19-1465; Rev 1; 7/99

MAXIM

Advanced Lithium-Ion Battery-Pack Protector

MAX1666S/V/X

General Description

The MAX1666 provides complete protection against overvoltage, undervoltage, overcharge current, overdischarge current, and cell mismatch for 2-cell to 4-cell Lithium-Ion 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 three versions: the "S" version monitors two Li-Ion cells, the "V" version monitors three cells, and the "X" version monitors four cells.

Applications

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

Features

- **Overvoltage Protection**
  Programmable Limits from +4.0V to +4.4V
  Accurate to ±0.5%
- **Undervoltage Protection**
  Programmable Limits from +2.0V to +3.0V
  Accurate to ±2.5%
- **Cell Mismatch Protection**
  Programmable Limits from 0 to 500mV
  Accurate to ±10%
- **Overcharge Current Protection**
- **Overdischarge Current Protection**
- **Low Operating Supply Current: 30µA typ**
- **Low Standby Current: 1µA max**
- **+28V max Input Voltage**
- **Available in Small 16-Pin QSOP (MAX1666S) and 20-Pin QSOP (MAX1666V/X) Packages**

Selector Guide

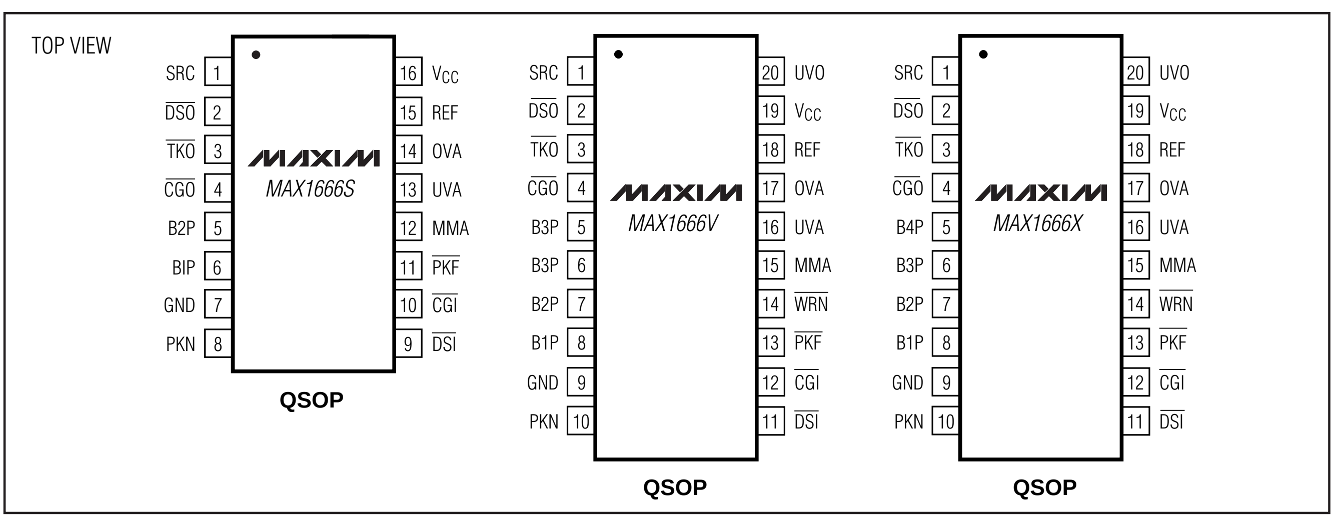
PART	NUMBER OF LI-ION CELLS
MAX1666S	2
MAX1666V	3
MAX1666X	4

Ordering Information

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

Typical Operating Circuits appear at end of data sheet.

Pin Configurations



ABSOLUTE MAXIMUM RATINGS

SRC, $\overline{DSO}$, $\overline{TKO}$, $\overline{CGO}$, UVO, $\overline{PKF}$, $\overline{WRN}$ to GND ...-0.3V to +28V
V_{CC}, 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 ....±2V
V_{CC}, $\overline{CGI}$, $\overline{DSI}$ to PKN..-0.3V to +6V
Continuous Power Dissipation (T_A = +70°C)
16-Pin QSOP (derate 8.3mW/°C above +70°C)...........667mW
20-Pin QSOP (derate 9.1mW/°C above +70°C)...........727mW
Operating Temperature Range ....-40°C to +85°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature (soldering, 10sec) ....+300°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_{SRC} = 16V, each cell voltage V_{CELL} = 3.6V, 330kΩ load at REF, T_A = 0°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Charge Mode Detection Threshold		V_{SRC} - V_{B_P}		1			V
SRC Input Current Range		V_{SRC} - V_{B_P} = 1V			2	10	µA
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
V_{CC} Output Voltage	V_{CC}	R_{LOAD} ≥ 665Ω, 2V < V_{CELL} < 4.4V		3.09	3.25	3.41	V
V_{CC} Undervoltage Lockout Threshold				2.7	2.85	3	V
Reference Output Voltage	V_{REF}	Pulse on			1.221		V
Overvoltage Threshold		Cell voltage rising	OVA = GND	3.980	4.000	4.020	V
			V_{OVA} = V_{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_{UVA} = V_{REF} / 2		2.500		
			UVA = REF	2.925	3.000	3.075	
Undervoltage Threshold Hysteresis					100		mV
$\overline{WRN}$ 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

ELECTRICAL CHARACTERISTICS (continued)

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

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Overcurrent Fault Timer Delay	$t_{P\text{-}DELAY}$		330	550	770	ms
Overdischarge/Overcharge Current Fault Blanking Time	$t_{I\text{-}DELAY}$		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
$\overline{TKO}$ Pull-Down Resistance			100	200		kΩ
$\overline{TKO}$ 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	$t_{F\text{-}DELAY}$	Fault persistent for 4 consecutive sample periods	180	320	460	ms

