

# ML5233

4- to 10-Series Cell Li-ion Rechargeable Battery Protection IC

## ■ General Description

The ML5233 is a protection IC for the 4- to 10-cell Li-ion rechargeable battery pack. It detects individual cell overvoltage/undervoltage and the pack overcurrent/over-temperature, and then automatically turns on or turns off the external charge/discharge NMOS-FETs accordingly. Also the ML5233 can be cascaded to handle battery packs with more than 10 cells.

## ■ Features

- 4 to 10 cell high-precision overvoltage and undervoltage detection function
  - Voltage monitoring function for individual cells
  - Overvoltage detection threshold                      4.25 V,            Detection accuracy:  $\pm 15$  mV (max)
  - Undervoltage detection threshold                      2.7 V,                    Detection accuracy:  $\pm 50$  mV (max)
- Overcurrent detection function
  - Discharge overcurrent detection threshold            150 mV,            Detection accuracy:  $\pm 10$  mV (max)
  - Charge overcurrent detection threshold               -40 mV,            Detection accuracy:  $\pm 15$  mV (max)
- Short circuit detection function
  - Short circuit detection threshold                      300 mV,            Detection accuracy:  $\pm 15$  mV (max)
  - Detection delays adjustable using an external capacitor
- Temperature detection function            : With external NTC (10 k $\Omega$ , B=3435) and 4.7 k $\Omega$  resistor
  - Discharge inhibition temperature: 75 °C or higher
  - Charge inhibition temperature            : 55 °C or higher
- External charge/discharge FET control: NMOS-FET gate driver built-in
  - External shut down command is accepted on the /CFOFF and /DFOFF pins
  - In a cascade configuration external circuits can be minimized with the power-up control pin VRSO
- Cell number selectable from predefined 4 values using the CS0 and CS1 pins
  - Product code 001 supports 7, 8, 9 or 10-cell connectivity
  - Cell numbers and other parameters can be redefined and supplied as an individual product code
- Low current consumption
  - Normal operation state            : 25  $\mu$ A (typ.),            60  $\mu$ A (max)
  - Power-down state                    : 0.1  $\mu$ A (typ.),            1  $\mu$ A (max)
- Supply voltage                                : +5 V to +60 V
- Operating temperature                      : -40°C to +85°C
- Package                                         : 32-pin LQFP

## ■ Application

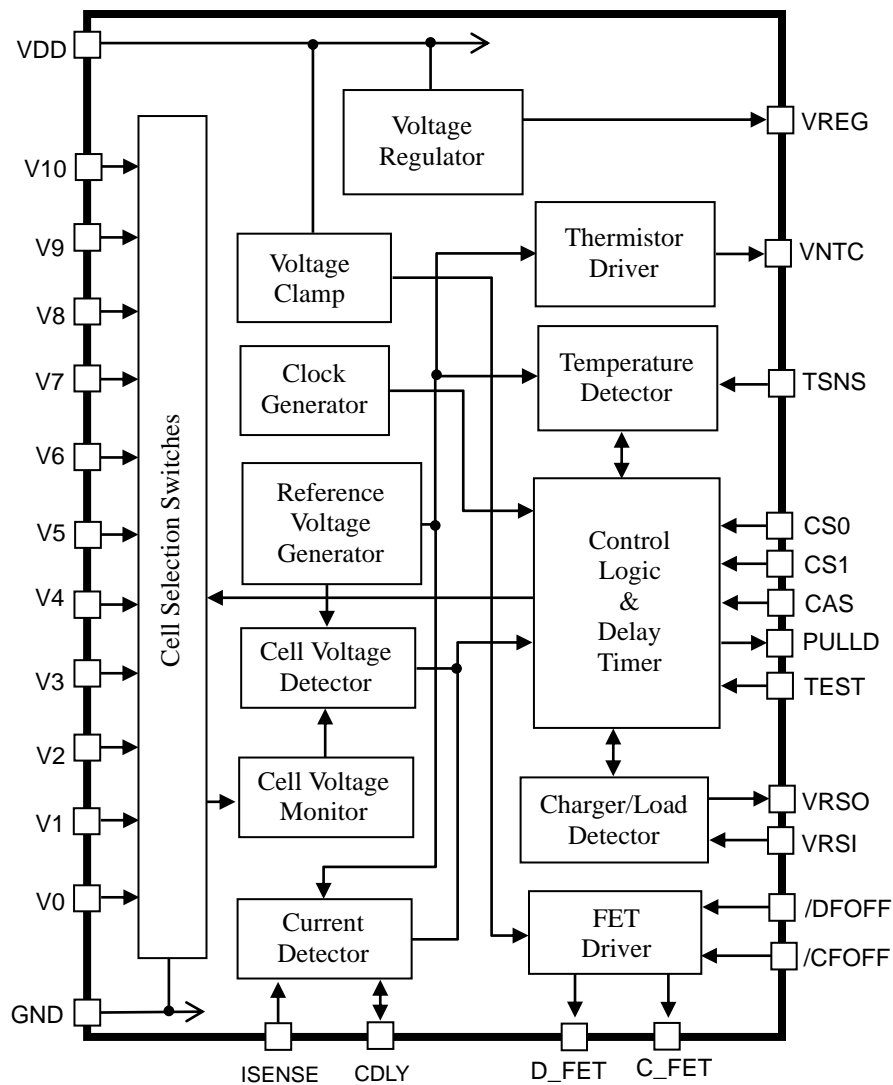
- Power tools and Garden tools
- Cordless Cleaner
- E-Bike and Electric assisted bicycle
- Uninterruptible Power Supplies (UPS)
- Energy Storage Systems (ESS)

## ■ Part number

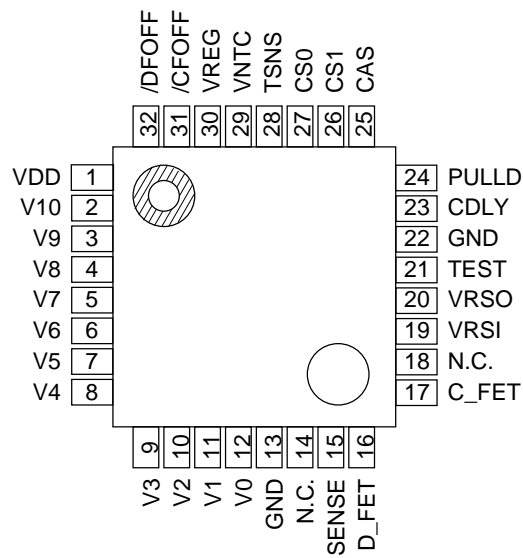
ML5233-001TC



■ Block Diagram



■ Pin Configuration (top view)



## ■ Pin Description

Pin No.	Pin	I/O	Description
1	VDD	—	Power supply input pin. Connect an external CR filter for noise rejection.
2	V10	I	Battery cell 10 high voltage input pin.
3	V9	I	Battery cell 10 low voltage input and Battery cell 9 high voltage input pin.
4	V8	I	Battery cell 9 low voltage input and Battery cell 8 high voltage input pin.
5	V7	I	Battery cell 8 low voltage input and Battery cell 7 high voltage input pin.
6	V6	I	Battery cell 7 low voltage input and Battery cell 6 high voltage input pin.
7	V5	I	Battery cell 6 low voltage input and Battery cell 5 high voltage input pin. Should be connected to GND for the 4 cell series connected battery pack application.
8	V4	I	Battery cell 5 low voltage input and Battery cell 4 high voltage input pin. Should be connected to GND for the 4 to 5 cell series connected battery pack application.
9	V3	I	Battery cell 4 low voltage input and Battery cell 3 high voltage input pin. Should be connected to GND for the 4 to 6 cell series connected battery pack application.
10	V2	I	Battery cell 3 low voltage input and Battery cell 2 high voltage input pin. Should be connected to GND for the 4 to 7 cell series connected battery pack application.
11	V1	I	Battery cell 2 low voltage input and Battery cell 1 high voltage input pin. Should be connected to GND for the 4 to 8 cell series connected battery pack application.
12	V0	I	Battery cell 1 low voltage input pin. Should be connected to GND for the 4 to 9 cell series connected battery pack application.
13, 22	GND	—	Ground pins.
15	ISENSE	I	Current sense resistor input pin. Connect a resistor of the resistance value corresponding to the detecting current between this pin and the GND pin. Should be tied to GND if not used.
16	D_FET	O	Discharge FET control signal output pin. Should be tied to the gate pin of the external NMOS FET.
17	C_FET	O	Charge FET control signal output pin. Should be tied to the gate pin of the external NMOS FET.
19	VRSI	IO	Negative terminal of the load/charger input pin. Load or charger presence is decided by this input level.
20	VRSO	O	Power-up signal output pin in cascade connection. Should be tied to the next upper VRSI pin.
21	TEST	I	LSI test input pin. Should be fixed to GND.
23	CDLY	IO	Short current detection delay time setting pin. Should be tied to GND through a capacitor.
24	PULLD	O	External pull-down control signal output for load removal detection. Should be tied to the gate of the external pull-down control NMOS-FET when cascaded.
25	CAS	I	Cascade mode selection input. Should be fixed to the VREG level when cascaded.
26	CS1	I	Pins to specify battery cell number. Either the VREG or the GND level should be applied.
27	CS0	I	
28	TSNS	I	Input pin for high temperature charge/discharge inhibition detection. Connect a thermistor between this pin and GND. Should be tied to the VNTC pin if not used.
29	VNTC	O	Thermistor power supply. Should be connected to TSNS through a 4.7 kΩ resistor. Should be pulled down with a 100 kΩ resistor if not used.
30	VREG	O	Built-in 4.3 V regulator output pin. Should be tied to GND through a 1 μF capacitor. Do not use this pin as power supply for an external circuit.
31	/CFOFF	I	OFF control command input pin for the charge FET. The "L" level input forces Hi-Z on the C_FET output. Should be tied to the next upper C_FET pin through an external resistor when cascaded.
32	/DFOFF	I	OFF control command input pin for the discharge FET. The "L" level input forces "L" on the D_FET output. Should be tied to the next upper D_FET pin through an external resistor when cascaded.
14, 18	N.C.	—	No connect. Leave them electrically unconnected.

