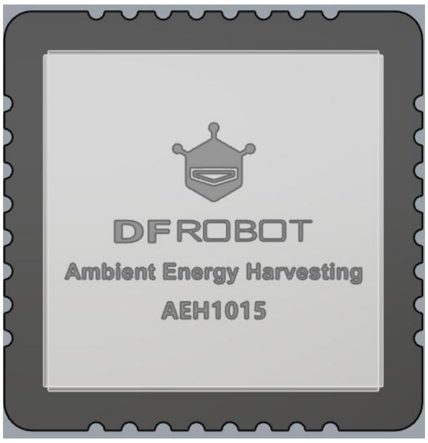
DFROBOT
Ambient Energy Harvesting
AEH1015

1.Introduction

The DFM8001 is a multi-functional Ambient energy harvesting and management module that integrates energy management, charge/discharge management, and energy storage device management. It supports cold start at energy inputs as low as 400mV and 15μW of power, harvests DC power from energy converters such as photovoltaic panels, microturbine generators, etc., and stores the energy in a rechargeable energy storage device, which provides stabilized operating voltages for different loads through two LDO regulators.

Supporting input currents up to 100mA, an ultra-low power boost converter is integrated internally for charging energy storage devices such as lithium-ion batteries, thin-film batteries, supercapacitors or conventional capacitors. The boost converter is capable of starting at an input voltage of only 400mV input power of 15uW through a unique cold-start circuit, and running continuously at inputs from 150mV to 5V.

Supporting dual LDO regulator outputs, the low-voltage LDO is typically used to drive 1.2V or 1.8V MCUs, and the high-voltage LDO is typically used to drive 1.8 to 4.0V wireless transceivers. These two highly efficient LDOs provide low noise and high stability output voltages.

Supports various configurations of the energy storage device and LDO via configuration pins, such as overcharge and overdischarge protection voltage, LDO output voltage, and whether to start the LDO output. Built-in 7 configuration modes cover most of the usage scenarios, and additional special modes can be configured through some resistors.

There is no need to connect any external electronic components when using, just connect the module's own configuration pins with GND/Vbuck, and then build an environmental energy power supply system after connecting to environmental energy collection devices, energy storage devices and power consumption devices. The extremely simple BOM list and the difficulty of R&D can effectively shorten the time-to-market and cost of the product.

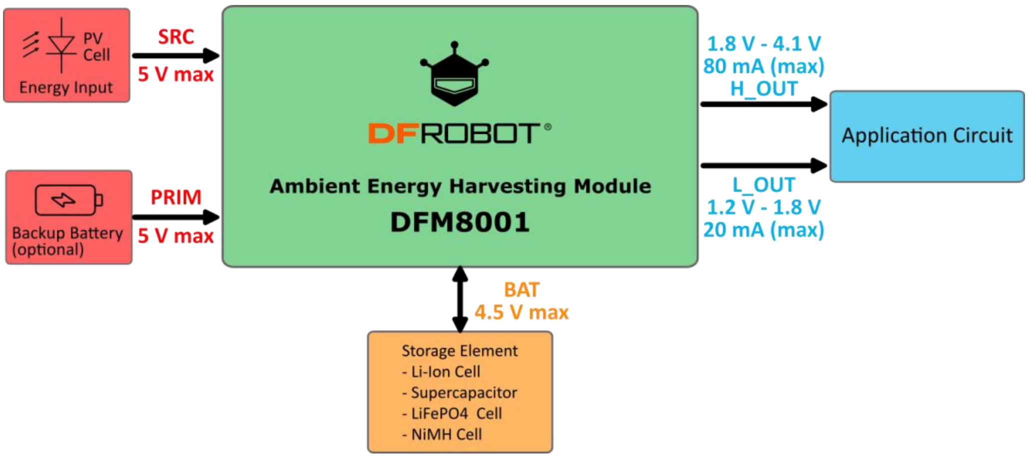

Figure 1.
Application Diagram

2.Specification

Ultra-low starting power

- 400mV 15uW cold boot
- Input voltage range after startup 150mV to 5V

Ultra-high energy conversion efficiency

- MPPT ratio 70%, 75%, 85, 90% multi-step adjustment
- Open circuit voltage detection for MPPT every 5 seconds

Integrated Dual LDO Regulator

- Low voltage output: 1.2/1.8V 20mA
- High voltage output: 1.8-4.1V 80mA
- Dynamic control of whether to activate the LDO output

Flexible energy storage management

- Adjustable overcharge and overdischarge protection
- Suitable for any type of rechargeable battery or capacitor
- Battery low warning
- LDO output available tips

Supports battery backup

- When the rechargeable battery is depleted, it automatically switches to the backup battery after 600ms.

