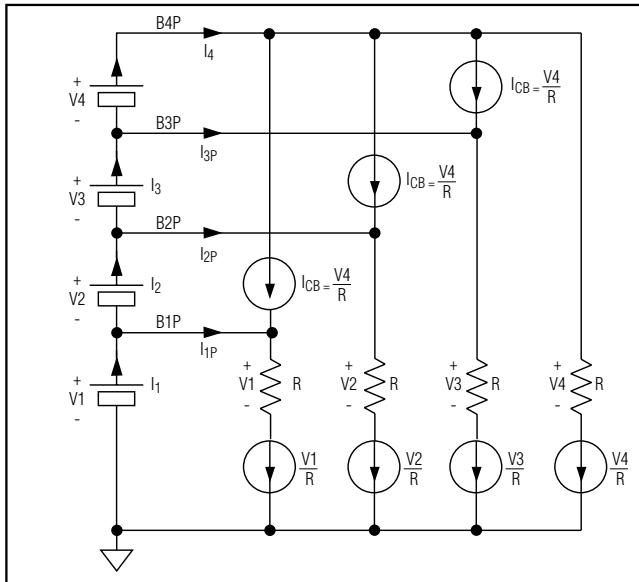


Figure 4. Cell Voltage Sampling

Maximum mismatch of 1% external resistor-dividers is $\pm 2\%$. The external adjusted overvoltage-threshold accuracy includes the internal overvoltage-threshold accuracy ($\pm 0.5\%$) and the error due to the external resistor-divider multiplied by maximum adjustment:

$$\pm 2\% \frac{4.4\text{V} - 4.0\text{V}}{4.4\text{V}} = \pm 0.2\%$$

The total external adjusted overvoltage-threshold (V_{OVT}) accuracy is $\pm 0.7\%$.

Undervoltage Protection

The MAX1666 provides undervoltage protection to avoid overdischarging the cells. When any cell is under voltage, $\overline{\text{UVO}}$, $\overline{\text{DSO}}$, and $\overline{\text{CGO}}$ go high, turning off the external charging and discharging MOSFETs. $\overline{\text{TKO}}$ remains low to keep the trickle-charge current on. Undervoltage threshold is linearly adjustable through an external resistor-divider (Figure 3) from REF. Determine the undervoltage threshold (V_{UVT}) required. V_{UVT} must be between 2V and 3V. Set $\text{R}_{\text{TOTAL}} = \text{R}_3 + \text{R}_4 = 1\text{M}\Omega$. Calculate R_3 and R_4 as follows:

$$R4 = [(V_{UVT} - 2V) / (3V - 2V)] R_{TOTAL}$$
$$R3 = R_{TOTAL} - R4$$

Maximum mismatch of 1% external resistor-dividers is $\pm 2.0\%$, and the error due to the external resistor-divider multiplied by maximum adjustment is $\pm 2\% (3V - 2V) / 3V = \pm 0.7\%$. The total external adjusted undervoltage-

threshold (V_{UVT}) accuracy including the internal under-voltage-threshold accuracy ($\pm 2.5\%$) is $\pm 3.2\%$.

Undervoltage Warning

When any cell drops to 100mV above the undervoltage threshold, \overline{WRN} goes low. \overline{WRN} returns high when all cells are 300mV above the undervoltage threshold.

Cell-Mismatch Protection

The MAX1666 disables charging or discharging when mismatch occurs. When any two cells are mismatched, $\overline{\text{TKO}}$, $\overline{\text{CGO}}$, $\overline{\text{UVO}}$, and $\overline{\text{DSO}}$ go high, turning off the external MOSFETs. PKF goes low. PKF has a strong pulldown current ($>4\text{mA}$), and can be used to control an external thermal fuse. The cell-mismatch threshold is linearly adjustable through an external resistor-divider (Figure 3) from REF. Determine the cell-mismatch threshold (VCMT) required. VCMT has to be between 0 and 500mV. Set $\text{RTOTAL} = \text{R5} + \text{R6} = 1\text{M}\Omega$. Calculate R5 and R6:

$$R6 = (VCMT / 500mV) RTOTAL$$

$$R5 = RTOTAL - R6$$

Maximum mismatch of a 1% external resistor-divider is $\pm 2\%$. The total external adjusted cell-mismatch threshold accuracy, including the internal cell-mismatch threshold accuracy ($\pm 10\%$), is $\pm 12\%$.