## ■ Absolute Maximum Ratings

GND=0V, Ta=25°C

Item	Symbol	Condition	Rating	Unit
Supply voltage	V <sub>DD</sub>	Applied to VDD pin	-0.3 to +86.5	V
Input voltage	V <sub>IN1</sub>	Applied to V0 to V10 pins	-0.3 to V <sub>DD</sub> +0.3	V
	V <sub>IN2</sub>	Applied to VRSI pin	V <sub>DD</sub> -86.5 to V <sub>DD</sub> +0.3	V
	V <sub>IN3</sub>	Applied to /CFOFF and /DFOFF pins	-0.3 to +86.5	V
	V <sub>IN4</sub>	Applied to CS0, CS1, CAS, TSNS, CDLY, and ISENSE pins	-0.3 to V <sub>REG</sub> +0.3	V
	V <sub>IN5</sub>	Applied to TEST pin	-0.3 to V <sub>DD</sub> +0.3	V
Output voltage	V <sub>OUT1</sub>	Applied to D_FET and VRSO pins	-0.3 to V <sub>DD</sub> +0.3	V
	V <sub>OUT2</sub>	Applied to C_FET pin	V <sub>DD</sub> -86.5 to V <sub>DD</sub> +0.3	V
	V <sub>OUT3</sub>	Applied to VREG pin	-0.3 to +6.5	V
	V <sub>OUT4</sub>	Applied to VNTC and PULLD pins	-0.3 to V <sub>REG</sub> +0.3	V
Power dissipation	P <sub>D</sub>	—	1.0	W
Short-circuit output current	I <sub>OS</sub>	Applied to VREG, VNTC, PULLD, C_FET, D_FET, and VRSO pins	10	mA
Storage temperature	T <sub>STG</sub>	—	-55 to +150	°C

## ■ Recommended Operating Conditions

(GND= 0 V)

Item	Symbol	Condition	Range	Unit
Supply voltage	V <sub>DD</sub>	Applied to VDD pin	5 to 60	V
Operational temperature	T <sub>OP</sub>	—	-40 to +85	°C

## ■ Electrical Characteristics

## ● DC Characteristics

 $V_{DD}=5\text{ V to }60\text{ V}$ ,  $GND=0\text{ V}$ ,  $T_a=-40\text{ to }+85^{\circ}\text{C}$ 

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Digital "H" input voltage (Note 1)	$V_{IH1}$	—	$0.8 \times V_{REG}$	—	$V_{REG}$	V
Digital "L" input voltage (Note 1)	$V_{IL1}$	—	0	—	$0.2 \times V_{REG}$	V
Digital "H" input current (Note 1)	$I_{IH1}$	$V_{IH} = V_{REG}$	—	—	2	$\mu\text{A}$
Digital "L" input current (Note 1)	$I_{IL1}$	$V_{IL} = GND$	-2	—	—	$\mu\text{A}$
Cell monitoring pin Input current (Note 2)	$I_{INVC}$	Average current in normal operation mode	-0.1	0.1	3	$\mu\text{A}$
Cell monitoring pin Input leakage current (Note 2)	$I_{ILVC}$	Power-down mode	—	—	2	$\mu\text{A}$
FET "H" output voltage (Note 3)	$V_{OH1}$	$I_{OH}=-10\text{ }\mu\text{A}$ $V_{DD}=18\text{ V to }60\text{ V}$	10	14	18	V
FET "L" output voltage (Note 4)	$V_{OL1}$	$I_{OL} = 100\text{ }\mu\text{A}$	—	—	0.2	V
C_FET output leakage current	$I_{LCF}$	$V_{CFET}=0\text{ V to }V_{DD}$	-5	—	5	$\mu\text{A}$
/CFOFF and /DFOFF pins "H" input voltage	$V_{IH2}$	—	$V_{DD}-0.1$	—	$V_{DD}+18$	V
/CFOFF and /DFOFF pins "L" input voltage	$V_{IL2}$	—	0	—	$V_{DD}-1.5$	V
/CFOFF and /DFOFF pins "H" input current	$I_{IH2}$	$V_{IH2}=V_{DD}$	—	—	2	$\mu\text{A}$
/CFOFF and /DFOFF pins "L" input current	$I_{IL2}$	$V_{IL2}=0\text{ V}$	-2	—	—	$\mu\text{A}$
PULLD pin "H" output voltage	$V_{OH2}$	$I_{OH} = -100\text{ }\mu\text{A}$	$V_{REG}-0.4$	—	$V_{REG}$	V
PULLD pin "L" output voltage	$V_{OL2}$	$I_{OL} = 100\text{ }\mu\text{A}$	—	—	0.1	V
CDLY pin "L" output voltage	$V_{OL3}$	$I_{OL} = 100\text{ }\mu\text{A}$	—	—	0.4	V
CDLY pin pull-up resistor	$R_{PUC}$	At short current detection	44	63	82	$\text{k}\Omega$
VREG pin output voltage	$V_{REG}$	With load current 1 mA or less	3.8	4.3	4.8	V
VNTC pin output voltage	$V_{NTC}$	With 14.7 $\text{k}\Omega$ resistor connection	2.2	2.4	2.6	V
VNTC pin output leakage current	$I_{LNTC}$	$V_{NTC}=0\text{ V to }3.5\text{ V}$	-2	—	2	$\mu\text{A}$
TSNS pin input leakage current	$I_{ILTS}$	$V_{TSNS}=0\text{ V to }3.5\text{ V}$	-2	—	2	$\mu\text{A}$
ISENSE pin input leakage current	$I_{ILIS}$	$V_{ISENSE}=0\text{ V to }3.5\text{ V}$	-2	—	2	$\mu\text{A}$
TEST pin pull-down resistance	$R_{PDT}$	—	50	100	200	$\text{k}\Omega$

Note 1: Applied to CS0, CS1, and CAS pins.

Note 2: Applied to V0 to V10 pins.

Note 3: Applied to C\_FET and D\_FET pins.

Note 4: Applied to D\_FET pin.

Note 5: Applied to C\_FET pin.

## ● Supply Current Characteristics

 $V_{DD}=5\text{ to }60\text{ V}$ ,  $GND=0\text{ V}$ ,  $T_a=-40\text{ to }+85^{\circ}\text{C}$ 

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Current consumption in normal operation	$I_{DD}$	No output load	—	25	60	$\mu\text{A}$
Current consumption in power-down mode	$I_{DDS}$	No output load	—	0.1	1.0	$\mu\text{A}$

## ● Detection/Release Threshold Characteristics (Ta = 25 °C)

V<sub>DD</sub>=36 V, GND=0 V, Ta=+25°C

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Overvoltage detection threshold	V <sub>OV</sub>	—	4.235	4.25	4.265	V
Overvoltage release threshold	V <sub>OVR</sub>	—	3.95	4.00	4.05	V
Undervoltage detection threshold	V <sub>UV</sub>	—	2.65	2.70	2.75	V
Undervoltage release threshold	V <sub>UVR</sub>	—	2.95	3.00	3.05	V
Discharge overcurrent detection threshold	V <sub>OCU</sub>	—	140	150	160	mV
Charge overcurrent detection threshold	V <sub>OCO</sub>	—	-55	-40	-25	mV
Short circuit detection threshold	V <sub>SHRT</sub>	—	285	300	315	mV
High temperature charge inhibition detection threshold	V <sub>CHD</sub>	—	0.99	1.02	1.05	V
High temperature charge inhibition release threshold	V <sub>CHR</sub>	—	1.16	1.21	1.26	V
High temperature discharge inhibition detection threshold	V <sub>DHD</sub>	—	670	700	730	mV
High temperature discharge inhibition release threshold	V <sub>DHR</sub>	—	800	850	900	mV

## ● Detection/Release Threshold Characteristics (Ta = 0 to 60 °C)

V<sub>DD</sub>=36 V, GND=0 V, Ta=0 to 60°C

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Overvoltage detection threshold	V <sub>OV</sub>	—	4.225	4.25	4.275	V
Overvoltage release threshold	V <sub>OVR</sub>	—	3.93	4.00	4.07	V
Undervoltage detection threshold	V <sub>UV</sub>	—	2.6	2.7	2.8	V
Undervoltage release threshold	V <sub>UVR</sub>	—	2.9	3.0	3.1	V
Discharge overcurrent detection threshold	V <sub>OCU</sub>	—	135	150	165	mV
Charge overcurrent detection threshold	V <sub>OCO</sub>	—	-65	-40	-15	mV
Short circuit detection threshold	V <sub>SHRT</sub>	—	270	300	330	mV
High temperature charge inhibition detection threshold	V <sub>CHD</sub>	—	0.97	1.02	1.07	V
High temperature charge inhibition release threshold	V <sub>CHR</sub>	—	1.14	1.21	1.28	V
High temperature discharge inhibition detection threshold	V <sub>DHD</sub>	—	650	700	750	mV
High temperature discharge inhibition release threshold	V <sub>DHR</sub>	—	780	850	920	mV
VREG drop detection threshold	V <sub>UREG</sub>	—	3.0	3.4	3.8	V
VREG drop release threshold	V <sub>RREG</sub>	—	3.4	3.8	4.2	V

● Charger Detection / Removal and Load Removal Threshold Characteristics (Ta=25 °C)

V<sub>DD</sub>=36 V, GND=0 V, Ta=+25°C

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Charger detection VRSI threshold	V <sub>PC</sub>	Wake-up from power-down mode	V <sub>DD</sub> X0.4	V <sub>DD</sub> X0.5	V <sub>DD</sub> X0.6	V
Charger removal VRSI threshold	V <sub>PLU1</sub>	In charge overcurrent state CAS pin = "L"	0.1	0.2	0.3	V
	V <sub>PLU2</sub>	In charge overcurrent state CAS pin = "H"	0.3	0.4	0.5	V
	V <sub>PLD</sub>	Power-down mode	V <sub>DD</sub> X0.7	V <sub>DD</sub> X0.75	V <sub>DD</sub> X0.8	V
Load removal VRSI threshold	V <sub>RL</sub>	In discharge overcurrent state	2.2	2.4	2.6	V

● Charger Detection / Removal and Load Removal Threshold Characteristics  
(Ta=0 to 60 °C)

V<sub>DD</sub>=36 V, GND=0 V, Ta=0 to 60°C

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Charger detection VRSI threshold	V <sub>PC</sub>	Wake-up from power-down mode	V <sub>DD</sub> X0.35	V <sub>DD</sub> X0.5	V <sub>DD</sub> X0.65	V
Charger removal VRSI threshold	V <sub>PLU1</sub>	In charge overcurrent state CAS pin = "L"	0	0.2	0.4	V
	V <sub>PLU2</sub>	In charge overcurrent state CAS pin = "H"	0.2	0.4	0.6	V
	V <sub>PLD</sub>	Power-down mode	V <sub>DD</sub> X0.65	V <sub>DD</sub> X0.75	V <sub>DD</sub> X0.85	V
Load removal VRSI threshold	V <sub>RL</sub>	In discharge overcurrent state	2.0	2.4	2.8	V
VRSI pin pull-up resistance	R <sub>PU</sub>	In charge overcurrent state, power-down mode	200	500	1000	kΩ
VRSI pin pull-down resistance	R <sub>PD</sub>	In discharge overcurrent state CAS pin = "L"	0.5	2	4	MΩ
VRSI pin input current	I <sub>LPS1</sub>	Without pull-up/-down resistor CAS pin = "L"	-2	—	2	μA
	I <sub>LPS2</sub>	Without pull-up/-down resistor CAS pin = "H"	-3	-0.2	2	μA
VRSO pin output current	I <sub>OL</sub>	CAS pin = "H" VRSI pin = "L" V <sub>OL</sub> = 5 V	0.5	1	2	μA
VRSO pin output leakage current	I <sub>OLK</sub>	VRSI pin = "H" V <sub>RSO</sub> = 36 V	0	—	2	μA
VRSO pin pull-down resistance	R <sub>PDR</sub>	CAS pin = "H" at wake-up	200	500	1000	kΩ



## ● Detection Delay and Monitor Cycle Characteristics (Ta = 25 °C)

V<sub>DD</sub>=36 V, GND=0 V, Ta=+25°C

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Overvoltage detection delay (Note)	t <sub>OV</sub>	—	2.6	3.0	4.0	sec
Undervoltage detection delay (Note)	t <sub>UV</sub>	—	0.85	1.00	1.65	sec
Charge overcurrent detection delay	t <sub>OCO</sub>	—	70	100	130	ms
Discharge overcurrent detection delay	t <sub>OCU</sub>	—	70	100	130	ms
Short circuit detection delay	t <sub>SC</sub>	C <sub>DLY</sub> =10 nF	0.7	1.0	1.3	ms
Cell voltage monitor cycle	t <sub>DET</sub>	—	320	400	480	ms
Temperature monitor cycle	t <sub>PT</sub>	—	320	400	480	ms
Temperature measurement time	t <sub>TM</sub>	—	2.3	3	3.7	ms
Load removal delay	t <sub>ORL</sub>	—	70	100	130	ms
Charger removal delay	t <sub>CHG</sub>	—	70	100	130	ms
Internal source oscillation clock cycle	t <sub>OSC</sub>	—	85	100	115	μs
Overvoltage detection delay for test mode (Note)	t <sub>OV<sub>T</sub></sub>	TSNS pin = V <sub>REG</sub>	70	100	610	ms
Undervoltage detection delay for test mode (Note)	t <sub>UV<sub>T</sub></sub>	TSNS pin = V <sub>REG</sub>	70	100	610	ms
Cell voltage monitor cycle for test mode	t <sub>DE<sub>T</sub></sub>	TSNS pin = V <sub>REG</sub>	70	100	130	ms
Temperature monitor cycle for test mode	t <sub>PT<sub>T</sub></sub>	TSNS pin = V <sub>REG</sub>	70	100	130	ms
TSNS pin input voltage for test mode	V <sub>TST</sub>	—	V <sub>REG</sub> -0.3	—	V <sub>REG</sub>	V

(Note) Time lag due to cell voltage monitor cycle should be added on top of these values.