3.Appliance

- Indoor Light Harvesting
- Smart home kit
- Wireless Sensor Nodes
- Intelligent electronic price tag
- Industrial monitoring
- Asset management

4.Pinout

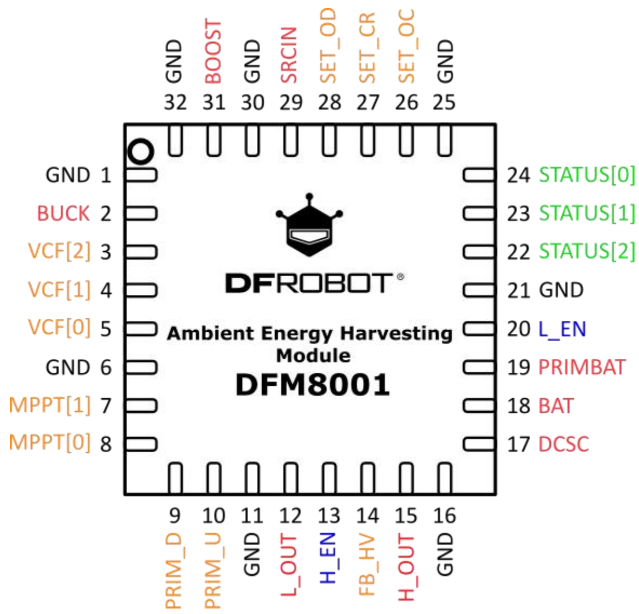

Figure 2. Pinout

Name	No.	Function
Power Pins		
BUCK	2	Output of buck converter
BOOST	31	Boost converter output
L_OUT	12	Low Voltage LDO Regulator Output
H_OUT	15	High Voltage LDO Regulator Output
DCSC	17	Connected to the midpoint of the two-cell supercapacitor (optional), must be connected to GND if not used
BAT	18	Connected to energy storage devices, rechargeable batteries, capacitors, etc., not suspended
PRIMBAT	19	Connected to primary battery (optional), must be connected to GND if not in use
SRCIN	29	Connected to an input energy source
GND		Ground
Configuration Pins		
VCF[2]	3	Threshold voltage for configuring energy storage elements and output voltage of LDOs
VCF[1]	4	
VCF[0]	5	
MPPT[1]	7	Configure the MPPT ratio
MPPT[0]	8	
PRIM_D	9	Configure the minimum voltage of the primary battery (optional), must be connected to GND if not in use.
PRIM_U	10	

FB_HV	14	Used to configure high-voltage LDOs in customized mode (optional), must be floated if not used
SET_OC	26	Threshold voltage for configuring the energy storage element when in customized mode (optional) Must float when using predefined mode Float is disabled when using customized mode
SET_CR	27	
SET_OD	28	
Control Pin		
H_EN	13	High voltage enable pin
L_EN	20	Low voltage enable pin
Status Pin		
STATUS[2]	22	Logic output, set when the module performs an MPPT calculation
STATUS[1]	23	Logic output, set when the battery voltage is below Vod or when the module is drawing energy from the primary battery
STATUS[0]	24	Logic output, set when LDO can be enabled