ELECTRICAL CHARACTERISTICS

(V_{SRC} = 16V, each cell voltage V_{CELL} = 3.6V, 330kΩ 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 Input Current Range		V_{SRC} - V_{B_P} = 1V to 4V			10	µA
Supply Current	I_{SUP}	No faults, long time average current from the top battery terminal B_P			45	µA
Shutdown Supply Current	I_{SHDN}				1	µA
V_{CC} Output Voltage	V_{CC}	R_{LOAD} ≥ 665Ω, 2V < V_{CELL} < 4.4V	3.09		3.41	V
V_{CC} Undervoltage Lockout Threshold			2.7		3	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

ELECTRICAL CHARACTERISTICS

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

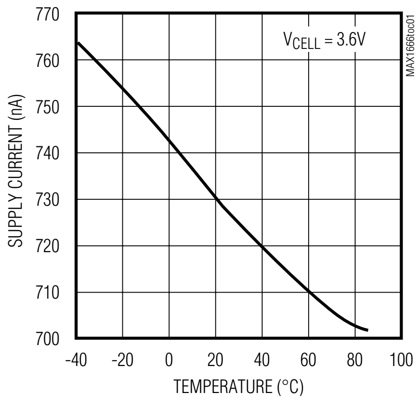
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Cell Mismatch Threshold		All cells > 2V, MMA = REF	±450		±550	mV
PKN to GND Overdischarge Current Threshold			270		330	mV
PKN to GND Overcharge Current Threshold			-220		-180	mV
Overcurrent Fault Timer Delay	$t_{P\text{-}DELAY}$		330		770	ms
Overdischarge/Overcharge Current Fault Blanking Time	$t_{I\text{-}DELAY}$		1.6		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		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			mA
$\overline{DSO}$, $\overline{CGO}$, UVO Leakage Current		$V_{\overline{DSO}}$ = $V_{\overline{CGO}}$ = V_{UVO} = 27V, fault condition			0.2	µA
$\overline{TKO}$ Pull-Down Resistance			100			kΩ
$\overline{TKO}$ Source Current		$\overline{TKO}$ = GND	1			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			mA
$\overline{PKF}$ Sink Current		Fault condition, $V_{\overline{PKF}}$ = 0.4V	4			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	$t_{F\text{-}DELAY}$	Fault persistent for 4 consecutive sample periods	180		460	ms

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

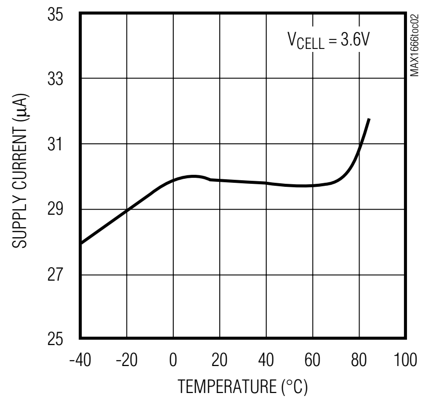
Typical Operating Characteristics

(T_A = +25°C, unless otherwise noted.)

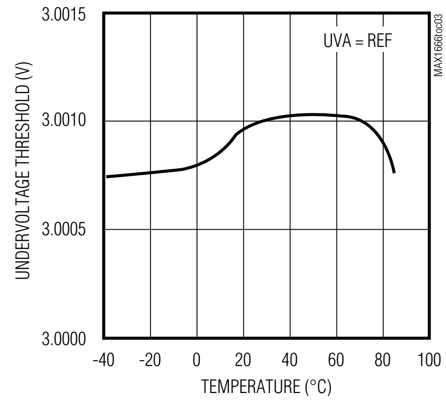
SHUTDOWN SUPPLY CURRENT vs. TEMPERATURE



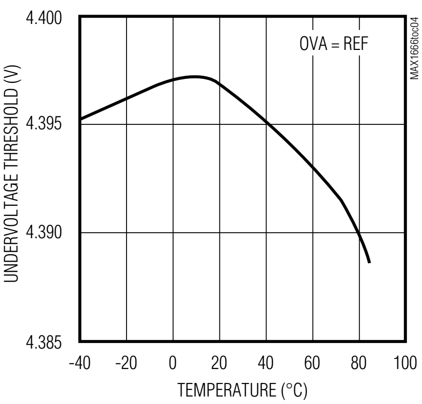
SUPPLY CURRENT vs. TEMPERATURE



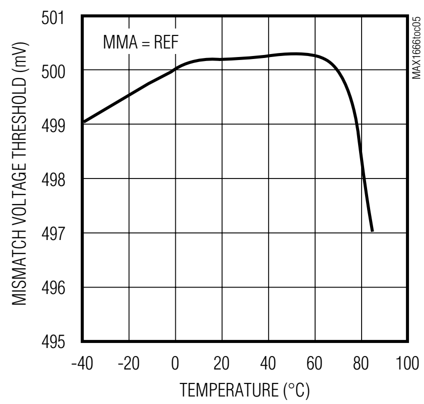
UNDERVOLTAGE THRESHOLD vs. TEMPERATURE



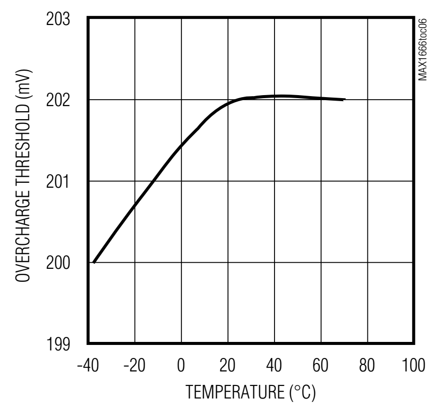
OVERVOLTAGE THRESHOLD vs. TEMPERATURE



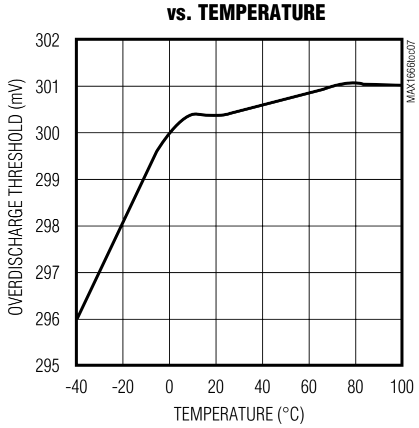
MISMATCH VOLTAGE THRESHOLD vs. TEMPERATURE



