Maxwell TECHNOLOGIES

Enabling Energy's Future™

USER MANUAL

Maxwell Technologies, Inc.
90V Ultracapacitor Modules

Models:	**Associated Datasheet**
BMOD0010 B090 B02	3001966
BMOD0010 B090 C02	3001966

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1 Introduction

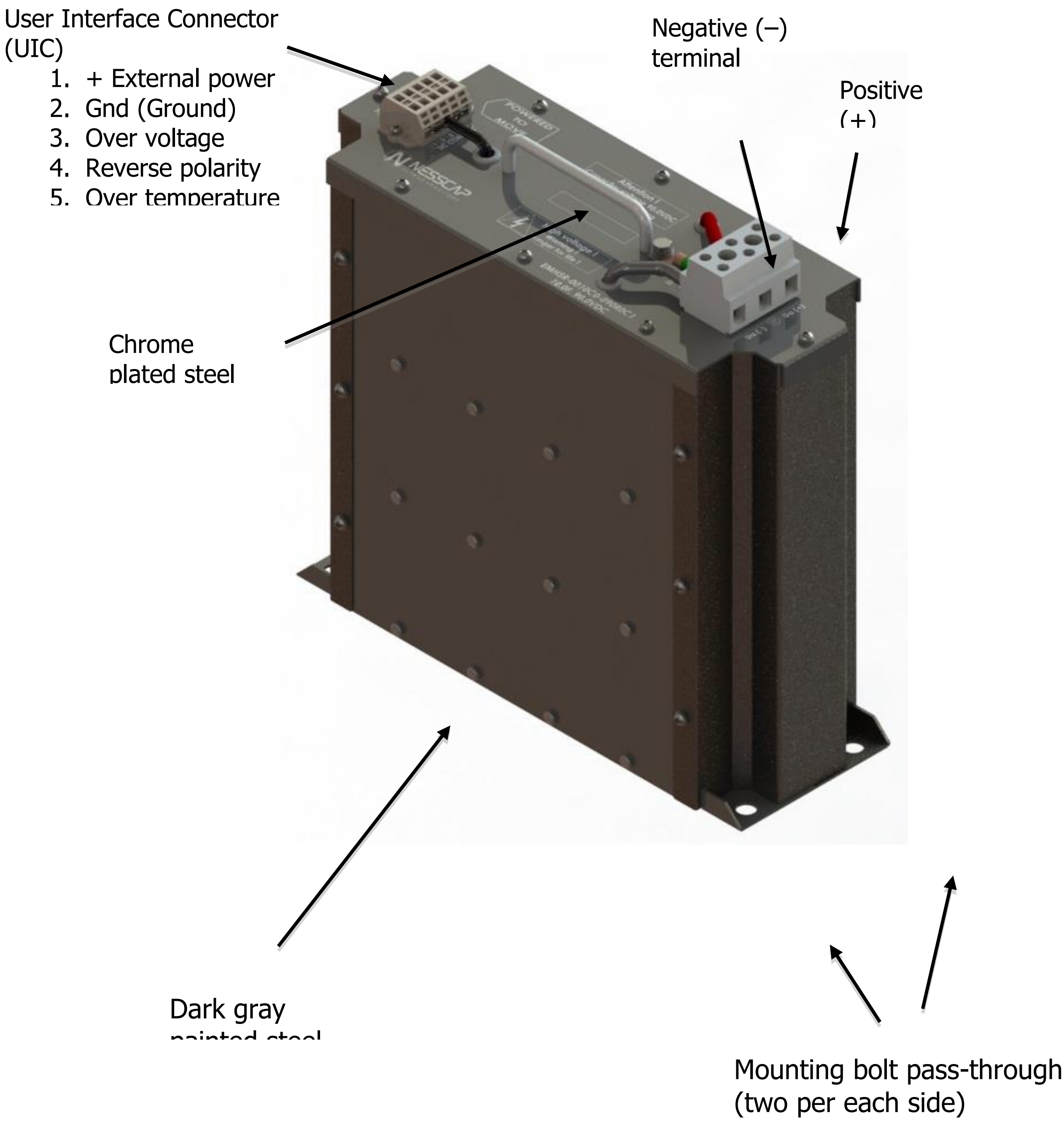
The BMOD0010 B090 B02 and BMOD0010 B090 C02 energy storage modules are self-contained energy storage devices comprised of individual ultracapacitor cells connected in series. The modules include integrated cell balance voltage management circuitry. The module described in this manual has over-voltage (OV), reverse-polarity (RP) and over-temperature (OT) alarms designed to warn the user if rated operating limits have been exceeded.

Multiple modules may be connected in series to obtain higher operating voltages, in parallel to provide additional energy storage, or a combination of series/parallel arrangements for higher voltages and energy. Voltage management circuit alarms are designed to warn if operating limits have been exceeded in an attempt to protect each cell from operating in a damaging overvoltage condition.

- ✓ Maximum stored energy of 11.2Wh with 90V/10F ultracapacitor module
- ✓ Monitoring functions for cell voltage, temperature, and polarity reversal detection
- ✓ Passive balancing with 100ohm resistor connected to each capacitor
- ✓ Lead-free wave soldering
- ✓ Ingress Protection compliant (IP 30)
- ✓ Steel enclosure
- ✓ Connector type terminal block

1.1 Module components and terminology

For reference only. The module exterior is shown below.



2 Unpacking and handling

2.1 Unpacking

Inspect the shipping packaging for signs of damage prior to unpacking each module. Damage to the packaging or module should be reported to the carrier immediately. Remove each module from the packaging and retain the shipping materials until the module has been inspected and is determined to be operational.