Table 1. Pinout Description

5.Electrical Characteristics at 25℃

Symbol	Parameter	Condition	MIN	TYP	MAX	UNIT
Input voltage and input power						
P_{SRC_CS}	Cold boot required power	Cold boot	15			μW
V_{SRC}	Input voltage	Cold boot	0.4		5	V
		Cold boot	0.15		5	V
I_{SRC}	Input current				100	mA
V_{MPP}	Voltage at maximum power point	Cold boot	0.15		4.5	V
DC-DC Convertor						
V_{BOOST}	Boost converter output voltage	Working	2.2		4.5	V
V_{BUCK}	Output Voltage of Buck Converter	Working	2	2.2	2.5	V
Energy Storage Component						
V_{BAT}	Energy Storage Device Voltage	Rechargeable battery	2.2		4.5	V
		capacitors	0		4.5	V
T_{DLY}	STATUS[1] Time from entry into force until closure		400	600	800	ms
V_{PRIM}	primary Backup Battery Voltage		0.6		5	V
I_{PRIM}	primary Backup Battery output current			20		mA

V_{PRIM_U}	Minimum voltage of primary Backup Batteries		0.15		1.1	V
Voc	Maximum voltage acceptable on the energy storage element before disabling the boost converter	See Table 6	2.3		4.5	V
Vcr	Minimum voltage required on the energy storage element before enabling the LDO after a cold start	See Table 6	2.25		4.45	V
Vod	Minimum voltage acceptable to the energy storage element before switching to primary battery or entering shutdown mode	See Table 6	2.2		4.4	V
LDO						
V_L	Low Voltage LDO output voltage	See Table 6	1.2		1.8	V
I_L	Low Voltage LDO output current		0		20	mA
V_H	High Voltage LDO output voltage	See Table 6	1.8		Vod-0.3	V
I_H	Low Voltage LDO output current		0		80	mA
Logic Output Pins						
STATUS[2:0]	Logic output status pins	Logic High	1.98	V_{BAT}		V
		Logic Low	-0.1	0	0.1	V

Table 2. Electrical Characteristics

6. Recommended Operating Conditions

Symbol	Parameter		MIN	TYP	MAX	UNIT
Optional External Devices						
RT	Resistor for setting battery threshold voltage in custom mode, RT = R1 + R2 + R3 + R4 (optional)		1	10	100	MΩ
RV	Resistor for setting high voltage LDO voltage in custom mode, RV=R5+R6 (optional)		1	10	40	MΩ
RP	primary Backup Battery configuration resistor, RP=R7+R8(optional)		100		500	KΩ
Logic Enable Pin						
H_EN	High Voltage LDO Enable Pin	HIGH	1.75	V_{BUCK}	V_{BUCK}	V
		LOW	-0.01	0	0.01	V

L_EN	Low Voltage LDO Enable Pin	HIGH	1.75		V_{BOOST}	V
		LOW	-0.01	0	0.01	V
MPPT[1:0]	MPPT Configuration Pin	HIGH	Connect to BUCK			
		LOW	Connect to GND			
VCF[2:0]	Energy Storage Component Configuration Pins	HIGH	Connect to BUCK			

Table 3. Recommended Operating conditions

Parameter	**Range**
V_{SRC}	5.5V
Operating temperature	-40 ℃ to +125℃
Storage temperature	-65 ℃ to +150℃

Table 4.Maximum operating conditions

7.Operating Principle

7.1 Power converter

7.1.1 Boost/Buck

The boost converter raises the voltage available on the input source to a level suitable for charging the energy storage component, and this voltage is V_{BOOST}, which is available at the BOOST pin in the range of 2.2 V to 4.5 V. The boost converter is connected to the BOOST pin at voltage V_{BAT}, and in normal mode, the battery is shorted to BOOST ($V_{BAT} = V_{BOOST}$). When energy is harvested, the boost converter will provide a current that is shared between the battery and the load.

The buck converter reduces the voltage from V_{BOOST} to a constant V_{BUCK} value of 2.2 V, which is available through the BUCK pin.

7.1.2 LDO output

The module has two LDOs to provide different operating voltages:

The High Voltage LDO supplies power to the load through H_OUT. The regulator provides a voltage V_H on H_OUT and a maximum current of 80 mA for I_H. In built-in configuration mode, an output voltage of 1.8 V, 2.5 V, or 3.3 V can be selected. In custom configuration mode, it is adjustable from 2.2 V to V_{BAT} - 0.3 V. The H_OUT output can be dynamically enabled or disabled via the logic control pin H_EN.