● Detection Delay and Monitor Cycle Characteristics (Ta = 0 to 60 °C)

V<sub>DD</sub>=36 V, GND=0 V, Ta=0 to 60°C

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Overvoltage detection delay (Note)	t <sub>OV</sub>	—	2.4	3.0	4.2	sec
Undervoltage detection delay (Note)	t <sub>UV</sub>	—	0.80	1.00	1.75	sec
Charge overcurrent detection delay	t <sub>OCO</sub>	—	50	100	150	ms
Discharge overcurrent detection delay	t <sub>OCU</sub>	—	50	100	150	ms
Short circuit detection delay	t <sub>SC</sub>	C <sub>DLY</sub> =10 nF	0.6	1.0	1.4	ms
Cell voltage monitor cycle	t <sub>DET</sub>	—	300	400	500	ms
Temperature monitor cycle	t <sub>PT</sub>	—	300	400	500	ms
Temperature measurement time	t <sub>TM</sub>	—	2	3	4	ms
Load removal delay	t <sub>ORL</sub>	—	50	100	150	ms
Charger removal delay	t <sub>CHG</sub>	—	50	100	150	ms
Internal source oscillation clock cycle	t <sub>OSC</sub>	—	80	100	120	μs

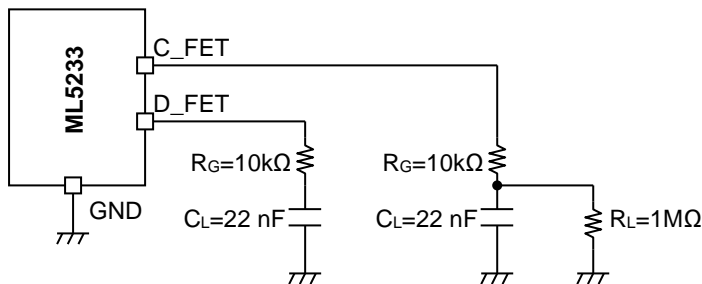
(Note) Time lag due to cell voltage monitor cycle should be added on top of these values.

● Transient Characteristics

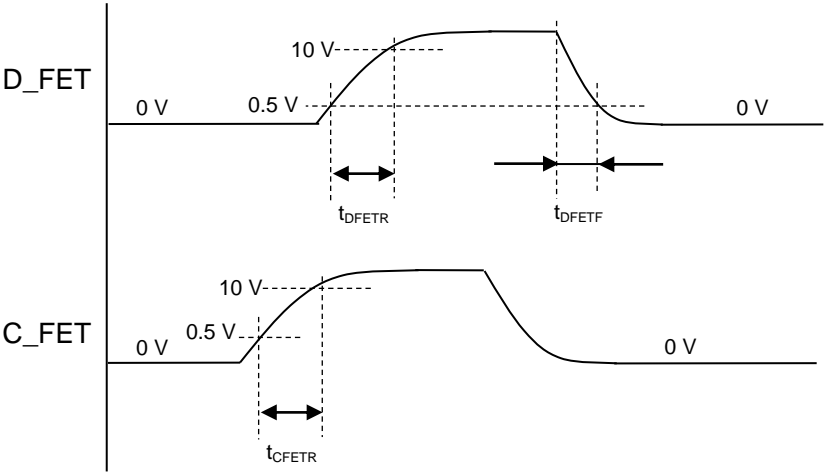
$V_{DD}=36\text{ V}$ ,  $GND=0\text{ V}$ ,  $T_a=0\text{ to }60^{\circ}\text{C}$

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
D_FET pin output rise time	$t_{DFETR}$	$C_L=22\text{ nF}$ , $R_G=10\text{ k}\Omega$	—	95	400	$\mu\text{s}$
C_FET pin output rise time	$t_{CFETR}$	$C_L=22\text{ nF}$ , $R_G=10\text{ k}\Omega$ $R_L=1\text{ M}\Omega$	—	95	400	$\mu\text{s}$
D_FET pin output fall time	$t_{DFETF}$	$C_L=22\text{ nF}$ , $R_G=10\text{ k}\Omega$	—	1	150	$\mu\text{s}$

◆ Measurement circuit



◆ Timing Diagrams

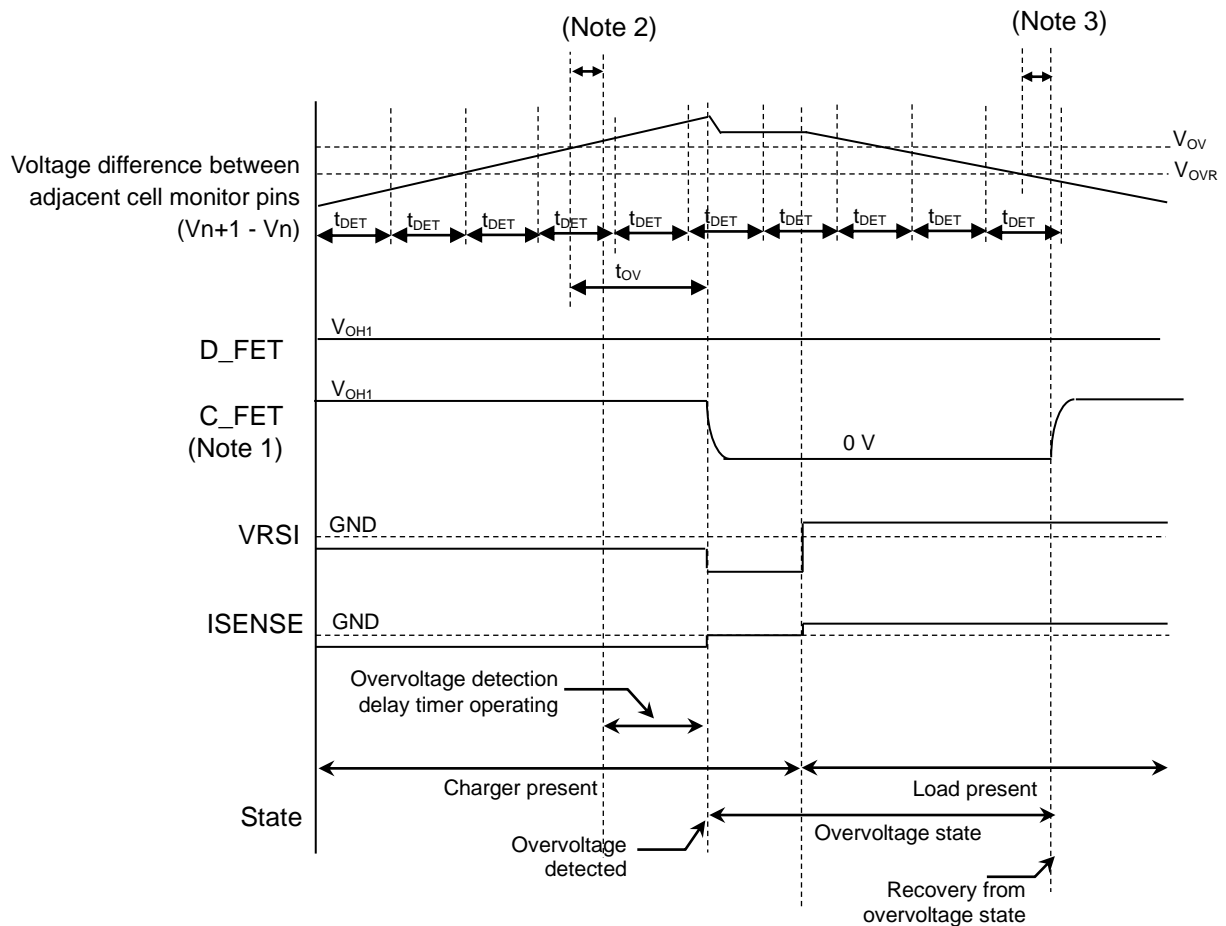


(Note) C\_FET output fall depends on the time constant of the external loads  $R_L$  and  $C_L$

## ■ Timing Diagrams

This section shows the timing diagrams of application circuit example 1 (without cascade connection).

### ● Overvoltage Detection and Recovery

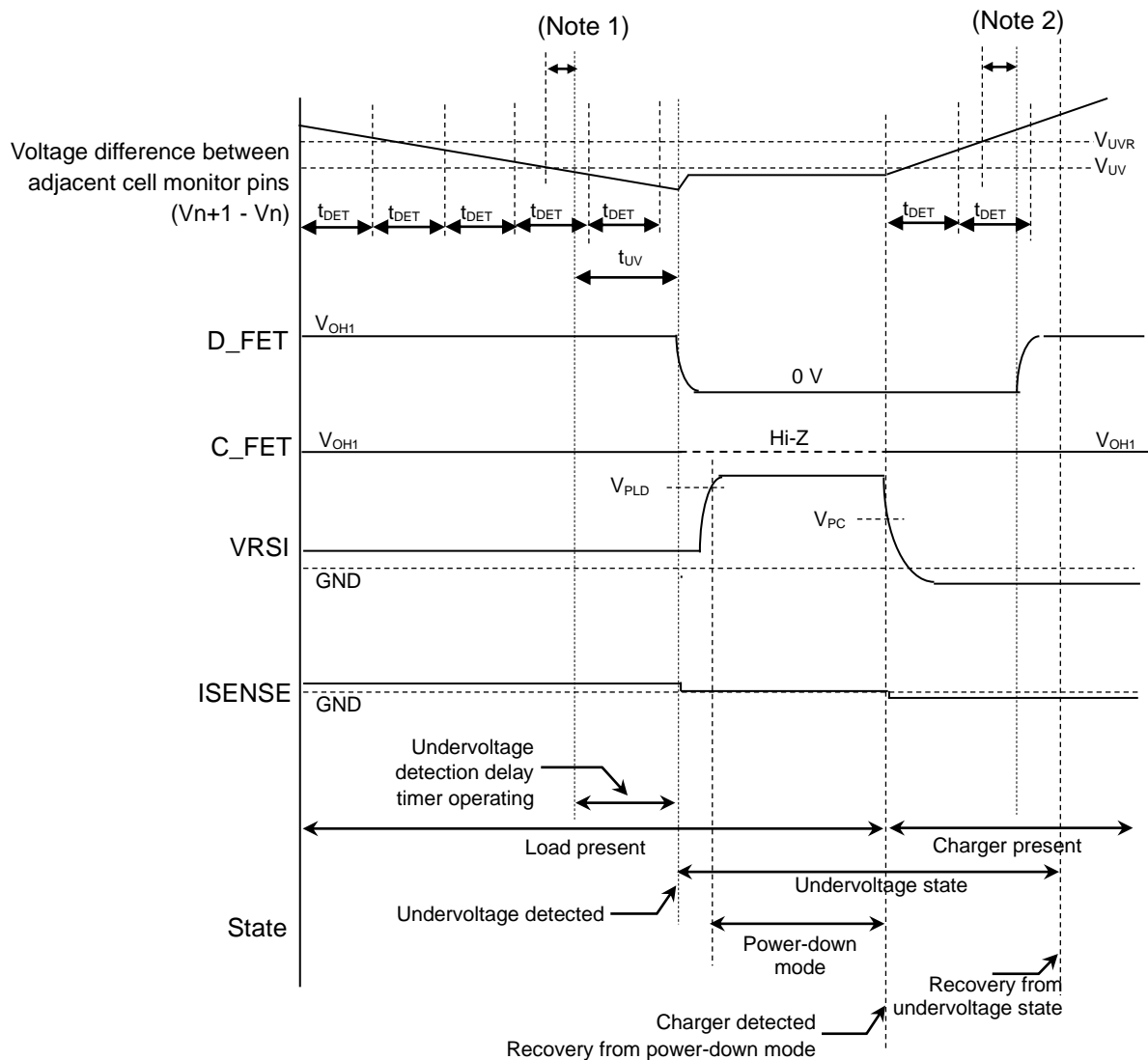


(Note 1) C\_FET pin is pulled down with a resistor.