Note: The original shipping materials are approved for both air and ground shipment. When removing the module from the packaging, lift it by the steel handle

If the unit is found to be defective or any parts are missing, contact your supplier. A Return Material Authorization (RMA) number must be requested and issued by Maxwell prior to returning the unit for repair or replacement.

2.2 Handling

Maxwell ultracapacitor modules are designed to provide years of trouble-free operation. Proper handling is required to avoid damage to the module. In particular, the following handling precautions should be observed:

- Do not stack modules once they have been removed from their shipping packaging
- Do not drop modules. Internal damage may occur that will not be visible from the module exterior
- Do not step on modules
- Protect the module from impact

3 Installation

3.1 Mechanical installation

3.1.1 Mounting

Modules can be mounted and operated in any orientation. The module must be mounted using the bottom surface. This bottom plate is designed to support the module.

For best results, mount the modules in locations where they are not directly exposed to harsh environments. In particular, always avoid areas of direct splash.

Use one high-quality mounting bolt per corner:

- Metric: Class 8.8 or 10.9, M8
- Standard: Grade 5 or 8, 5/16”

Each bolt should reach completely through the mounting bolt pass-through on the module corner. Use the appropriate bolt length for the specific installation; include length for the use of lock washers or lock nuts.

Installation should not exert bending or twisting torque to the module enclosure. Torque may be caused by uneven mounting points or surfaces. Ensure that the module's mounting points are all flat within ±1 mm.

The figure below illustrates flatness.

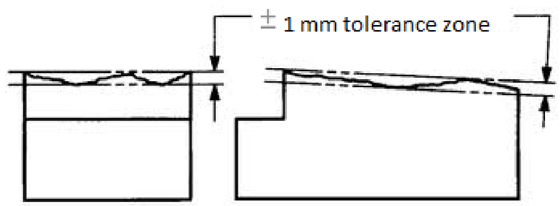


Figure 1. Flatness example

3.1.2 Vibration and shock

To ensure successful, long-life operation, please ensure that the vibration and shock experienced by the module is compatible with the accelerated vibration and shock qualification standard referenced on the module datasheet.

3.2 *Electrical performance and installation*

WARNING
To avoid arcing, the energy storage module should be in a discharged state and the system power disconnected during installation. The module is shipped discharged with a shorting wire connecting the positive (+) and negative (–) terminals. You must remove the shorting wire before making the electrical connections.
To provide the lowest possible equivalent series resistance, the energy storage modules are not fused. Care must be taken, within the application, to prevent excessive current flow. Excessive current and/or duty cycle will result in overheating the module, which will cause irreparable damage. **Please refer to the product datasheet for maximum allowable RMS current values.**

Module-to-module cabling must be sized for the application's peak and/or RMS current. Undersized cables may cause excessive cable or interconnect temperature rise and system electrical resistance. High-resistance wiring/cables or module power connections will increase terminal cell temperature and degrade module lifetime and long-term performance. Refer to applicable wire sizing guides. Wire temperature must not exceed module temperature.

Note: The module chassis should be grounded to the system chassis through any of the module mounting bolt pass-through holes. Refer to applicable ground wiring guides and standards for the application.

3.2.1 Capacitance Measurement

Capacitance is measured by the formula shown in Figure 2. Where the time to discharge a capacitor or a capacitor module from 80% of the rated voltage to 40% of the rated voltage using constant current output.

$$\textbf{Capacitance (F)} = I_{dch} \times (T_2 - T_1) / 0.4V_R$$

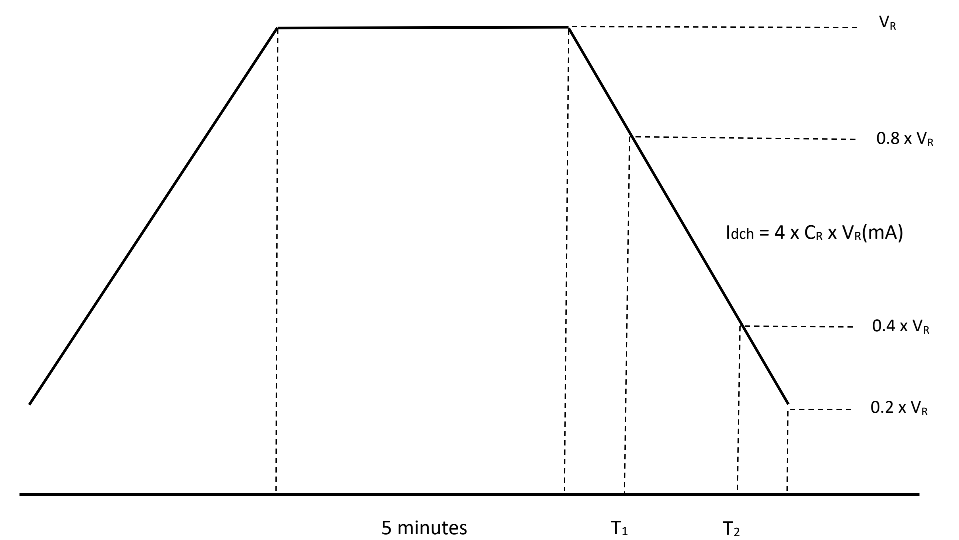


Figure 2. Capacitance Measurement

3.2.2 Internal Resistance (ESR) Measurement

Internal resistance of 90V/10F module is measured using an impedance analyzer. The parameters used are as follows:

Voltage at measurement: Open Circuit Voltage
Amplitude: 5mV
Frequency: 100Hz

Initial ESR measurements are made before the initial charging of the module, i.e. when all the cells are at their shorted open circuit voltage. Typically, this is around 400mV per cell. It should be noted that the voltage of an ultracapacitor module, once it has been charged and discharged, will “recover” or increase over time. Therefore, any measurement made during this period when the voltage is changing is unreliable. Maxwell recommends at least 8 hours of shorting before any AC-ESR measurements are made.