The Low Voltage LDO supplies power to the load through L_OUT. The regulator provides a voltage V_L of 1.8 V or 1.2 V on L_OUT, with a maximum current of 20 mA at I_L. The L_OUT output can be dynamically enabled or disabled via the logic control pin L_EN.

L_EN	H_EN	L_OUT	H_OUT
1	1	Enabled	Enabled
1	0	Enabled	Disabled
0	1	Disabled	Enabled
0	0	Disabled	Disabled

Table 5. LDO Output Configuration

7.2 Working mode

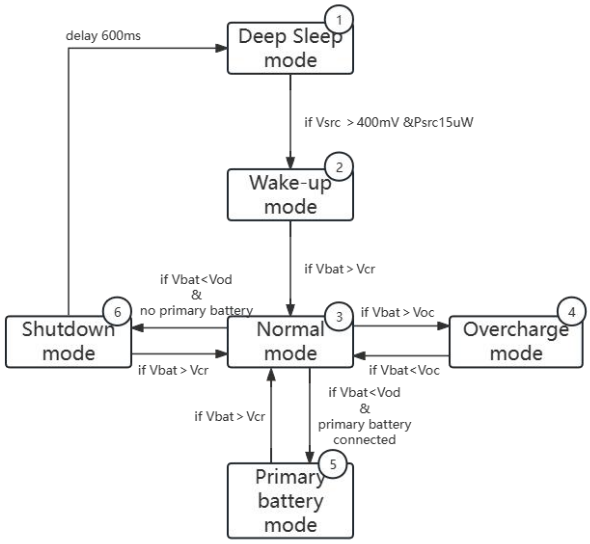

Figure3. Working mode Diagram

7.2.1 Deep sleep and wake-up mode

Under deep sleep mode, all nodes are deeply discharged and no available energy is collected by the module. When the SRCIN pin meets a cold-start voltage of 400mV and a power input of 15μW, the module is activated into wake-up mode, and the voltages of V_{BAT} and V_{BUCK} are raised to 2.2 V, and then the voltage of VBAT is raised individually to Voc. During the cold-start process both LDOs are internally deactivated with no output.

In the case of a supercapacitor as an energy storage component, the storage component may need to be charged from 0 V. The boost converter will charge the BAT through the input source.

During the charging of the BAT node, both LDOs are disabled. When V_{BAT} reaches Vcr, the circuit enters the normal mode, and the user can activate or deactivate the outputs of the LDOs using the H_EN and L_EN pins controls.

In the case where the battery is used as a storage element, if its voltage falls below Vcr, the storage element first needs to be charged until the voltage reaches Vcr. When V_{BAT} exceeds Vcr, the circuit re-enters normal mode.

7.2.2 Normal Mode

After entering normal mode, the following three situations may occur:

- The power supplied by the input source is equal to the load power, V_{BAT} remains between Vod~Voc and the circuit remains in normal mode;

- The power supplied by the input source exceeds the power consumed by the load, V_{BAT} gradually exceeds Voc and the circuit enters the overvoltage mode;

- The power supplied by the input source is less than the power consumed by the load, V_{BAT} gradually drops below Vod and the circuit will go into shutdown mode or, if there is a primary battery connected to PRIM, the circuit will go into primary battery charging mode.

7.2.3 Overcharge Mode

When V_{BAT} reaches Voc, charging is complete and internal logic components maintain the VBAT voltage value around Voc with a hysteresis of a few mV to prevent damage to the energy storage components and internal circuitry. In this configuration, the boost converter activates periodically to maintain VBAT and the output of the LDO remains available.

7.2.4 Primary battery mode

When V_{BAT} drops below Vod, the circuit compares the voltage on PRIM to the voltage on PRIM_U to determine if a sufficiently charged battery is connected to PRIM. The voltage on PRIM_U is set by two optional resistors. if the voltage on PRIM divided by 4 is higher than the voltage on PRIM_U, the circuit assumes that a battery backup is available and the circuit enters the battery backup mode. If the voltage on PRIM divided by 4 is higher than the voltage on PRIM_U, the circuit assumes that a backup battery is available and the circuit enters the primary battery mode, in which the module remains until VBAT reaches Vcr. When VBAT reaches Vcr, the circuit enters the normal mode. If the application does not use a primary battery, PRIM, PRIM_U, and PRIM_D must be connected to GND.