Cell Voltage Sampling

The MAX1666 does not introduce cell mismatch. When the battery cells are matched, the MAX1666 draws close to zero current from the intermediate cells. Figure 4 shows a simplified diagram of the voltage sampling scheme:

B4P: $I_4 = 3I_{CB} + V_4 / R = 4V_4 / R = \text{BAT4 current}$

B3P: $I_3 = I_{3P} + I_4 = \text{BAT3 current}$

$$I_{3P} + I_{CB} = V_3 / R \Rightarrow I_{3P} = V_3 / R - V_4 / R$$

$$I_3 = I_4 + (V_3 - V_4) / R = (3V_4 + V_3) / R$$

B2P: $I_2 = I_{2P} + I_3 = \text{BAT2 current}$

$$I_{2P} + I_{CB} = V_2 / R \Rightarrow I_{2P} = V_2 / R - V_4 / R$$

$$I_2 = I_3 + V_2 / R - V_4 / R = I_4 + (V_3 - V_4) / R + (V_2 - V_4) / R = (2V_4 + V_3 + V_2) / R$$

B1P: $I_1 = I_{1P} + I_2 = \text{BAT1 current}$

$$I_{1P} + I_{CB} = V_1 / R \Rightarrow I_{1P} = V_1 / R - V_4 / R$$

$$I_1 = I_2 + V_1 / R - V_4 / R = I_4 + (V_3 - V_4) / R + (V_2 - V_4) / R + (V_1 - V_4) / R$$

$$= (V_4 + V_3 + V_2 + V_1) / R$$

when $V_1 = V_2 = V_3 = V_4$, $I_{1P} = I_{2P} = I_{3P} = 0$, and
 $I_1 = I_2 = I_3 = I_4 = 4V_4 / R$