3.2.3 Self-Discharge Trend

The 90V module is passively balanced. Self-discharge characteristics of Maxwell 90V/10F ultracapacitor module is shown in Figure 3. If the ultracapacitor module is kept at open-circuit voltage just after 3A constant current charge to 90V, at room temperature, the module voltage will decrease gradually over time due to the resistors connected in parallel to each cell. The charged 90V module self-discharge will be about 20% of initial voltage over a period of 120 minutes.

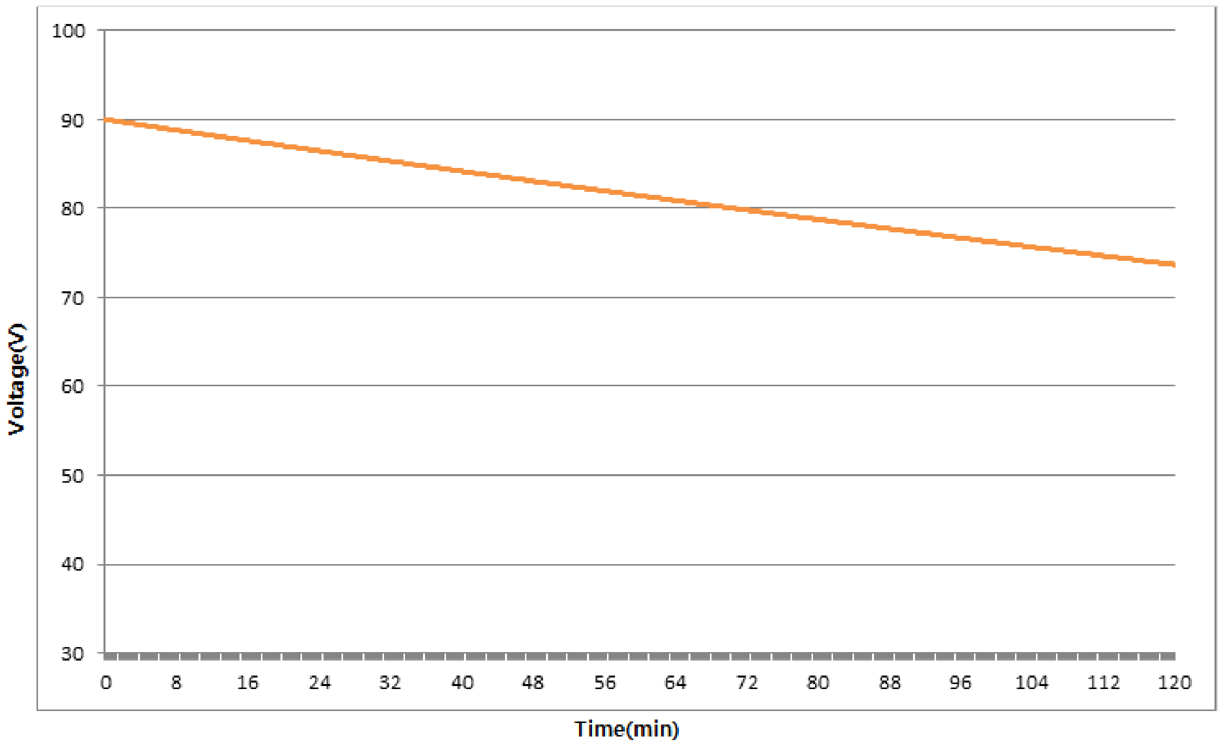


Figure 3. Self-Discharge profile of 90V/10F module

3.2.4 Simulated Electrical Performance

Simulated constant current discharge voltage and current profiles of a 90V 10F configuration are shown in Figure 4.

Simulated constant power discharge voltage profiles of a 90V 10F configuration are shown in Figure 5.