7.2.5 Shutdown Mode

When V_{BAT} drops below Vod and the backup battery is unavailable, the circuit enters a shutdown mode to prevent damage to the energy storage components and LDO instability due to deep discharges, but the LDO does not shut down immediately at this point. If the primary battery is not used, the load can be interrupted by a low-to-high transition from STATUS[1], regardless of whether the load is powered by L_OUT or H_OUT. If energy is available from the input source and V_{BAT} returns to Vcr within TDLY (about 600 ms), the module returns to normal mode. However, if V_{BAT} does not reach Vcr after TDLY, the circuit enters deep sleep mode, the LDO is disabled, and the BAT is disconnected from the BOOST to avoid damaging the battery due to over-discharge. After this, the module will have to perform the wake-up process described in the Deep Sleep and Wake-up Mode section.

7.3 MPPT

The boost converter is regulated with the help of an internal MPPT (Maximum Power Point Tracking) module during switching between Normal, Shutdown and wake-up modes. The MPPT module receives and maintains information about the V_{MPP}, with sampling taking place approximately every 5 seconds. The module supports any V_{MPP} level in the 0.15 V to 5 V range. It provides a choice of four values for V_{MPP}/ V_{OV} (input source open-circuit voltage) via configuration pins MPPT[1:0].

7.4 Dual-cell Supercapacitor

When using a Dual-cell Supercapacitor, it is important to keep both battery at the same voltage to avoid damaging the supercapacitor due to excessive voltage on one battery, which is accomplished by a balancing circuit inside the module.

If a normal single battery supercapacitor is used, only the positive of the capacitor needs to be connected to BAT, in which case DCSC must be connected to GND to disable the balancing circuit.

If a Dual-cell Supercapacitor is used, the midpoint of the Dual Battery capacitor needs to be connected to DCSC, and the balancing circuit compensates for any mismatch between the two cells that might cause one of them to overcharge. The balancing circuit ensures that the DCSC voltage remains close to VBAT/2.

8.System configuration

8.1 Energy storage components and LDO related configurations

8.1.1 Predefined Mode

In Predefined Mode, three configuration pins (VCF[2:0]) can be used to quickly set up a specific operation mode without the need for any external devices, and the Predefined Mode can meet the needs of most application scenarios

Configuration Pin			Energy Storage Component Voltage			LDO Output voltage		Recommended Applications
VCF[2]	VCF[1]	VCF[0]	Voc	Vcr	Vod	V_H	V_L	
1	1	1	4.12	3.67	3.60	3.3	1.8	Li-ion Bettery
1	1	0	4.12	4.04	3.60	3.3	1.8	Solid State Battery
1	0	1	4.12	3.67	3.01	2.5	1.8	Li-ion/NiMH Battery
1	0	0	2.70	2.30	2.20	1.8	1.2	Single-core supercapacitor
0	1	1	4.50	3.67	2.80	2.5	1.8	Dual-cell supercapacitor
0	1	0	4.50	3.92	3.60	3.3	1.8	Dual-cell supercapacitor
0	0	1	3.63	3.10	2.80	2.5	1.8	LiFePO4 Battery
0	0	0	Customized Mode (R1-R8)				1.8	

Table 6. VCF[2:0] Configuration

The three voltage threshold levels are:

Voc: Overcharge Voltage. Usually the maximum voltage acceptable on the energy storage element.

Vcr: Charge Ready Voltage. The minimum voltage required on the energy storage component after a cold start and before enabling the LDO.

Vod: Over discharge Voltage. The minimum voltage acceptable to the energy storage device before switching to primary batteries or entering shutdown mode.

The SET_OC, SET_CR, SET_OD, and FB_HV pins must remain floating when using the predefined modes.

The SET_OC, SET_CR, and SET_OD pins are prohibited from being in the floating state when using the customized mode, otherwise the module will be damaged.

To prevent misoperation, please disconnect the energy storage device when adjusting VCF[2]-VCF[0], and strictly observe the current voltage of the energy storage device <Voc when connecting the energy storage device, otherwise the system will be damaged.