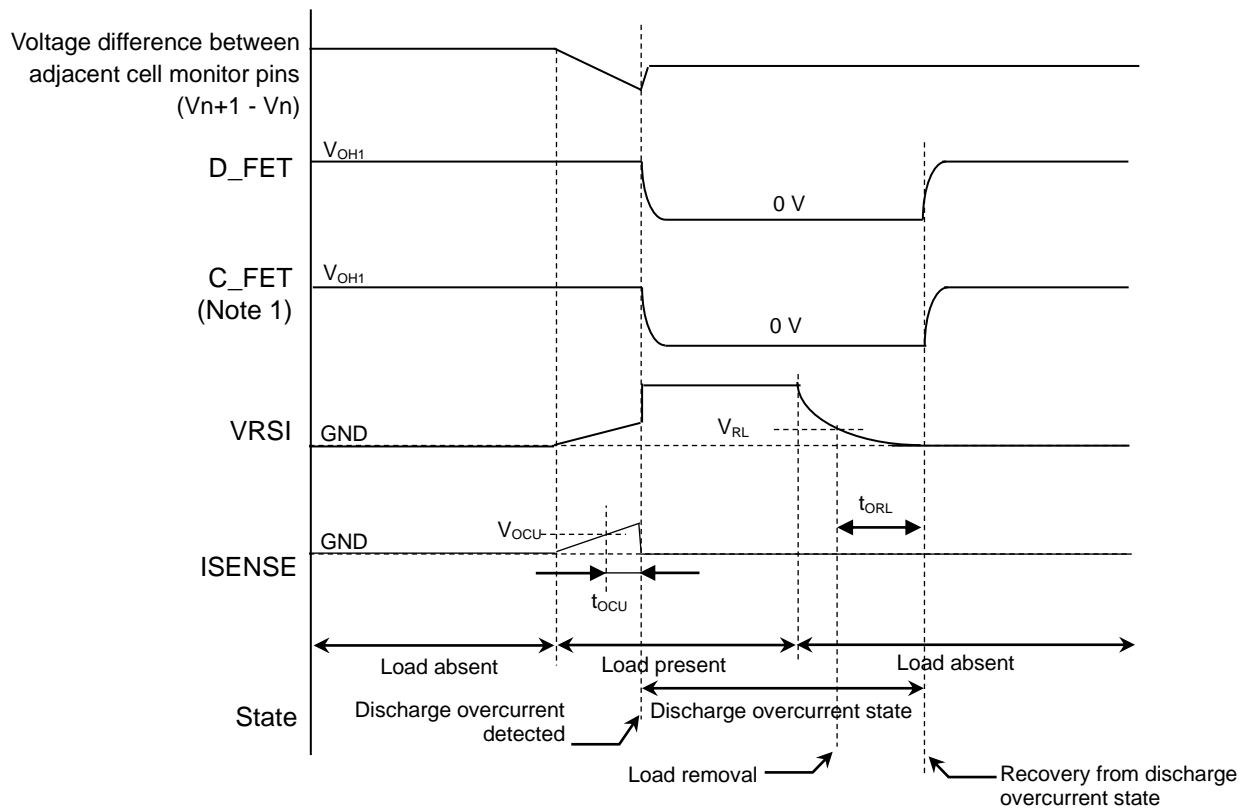
(Note 2) Even if the voltage difference between  $V_{n+1}$  and  $V_n$  reaches or exceeds the overvoltage detection threshold  $V_{OV}$ , there may be a time lag before starting the overvoltage detection delay timer because cell voltages are monitored every 400 ms (typ.).

(Note 3) Even if the voltage difference between  $V_{n+1}$  and  $V_n$  reaches or exceeds the overvoltage release threshold  $V_{OVR}$ , there may be a time lag before recovering from the overvoltage state because cell voltages are monitored every 400 ms (typ.).

● Overvoltage Detection, Transition to Power-down Mode and Recovery

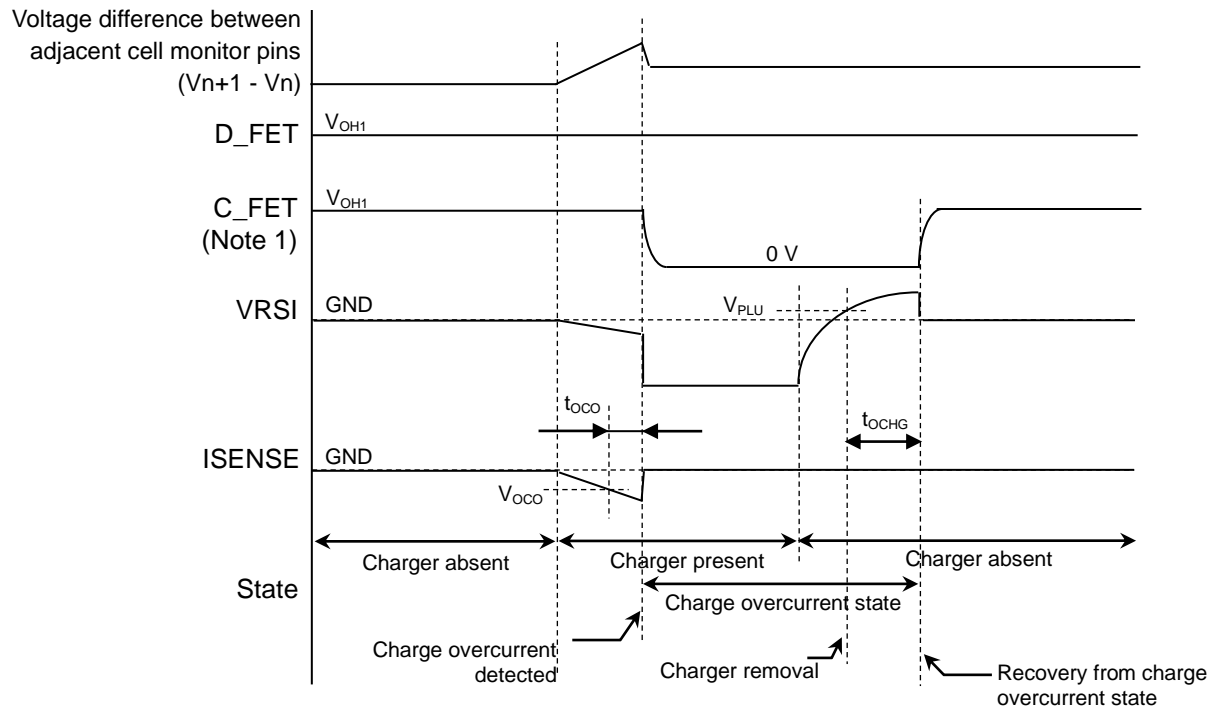


## ● Discharge Overcurrent Detection and Recovery



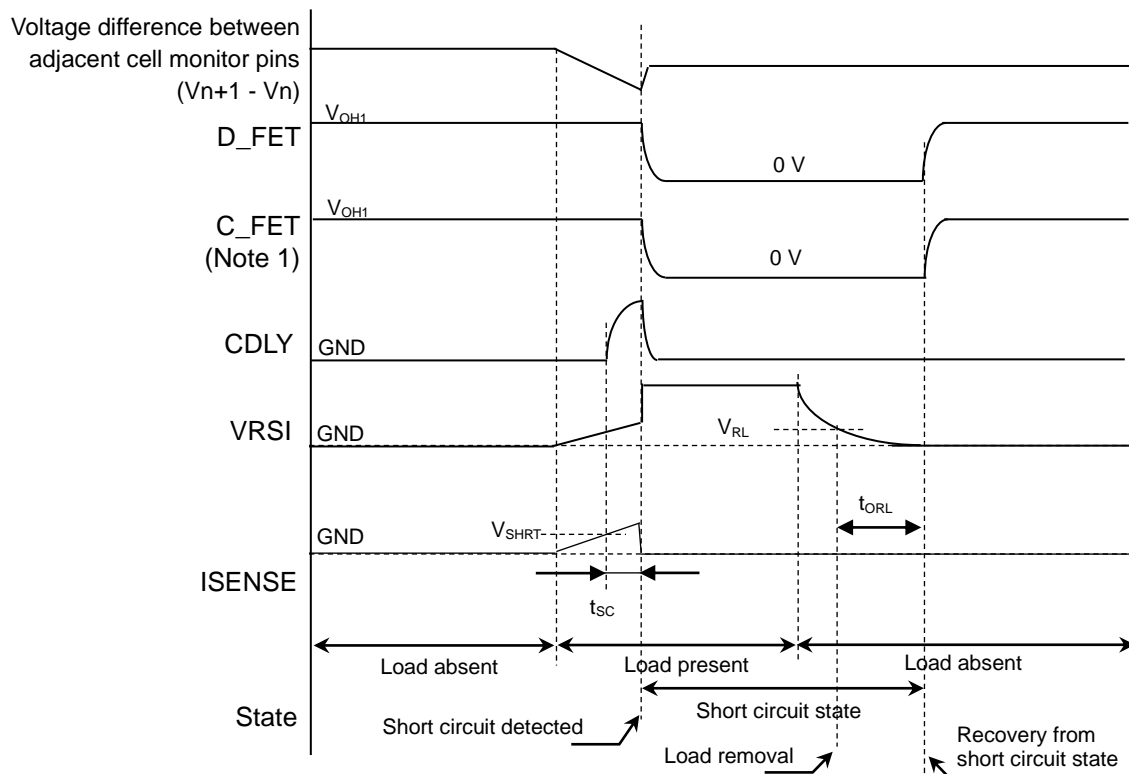
(Note 1) C\_FET pin is pulled down with a resistor.

### ● Charge Overcurrent Detection and Recovery



(Note 1) C\_FET pin is pulled down with a resistor.