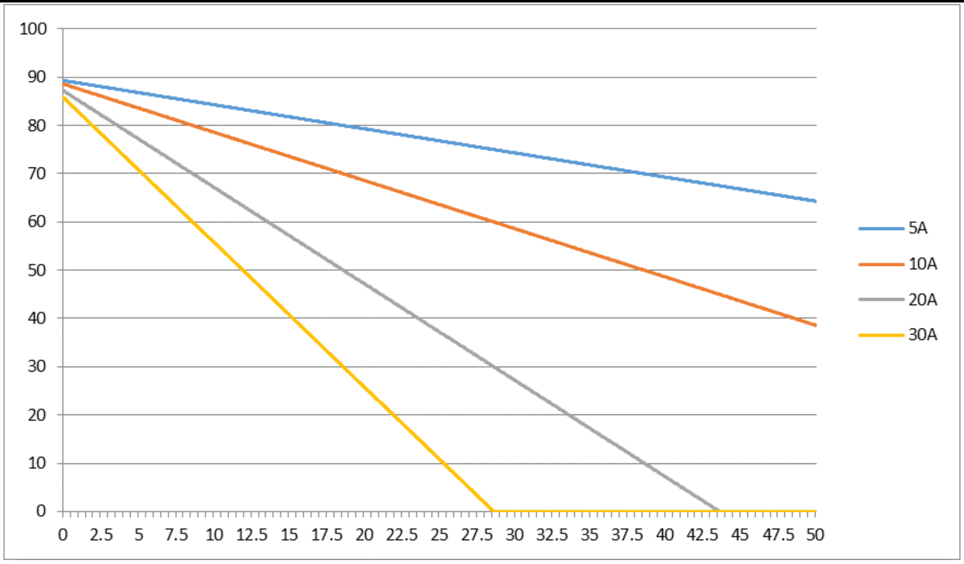


Figure 4. Constant Current Discharge Profile of 90V/10F

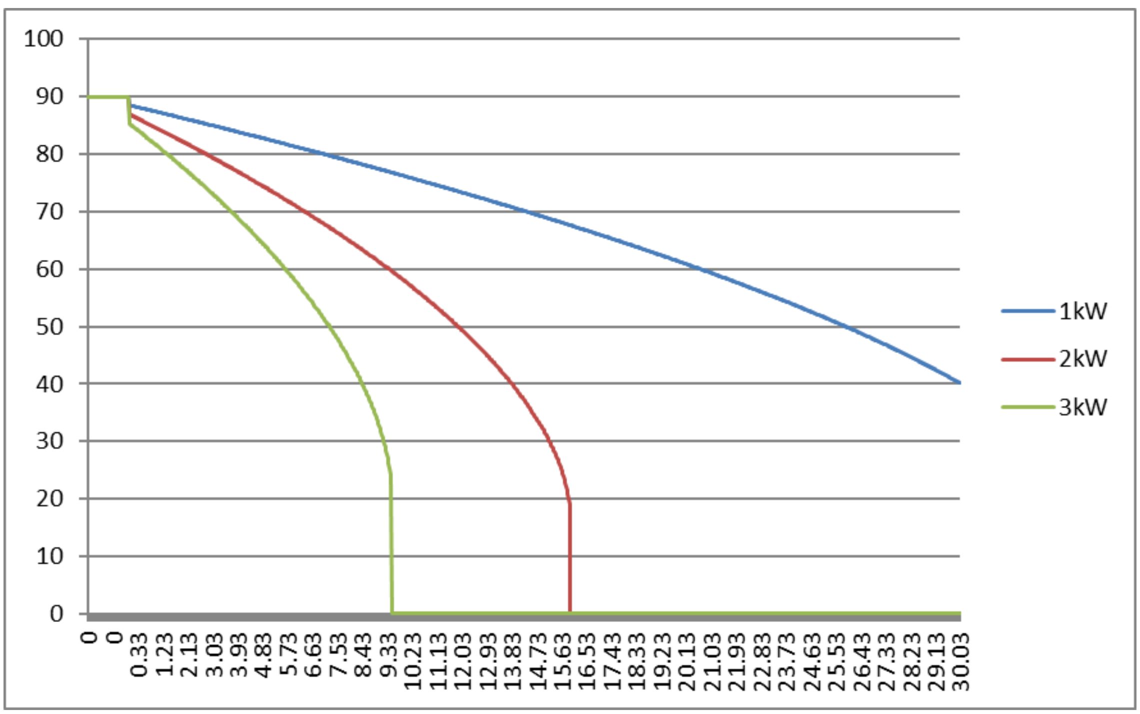


Figure 5. Simulated constant power discharge of 90V 10F

Simulated profile may be different from a real system.

3.3 Functional Description of Terminal

3.3.1 Connecting to the Power Terminal

Figure 6. Main Power Terminal

Remove the shorting wire from the main terminal block. Check the polarity of the terminals and then connect power cables (AWG 8 to AWG 12) to connector accordingly. Connect the No.1 and the No.3 poles to the charger, respectively. Connect No.2 pole to the system ground or panel earth for protection of the pitch control system and for the operator safety. The slot assignment and the markings are summarized in Table 1.

Table 1. Pin Assignment of Main Power Terminal

No.	Marking	Function	Color
1	+Ua	Capacitor "+"	Red
2		Panel Earth	Green/Yellow
3	-Ua	Capacitor "-"	Black

3.3.2 Connecting to the User Interface Connector

Figure 7. Monitoring Signal Output Terminal

The spring-type 5-pin connector, located on the opposite side of power terminal, is connected to the charger to transmit information about the module. As shown in Figure 7. check the pin number of the connector for monitoring and then insert cables (AWG 14 to AWG 18) to the correct corresponding slots.

The pin assignment for the monitoring signal output is summarized in Table 2.

Table 2. Pin Assignment of Monitoring Connector

No.	Marking	Function	Color	Ref.
1	1	Vep(+5, 24V_{DC})	Red	B02: 5V_{DC}, C02: 24V_{DC}
2	2	GND(Ground)	Black	
3	3	Over Voltage	Blue	Normal: High(5 V_{DC}, 24 V_{DC})
4	4	Reverse Polarity	White	
5	5	Over Temperature	Yellow	

Pin #1 is the +5V_{DC} or +24V_{DC} input from the charger and powers the monitoring circuit.

Pin #2 is the GND or Ground at the charger.

Pin #3 generates the Voltage Monitoring signal used by the charger to determine the status of the module. This signal also tells the charger if the module is in an Over Voltage state.

Pin #4 generates the Polarity Check signal used by the charger to determine if the modules were connected in reverse.

Pin #5 generates the Over Temperature signal used by the charger to determine the status of the module. This signal also tells the charger if the module is in an Over Temperature state.

Note: Be sure to check power supply to pin 1 of the UIC. For B02 module, +5V_{DC} should connect to pin1 of the UIC. For C02 module, connect +24V_{DC}. The circuit may fail to operate or become damaged if the power supply is not set properly.

Note: For multi-module strings, it is recommended that the user monitor overvoltage alarm and temperature signal for every module. Individual monitoring of overvoltage alarm, reverse polarity alarm and over temperature alarm signals will improve system safety and diagnostic capability in the field.

