MILLSWOOD
engineering

250W PMU

PRODUCT MANUAL

General Description

The Millswood Engineering 250W Power Management Unit provides up to 250 Watts of on-board electrical power generation for small to medium-sized UAVs. The -S version includes an integrated engine starter.

The 250W PMU simplifies UAV power distribution by providing multiple power outputs, which are individually programmable for voltage as well as being battery-backed. Dual (redundant) battery support is also included as standard.

Figure 1: 250W PMU

The PMU connects to a suitable brushless DC electric motor, which is in turn driven by the aircraft’s primary power plant, usually an internal combustion engine.

Features

- Optional engine starter may be activated locally via a momentary push-button switch, or remotely via command (facilitating in-flight engine restarts).
- Multiple independent, individually programmable power outputs:
    - Avionics: 12 – 21 VDC
    - Payload: 12 – 21 VDC
    - Servo: 5 – 12 VDC

  Outputs are battery-backed and switchable (on/off) via hardware signal or remotely via command.
- Dual (redundant) battery support. The PMU includes two independent and identical battery chargers. Supported battery types include:
    - LiPo: 5S, 6S
    - LiS: 7S, 8S, 9S, 10S
    - LiFe: 5S, 6S, 7S
- Industry-standard 28 VDC output (available during power generation and when the PMU is connected to umbilical power).
- RS232 and CAN control and monitoring interface provides extensive monitoring and reporting of voltages, currents, battery charge status, temperature.
- Buck-boost converter allows electrical power generation over 4:1 RPM range.
- Weight: 290 grams (10.2 ounces).
- Dimensions: 124.4 x 85.0 x 32.5mm.

Contents

Absolute Maximum Ratings*Note 1*

Symbol	**Parameter**	**Min**	**Max**	**Unit**
V_{BLDC}	BLDC motor voltage, phase-to-phase*Note 2*	-77.8	+77.8	V
V_{UMB}	Umbilical input voltage	-50	+50	V
V_{BAT}	Battery voltage*Note 2*	-30	+33.3	V
V_{28VDC}	28VDC bus voltage*Note 3*	-1	+33.3	V
V_{AVI}	Avionics output voltage*Note 3*	-1	+26.7	V
V_{PAY}	Payload output voltage*Note 3*	-1	+26.7	V
V_{SERVO}	Servo output voltage*Note 3*	-1	+13.3	V
V_{RS232_I}	RS232 input voltage	-25	+25	V
V_{RS232_O}	RS232 output voltage	-13.2	+13.2	V
V_{CAN_L}, V_{CAN_H}	CAN L and H voltage	-42	+42	V
T_{ST}	Storage temperature range	-55	+85	°C

Note 1: Absolute maximum ratings are those values beyond which damage to the product may occur. Functional operation under these conditions is not implied (or recommended).

Note 2: Pin protected from overvoltage by a Transient Voltage Suppressor (TVS) diode. Excursions above absolute maximum rating will be clamped, resulting in large current flows.

Note 3: Pin protected from reverse and overvoltage by a TVS diode. Excursions below absolute minimum or above absolute maximum ratings will be clamped, resulting in large current flows.

Recommended Operating Conditions

Symbol	**Parameter**	**Min**	**Max**	**Unit**
V_{BLDC}	BLDC motor voltage, phase-to-phase	18	72	V_{PP}
V_{UMB}	Umbilical input voltage	24	48	V_{DC}
V_{BAT}	Battery charging voltage	16.8	25.2	V_{DC}
I_{BAT}	Battery charging current (per charger)		2.5	A_{DC}
P_{BAT}	Battery charging power (per charger)		60	W
I_{28VDC}	28VDC bus current (out)		9	A_{DC}
P_{28VDC}	28VDC bus power (out)		250	W
V_{AVI}	Avionics output voltage	12	21	V_{DC}
I_{AVI}	Avionics output current*Note 1*		7.5	A_{DC}
P_{AVI}	Avionics output power		120	W
V_{PAY}	Payload output voltage	12	21	V_{DC}
I_{PAY}	Payload output current*Note 1*		7.5	A_{DC}
P_{PAY}	Payload output power		120	W
V_{SERVO}	Servo output voltage	5	12	V_{DC}
I_{SERVO}	Servo output current		10	A_{DC}
P_{SERVO}	Servo output power		120	W
P_{TOTAL}	Total output power (all chargers, buses and outputs)		250	W
T_{OP}	Operational temperature range	-40	+70	°C
Alt	Altitude	0	10,000	m_{AMSL}

Note 1: Derate current linearly above 16VDC to observe maximum power rating.