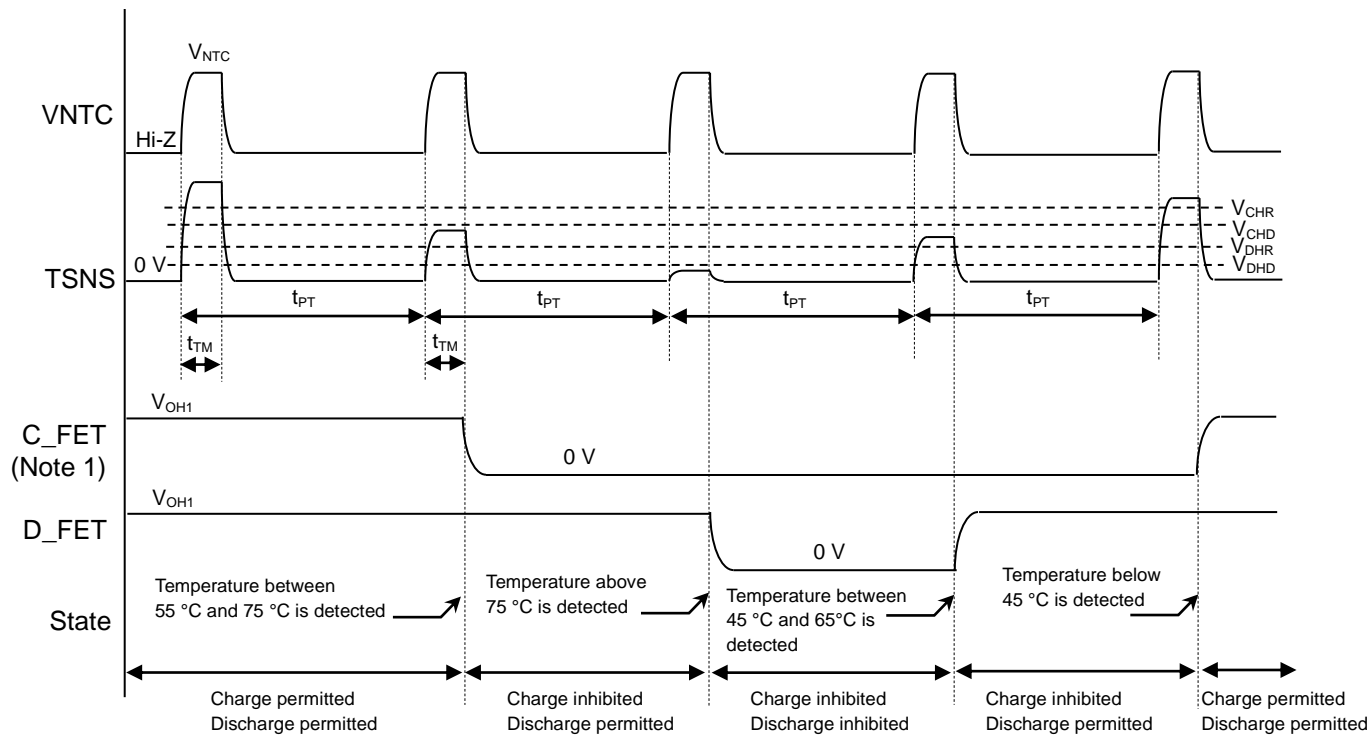
### ● Short Circuit Detection and Recovery



(Note 1) C\_FET pin is pulled down with a resistor.



● High Temperature Detection and Recovery



(Note 1) C\_FET pin is pulled down with a resistor.

(Note 2) NTC(10k  $\Omega$ , B=3435) and 4.7k  $\Omega$  resistor is connected.

## ■ Functional Description

### ● States of ML5233

The ML5233 has the following eight states which depend on individual cell voltages and the input levels of the ISENSE and TSNS pins.

1. Initial state
2. Normal operation state
3. Overvoltage state
4. Undervoltage state (including power-down mode)
5. Discharge overcurrent state
6. Charge overcurrent state
7. Short circuit state
8. High temperature state

Each state is described below, without cascade connection (CAS pin fixed to GND).

#### 1. Initial State

The initial state refers to the period while the battery cells are being connected to the ML5233 and connection of all the battery cells specified by the CS0 and CS1 pins is completed, before transitioning to the normal state. In the initial state, when the VREG pin voltage reaches or exceeds the VREG drop detection threshold, the D\_FET pin output is set to the "L" level and the C\_FET pin output to the "H" level, where discharge is inhibited and charge is permitted.

When the VREG pin level reaches or exceeds the VREG drop release threshold, individual cell voltage monitoring takes place. If all the battery cells specified by the CS0 and CS1 pins reach or exceed the undervoltage release threshold  $V_{UVR}$ , the system transitions to the normal state. Overvoltage and overcurrent detection is also performed in parallel.

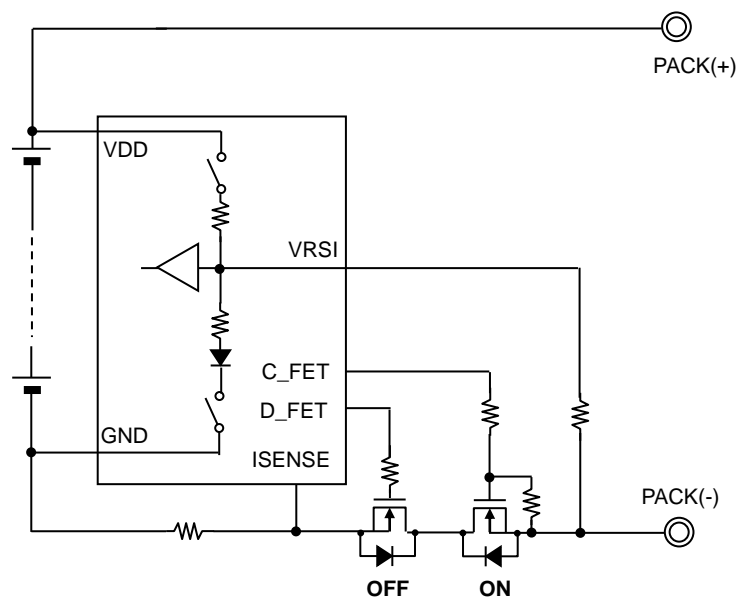


Figure 1 Initial State

## 2. Normal Operation State

The normal state refers to the period where all the battery cell voltages do not reach or exceed the overvoltage/undervoltage detection threshold, the ISENSE pin voltage is below the overcurrent detection threshold, and the TSNS pin voltage is above the high temperature detection threshold. In the normal state, both the D\_FET and C\_FET pin outputs are set to the "H" level, where both charge and discharge is permitted.

Individual cell voltages are monitored every 0.4 second for performing overvoltage/undervoltage detection, while the pack temperature is also monitored using an external thermistor every 0.4 second. The ISENSE pin voltage is always monitored to detect overcurrent in parallel.

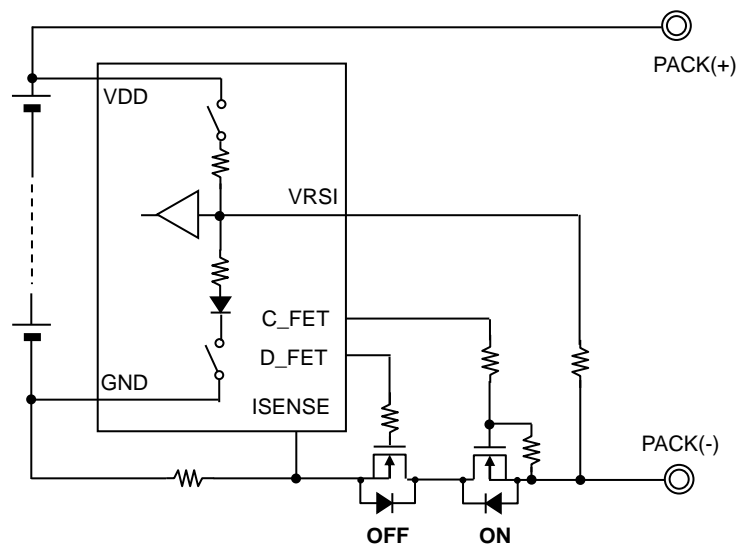


Figure 2 Normal Operation State

### 3. Overvoltage State

When any one or more battery cell voltages reach or exceed the overvoltage detection threshold  $V_{OV}$  for longer than the overvoltage detection delay time  $t_{OV}$ , the system enters the overvoltage state. In the overvoltage state, the C\_FET pin output is set to "Hi-Z" to inhibit charge, while the D\_FET pin output maintains the value in the previous state.

Battery cell voltages decrease gradually by self-discharge or a connected light load. When all of them reach or exceed the overvoltage detection release threshold  $V_{OVR}$ , the system recovers from the overvoltage state.

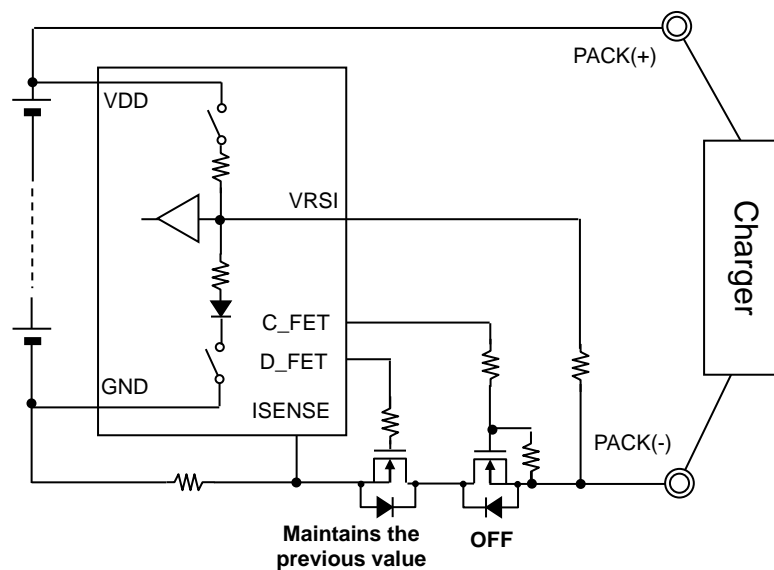


Figure 3 Overvoltage State

#### 4. Undervoltage State

When any one or more battery cell voltages reach or exceed the undervoltage detection threshold  $V_{UV}$  for longer than the undervoltage detection delay time  $t_{UV}$ , the system enters the undervoltage state. In the undervoltage state, the D\_FET pin output is set to the "L" level to inhibit discharge, while the C\_FET pin output maintains the value in the previous state.

In the undervoltage state, a 500 k $\Omega$  pull-up resistor is connected between the VRSI pin and VDD. When the VRSI pin voltage increases and reaches the charger removal VRSI threshold  $V_{PLD}$  after turning off the external discharge FET, the system enters power-down mode to reduce current consumption. The VRSI pin voltage decreases when a charger is present. If it reaches or exceeds the charger detection voltage  $V_{PC}$ , the system wakes up all the circuits to resume monitoring individual battery cell voltages.

If the system was in the overvoltage, undervoltage, high temperature or any overcurrent state before entering power-down mode, these error flags are cleared during power-down. After wake-up, if these errors are detected again for longer than the specified detection delay time, the system reenters the corresponding error state.

Battery cell voltages increase gradually while charging, and if all cell voltages reach or exceed the undervoltage detection release threshold  $V_{UVR}$ , the system recovers from the undervoltage state and the pull-up resistor between VRSI pin and VDD is disconnected.