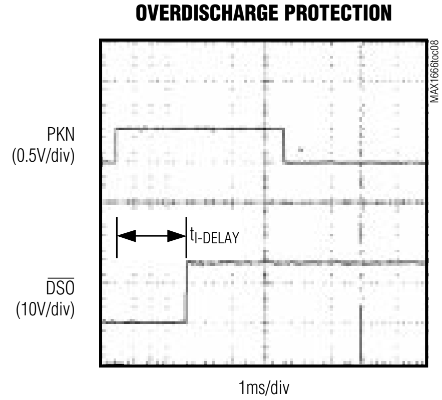
OVERCHARGE THRESHOLD vs. TEMPERATURE



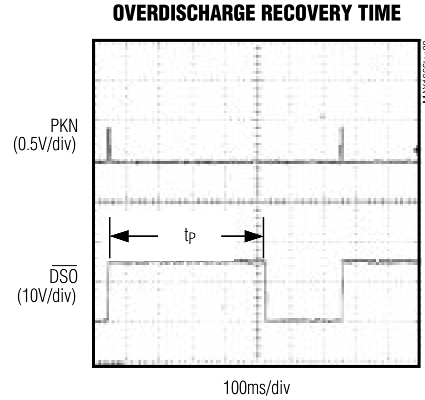
OVERDISCHARGE THRESHOLD vs. TEMPERATURE



OVERDISCHARGE PROTECTION



OVERDISCHARGE RECOVERY TIME

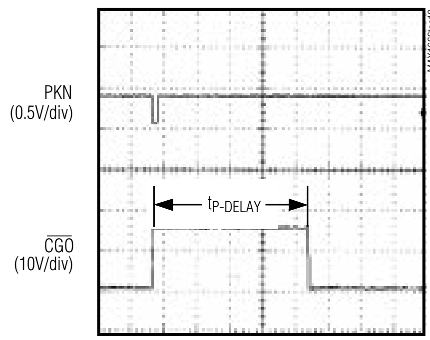


Advanced Lithium-Ion Battery-Pack Protector

Typical Operating Characteristics (continued)

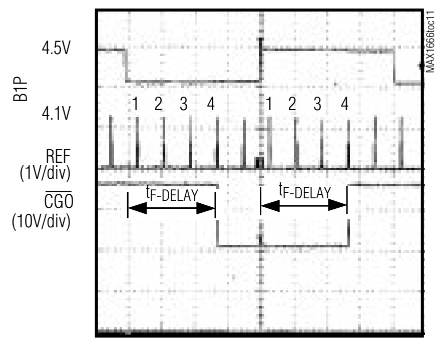
(T_A = +25°C, unless otherwise noted.)

OVERCHARGE



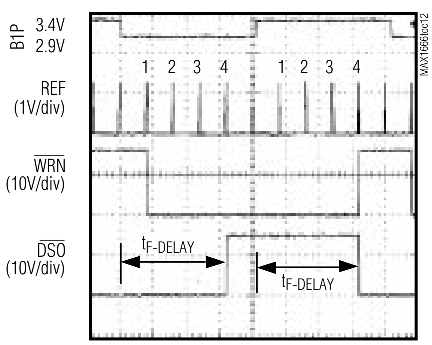
100ms/div

OVERVOLTAGE FAULT



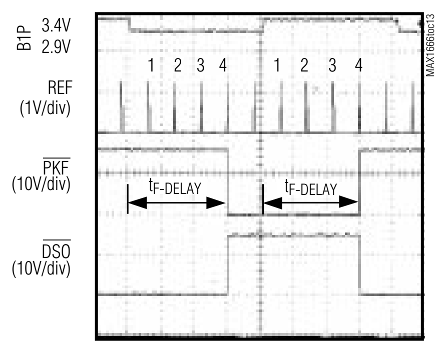
100ms/div
$V_{CELL2} = V_{CELL3} = V_{CELL4}$ = 4.15V,
OVERVOLTAGE THRESHOLD = 4.4V

UNDERVOLTAGE FAULT



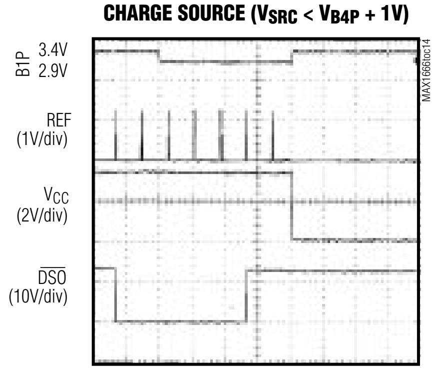
100ms/div
$V_{CELL2} = V_{CELL3} = V_{CELL4}$ = 3.35V,
UNDERVOLTAGE THRESHOLD = 3.0V,
UVA = REF

CELL MISMATCH FAULT



100ms/div
$V_{CELL2} = V_{CELL3} = V_{CELL4}$ = 3.6V,
CELL MISMATCH THRESHOLD = 0.5V,
MMA = REF

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



100ms/div
$V_{CELL2} = V_{CELL3} = V_{CELL4}$ = 3.35V,
UNDERVOLTAGE THRESHOLD = 3.0V,
UVA = REF

Pin Description

PIN			NAME	FUNCTION
MAX1666X	MAX1666V	MAX1666S		
1	1	1	SRC	Charge Source Input. Provides current for gate drivers $\overline{DSO}$, $\overline{TKO}$, $\overline{CGO}$, and UVO.
2	2	2	$\overline{DSO}$	Discharge Driver Output. Drives external P-channel MOSFET to control discharge.
3	3	3	$\overline{TKO}$	Trickle-Charge Driver Output. Drives external P-channel MOSFET to control trickle-charge current. Internally grounded when inactive.
4	4	4	$\overline{CGO}$	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 MAX1666V.
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 $\overline{DSI}$ and $\overline{CGI}$.
11	11	9	$\overline{DSI}$	Discharge Control Input
12	12	10	$\overline{CGI}$	Charge Control Input
13	13	11	$\overline{PKF}$	Pack Fail Output. $\overline{PKF}$ goes low when any cell voltage exceeds the mismatch threshold or when a shorted cell is detected.
14	14	—	$\overline{WRN}$	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 PCB stray capacitance on this node.
19	19	16	V_{CC}	3.3V Linear Regulator Output. Bypass with a 0.47µF min capacitor to GND.
20	20	—	UVO	Undervoltage Fault Output