Electrical Characteristics

Placeholder (TBD)

Typical Performance Characteristics

Placeholder (TBD)

Thermal Management

All power conversion devices generate heat, and getting rid of this unwanted heat is one of the main factors limiting maximum continuous output power. Operation at elevated temperatures for extended periods of time also impacts negatively on reliability and service life. For these reasons it is worth taking some time to ensure that the PMU is operated at the lowest possible internal temperature.

Most devices quote a maximum ambient operating temperature, but this figure is of little practical value. A more useful measure of thermal performance is thermal resistance – this figure is given in degrees per Watt and allows calculation of the device temperature under different operating conditions. Note that the power used in thermal resistance calculations is the dissipated power, not the output power. To calculate the dissipated power the following formula is used:

$\mathbf{P_{DISSIPATED} = P_{OUTPUT} \times (1-\eta) / \eta}$ where η is the efficiency ranging from 0 to 1

The dissipated power is then multiplied by the thermal resistance to give temperature rise above ambient. The PMU has a worst-case thermal resistance of X.X°C/W (mounted horizontally in still air). This can be improved to 0.XX°C/W with sufficient airflow.

Recommendations

The goal of thermal design should be to maintain the PMU's internal temperature below +70°C. Operation between +70 and +85°C is permitted but not recommended for extended periods of time. Internal temperature is reported in the telemetry data stream, and there is a user-programmable thermal cutout that is set to +85°C by default.

- If no fan is to be used and the PMU is installed in a stagnant environment, the PMU should be mounted such that the top and bottom panels are oriented vertically. This promotes the formation of natural convection currents.
- If possible the PMU should be installed such that natural airflow is able to pass across as much surface area as possible. PMU orientation is less important when airflow is present. Many of the heat-generating components within the PMU are in thermal contact with the top panel, and this is where airflow will have the most benefit.
- If high power is to be drawn from the PMU and natural airflow is limited, then a fan should be installed. PMU orientation is irrelevant if a fan is present. EBM-Papst 414F is a reasonable choice for 28VDC operation, although obviously other possibilities exist. Airflow should pass along the fins on the top of the PMU.

As a rough guide, if more than 150W is to be drawn from the PMU continuously a fan is recommended.

Communications

The 250W PMU has both RS232 and CANbus interfaces that perform essentially the same functions, these being:

1. Configuration (of parameters stored in the PMU's non-volatile memory),
2. Control (real-time control of the PMU's various features),
3. Monitoring (of measured voltages, currents, temperatures, etc), and
4. Updating the PMU's firmware.

Once the PMU has been configured, there is no requirement to connect anything to either communications interface – the PMU will operate quite normally with no communications at all.

RS232 interface

The RS232 interface operates at 57600 baud, full-duplex, with 8 data bits and no parity (57600 8N1). The RS232 hardware layer is compliant with TIA/EIA-232-F and ITU V.28.

A Windows application that provides easy access to most of the 250W PMU's various features may be downloaded from www.millswoodeng.com.au/downloads.html

Configuration utility for the Millswood Engineering 250W PMU
Version 1.0.0.0

Port: COM4

Serial port COM4 opened.

Figure 2 – 250W PMU configuration utility

Using the configuration utility relieves the user from the burden of writing software in order to configure and control the PMU. The RS232 protocol is described in a separate document for the purpose of more tightly integrating the PMU with other hardware and software.

CAN interface

CAN offers faster and more reliable communication than is possible with RS232. The PMU's CAN interface operates at up to 1Mbit/s and is compatible with Cloud Cap Technology CAN devices.

The CAN bus may be left unterminated (default), or terminated with a 120Ω resistor across the CANH and CANL lines, or terminated with a biased split termination for the best possible EMC performance.

Interfacing

The internal architecture of the PMU is shown in Figure 3 below. Only the main power pathways are shown. Diodes shown are not physical diodes; they are "ideal diodes" implemented with FET switches.