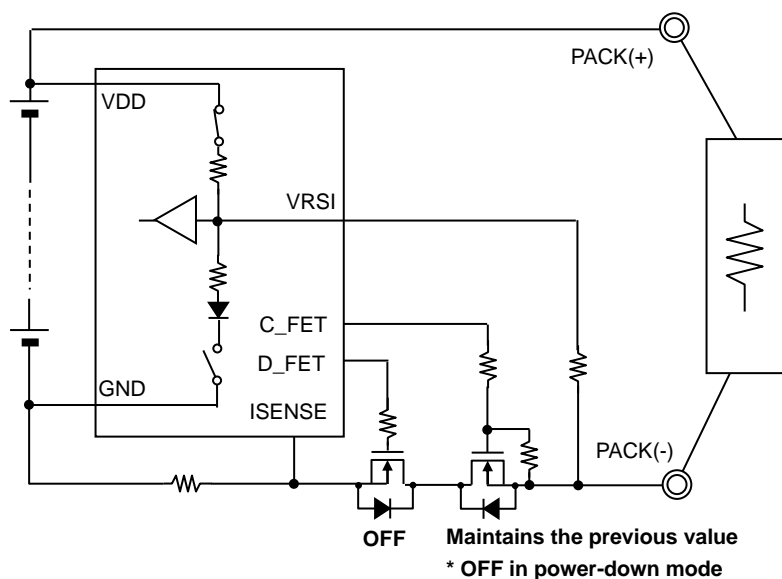


Figure 4 Undervoltage State (Power-down mode)

## 5. Discharge Overcurrent State

When the load is connected and ISENSE pin voltage reaches or exceeds the discharge overcurrent detection threshold  $V_{OCU}$  for longer than the discharge overcurrent detection delay time  $t_{OCU}$ , the system enters the discharge overcurrent state, regardless of the individual battery cell voltages. In the discharge overcurrent state, the D\_FET pin output is set to the "L" level to inhibit discharge, while the C\_FET pin output is set to "Hi-Z" to monitor load removal.

In the discharge overcurrent state, the VRSI pin is pulled-down with a  $2\text{ M}\Omega$  resistor and a backflow prevention diode. If the load is released, the VRSI pin level approaches the GND level. The system recovers from the discharge overcurrent state when the VRSI pin level reaches or exceeds the load disconnection detection threshold  $V_{RL}$  for longer than the load disconnection detection delay time  $t_{ORL}$ .

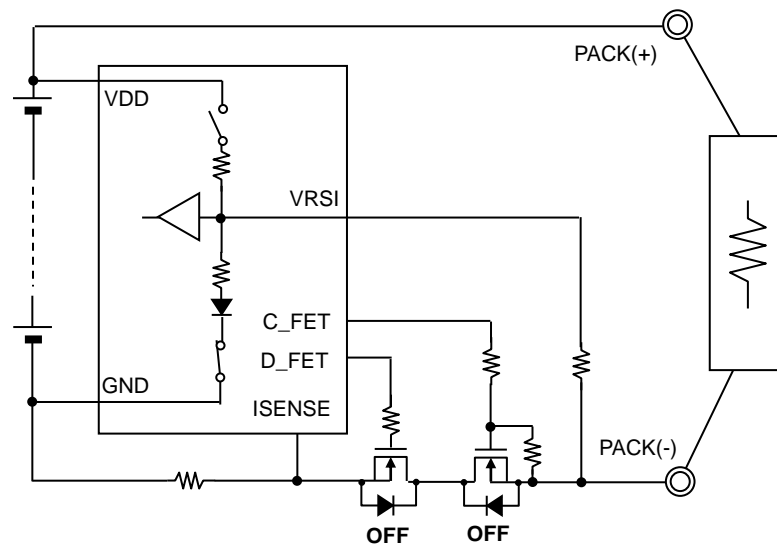


Figure 5 Discharge Overcurrent State

## 6. Charge Overcurrent State

When the charger is connected and ISENSE pin voltage reaches or exceeds the charge overcurrent detection threshold  $V_{OCO}$  for longer than the charge overcurrent detection delay time  $t_{OCO}$ , the system enters the charge overcurrent state, regardless of the individual battery cell voltages. In the charge overcurrent state the C\_FET pin output is set to "Hi-Z" to inhibit charge, while the D\_FET pin output maintains the value in the previous state.

In the charge overcurrent state, a 500 k $\Omega$  pull-up resistor is connected between the VRSI pin and VDD pin to detect charger removal. If the charger is removed, the VRSI pin level increases. The system recovers from the charge overcurrent state when the VRSI pin voltage reaches or exceeds the charger removal detection threshold  $V_{PLU}$  for longer than the charger removal delay time  $t_{OCHG}$ .

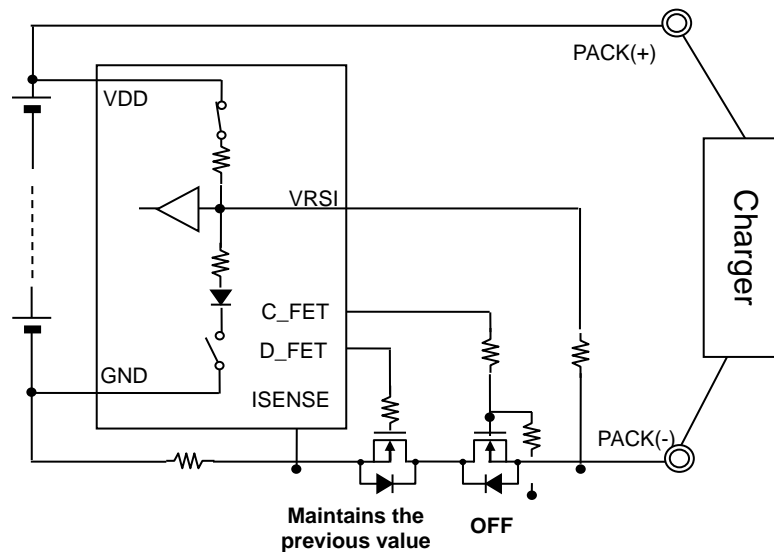


Figure 6 Charge Overcurrent State

## 7. Short Circuit State

When the pack is overloaded and the ISENSE pin voltage reaches or exceeds the short circuit detection threshold  $V_{SHRT}$ , the capacitor connected to the CDLY pin is started to charge, regardless of the battery cell voltages. When the CDLY pin voltage is increased to a specific level, the system enters the short circuit state. In the short circuit state, the D\_FET pin output is set to "L" level to inhibit discharge, while the C\_FET pin output is set to "Hi-Z" to detect load removal. Also, a  $2\text{ M}\Omega$  pull-down resistor is connected between the VRSI pin and the GND pin through a backflow prevention diode.

If the load is removed, the VRSI pin level approaches the GND level. The system recovers from the short circuit state when the VRSI pin level reaches or exceeds the load removal detection threshold  $V_{RL}$  for longer than the load removal detection delay time  $t_{ORL}$ .

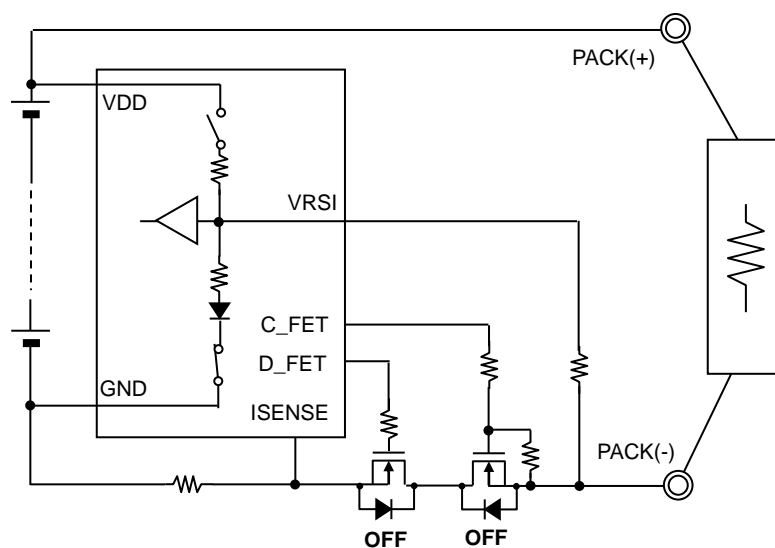


Figure 7 Short Circuit State



## 8. High Temperature State

Pack temperature is monitored using an external thermistor every 0.4 seconds when the ML5233 is not in power-down mode, regardless of battery cell voltages. When the TSNS pin voltage reaches or exceeds the high temperature charge inhibition detection threshold  $V_{CHD}$ , the C\_FET pin output is set to the "Hi-Z" state to inhibit charge.

As temperature increases further, if the TSNS pin voltage reaches or exceeds the high temperature discharge inhibition detection threshold  $V_{DHD}$ , the D\_FET pin output is set to the "L" level to inhibit discharge. Temperature monitoring is continued every 0.4 second in the high temperature state, too, and if the TSNS pin voltage reaches or exceeds the high temperature release threshold, the system recovers from the high temperature state.

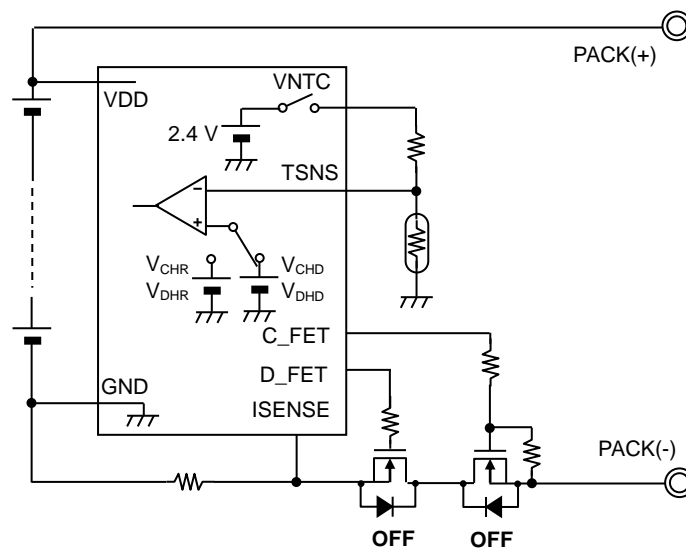


Figure 8 High Temperature State

- **Selecting the Number of Battery Cells**

Cell count is selectable from predefined 4 values using the CS0 and CS1 pins.

Product code 001 supports 7, 8, 9 or 10 cells, and its configuration is given in the table below.

CS1	CS0	Battery cell number	Unused Vn pins
GND	GND	10 cell	None
GND	VREG	9 cell	V0
VREG	GND	8 cell	V0, V1
VREG	VREG	7 cell	V0, V1, V2

All unused Vn pins should be tied to GND.

- **Power-on/Power-off Sequence**

Battery cells can be connected in any order, but it is recommend that the GND and VDD pins are connected first, and then connection continues from lower to higher voltage cells. There are no restrictions on the power supply voltage rise time at power-on, and power-off sequence or power supply voltage fall time at power-off.

After power-on, the system usually transitions to the normal state. However, it may transition to the undervoltage state due to chattering at power-on or other reasons. If it has transitioned to the undervoltage state and moved to power-down mode, apply the charger connection detection threshold  $V_{PC}$  or lower level to the VRSI pin to power it up again.

- **Handling VDD Pin and V0 to V10 Pins**

Since the VDD pin is the power supply input, put a noise elimination RC filter in front of the VDD input for stabilization. If the drive current on the external charge/discharge control FETs is large, the resistor value of this noise filter should be adjusted so that the voltage drop across the resistor is smaller than 1 V.

The V0 to V10 pins are the monitor pins for individual cell voltages. Put a noise elimination RC filter in front of each battery cell to prevent false detection. On a system with less than 10 battery cells, unused Vn pins should be tied to GND.

- **Handling VREG Pin**

The VREG pin is the power source of the built-in regulator which supplies power to the internal modules. Connect a 1  $\mu$ F or larger capacitor between this pin and GND for stabilization. Do not use it as a power supply for external circuits since the supply current of the built-in regulator is limited.