3.4 *Functional Description of Monitoring Circuit*

3.4.1 UMU (Ultracapacitor Management Unit)

UMU provides real-time status of the module to the users. The UMU also detects three types of failures in the ultracapacitor module and delivers appropriate status signals to external monitoring systems. The UMU requires an external $5V_{DC}$ or $24V_{DC}$ power supply to operate. The output voltage is either + 5V (+/- 0.5V), + 24V (+/- 2V) or 0V (+/- 0.5V) for 'Normal' and 'Abnormal', respectively.

The micro controller unit (MCU) is an 8-bit, 16 MIPS processor with a 10-bit analog-to-digital converter. The MCU processes information from various points inside the module to generate appropriate status signals for output through a 5-pin connector. For cell balancing, resistors are used to passively balance each of the thirty-six cells in the module.

- 4-cell groups are monitored by a voltage monitor to determine whether they are over-charged. If voltage across any of the nine 4-cell groups in the module is over 11.4V, or if the overall voltage of the module is over 102V, "Failure 1" signal is generated by the MCU.
- The MCU generates a "Failure 2" signal when it detects that the polarity of the module has been reversed.
- The temperature monitor is a NTC thermistor with a β constant of 3435K, which has a resistance of 10kΩ at room temperature. The MCU will calculate the temperature using the resistance and generate a "Failure 3" signal when the temperature inside the module is higher than 65°C.

Pin assignments for the UMU output connector are summarized in Table 3. Note, the "Normal" signal is always the High signal.

Table 3. Pin assignment for UMU connector

Pin No	Pin Assignment	Description
1	V_{ep} (Voltage of External Power, +)	External power for operating the UMU (B02: $+5V_{DC}$, C02: $+24V_{DC}$)
2	Gnd (Ground, -)	Ground
3	Failure 1 (Over voltage)	Normal (High, 5V,24V): $V_{CAP} \leq 11.4V$, $V_{MODULE} \leq 102V$ Abnormal (Low, 0V): $V_{CAP} > 11.4V$, $V_{MODULE} > 102V$
4	Failure 2 (Reverse polarity)	Normal (High, 5V,24V) Abnormal (Low, 0V): Polarity reversed
5	Failure 3 (Over temperature)	Normal (High, 5V,24V): $T_{MODULE} \leq 65$℃ Abnormal (Low, 0V): $T_{MODULE} > 65$℃

3.4.2 Over Voltage Monitoring

4-cell groups are monitored by a voltage monitor to determine whether they are over-charged. If voltage across any of the nine 4-cell groups in the module is over 11.4V, or if the overall voltage of the module is over 102V, "Failure 1" signal is generated by the MCU.