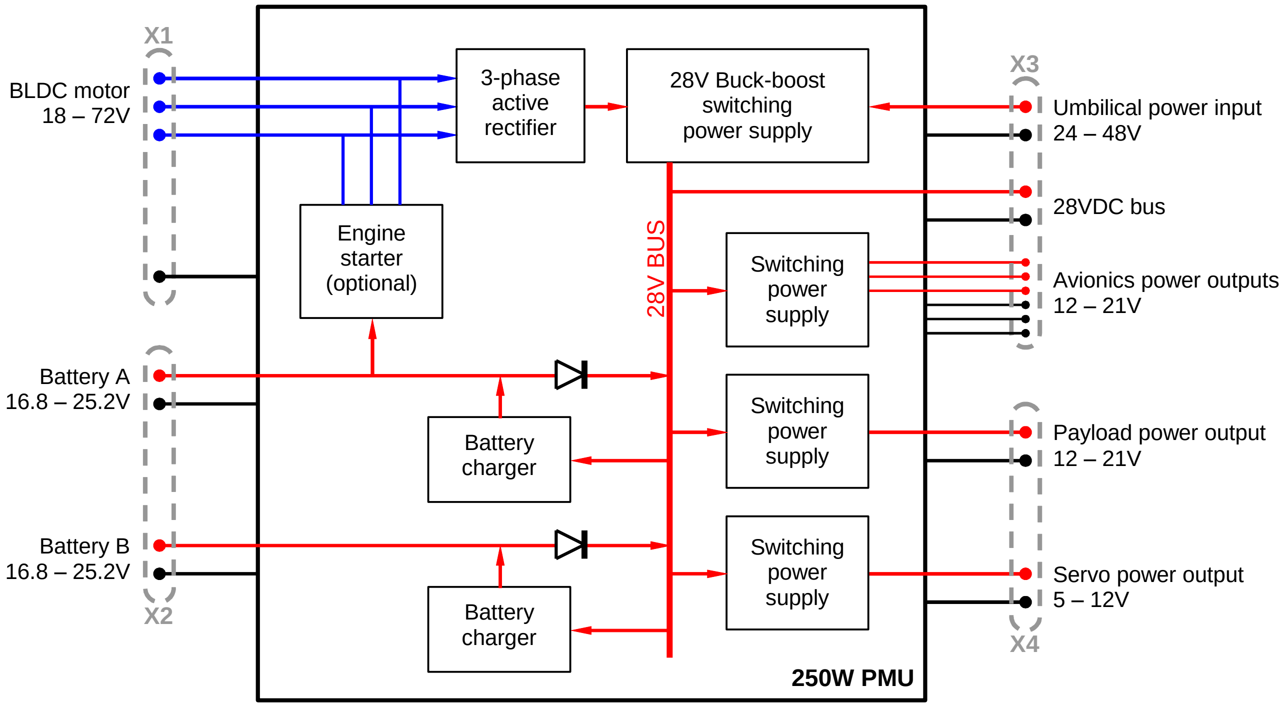


Figure 3 – PMU internal architecture

The Avionics, Servo and Payload outputs are battery-backed. In other words, when electrical power generation is not occurring, outputs are maintained using battery power (or umbilical power if present). The 28VDC bus assumes the highest available battery voltage when electrical power generation is not occurring.

The Avionics, Servo and Payload outputs each have a dedicated shutdown input pin. When a shutdown pin is pulled low (via a switch or open collector output), the respective output is turned off. The shutdown inputs may be connected together to form a master shutdown input if desired. The 28VDC bus and communications interface remain active regardless of the state of the shutdown inputs.

Although the case is nominally at ground potential, if a chassis earth return system is implemented the case should not be used as the ground connection. A dedicated ground pin is provided for this purpose (X1, pin D). All ground pins are connected together internally.

X1 – BLDC motor

Connect the 3 terminals of a suitable (see Appendix 1) brushless DC motor to pins A, B and C of X1. Over the operating rpm range that electrical power generation is desired, the peak voltage must be in the range 18 to 72V. This corresponds to an operating rpm range of 4:1.

The voltage can be calculated using the following formula:

$$V_p = rpm / K_v$$

For example, a brushless DC motor with a Kv of 346 rpm/V rotating at 20,000 rpm will generate 20,000 / 346 = 57.8V peak. Note that this formula neglects losses and gives an upper bound on the peak voltage. Under load, the voltage will be somewhat less.