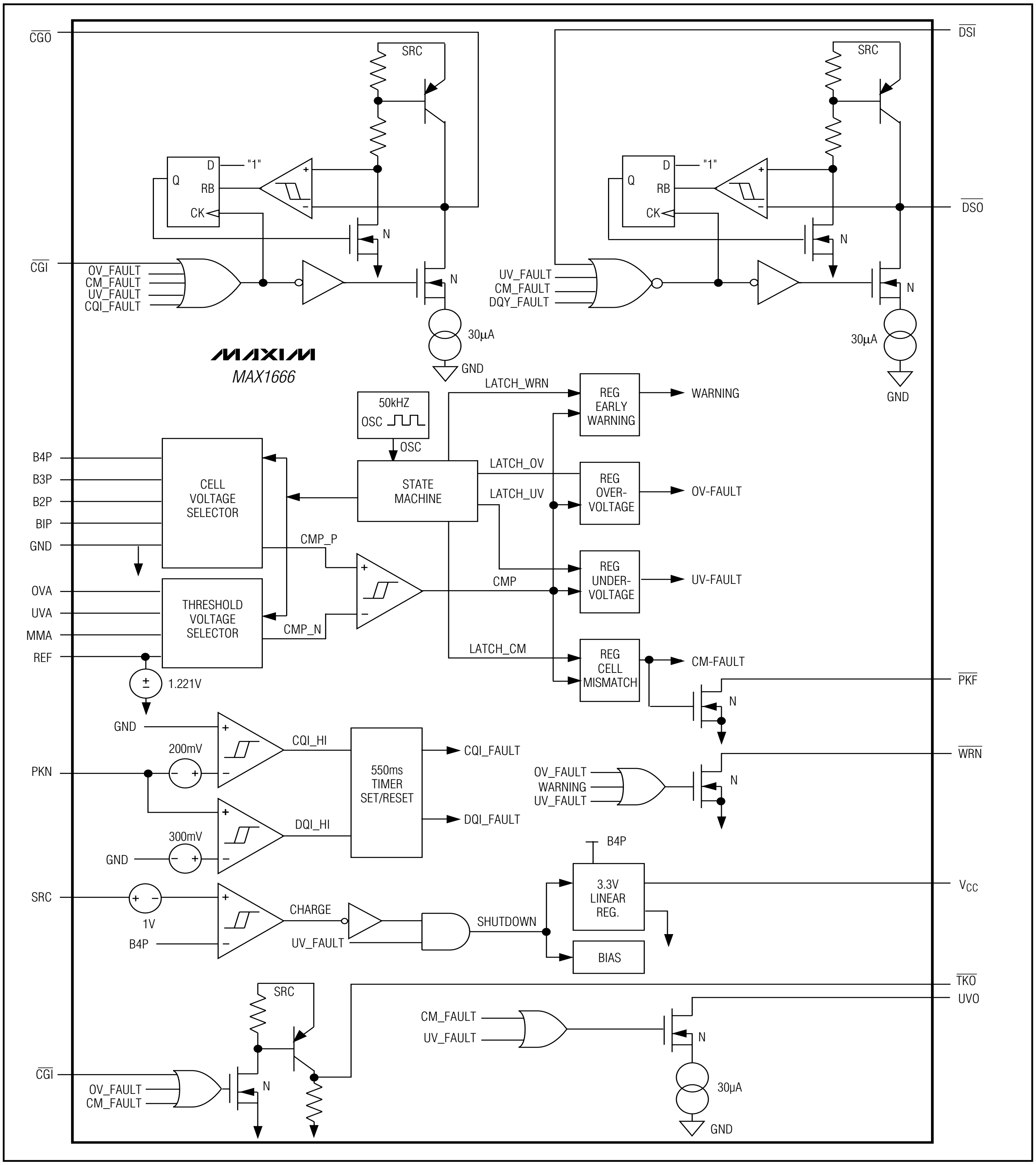


Figure 1. Functional Diagram

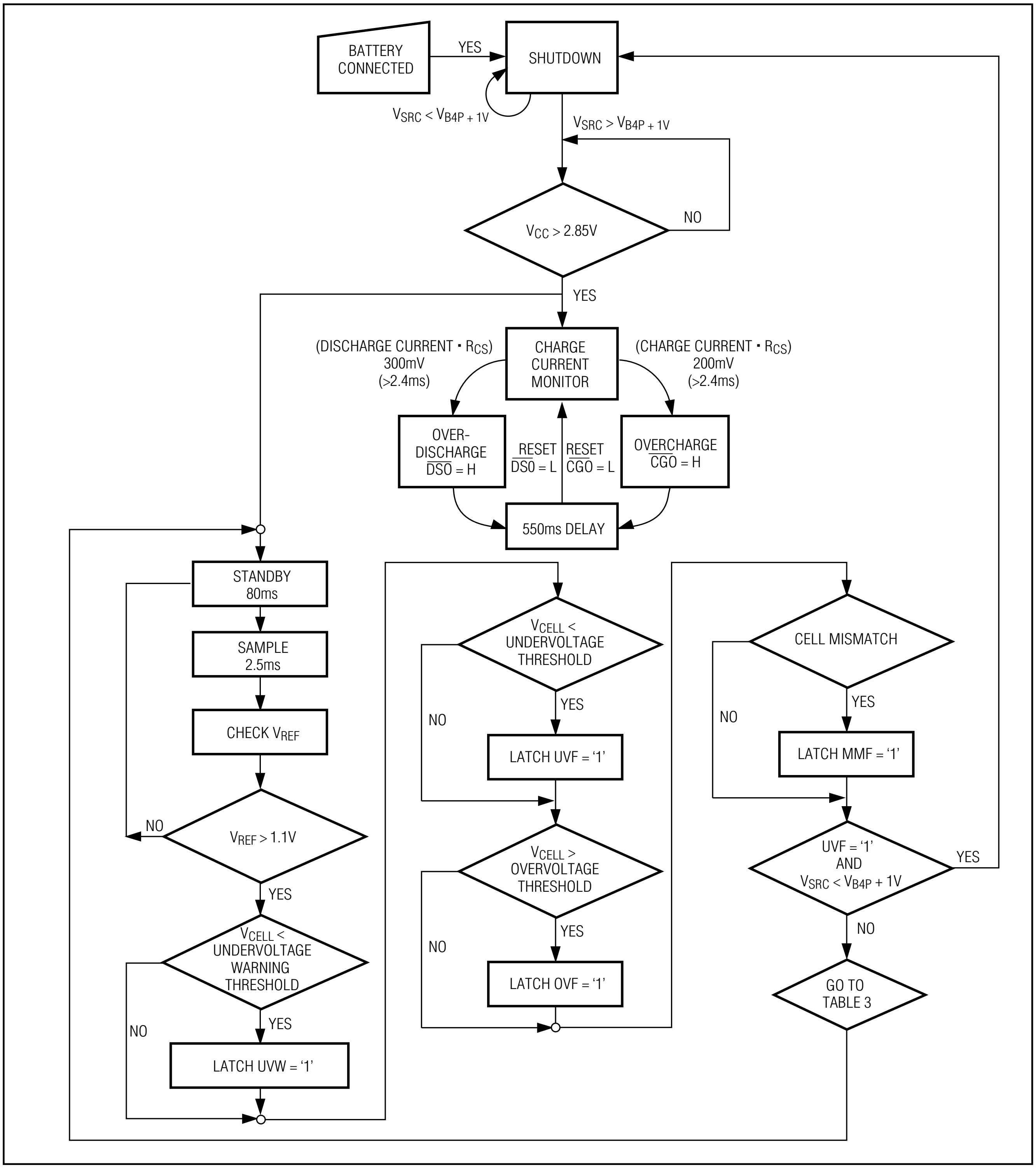


Figure 2. Cell Fault Monitor

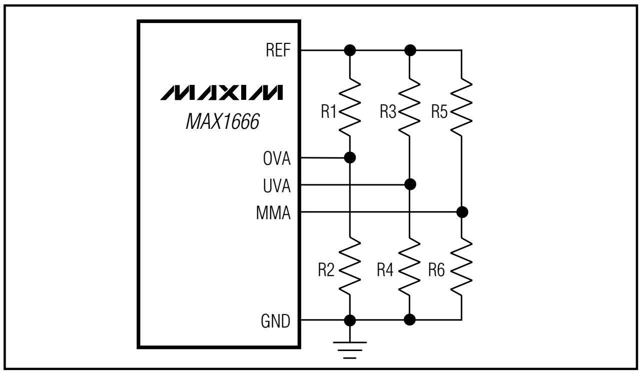


Figure 3. Using an External Resistor-Divider to Adjust Overvoltage Threshold

Detailed Description

The MAX1666 battery-pack protectors supervise the charging and discharging processes of Lithium-Ion 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 overcurrent damage.

Control pins $\overline{CGO}$, $\overline{TKO}$, and $\overline{DSO}$ allow control of external MOSFET gates. This allows fast charging, trickle charging, and discharging processes (see *Typical Operating Circuit*). 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 $\overline{CGO}$, UVO, $\overline{TKO}$, $\overline{DSO}$, $\overline{WRN}$, and $\overline{PKF}$ (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 