To prevent misoperation, before configuring to customized mode, you must solder R1-R8 resistors first, then adjust the jumper cap configuration, and finally access the energy storage device.

8.1.2 Customized Mode

Resistors R1-R4 must be soldered before selecting custom mode, which will be selected when VCF[2:0] is connected to GND. Configuration is done through R1-R6 and the connection schematic is shown in Figure 4.

Voc, Vcr and Vod are configured by R1, R2, R3 and R4. The resistors are calculated as follows:

- RT=R1+R2+R3+R4
- 1 MΩ ≤ RT ≤ 100 MΩ
- R1=RT(1 /Voc)
- R2=RT(1 /Vcr - 1 /Voc)
- R3=RT(1 /Vod - 1 /Vcr)
- R4=RT(1 - 1 /Vod)

V_H is configured by R5 and R6. The resistor is calculated as follows:

- RV=R5+R6
- 1 MΩ ≤ RV ≤ 40 MΩ
- R5=RV(1 /Vh)
- R6=RV(1 - 1 /Vh)

Note: If H_EN = 0 (H_OUT is disabled), R5 and R6 are not needed and FB_HV should remain floating at this time.

Resistor values should be as large as possible so that excess power consumption is negligible. In addition, the configuration should follow the following constraints to ensure proper functioning of the chip

- Vcr + 0.05 V ≤ Voc ≤ 4.5 V
- Vod + 0.05 V ≤ Vcr ≤ Voc - 0.05 V
- 2.2 V ≤ Vod
- Vh ≤ Vod-0.3V

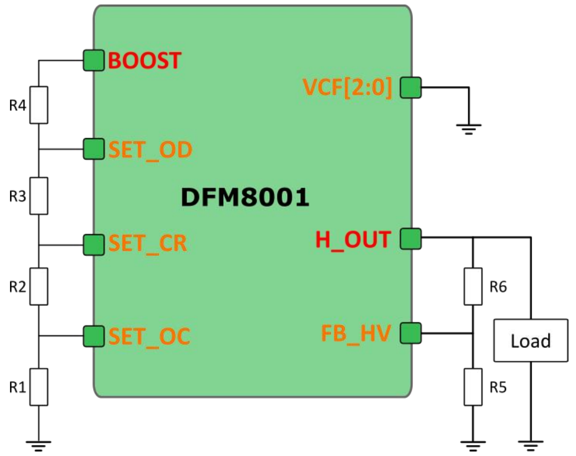

Figure 4. Customized Configuration Connection Diagram

8.2 MPPT Configuration

Two dedicated configuration pins, MPPT[1:0], allow the MPP tracking ratio to be selected based on the characteristics of the input energy source.

MPPT[1]	MPPT[0]	V_{MPP}/V_{OV}
1	1	70%
1	0	75%
0	1	85%
0	0	90%

Table 6. MPPT Configration

8.3 Primary Battery Configuration

When using a primary battery, VPRIM_U, the voltage used to determine that the primary battery has been depleted, must be determined, at which point it is necessary to connect a voltage divider resistor to PRIM_D. When the primary battery is not being used, PRIM_D must keep floating to avoid quiescent currents on the resistor.

- RP=R7+R8
- 100kΩ ≤ RP ≤ 500kΩ
- R7=(VPRIMBAT_MIN / 4) RP (1 / 2.2)
- R8=RP-R7

Note: PRIM_U, PRIM_D and PRIMBAT must be connected to to GND if the main battery is not used.

8.3 No Energy Storage Component Configuration

If the energy collected from the environment is permanently available and meets the needs of the whole system, or if there is no need to store energy when there is no energy to be collected, an external capacitor with a minimum of 150 µF can be used instead of the energy storage component connected to the BAT.