Table 2. Truth Table

| CONTROL INPUTS | | | | | | | | | | | | | CONTROL OUTPUTS | | | | | NOTES |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----------------|--|--|--|--|-------|
| UW | LVF | OVF | MMF | CGI | DSI | OCC | ODC | DSO | CGO | TKO | WRN | PKF | UVU | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | L | L | L | H | H | L | Normal operation | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | PS | L | L | H | H | L | Overdischarge current fault | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | L | PS | L | H | H | L | Overcharge current fault | | | | |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | H | L | L | H | H | L | Disable discharge path | | | | |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | H | PS | L | H | H | L | Disable discharge path, overcharge current fault | | | | |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | L | H | H | H | H | L | Disable charge path | | | | |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | PS | H | H | H | H | L | Disable charge path, overdischarge current fault | | | | |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | H | H | H | H | H | L | Disable charge and discharge path | | | | |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | H | H | H | H | L | H | Mismatch fault | | | | |
| 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | H | H | H | H | L | H | Mismatch fault, disable discharge path | | | | |
| 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | H | H | H | H | L | H | Mismatch fault, disable charge path | | | | |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | H | H | H | H | L | H | Mismatch fault, disable charge and discharge path | | | | |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | L | H | H | L | H | L | Overvoltage fault | | | | |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | L | H | H | L | H | L | Overvoltage fault, overdischarge current fault | | | | |
| 0 | 0 | 1 | 0 | 0 | 0 | 1 | PS | H | H | H | L | H | L | Overvoltage fault, disable discharge path | | | | |
| 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | PS | H | H | L | H | L | Overvoltage fault, disable charge path, overdischarge current fault | | | | |
| 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | H | H | H | L | L | H | Overvoltage fault, disable charge and discharge path | | | | |
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | H | H | H | L | L | H | Overvoltage fault, mismatch fault, disable discharge path | | | | |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | H | H | H | L | L | H | Overvoltage fault, mismatch fault, disable charge path | | | | |
| 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | H | H | H | L | L | H | Overvoltage fault, mismatch fault, disable charge and discharge path | | | | |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | H | H | L | L | H | H | Undervoltage fault | | | | |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | H | H | L | L | H | H | Undervoltage fault, disable discharge path | | | | |
| 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | H | H | L | L | H | H | Undervoltage fault, disable charge path | | | | |
| 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | H | H | L | L | L | H | Undervoltage fault, mismatch fault | | | | |
| 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | H | H | L | L | L | H | Undervoltage fault, mismatch fault, disable discharge path | | | | |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | H | H | L | L | L | H | Undervoltage fault, overvoltage fault, mismatch fault, disable discharge path | | | | |
| 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | H | H | L | L | L | H | Undervoltage fault, overvoltage fault, mismatch fault, disable charge path | | | | |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | H | H | L | L | L | H | Undervoltage fault, overvoltage fault, mismatch fault, disable charge and discharge path | | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | PS | L | L | L | H | L | Undervoltage fault early warning | | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | PS | L | L | L | L | L | Undervoltage fault early warning, overdischarge current fault | | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | L | PS | L | L | H | L | Undervoltage fault early warning, overcharge current fault | | | | |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | H | L | L | L | H | L | Undervoltage fault early warning, disable discharge path, overcharge current fault | | | | |
| 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | L | H | H | L | L | L | Undervoltage fault early warning, disable charge path | | | | |
| 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | PS | H | H | L | H | L | Undervoltage fault early warning, disable charge path, overdischarge current fault | | | | |
| 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | H | H | H | L | L | L | Undervoltage fault early warning, disable charge and discharge path | | | | |
| 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | H | H | L | L | L | H | Undervoltage fault early warning, mismatch fault | | | | |
| 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | H | H | L | L | L | H | Undervoltage fault early warning, mismatch fault, disable discharge path | | | | |
| 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | H | H | L | L | L | H | Undervoltage fault early warning, mismatch fault, disable charge path | | | | |
| 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | H | H | L | L | L | H | Undervoltage fault early warning, mismatch fault, disable charge and discharge path | | | | |
| 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | H | H | L | L | L | H | Undervoltage fault early warning, overvoltage fault, mismatch fault, disable discharge path | | | | |
| 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | H | H | L | L | L | H | Undervoltage fault early warning, overvoltage fault, mismatch fault, disable charge path | | | | |
| 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | H | H | L | L | L | H | Undervoltage fault early warning, overvoltage fault, mismatch fault, disable charge and discharge path | | | | |

PS: Overcurrent fault pulse sampling. (Output goes high for 500ms then resets low to monitor charge/discharge current. Output goes high again if fault persists.)

UW: Undervoltage fault early warning

OCC: Overcharge current fault

DSO: Overdischarge current fault

CGO: Charge control input

TKO: Undervoltage fault

WRN: Undervoltage fault

PKF: Mismatch fault

UVU: Discharge control input

Advanced Lithium-Ion Battery-Pack Protector

MAX1666A/S/W/X

Advanced Lithium-Ion Battery-Pack Protector

Overcharge/Overdischarge Current Protection

The MAX1666 checks for overcharge or overdischarge current in standby and sample states. The thresholds are factory preset to 200mV and 300mV, respectively. A charge current makes PKN go below GND. A discharge current makes PKN go above GND. When PKN exceeds the threshold, a fault is acknowledged. $\overline{\text{CGO}}$ goes high when the overcharge threshold is exceeded. $\overline{\text{DSO}}$ goes high when the overdischarge threshold is exceeded. An internal 550ms timer starts. At the end of 550ms, $\overline{\text{DSO}}$ or $\overline{\text{CGO}}$ goes low while the MAX1666 rechecks for an overcharge/overdischarge fault. A persistent fault causes $\overline{\text{DSO}}$ and $\overline{\text{CGO}}$ to return high and restarts the 550ms timer again.

Truth Table

The MAX1666 has a total of eight signal inputs and six outputs. Table 2 lists all the possible states.

Applications Information

Choosing an External MOSFET

The external P-channel MOSFETs act as a gated switch to enable or disable the charging/discharging process.