1µA. All circuitry is inactive except the comparator 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 reconnected, 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, $\overline{CGO}$ and $\overline{TKO}$ go high, turning off the external MOSFETs and stopping the charging process (*Typical Operating Circuits*). $\overline{WRN}$ 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 R_{TOTAL} = R1 + R2 = 1MΩ. Calculate R1 and R2 as follows:

$$R2 = [(V_{OVT} - 4V) / (4.4V - 4V)] \cdot R_{TOTAL}$$

$$R1 = R_{TOTAL} - R2$$

Table 1. Operating Modes

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

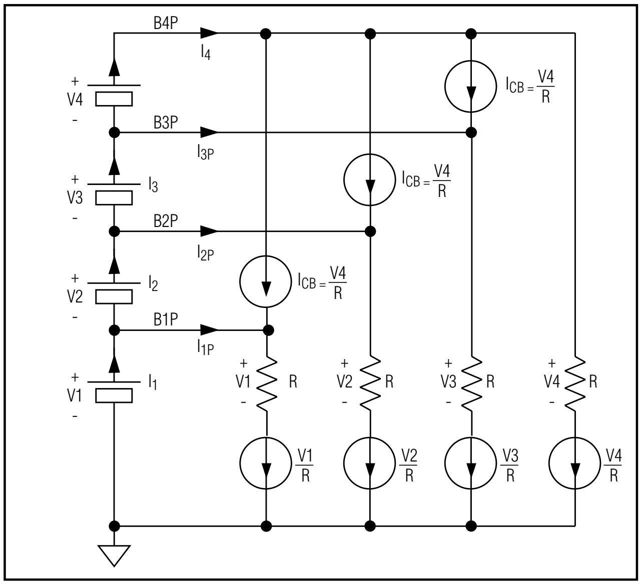


Figure 4. Cell Voltage Sampling

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

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

The total external adjusted overvoltage threshold (V_{OVT}) accuracy is ±0.7%.