9. Typical Application Circuit

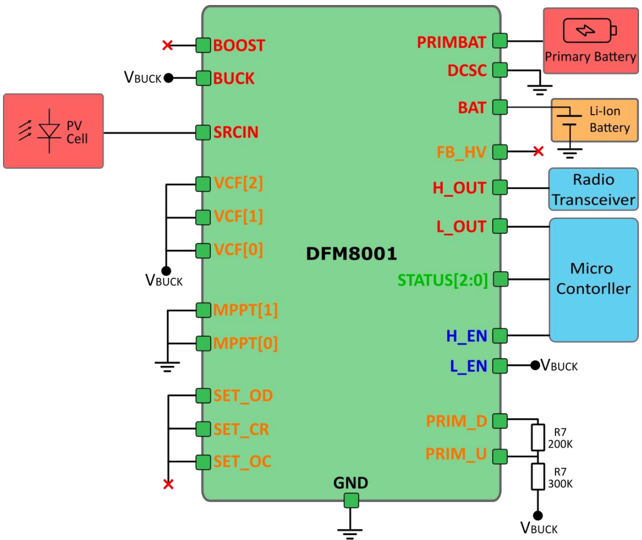

Figure 5. Typical Application Circuit Diagram

In a typical circuit, the energy source is a photovoltaic cell and the storage element is a standard lithium-ion battery. Microcontroller power is provided by L_OUT set to 1.8V. Radio communication is provided by H_OUT set to 3.3V and controlled by the microcontroller to turn the output on or off.

The circuit uses a predefined operating mode with VCF[2:0] configured as 1 1 1.

The threshold voltage is：

Voc=4.12V，Vcr=3.67V，Vod=3.6V

The LDO output is：

H_OUT=3.3V，L_OUT=1.8V

A spare primary battery is connected and the minimum voltage of the battery is set to 3.5V

- RP=0.5MΩ

- R7=(3.5/4)*0.5*(1/2.2)=200kΩ

- R8=0.5MΩ-0.2MΩ=300MΩ

MPPT configuration pins MPPT[1:0] are connected to GND and configured to 70%

10.Package

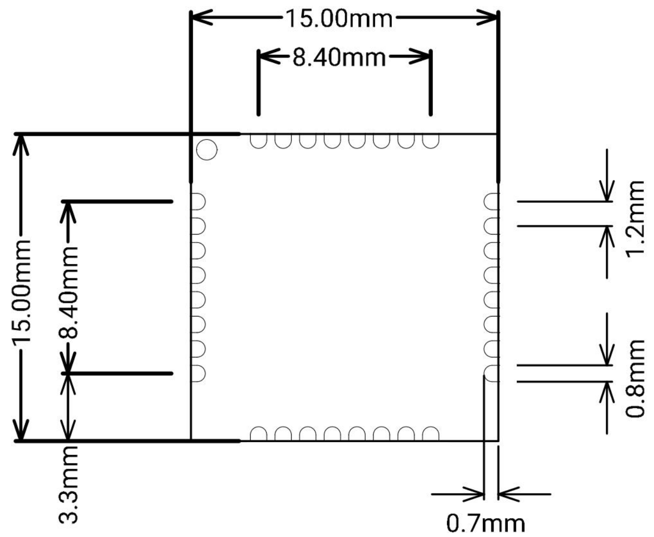

Figure 6. Module package

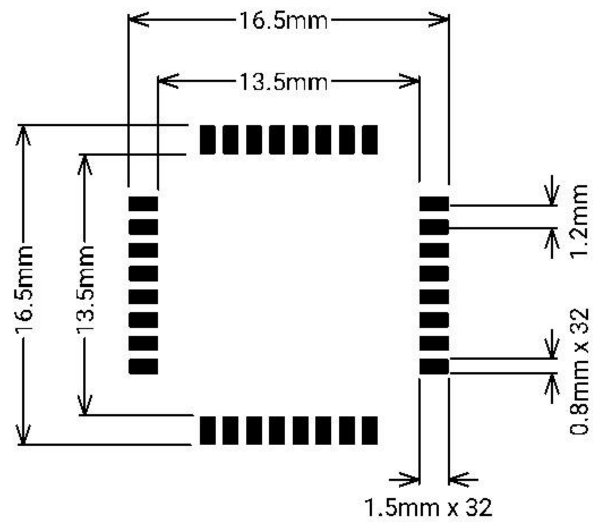

Figure 7. Board layout

Revision History

Revision	Date	Description
Rev_1.0	2024/05/22	Creating Documents
Rev_1.1	2024/05/28	Optimized the packaging diagram