If the brushless DC motor has a star-connected winding and the neutral is externalised, ***do not connect it to anything***. It must be securely insulated from all other connections.

Pin D of X1 is a low-impedance ground that may be connected to airframe ground if desired. Connection of this pin is optional.

Pins 1, 2 and 3 of X1 are inputs for the motor's Hall-effect sensors, and pins 5 and 6 are the Hall power and ground. Connection of Hall sensors is optional, although the PMU requires Hall input 1 to be connected and operational if monitoring of the BLDC motor's speed is required. For engine starting, all Hall sensor pins must be connected.

The remaining pins on X1 all relate to engine starting and are described in Table 1 below.

Pin	**Name**	**Type**	**Description**
X1:A	BLDC phase A	I/O	Connect to one of the 3 BLDC motor terminals.
X1:B	BLDC phase B	I/O	Connect to one of the 3 BLDC motor terminals.
X1:C	BLDC phase C	I/O	Connect to one of the 3 BLDC motor terminals.
X1:D	Airframe ground	Ground	Optional connection.
X1:1	Hall 1	Input	Connect to open-collector output of Hall sensor 1.
X1:2	Hall 2	Input	Connect to open-collector output of Hall sensor 2.
X1:3	Hall 3	Input	Connect to open-collector output of Hall sensor 3.
X1:4	Direction	Input	Provides hardware control of direction of rotation during engine starting. Applying logical high reverses the direction of rotation. Hall power/ground may be used as source of logic levels. May be left open-circuit if feature not required.
X1:5	Hall power	Output	+5VDC power output for Hall sensors.
X1:6	Hall ground	Ground	Ground connection for Hall sensors.
X1:7	Arm	Input	Hardware interlock to arm/disarm engine starting. Shorting to pin X1:8 enables engine starting. ***For safety reasons this is a purely hardware interlock that cannot be overridden.***
X1:8	Arm ground	Ground	Ground connection for arm input.
X1:9	BLDC motor temperature sensor	Input	Connect to the anode (positive terminal) of a KTY83 temperature sensor that is in intimate thermal contact with the BLDC motor. Motor temperature sensing is optional.
X1:10	Sensor ground	Ground	Ground reference for motor temperature sensor.
X1:11	Start	Input	Shorting to pin X1:12 starts the engine.
X1:12	Start ground	Ground	Ground connection for start input.

Table 1 – X1 pin descriptions

X2 – Batteries

The PMU supports the connection of up to two batteries, and these are managed completely independently. Internal low-loss battery switching is implemented such that disconnection or failure of either battery – even to a dead short – has no affect on operation of the PMU as long as the other battery remains viable, or electrical power generation is occurring. It is possible – although perhaps not all that sensible – to operate the PMU with no batteries at all.

The PMU is operational whenever a battery is connected. It is therefore recommended to have a switch in series with the positive battery lead in order to be able to turn the PMU off.

If engine starting is anticipated then Battery A must be fitted, as cranking current is drawn solely from Battery A. Battery B is highly recommended if in-flight engine re-starts are anticipated to prevent loss of electrical power if Battery A becomes depleted from repeated cranking.

Pin	**Name**	**Type**	**Description**
X2:A	Battery A +	I/O	Connect to positive terminal of Battery A.
X2:B	Battery A –	Ground	Connect to negative terminal of Battery A.
X2:C	Battery B +	I/O	Connect to positive terminal of Battery B. A second battery is optional.
X2:D	Battery B –	Ground	Connect to negative terminal of Battery B.
X2:1	Battery A temperature sensor	Input	Connect to the anode (positive terminal) of a KTY83 temperature sensor that is in intimate thermal contact with Battery A. Battery A temperature sensing is optional.
X2:2	Sensor ground	Ground	Ground reference for Battery A temperature sensor.
X2:3	Battery B temperature sensor	Input	Connect to the anode (positive terminal) of a KTY83 temperature sensor that is in intimate thermal contact with Battery B. Battery B temperature sensing is optional.
X2:4	Sensor ground	Ground	Ground reference for Battery B temperature sensor.