Table 3. MOSFET Selection

| P-CHANNEL MOSFETs | MAXIMUM DRAIN CURRENT (A) |
|-------------------|---------------------------|
| IRF7404 | 5.3 |
| IRF7406 | 4.7 |
| Si4431 | 4.5 |
| Si4947 (dual) | 2.5 EA |

$\overline{\text{CGO}}$ controls the MOSFET for normal charging of the battery. $\overline{\text{TKO}}$ controls the MOSFET for trickle charge of the cells. $\overline{\text{DSO}}$ controls the discharging MOSFET. Use different MOSFETs to optimize each function depending on the maximum charge and discharge rates. Table 3 lists some suitable MOSFETs in a small 8-pin SO package.

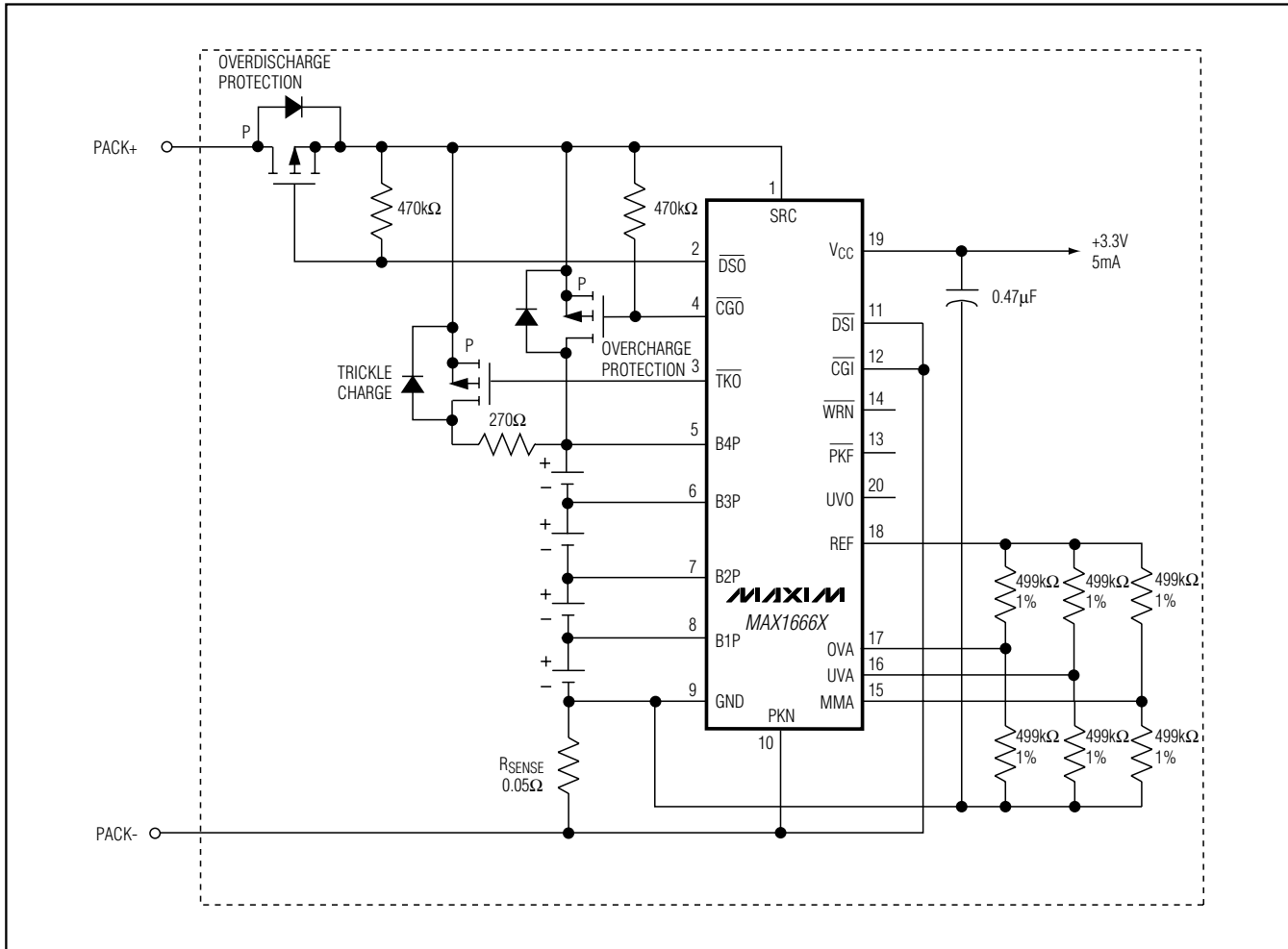
Layout Considerations and Bypassing

As with all PC board designs, a careful layout is suggested. Minimize lead lengths to reduce losses in the traces.