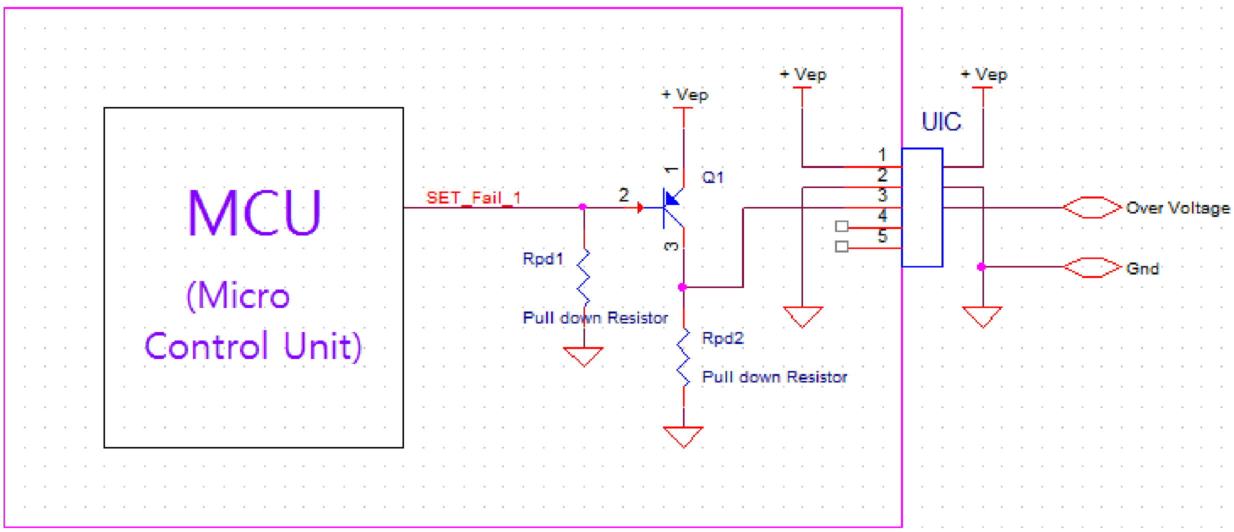


Figure 8. Diagram of Over Voltage Monitoring Circuit

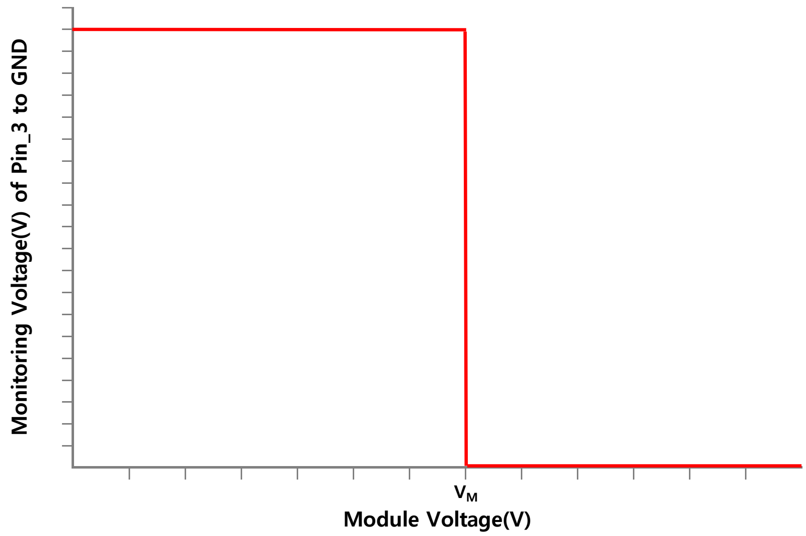


Figure 9. Over Voltage Monitoring Output Signal

3.4.3 Reverse Polarity Detection

The objective of the polarity reversal detection circuit is to prevent reverse charging of an ultracapacitor module. If the output signal for polarity check was normal during the initial operation after installation or service of an ultracapacitor module or charger, but later indicates a reverse polarity error, the detection circuit may have been damaged during use. However, this will not negatively impact performance of the ultracapacitor module or voltage balancing between modules connected in series.

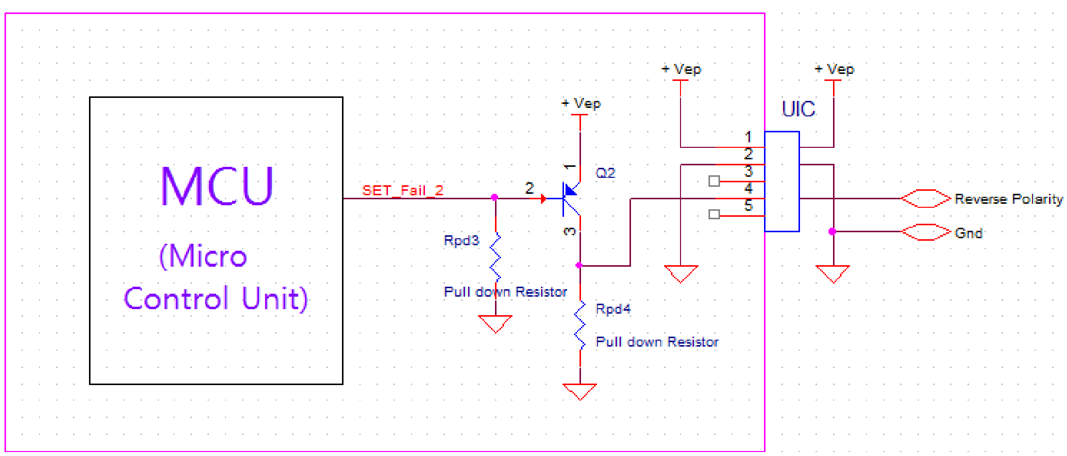


Figure 10. Diagram of Reverse Polarity Monitoring Circuit

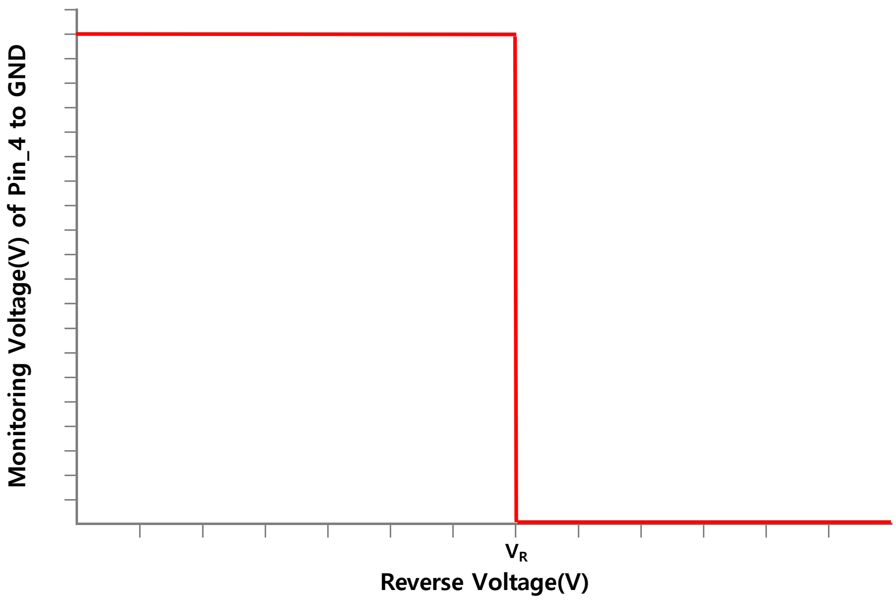


Figure 11. Output Signal when Polarity is reversed

3.4.4 Over Temperature Monitoring

The MCU will calculate the temperature using the resistance and generate a "Failure 3" signal when the temperature inside the module is higher than 65°C.