Table 2 – X2 pin descriptions

Choosing batteries

The following battery types are supported:

Battery type	**Fully-charged terminal voltage**
LiPo: 5S, 6S	21.0V, 25.2V
LiS: 7S, 8S, 9S, 10S	17.5V, 20.0V, 22.5V, 25.0V
LiFe: 5S, 6S, 7S	18.0V, 21.6V, 25.2V

Table 3 – Supported battery types

If two batteries are fitted they must have the same terminal voltage, although they may have different mAH capacities.

The PMU does not balance battery cell voltages. If the batteries do not have internal cell balancing circuitry they should be periodically removed from the aircraft for rebalancing.

Additional considerations when choosing battery voltage

When operating from battery power, output voltages will always be less than the applied battery voltage, some quite significantly so. Each switching power supply has its own particular dropout voltage (see graphs XX to XX); these subtract from the battery voltage to limit the maximum possible output voltages.

As a rough guide, if the highest output voltage is greater than 15V, then 6S LiPo (or equivalent) should be used. If the highest output voltage is less than 15V, then 5S or 6S LiPo (or equivalent) may be used. Using higher battery voltages is generally preferable as it gives greater headroom for the various switching converters and therefore longer running times when electrical power generation is not occurring.

Maintaining high output voltages from battery power alone is problematic. Even with 6S LiPos, under sustained load the battery voltage will eventually fall to the point where outputs come out of regulation and are limited to the battery voltage minus the dropout voltage. Connecting peripheral devices directly across batteries is possible but not recommended, as the battery energy measurement will be invalid, and if the current drawn averages more than 2.5Amps the battery will never be charged.

Connecting peripheral devices that require a high voltage to the 28VDC bus is a better solution, as the 28VDC bus does not incur any significant dropout and will track the battery voltage very closely when electrical power generation is not occurring. Obviously this requires that the peripheral device can tolerate 28V when electrical power generation is occurring.

Battery chargers

The battery chargers are constant-current constant-voltage types. When the battery voltage is less than the programmed battery voltage V_B, the chargers apply a constant charging current of approximately 2.5Amps. Once the battery voltage reaches V_B, the battery chargers transition to constant-voltage mode (and the charging current reduces) to maintain full charge without overcharging the battery.

X3 – Avionics

The Avionics connector provides access to a range of different functions, these being:

- 28VDC (bi-directional bus)
- Umbilical power (input)
- Avionics power (output)
- Communications

The 28VDC bus provides 28VDC when electrical power generation is occurring. When electrical power generation is not occurring (i.e. the PMU is operating from battery power), the 28VDC bus is maintained at the highest available battery voltage. The 28VDC bus is bi-directional: if another source of 28VDC is present in the aircraft (such as from a second PMU in twin-engine aircraft), it may be connected directly to the 28VDC bus. This provides a level of power system redundancy.

The Umbilical power input is intended for powering the PMU externally when the aircraft is on the ground and electrical power generation is not occurring. The recommended voltage for the Umbilical input is 24 to 48VDC, although the PMU will operate more efficiently (and run cooler) if the applied voltage is between 38 and 48VDC.

Avionics power is provided on 3 pairs of pins to simplify harness wiring. It is intended to power mission-critical flight systems such as autopilot, ECU (Engine Control Unit), etc. The Avionics output voltage is user-programmable to any voltage from 12 to 21VDC. A hardware shutdown input is provided; if this pin is pulled low the Avionics output is turned off.

The Communications interfaces are described separately in this document.

Pin	**Name**	**Type**	**Description**
X3:A	28VDC bus	I/O	Industry-standard 28VDC bus.
X3:B	28VDC ground	Ground	Ground connection for 28VDC bus.
X3:C	Umbilical power	Input	Connect to an external source of DC power.
X3:D	Umbilical ground	Ground	Ground connection for umbilical power input.
X3:1	CAN H	I/O	
X3:2	Avionics shutdown	Input	Shorting to ground turns avionics power off. Leave open-circuit if functionality not required.
X3:3	RS232 Rx	Input	
X3:4	Avionics power	Output	Programmable-voltage uninterruptible power output. Intended for low-power mission-critical aircraft systems, such as autopilot, ECU, etc.
X3:5	Avionics power	Output	Duplicate of X3:4.
X3:6	Avionics power	Output	Duplicate of X3:4.
X3:7	CAN L	I/O	
X3:8	Comms ground	Ground	Ground reference for CAN and RS232.
X3:9	RS232 Tx	Output	
X3:10	Avionics ground	Ground	Ground connection for avionics power output
X3:11	Avionics ground	Ground	Duplicate of X3:10.
X3:12	Avionics ground	Ground	Duplicate of X3:10.