Undervoltage Protection

The MAX1666 provides undervoltage protection to avoid overdischarging the cells. When any cell is under voltage, UVO, $\overline{DSO}$, and $\overline{CGO}$ go high, turning off the external charging and discharging MOSFETs. $\overline{TKO}$ 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 R_{TOTAL} = R3 + R4 = 1MΩ. Calculate R3 and R4 as follows:

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

$$R3 = R_{TOTAL} - R4$$

Maximum mismatch of 1% external resistor-dividers is ±2.0%, and the error due to the external resistor-divider multiplied by maximum adjustment is ±2% (3V - 2V) / 3V = ±0.7%. The total external adjusted undervoltage threshold (V_{UVT}) accuracy including the internal undervoltage threshold accuracy (±2.5%) is ±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, $\overline{TKO}$, $\overline{CGO}$, UVO, and $\overline{DSO}$ go high, turning off the external MOSFETs. $\overline{PKF}$ goes low. $\overline{PKF}$ has a strong pull-down current (>4mA), 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 (V_{CMT}) required. V_{CMT} has to be between 0 and 500mV. Set R_{TOTAL} = R5 + R6 = 1MΩ. Calculate R5 and R6:

$$R6 = (V_{CMT} / 500mV)\ R_{TOTAL}$$

$$R5 = R_{TOTAL} - R6$$

Maximum mismatch of 1% external resistor-divider is ±2%. The total external adjusted cell-mismatch threshold accuracy, including the internal cell-mismatch threshold accuracy (±10%), is ±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: $I_4 = 3I_{CB} + V_4 / R = 4V_4 / R$ = BAT4 Current

B3P: $I_3 = I_{3P} + I_4$ = BAT3 Current

$$I_{3P} + I_{CB} = V3 / R \Rightarrow I_{3P} = V_3 / R - V_4 / R$$

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

B2P: $I_2 = I_{2P} + I_3$ = BAT2 Current

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

$$I_2 = I_3 + V_2 / R - V_4 / R = I_4 + (V3 - V_4) / R + (V_2 - V_4) / R = (2V_4 + V_3 + V_2) / R$$

B1P: $I_1 = I_{1P} + I_2$ = 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

$$I_1 = I_2 = I_3 = I_4 = 4V_4 / R$$

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. CGO goes high when the overcharge threshold is exceeded. DSO goes high when the overdischarge threshold is exceeded. An internal 550ms timer starts. At the end of 550ms, DSO or CGO goes low, while the MAX1666 rechecks for an overcharge/overdischarge fault. A persistent fault causes DSO and 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. CGO controls the MOSFET for normal charging of the battery. TKO controls the MOSFET for trickle charge of the cells. 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 SO-8 package.