- **Setting Short Circuit Detection Delay**

The short circuit detection delay ( $t_{SC}$ ) depends on the charge time of the capacitor ( $C_{DLY}$ ) connected to the CDLY pin, which is described by the following equation.

$$\text{Short circuit detection delay } t_{SC} [\text{ms}] = C_{DLY} [\text{nF}] \times 0.1$$

A 1 nF or larger capacitor is recommended for  $C_{DLY}$ . For a smaller capacitance, 20  $\mu$ s (typ.) should be added as a delay for the short current detection comparator. Note that the external CR filter on the ISENSE pin also comprises the total delay.

- **External Control of Charge/Discharge Control FET**

The C\_FET and D\_FET pin output values can be directly controlled by the /CFOFF and /DFOFF pin inputs, regardless of the detected state on the ML5233.

When the /CFOFF pin input is set to "L", the C\_FET pin output is fixed to "Hi-Z".

When the /DFOFF pin input is set to "L", the D\_FET pin output is fixed to GND.

When the /CFOFF and /DFOFF pin inputs are set to "H", the C\_FET and D\_FET pin outputs depend on the detected state on the ML5233.

- Output Pin Values in Each Detection State

The output pin values in each detection state are shown in the table below.

State	D_FET	C_FET	VRSI	VREG
Initial state	GND	14 V	Hi-Z	4.3 V
Normal operation state	14 V	14 V	Hi-Z	4.3 V
Overvoltage state	No change	Hi-Z	No change	4.3 V
Undervoltage state	GND	No change	Pull-up	4.3 V
Power-down mode	GND	Hi-Z	Pull-up	0 V
Discharge overcurrent state	GND	Hi-Z	Pull-down	4.3 V
Charge overcurrent state	No change	Hi-Z	Pull-up	4.3 V
Short circuit state	GND	Hi-Z	Pull-down	4.3 V
High temperature charge inhibition state	No change	Hi-Z	No change	4.3 V
High temperature discharge inhibition state	GND	Hi-Z	No change	4.3 V

(Note) "No change" means that the previous pin value is maintained in a new state.

- Unused Pin Treatment

The following table shows how to handle unused pins.

Unused pins	Recommended treatment
V0 to V5	Pull down
ISENSE	Pull down
CDLY	Open
/CFOFF,/DFOFF	Pull up
VRSO	Open
TSNS	Tied to the VNTC pin
VNTC	Pull down with a 100 kΩ resistor
PULLD	Open

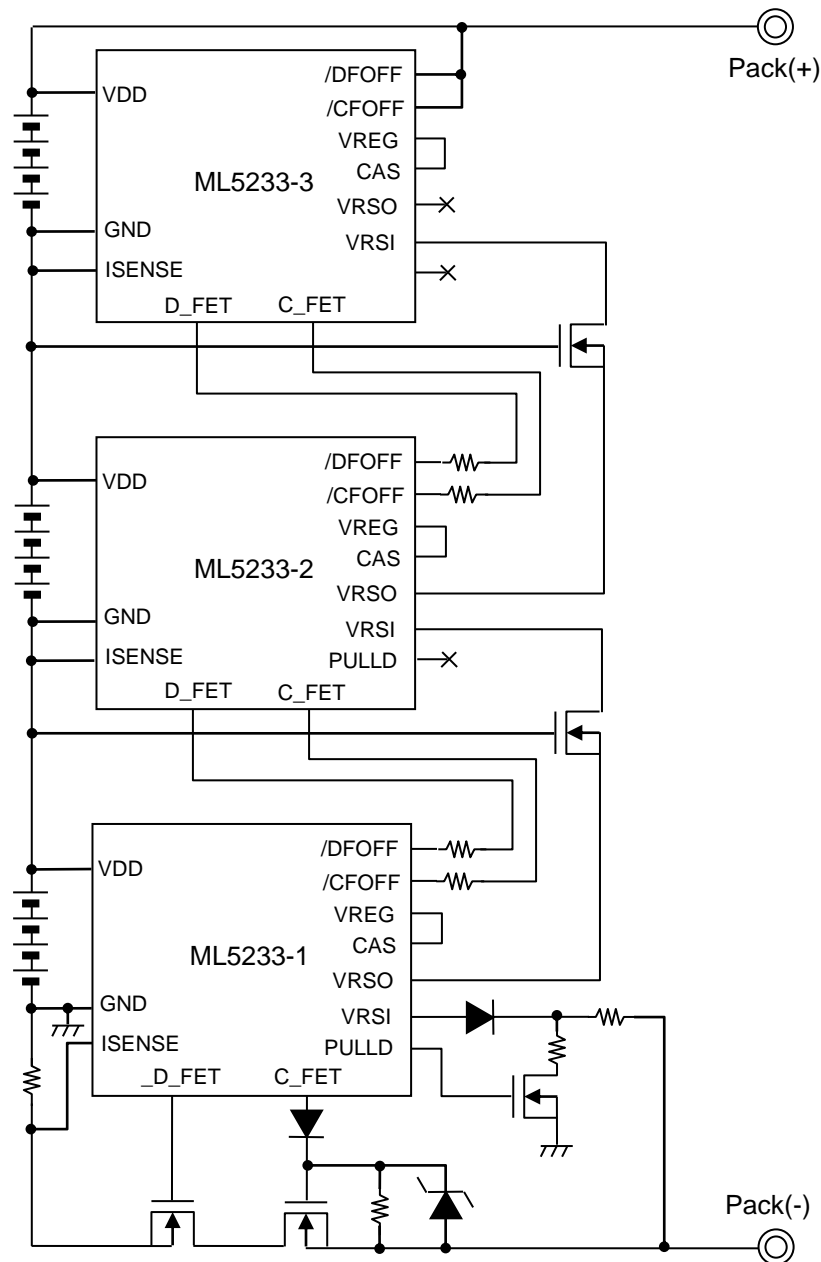
- Reducing Monitor Cycles and Detection Delays

The cell monitor cycle and overvoltage/undervoltage detection delays are reduced to 100 ms (typ.) by applying the VREG level to the TSNS pin. The temperature monitor cycle is also reduced to 100 ms (typ.), but high temperature detection does not work because the TSNS pin is fixed to the VREG level.

### ● Cascade Connection

Cascade wiring for three ML5233 devices is shown below.

1. Fix the CAS pin to the VREG level.
2. Connect the higher C\_FET pin and the lower /CFOFF pin through a resistor.
3. Connect the higher D\_FET pin and the lower /DFOFF pin through a resistor.
4. Connect the highest /CFOFF and /DFOFF pins to VDD pin.
5. Connect the lower VRSO pin and the higher VRSI pin through an NMOS-FET.
6. Connect the lowest VRSI pin to Pack(-) through a diode and a resistor.
7. Leave the top VRSO pin electrically open.
8. Connect the lowest PULLD pin to the NMOS-FET gate, whose drain terminal should be tied to Pack(-) through a resistor.



It is recommended that a greater number of cells should be assigned to the lowest IC to drive the charge/discharge control FETs on the GND correctly. For example, when 7 cells and 10 cells are cascaded, the 10 cells should be assigned to the lower IC and the 7 cells to the higher one.

- **Redefinition of Battery Cell Number**

4 cell numbers can be redefined so that one of them is selectable with CS0 and CS1 in the range shown in the following table.

CS1	CS0	Range of cell numbers						
GND	GND	4	5	6	7	8	9	10
GND	VREG	4	5	6	7	8	9	10
VREG	GND	4	5	6	7	8	9	10
VREG	VREG	4	5	6	7	8	9	10

- **Redefinition of Detection/Release Threshold Range and Step**

The detection/release thresholds can be redefined as shown in the following table.  
Since some combinations are unavailable, contact us for details.

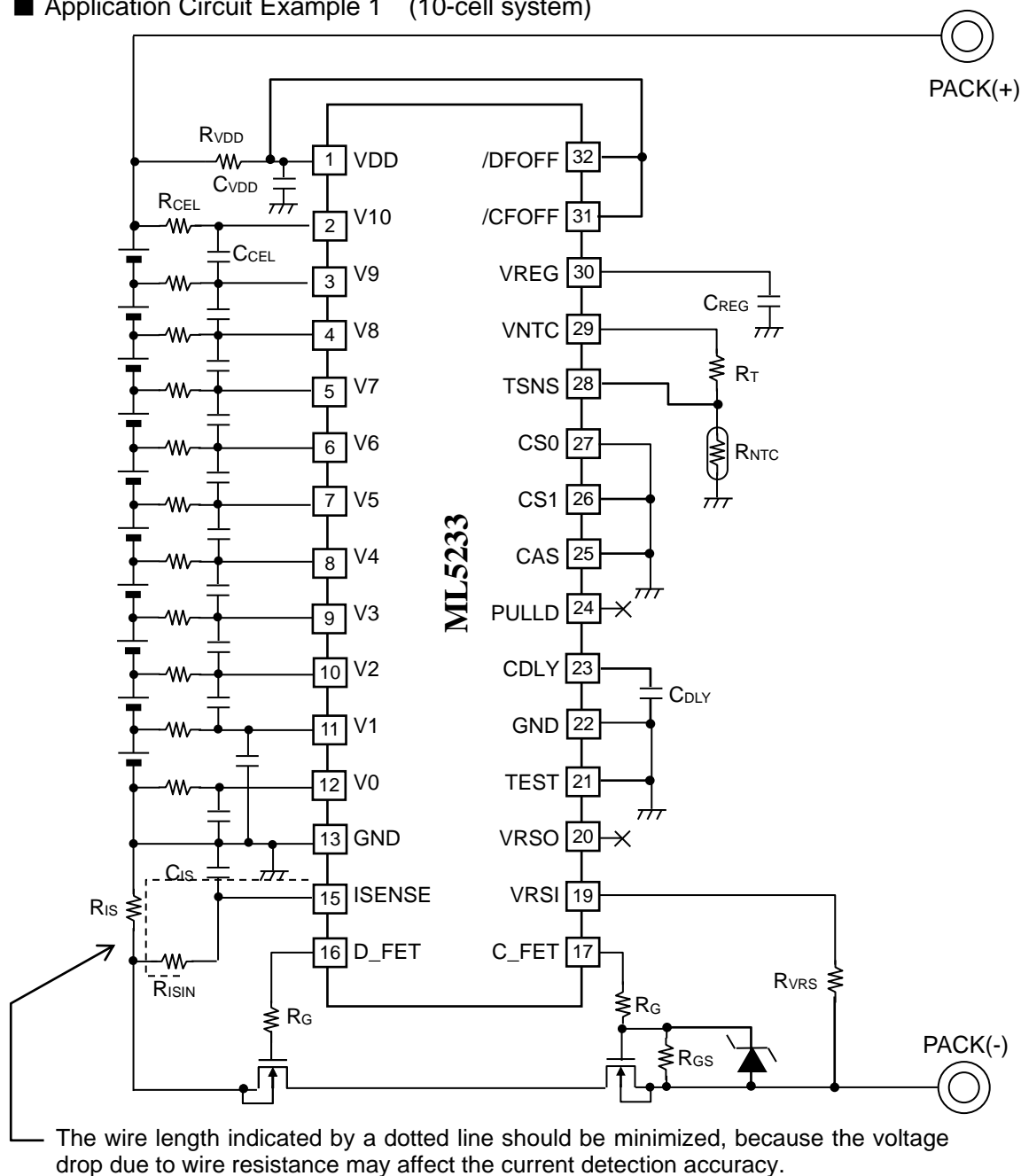
Detecting voltage	Threshold range	Threshold step
Overvoltage detection threshold	3.65 V to 4.35 V	25 mV
Overvoltage release threshold	3.5 V to 4.25 V	25 mV
Undervoltage detection threshold	1.6 V to 3 V	100 mV
Undervoltage release threshold	2.3 V to 4.3 V	100 mV
Discharge overcurrent detection threshold	50 mV to 200 mV	10 mV
Charge overcurrent detection threshold	-60 mV to -20 mV	10 mV
Short circuit detection threshold	100 mV to 500 mV	10 mV
High temperature detection threshold	0.6 V to 1.2 V	10 mV
High temperature release threshold	0.7 V to 1.3 V	10 mV

- **Redefinition of Detection Delay Time**

The detection delay times can be redefined as shown in the following table.