Table 3 – X3 pin descriptions

X4 – Servo / Payload

The Servo output voltage is user-programmable to any voltage from 5 to 12VDC. A hardware shutdown input is provided; if this pin is pulled low the Servo output is turned off.

The Payload output voltage is user-programmable to any voltage from 12 to 21VDC. A hardware shutdown input is provided; if this pin is pulled low the Payload output is turned off.

Pin	Name	Type	Description
X4:A	Servo power	Output	Programmable-voltage uninterruptible power output. Intended for driving servos via a servo bus. Can be turned off via remote command or hardware signal.
X4:B	Servo ground	Ground	Ground connection for servo power output.
X4:C	Payload power	Output	Programmable-voltage uninterruptible power output. Intended for driving payload devices via a payload bus. Can be turned off via remote command or hardware signal.
X4:D	Payload ground	Ground	Ground connection for payload power output.
X4:1	Servo shutdown	Input	Shorting to ground turns servo power off. Leave open-circuit if functionality not required.
X4:2	Shutdown ground	Ground	Ground reference for servo shutdown input.
X4:3	Payload shutdown	Input	Shorting to ground turns payload power off. Leave open-circuit if functionality not required.
X4:4	Shutdown ground	Ground	Ground reference for payload shutdown input.

Table 4 – X4 pin descriptions

Mating harness connectors

Four connectors required to interface with the PMU, two of each type listed in the table below. The connectors specified are from the Harwin M80 Datamate MixTek series. Connectors are available ex-stock from the major online distributors.

Connector	Harwin part number	Online distributors
X1, X3	M80-4C11205F1-04-325-00-000	Mouser (PN: 855-M804C11205F14325) Digi-Key (PN: 952-1264-ND)
X2, X4	M80-4C10405F1-04-325-00-000	Mouser (PN: 855-M804C10405F14325) Digi-Key (PN: 952-1258-ND) Verical (use Harwin part number)

Table 5 – Connector part numbers

Front Panel Arrangement

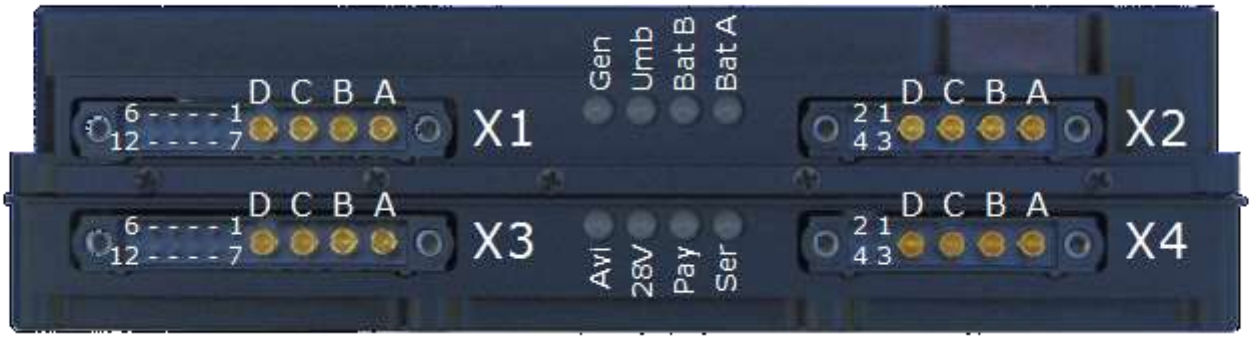


Figure 1 – Locations of connectors and visual indicators on the front panel

Connector pin locations

X1	BLDC MOTOR
A	BLDC phase A
B	BLDC phase B
C	BLDC phase C
D	Airframe ground
1	Hall 1
2	Hall 2
3	Hall 3
4	Direction
5	Hall power
6	Hall ground
7	Arm
8	Arm ground
9	BLDC temp sensor
10	Sensor ground
11	Start
12	Start ground