Advanced Lithium-Ion Battery-Pack Protector

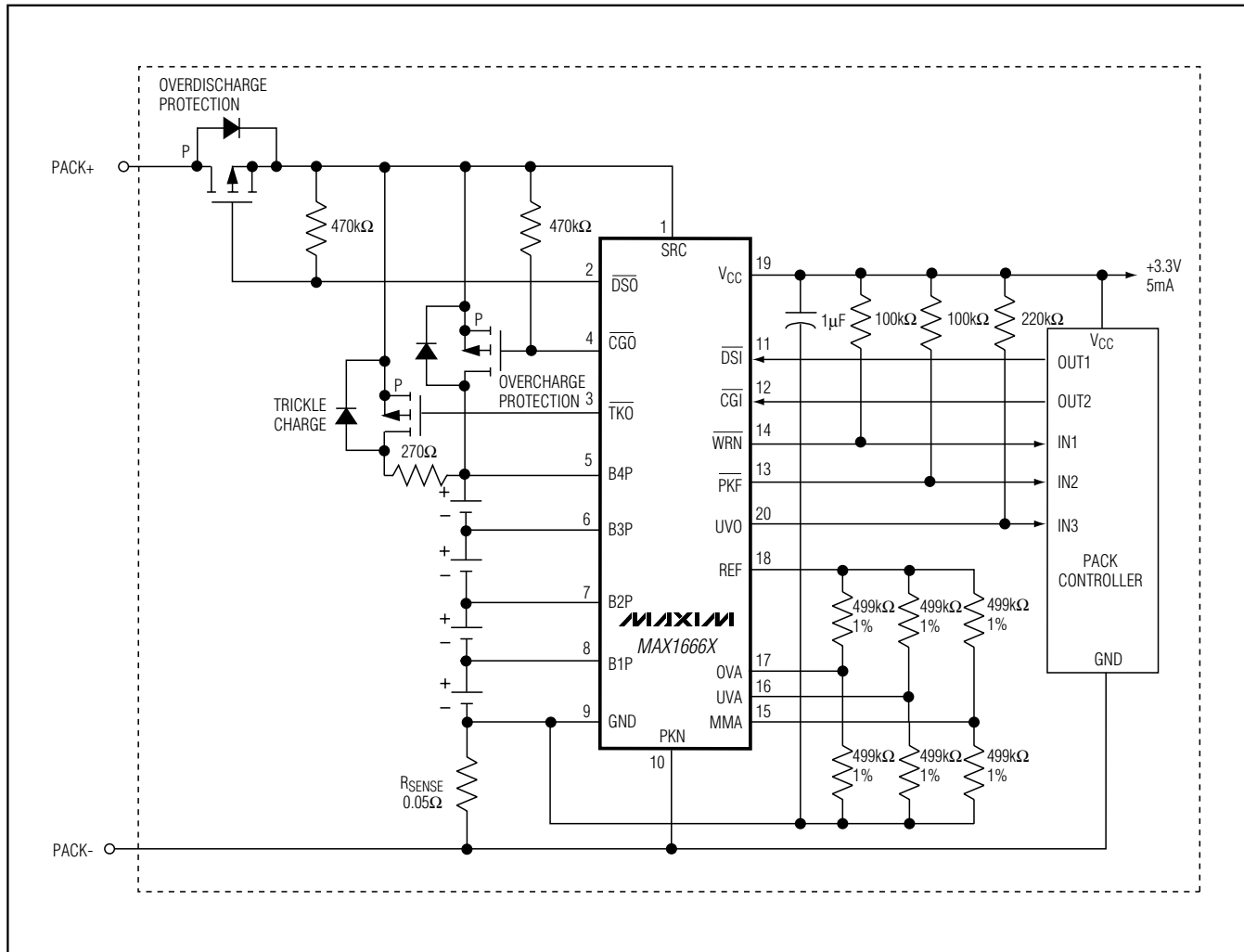
Typical Operating Circuits

MAX1666A/S/V/X



Advanced Lithium-Ion Battery-Pack Protector

Typical Operating Circuits (continued)



Chip Information

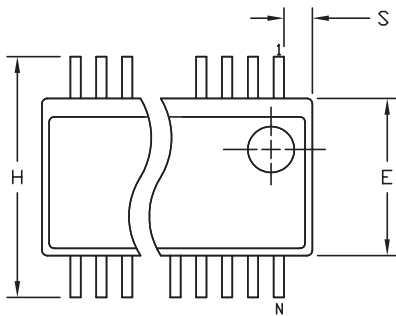
TRANSISTOR COUNT: 4835

Advanced Lithium-Ion Battery-Pack Protector

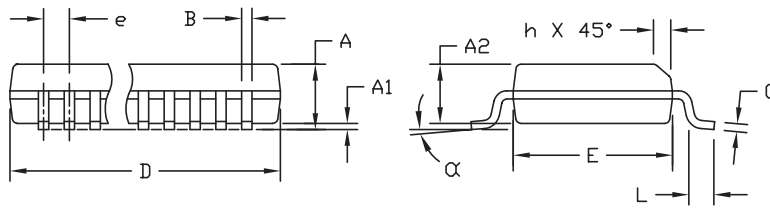
Package Information

MAX1666A/S/V/X

QSOP-EP



| DIM | INCHES | | MILLIMETERS | |
|-----|----------------|-------|-------------|-------|
| | MIN | MAX | MIN | MAX |
| A | .061 | .068 | 1.55 | 1.73 |
| A1 | .004 | .0098 | 0.102 | 0.249 |
| A2 | .055 | .061 | 1.40 | 1.55 |
| B | .008 | .012 | 0.20 | 0.30 |
| C | .0075 | .0098 | 0.191 | 0.249 |
| D | SEE VARIATIONS | | | |
| E | .150 | .157 | 3.81 | 3.99 |
| e | .025 BSC | | 0.635 BSC | |
| H | .230 | .244 | 5.84 | 6.20 |
| h | .010 | .016 | 0.25 | 0.41 |
| L | .016 | .035 | 0.41 | 0.89 |