Layout Considerations and Bypassing

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

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

Table 2. Truth Table

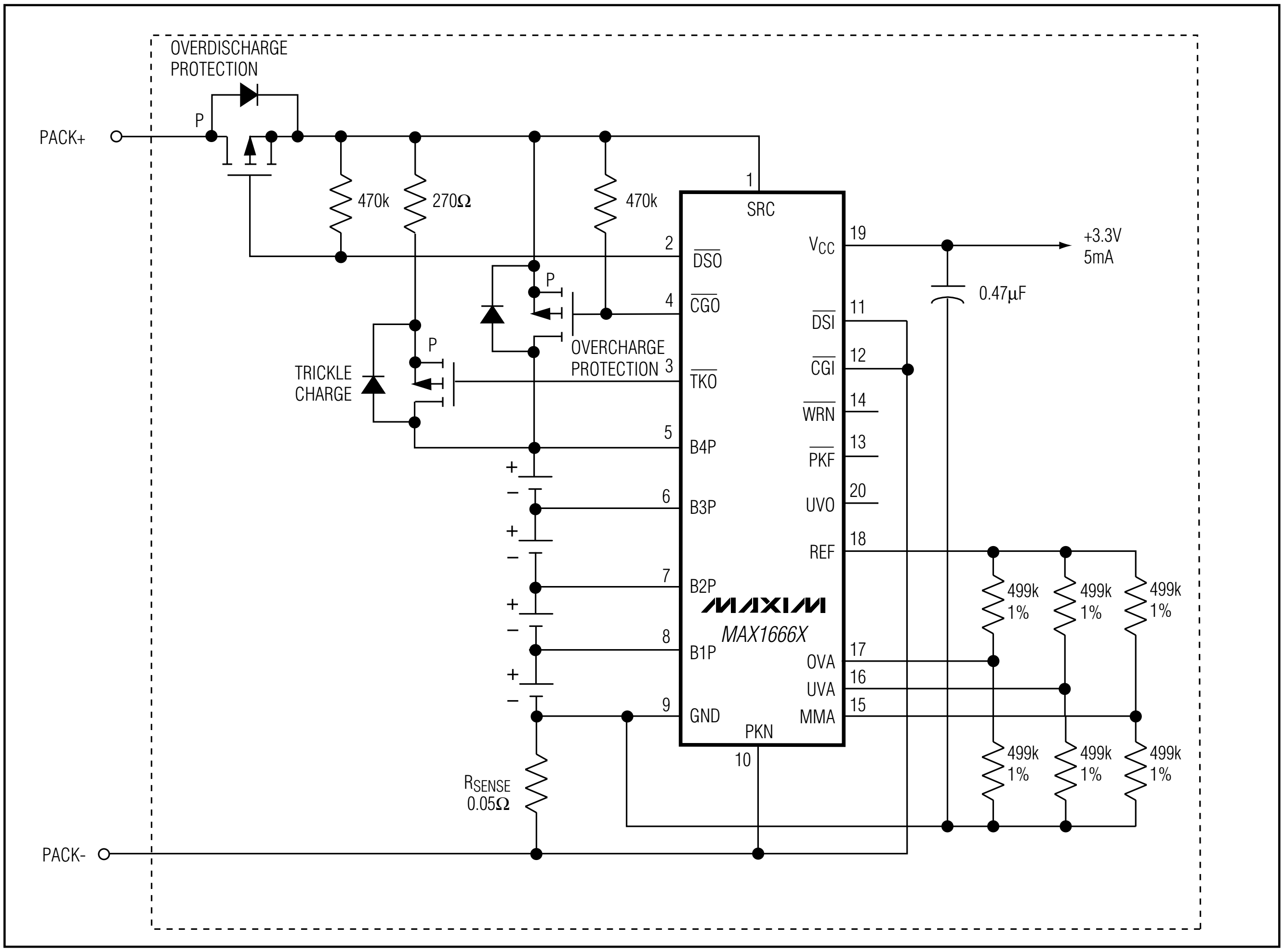
Control Inputs								Control Outputs						Notes
UVW	UVF	OVF	MMF	$\overline{CGI}$	$\overline{DSI}$	OCC	ODC	$\overline{DSO}$	$\overline{CGO}$	$\overline{TKO}$	$\overline{WRN}$	$\overline{PKF}$	UVO	
0	0	0	0	0	0	0	0	L	L	L	H	H	L	Normal operation
0	0	0	0	0	0	0	1	PS	L	L	H	H	L	Overdischarge current fault
0	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	1	0	0	0	H	H	H	H	L	H	Mismatch fault, disable charge path
0	0	0	1	1	1	0	0	H	H	H	H	L	H	Mismatch fault, disable charge and discharge path
0	0	1	0	0	0	0	0	L	H	H	L	H	L	Overvoltage fault
0	0	1	0	0	0	0	1	PS	H	H	L	H	L	Overvoltage fault, overdischarge current fault
0	0	1	0	0	1	0	0	H	H	H	L	H	L	Overvoltage fault, disable discharge path
0	0	1	0	1	0	0	0	L	H	H	L	H	L	Overvoltage fault, disable charge 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	H	L	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
0	0	1	1	0	1	0	0	H	H	H	L	L	H	Overvoltage fault, mismatch fault, disable discharge path
0	0	1	1	1	0	0	0	H	H	H	L	L	H	Overvoltage fault, mismatch fault, disable charge path
0	0	1	1	1	1	0	0	H	H	H	L	L	H	Overvoltage fault, mismatch fault, disable charge and discharge path
1	1	0	0	0	0	0	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	H	L	H	H	Undervoltage fault, disable charge path
1	1	0	0	1	1	0	0	H	H	H	L	H	H	Undervoltage fault, disable charge and discharge path
1	1	0	1	0	0	0	0	H	H	H	L	L	H	Undervoltage fault, mismatch fault
1	1	0	1	0	1	0	0	H	H	H	L	L	H	Undervoltage fault, mismatch fault, disable discharge path
1	1	0	1	1	0	0	0	H	H	H	L	L	H	Undervoltage fault, mismatch fault, disable charge path
1	1	0	1	1	1	0	0	H	H	H	L	L	H	Undervoltage fault, mismatch fault, disable charge and discharge path
1	1	1	1	0	0	0	0	H	H	H	L	L	H	Undervoltage fault, overvoltage fault, mismatch fault
1	1	1	1	0	1	0	0	H	H	H	L	L	H	Undervoltage fault, overvoltage fault, mismatch fault, disable discharge path
1	1	1	1	1	0	0	0	H	H	H	L	L	H	Undervoltage fault, overvoltage fault, mismatch fault, disable charge path
1	1	1	1	1	1	0	0	H	H	H	L	L	H	Undervoltage fault, overvoltage fault, mismatch fault, disable charge and discharge path
1	0	0	0	0	0	0	0	L	L	L	L	H	L	Undervoltage fault early warning
1	0	0	0	0	0	0	1	PS	L	L	L	H	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
1	0	0	0	0	1	1	0	H	PS	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	H	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	H	L	Undervoltage fault early warning, disable charge and discharge path
1	0	0	1	0	0	0	0	H	H	H	L	L	H	Undervoltage fault early warning, mismatch fault
1	0	0	1	0	1	0	0	H	H	H	L	L	H	Undervoltage fault early warning, mismatch fault, disable discharge path
1	0	0	1	1	0	0	0	H	H	H	L	L	H	Undervoltage fault early warning, mismatch fault, disable charge path
1	0	0	1	1	1	0	0	H	H	H	L	L	H	Undervoltage fault early warning, mismatch fault, disable charge and discharge path
1	0	1	1	0	0	0	0	H	H	H	L	L	H	Undervoltage fault early warning, overvoltage fault, mismatch fault
1	0	1	1	0	1	0	0	H	H	H	L	L	H	Undervoltage fault early warning, overvoltage fault, mismatch fault, disable discharge path
1	0	1	1	1	0	0	0	H	H	H	L	L	H	Undervoltage fault early warning, overvoltage fault, mismatch fault, disable charge path
1	0	1	1	1	1	0	0	H	H	H	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.)