X2	BATTERIES
A	Battery A +
B	Battery A –
C	Battery B +
D	Battery B –
1	Bat A temp sensor
2	Sensor ground
3	Bat B temp sensor
4	Sensor ground

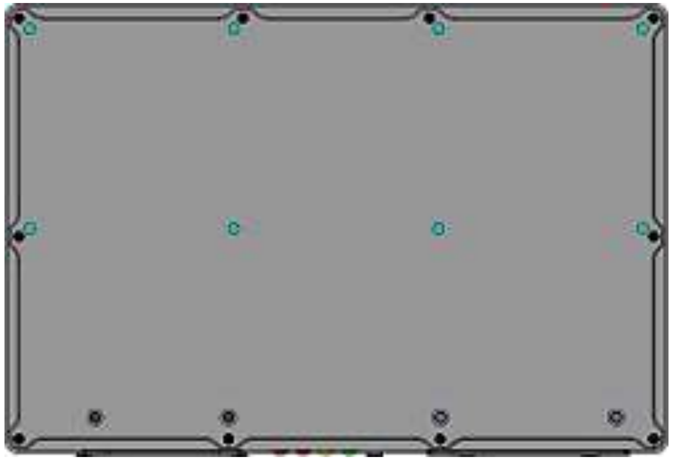
X3	AVIONICS
A	28VDC power
B	28VDC ground
C	Umbilical power
D	Umbilical ground
1	CAN H
2	Avionics shutdown
3	RS232 Rx
4	Avionics power
5	Avionics power
6	Avionics power
7	CAN L
8	Comms ground
9	RS232 Tx
10	Avionics ground
11	Avionics ground
12	Avionics ground

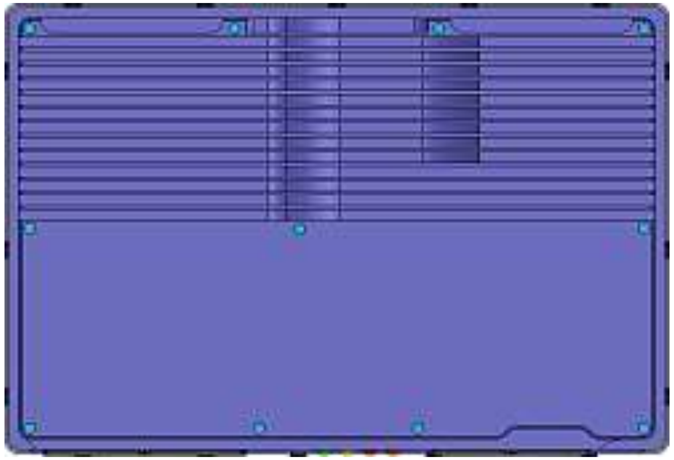
X4	SERVO / PAYLOAD
A	Servo power
B	Servo ground
C	Payload power
D	Payload ground
1	Servo shutdown
2	Shutdown ground
3	Payload shutdown
4	Shutdown ground

Visual indicator locations

NAME	FUNCTION	GREEN	RED	DARK
Gen	Generator status indicator	Generating	Starting	Neither
Umb	Umbilical power indicator	Present	–	Absent
Bat B	Battery B indicator	Charging	Discharging	Battery absent
Bat A	Battery A indicator	Charging	Discharging	Battery absent
Avi	Avionics power indicator	On	Overcurrent	Off
28V	28VDC power indicator	On	Overcurrent	Off
Pay	Payload power indicator	On	Overcurrent	Off
Ser	Servo power indicator	On	Overcurrent	Off

Mechanical Data





Dimensions: 124.4 x 85.0 x 32.5mm
Mass: 290 grams (excluding harnesses)

Mounting

The underside of the enclosure has 10 x M2 tapped holes for mounting the PMU to a flat surface. A template for drilling holes into the mounting surface is given below:

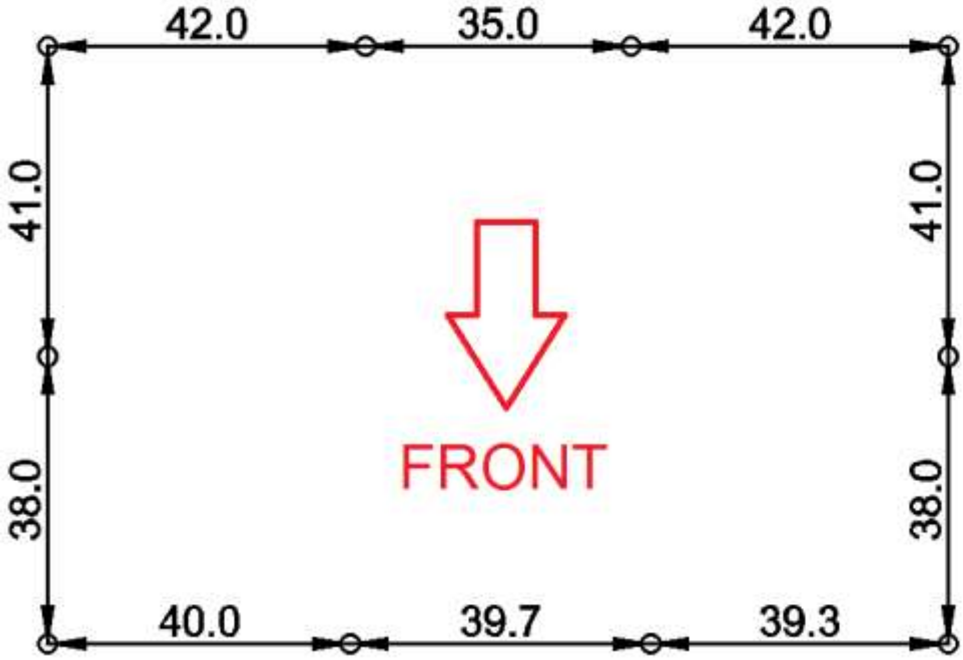


Figure X – Mounting hole locations (approximately 1:1)

Be careful not to distort the enclosure by mounting to a warped surface. Mounting screws should project no more than 4.0mm into the enclosure.

Ordering Information

Placeholder (TBD)

Further Information

Visit us on the web at www.millswoodeng.com.au

Didn't find what you wanted? Send us an email or give us a call – contact details are on our website.

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The Fine Print

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Appendix 1 – Choosing a suitable BLDC motor

Types of BLDC motors

BLDC motors are available in two basic configurations, commonly known as "inrunners" and "outrunners". Inrunners have the magnets attached to the central shaft, and this assembly rotates within the surrounding (fixed) windings. Outrunners have the opposite arrangement, with the magnets attached to the external housing which rotates around the inner (fixed) windings.

Outrunners with suitable Kv and power ratings for use in electric power generation are cheap and readily available. They have excellent power density per unit volume and per unit weight. However, outrunners tend to have an open style of construction and this makes them vulnerable to ingesting airborne contaminants.

Inrunners have a non-rotating outer case and can therefore be sealed against the ingress of airborne contaminants. This makes inrunners a better choice for most UAV applications.

Calculating the optimal Kv

In order to maximise power output, the PMU's BLDC input should be operated as near to 72V as possible ***but without ever exceeding this value***. In other words, 72V should correspond to the maximum RPM ever expected from the internal combustion engine.

The equation relating these parameters is:

BLDC_voltage = RPM x Gear_ratio / Kv

Where **Gear_ratio = BLDC motor speed / Internal combustion engine speed**

Rearranging the first equation for Kv:

Kv = RPM x Gear_ratio / BLDC_voltage

Example

A system has a maximum engine speed of 8500 RPM and a 53:19 (2.79) step-up belt drive to the BLDC motor. The equation for Kv is:

Kv = 8500 x 2.79 / 72
Kv = 329 RPM/V

The Kv calculated is a ***minimum*** value (i.e. using Kv values less than 329 RPM/V will generate ***more*** than 72V at 8500 RPM). A BLDC motor should be chosen with a Kv as close as possible to 329 RPM/V, but not less than this value.

The maximum permissible speed rating of the BLDC motor must also be observed. In the example above the maximum speed is 8500 x 2.79 = 23,711 RPM, and so the BLDC must be rated for operation to this speed.

Pole count

At least 4 poles (2 pole pairs) are recommended. There is no upper limit on the number of poles.

Recommended BLDC motors

Maxon EC (Externally Commutated) motors have been widely used in UAVs, and have proved to be reliable workhorses. A suitable motor for the example given above is Maxon 305015 – this device has a Kv of 346 RPM/V and a maximum permissible speed of 25,000 RPM.