- Temperature Sensor Type: NTC Thermistor, Chip Type (1608)
- Model Name: LNS16K103HP, DK SENSOR (KOREA)
- R: 10.0 kΩ +/- 3% at 25°C
- β constant: B25/B85 = 3435K +/- 1%

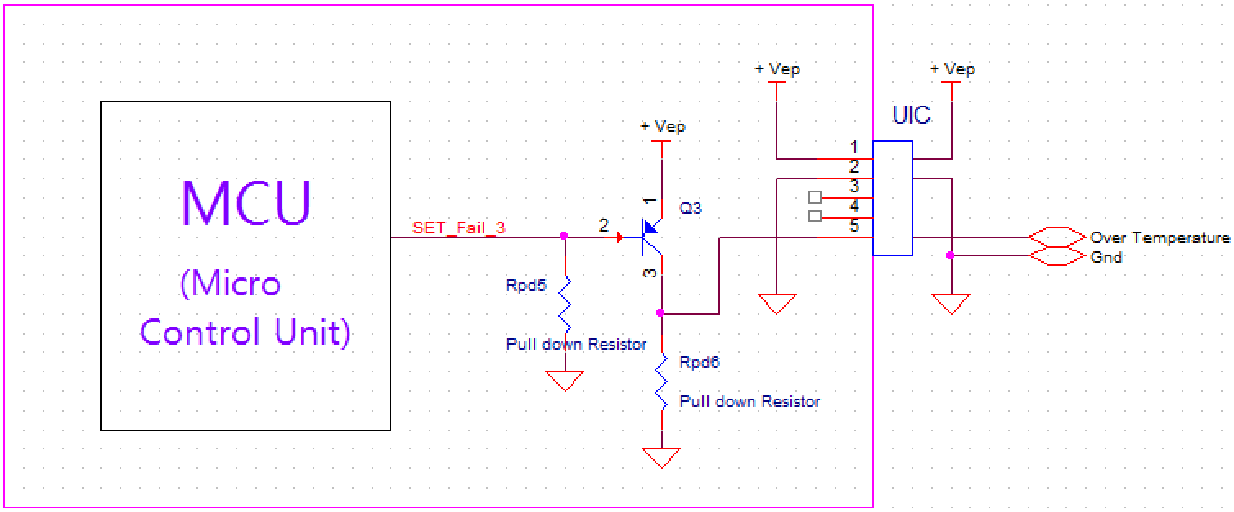


Figure 12. Diagram of Over Temperature Monitoring Circuit

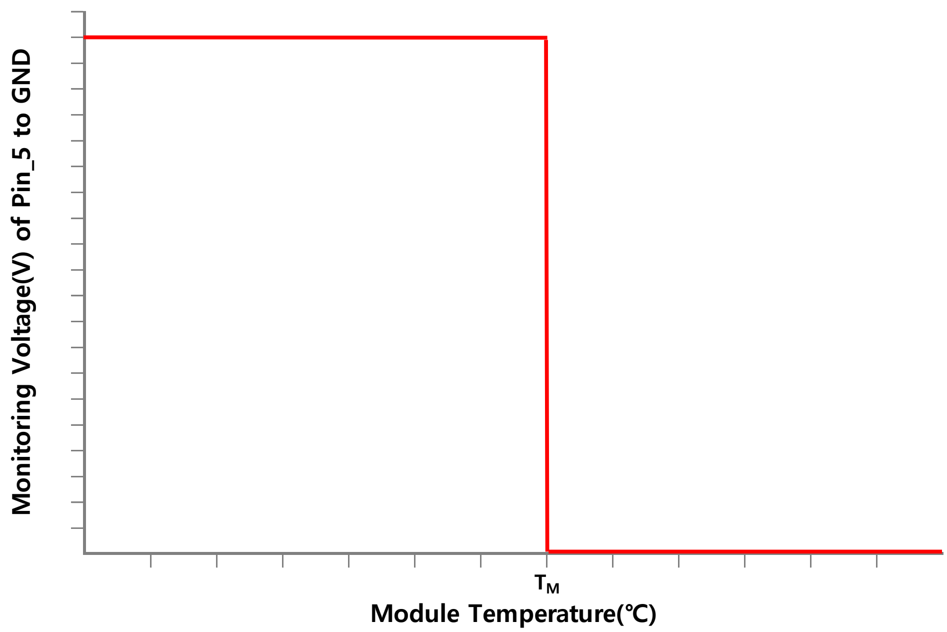


Figure 13. Output Signal of Over Temperature

3.4.5 ESD (Electrostatic Discharge) and Surge Voltage Protection

Transient voltage suppression diodes are used in the monitoring circuit to withstand ESD (Electrostatic Discharge) and transient voltage events. These diodes satisfy Severity Level 4 according to IEC61000-4-2 standard. At Severity Level 4, the maximum ESD suppression is 15kV for 1 nano-second.

Table 4. Severity Level for ESD Protection Test According to IEC61000-4-2

Severity Level	Air Discharge (kV)	Direct Discharge (kV)
1	2	2
2	4	4
3	8	6
4	15	8

3.5 Thermal performance

The modules generate small amounts of heat during use. As with most electronic components, reduced operating temperature will extend the service life. In most applications, natural air convection is adequate for cooling; when operated at the rated module current. Majority of module heat rejection occurs from the flat top and bottom cover plates. Increasing airflow over these two module surfaces will further improve module heat rejection performance and reduce operating temperature.

The thermal resistance, R_{TH}, of the units has been experimentally determined assuming free convection at ambient temperature (~ 25 °C). The R_{TH} value provided on the datasheet is useful for determining the operating limits for the units.

Using the R_{TH} value, a module temperature rise can be determined based upon any current and duty cycle. The temperature rise can be expressed by the following equation.

where:

I	= RMS current (amps)
R_{ESR}	= equivalent series resistance, R_{DC} (ohms)
R_{TH}	= thermal resistance (°C/W)
d_f	= duty cycle fraction

The ΔT value calculated above and ambient temperature must remain below the specified maximum operating temperature for the module (for maximum operating temperature, refer to the module datasheet) as measured by the thermistor output. If supplemental cooling methods are employed, it may be possible to operate at higher currents or duty cycles than if cooling occurs by natural air convection only.