Detection delay time	Settable time					Unit
Overvoltage detection delay time	1	2	3	4	5	sec
Undervoltage detection delay time	1	2	3	4	5	sec
Discharge overcurrent detection delay time	25	50	100	200	400	ms
Charge overcurrent detection delay time	25	50	100	200	400	ms

## ■ Application Circuit Example 1 (10-cell system)

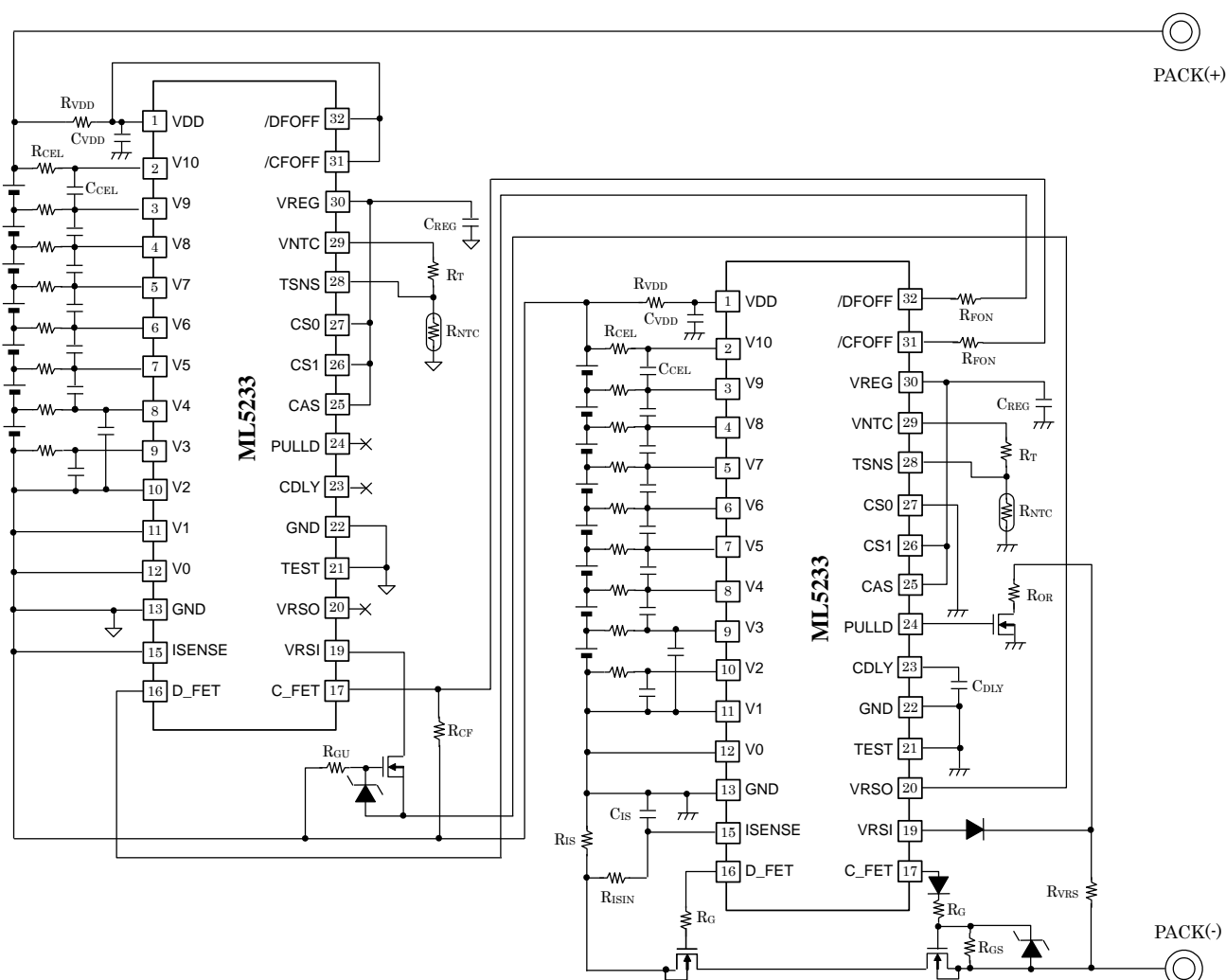


## ■ Recommended Values for External Components

Component	Recommended value	Component	Recommended value
R <sub>VDD</sub>	510 Ω	R <sub>GS</sub>	1 MΩ
C <sub>VDD</sub>	10 μF or more	R <sub>G</sub>	10 kΩ to 47 kΩ
R <sub>CEL</sub>	1 kΩ to 10 kΩ	R <sub>VRS</sub>	1 kΩ
C <sub>CEL</sub>	0.1 μF or more	R <sub>IS</sub>	1 mΩ to 5 mΩ
C <sub>REG</sub>	1 μF	R <sub>ISIN</sub>	1 kΩ
C <sub>IS</sub>	10 nF	R <sub>T</sub>	4.7 kΩ
C <sub>DLY</sub>	1 nF to 10 nF	R <sub>NTC</sub>	10 kΩ, B3435

(Note) This circuit example and the recommended values of external components are not always warranted. Evaluation on customer's application is required and select circuit and parts depend on customer's application.

### ■ Application Circuit Example 2 (15-cell system, 8 cells and 7 cells)

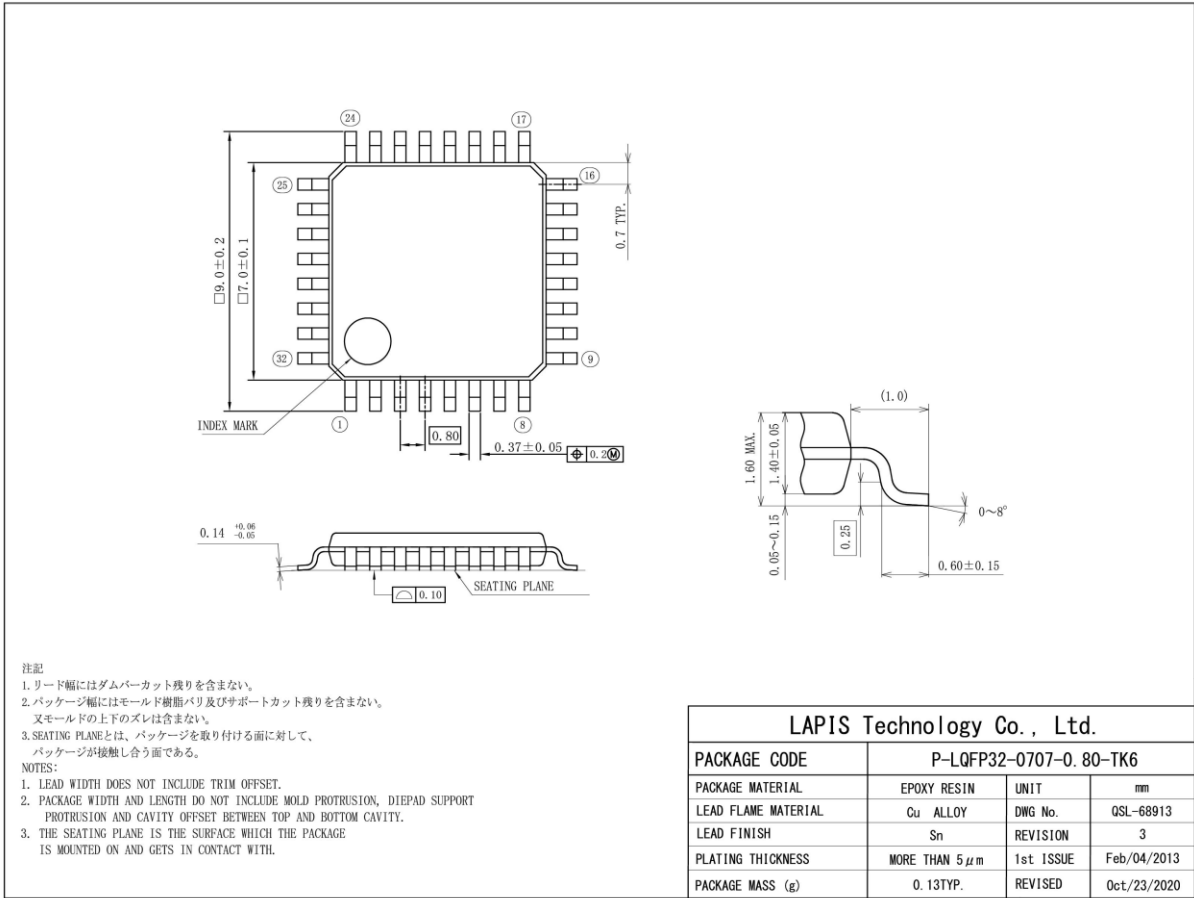


### ■ Recommended Values for External Components

Component	Recommended value	Component	Recommended value
R <sub>VDD</sub>	510 Ω	R <sub>G</sub>	10 kΩ to 47 kΩ
C <sub>VDD</sub>	10 μF or more	R <sub>VRS</sub>	1 kΩ
R <sub>CEL</sub>	1 kΩ to 10 kΩ	R <sub>IS</sub>	1 mΩ to 5 mΩ
C <sub>CEL</sub>	0.1 μF or more	R <sub>ISIN</sub>	1 kΩ
C <sub>REG</sub>	1 μF	R <sub>T</sub>	4.7 kΩ
C <sub>IS</sub>	10 nF	R <sub>NTC</sub>	10 kΩ, B3435
C <sub>DLY</sub>	1 nF to 10 nF	R <sub>GU</sub> , R <sub>FON</sub>	5.1 MΩ
R <sub>GS</sub>	1 MΩ	R <sub>OR</sub>	1 MΩ
		R <sub>CF</sub>	1.2 MΩ

(Note) This circuit example and the recommended values of external components are not always warranted. Evaluation on customer's application is required and select circuit and parts depend on customer's application.

■ Package Dimensions



Caution regarding surface mount type packages

Surface mount type packages are susceptible to heat applied in solder reflow and moisture absorbed during storage. Please contact your local ROHM sales representative for recommended mounting conditions (reflow sequence, temperature and cycles) and storage environment.



## ■ Revision History

Document No.	Issue date	Page		Revision description
		Before revision	After revision	
FEDL5233-01	14 Sep, 2015	-	-	Initial release, based on FJDL5233-01.
FEDL5333-02	25 Dec, 2015	28	28	Cascade connection, pin name is corrected.
FEDL5333-03	25 Mar, 2016	6	6	High temperature charge inhibition detection threshold (Ta=25°C) is 0.97(min)->0.99(min)
		17	17	High Temperature Detection and Recovery, note2 is added.
		30,31	30,31	Application Circuit examples; capacitor connection of lowest cell is modified. Note is added
		31	31	Application Circuit example 2; the value of R <sub>GU</sub> is modified.
FEDL5333-04	1 Dec, 2020	-	-	Changed Company name
		34	34	Changed “Notes”
FEDL5333-05	Jan. 9, 2024	1	1	Add Application Part number, Delete notes
		34	34	Add Notes

Notes

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