| N | SEE VARIATIONS | | | |
| α | 0° | 8° | 0° | 8° |



VARIATIONS:

| | INCHES | | MILLIMETERS | | N |
|---|--------|-------|-------------|-------|-------|
| | MIN. | MAX. | MIN. | MAX. | |
| D | .189 | .196 | 4.80 | 4.98 | 16 AB |
| S | .0020 | .0070 | 0.05 | 0.18 | |
| D | .337 | .344 | 8.56 | 8.74 | 20 AD |
| S | .0500 | .0550 | 1.270 | 1.397 | |
| D | .337 | .344 | 8.56 | 8.74 | 24 AE |
| S | .0250 | .0300 | 0.635 | 0.762 | |
| D | .386 | .393 | 9.80 | 9.98 | 28 AF |
| S | .0250 | .0300 | 0.635 | 0.762 | |

NOTES:

- 1). D & E DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
- 2). MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .006" PER SIDE.
- 3). CONTROLLING DIMENSIONS: INCHES.
- 4). MEETS JEDEC MQ137.

| | |
|--|--|
| | |
| PROPRIETARY INFORMATION | |
| TITLE: PACKAGE OUTLINE, QSOP .150", .025" LEAD PITCH | |
| APPROVAL | DOCUMENT CONTROL NO. 21-0055 |
| REV. E | 1/1 |

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