Thermal capacitance is a parameter that is useful in calculating or estimating how fast the module will reach its stable temperature state under given I_{RMS}. This value can be estimated by the following equation.

where:

t	= time (sec.)
C_{TH}	= thermal capacitance, (J/°C)
R_{TH}	= thermal resistance (°C/W)

4 Operation

The module should only be operated within specified voltage and temperature ratings specified on the datasheet. Determine whether current limiting is necessary based on the current ratings of attached components. Observe polarity indicated on module. Do not reverse polarity.

The modules covered by this user manual (BMOD0010 B090 B02 and BMOD0010 B090 C02) are different Ultracapacitor Management Units (UMU) (see datasheets). They ARE NOT interchangeable and cannot be mixed. Mixing different model numbers in a single series string may cause voltage imbalance, damage to cells/module(s), or may trigger over-voltage alarms.

5 Safety

DANGER
HIGH VOLTAGE HAZARD Never touch the positive (+) or negative (–) terminals as the module can be charged and cause **severe bodily harm**. Always verify that the module is fully discharged before handling the module. Refer to the instructions in section 5.1 below for the manual discharge procedure. Wear adequate safety protection (safety glasses, gloves, etc.)

- Do not operate unit above the specified voltage
- Do not operate unit above the specified temperature rating
- Do not touch terminals with conductors while the module is charged. Serious burns, shock, or material fusing may occur
- Protect surrounding electrical components from incidental contact
- Provide sufficient electrical isolation when working above 50 VDC
- Prior to installation in or removal from the system, fully discharge the module to guarantee the safety of all personnel

5.1 Discharge procedure

To discharge an individual module:

1. Using a voltmeter, measure the voltage between the positive (+) and negative (–) terminals.
2. If the voltage is above 2 V, a power resistor (not supplied with the module) may be connected between the terminals to discharge the module. Proper care must be taken in the design and construction of such a resistor. The discharge time, current, power and temperature will depend on the resistor value and the amount of energy to be discharged.

NOTE	Customers may also use a DC electronic load tool to support the safe/controlled discharge of individual modules prior to service (for example, the BK Precision DC Electronic Load Model 8500 or a similar tool).  300 W

3. If the voltage is under 2 V, connect a shorting wire between the positive (+) and negative (–) terminals.
4. The module is now safe for handling. However, leave the shorting wire connected **at all times** until installing the module and connecting power cables to the terminals.

6 Maintenance

Prior to removal from the system, cable removal, or any other handling ensure that the energy storage module is completely discharged in a safe manner. The stored energy and the voltage levels may be lethal if mishandled. Maintenance should only be conducted by trained personnel on discharged modules (see the "Discharge procedure" section 5.1 above).

6.1 Routine maintenance

WARNING
Do not use high-pressure sprays or immersion to clean the module. Keep excess amounts of water away from the Ultracapacitor Management Unit cover and power terminals.

	Outside use / dirty / dusty / high-vibration environment	**Inside use / clean / low-vibration environment**
Use a damp cloth to clean the exterior of the module and remove dirt and grime	At least every 6 months (more frequently in very dusty-dirty environments)	Annually
Use a calibrated torque wrench to check mounting fasteners for proper torque		
Inspect housing for signs of internal damage		
Check signal/ground connections for false signals or shock hazards		

7 Storage

The discharged module can be stored in the original package in a dry place. Discharge a used module prior to stock or shipment. After discharging the module, connect a shorting wire between the positive (+) and negative (–) terminals to maintain a short circuit.

For more information about discharging a module, see the "Discharge procedure" section 5.1.

8 Disposal

Do not dispose module in the trash. Dispose according to local environmental regulations.

9 Specification

Refer to datasheets at our website, www.maxwell.com, for specifications of each product.

10 Installation checklist

The following checklist details best practices and requirements for the 90V energy storage module. Requirements are highlighted in the table for easy identification.

MOUNTING MODULES	
REQUIREMENT	Modules must be fastened to a flat mounting surface using all 4 mounting bolt pass-through holes available on the module. No deformation of the module's bottom or top plates should be allowed.
BEST PRACTICE	Maxwell suggests that each module be fastened using high-quality fasteners. • Metric: Class 8.8 or 10.9, M8 • Standard: Grade 5 or 8, 5/16” Use the appropriate bolt length for the specific installation; include length for the use of lock washers or lock nuts.

CABLING CONNECTIONS	
REQUIREMENT	Maxwell requires that the main positive (+) and negative (–) power cables are properly restrained to prevent movement and stress to the terminals of the module.
BEST PRACTICE	When connecting the power terminal to the ring terminal, strip cable sheath 1 to 2 mm longer than the crimp area of the ring terminal. Insert the cable until it reaches the ring terminal. The bolts must be tightened with a specified force. It is recommended to use an appropriate torque wrench or other similar tool. • Max. 1.8Nm, 18kgf Over-tightening may damage the terminal. Under-tightening may cause the cable to become loose.
BEST PRACTICE	Maxwell recommends that each module case be grounded to the chassis ground for optimal safety.

MONITORING	
REQUIREMENT	Maxwell requires that the monitoring system use the provided overvoltage and temperature signals from the module. Additionally, the monitoring system must be able to indicate to the operator that an overvoltage or over temperature condition has occurred or is occurring.

THERMAL CONTROL	
BEST PRACTICE	Maxwell recommends that the output of the over temperature monitoring of each module is monitored separately by the monitoring system. Maxwell's specification for maximum operating cell temperature is 65 °C. Cell temperature should ideally be maintained at or below 45 °C to maximize cell lifetime.