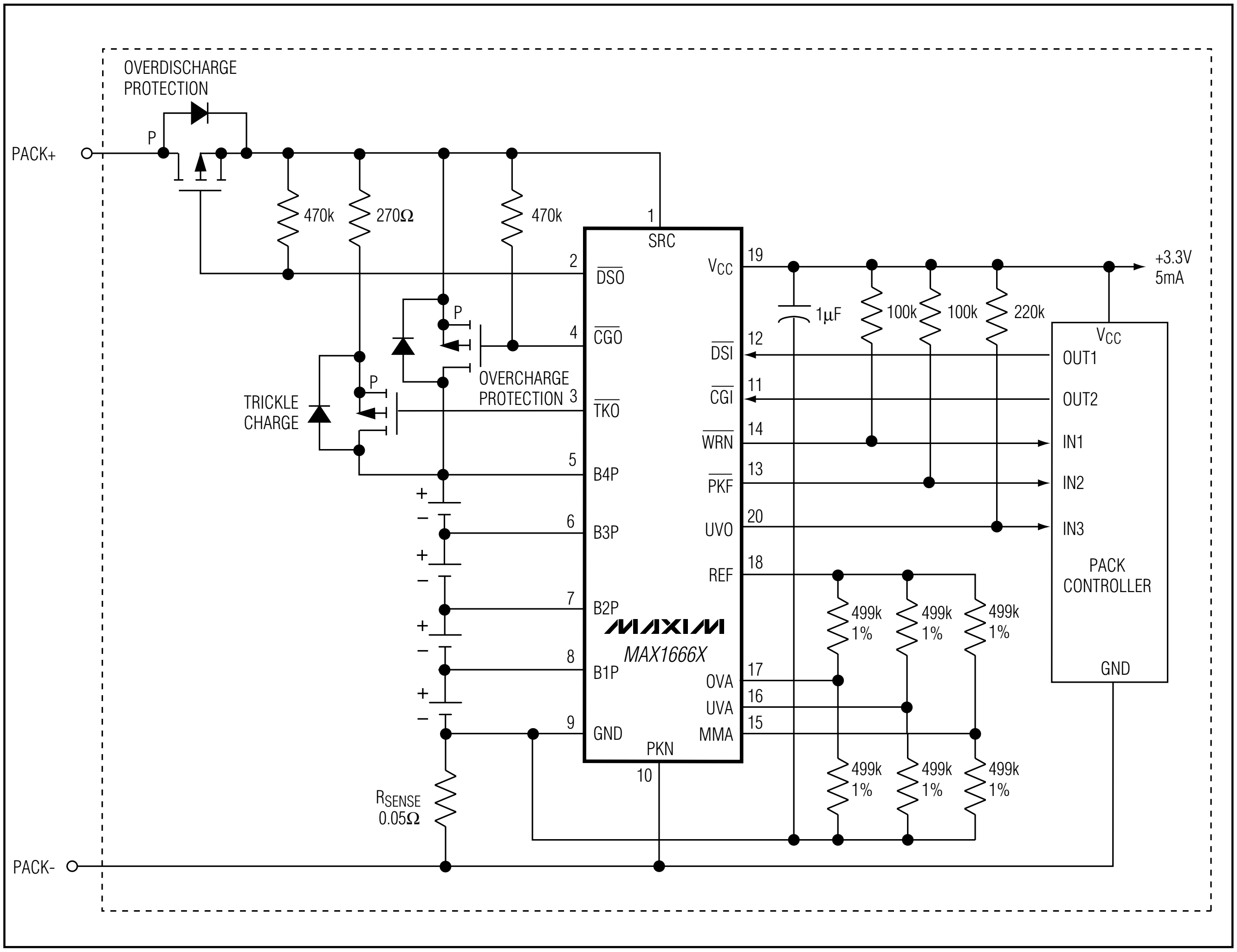
UVW: Undervoltage fault early warning; UVF: Undervoltage fault; OVF: Overvoltage fault; MMF: Mismatch fault

OCC: Overcharge current fault; ODC: Overdischarge current fault; $\overline{CGI}$: Charge control input; $\overline{DSI}$: Discharge control input

Typical Operating Circuits



Typical Operating Circuits (continued)



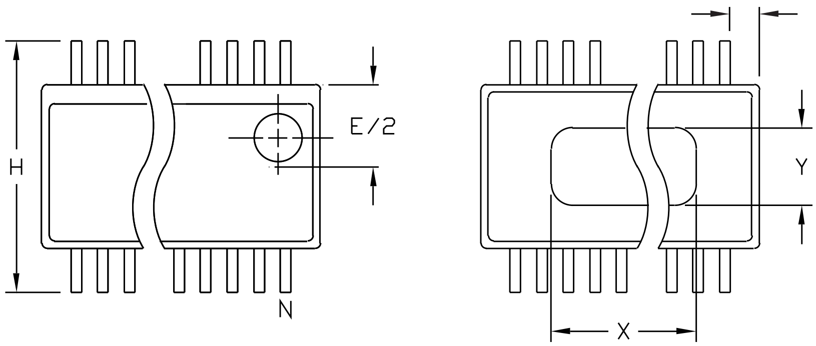
Chip Information

TRANSISTOR COUNT: 4835

Advanced Lithium-Ion Battery-Pack Protector

Package Information

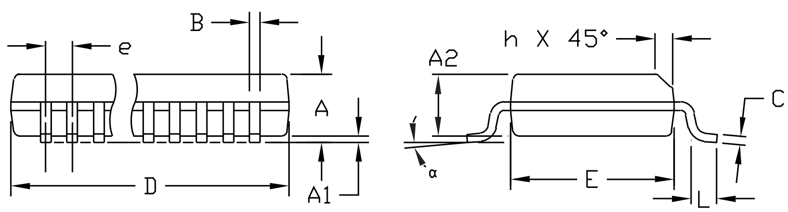
QSOP.EPS



	INCHES		MILLIMETERS	
DIM	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	0.31
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			
X	SEE VARIATIONS			
Y	.071	.087	1.803	2.209
α	0°	8°	0°	8°

VARIATIONS:

	INCHES		MILLIMETERS			
	MIN.	MAX.	MIN.	MAX.	N	
D	.189	.196	4.80	4.98	16	AA
S	.0020	.0070	0.05	0.18		
X	.107	.123	2.72	3.12		
D	.337	.344	8.56	8.74	20	AB
S	.0500	.0550	1.270	1.397		
D	.337	.344	8.56	8.74	24	AC
S	.0250	.0300	0.635	0.762		
D	.386	.393	9.80	9.98	28	AD
S	.0250	.0300	0.635	0.762		
X	.271	.287	6.88	7.29		



NOTES:

1. D & E DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .006" PER SIDE.
3. HEAT SLUG DIMENSIONS X AND Y APPLY ONLY TO 16 AND 28 LEAD POWER-QSOP PACKAGES.
4. CONTROLLING DIMENSIONS: INCHES.

MAXIM

PROPRIETARY INFORMATION

TITLE:

PACKAGE OUTLINE, QSOP, .150", .025" LEAD PITCH

APPROVAL	DOCUMENT CONTROL NO.	REV	
	21-0055	B	1/1