FIRST LAYER
ROBOTICS

MOTION CORE

USB Motion Controller for Differential-Drive Mobile Robots

Engineering Datasheet

PART NUMBER

FLR-MC-1-2M12-4

KEY FEATURES

- Dual H-bridge motor drive, 4A continuous / 8A peak per channel
- Wide-range 9–20V DC supply (multi-chemistry battery support)
- Integrated quadrature encoder acquisition (×2)
- Hardware E-stop input and safe-start interlock
- 5V / 6A regulated auxiliary output with current monitoring
- USB-C host interface running open ORCP protocol
- Optional CAN bus interface (factory-fit)
- Python and ROS 2 integration (MATLAB in preparation)

APPLICATIONS

- Indoor autonomous mobile robots (AMRs)
- Service and inspection robots
- Educational and university robotics platforms
- Research and experimental robotics
- Internal R&D and proof-of-concept robots
- OEM differential-drive robotics platforms

DOCUMENT INFORMATION

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Revision History

REVISION	DATE	CHANGES
Rev A	June 2026	Initial release. Architecture, feature set and validated parameters documented. Some parametric values to be finalised at production release.
Rev B	July 2026	Compliance section revised: applicable directives and standards corrected, declarations separated from conformity marks, limitations stated. ORCP protocol examples in Section 11 corrected. Software integration claims aligned to released tooling. Reverse-polarity protection specified. Editorial corrections throughout.

Related Documents

PARAMETER	VALUE
ORCP v1.1 Specification	github.com/orcp-protocol/orcp — Open Robot Control Protocol specification
Motion Core Product Specification	Marketing / OEM overview (companion document)
ORCP Python Client Library	github.com/orcp-protocol/orcp-python — reference implementation
ROS 2 Driver Node	github.com/orcp-protocol/orcp-ros2 — ORCP driver for ROS 2
Motion Core Getting Started — Python	Host-side integration guide, available at FirstLayerRobotics.com
Motion Core Getting Started — ROS 2	ROS 2 driver integration guide, available at FirstLayerRobotics.com
ORCP Simulator	github.com/orcp-protocol/orcp-sim — develop and test host software without hardware

Legal Notices

This document is provided as preliminary technical information for the Motion Core motor controller. Specifications, electrical characteristics and pinouts are subject to change without notice prior to production release. First Layer Robotics Ltd reserves the right to modify the product and this document at any time. Customers integrating Motion Core into their products are responsible for verifying suitability for their specific application.

Motion Core has not been evaluated for use in life-support, safety-critical, medical, automotive, aerospace, military, or nuclear applications, and is not authorised for such use. Use of Motion Core in any such application is at the customer's sole risk.

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1. DESCRIPTION

Motion Core is a USB-connected motion subsystem that runs under any Linux host or ROS 2 stack, including NVIDIA Jetson and Raspberry Pi — integrating dual H-bridge motor drive, motor controller with wheel-velocity PID and kinematics, power distribution and a hardware safety architecture in a single robotics-native platform.

The primary host interface is USB-C running the open ORCP (Open Robot Control Protocol), allowing host software to issue velocity commands, receive encoder-derived odometry, and monitor system status without writing or maintaining low-level embedded code. Reference client libraries are provided for Python and ROS 2, with MATLAB integration in preparation. A protocol-level simulator is also available, allowing host software to be developed and tested before hardware is connected.

Motion Core is intended for integration engineers building mobile robotics platforms. It replaces the bespoke motor-control electronics typically rebuilt from scratch on each robotics project, providing a stable, repeatable motion subsystem on which higher-level autonomy, perception and application code can be developed.

1.1 Key Specifications Summary

PARAMETER	VALUE
Drive topology	Dual independent H-bridge, configured for differential drive
Continuous output current	4A per channel (0 to 40 °C ambient, full-rated)
Peak output current	8A per channel
Supply voltage range	9 to 20V DC (multi-chemistry battery support)
Auxiliary output	5V / 6A regulated, with on-board current monitor
Internal logic supply	3.3V
Encoder inputs	2 × quadrature, integrated on-board acquisition
Host interface	USB-C (CDC class) running ORCP protocol
Optional interface	CAN bus (factory-fit option)
Safety inputs	Hardware E-stop and charger-detect interlocks (both NC, mandatory)
Operating ambient	0 to 40 °C (full-rated)
Compliance	CE / UKCA assessment in progress — see Section 15
Traceability	Unique board serial number, programmed at manufacture and reported over ORCP

2. FEATURES AND APPLICATIONS

2.1 Features

- Single USB-C cable integration to host SBC — no bespoke embedded motor-control layer required
- Dual H-bridge motor drive, fully protected, 4A continuous and 8A peak per channel
- Wide-range 9–20V DC input — supports lead-acid, LiFePO4, Li-ion and NiMH battery chemistries without reconfiguration
- Integrated quadrature encoder acquisition for closed-loop differential-drive control
- Hardware E-stop input with relay-based de-energise-to-trip interlock
- Mandatory hardware charger-detect interlock — drive cannot be enabled while a charger is connected; state also reported to host via ORCP
- Regulated 5V / 6A auxiliary output with on-board current monitoring for sensor and SBC peripheral power
- Internal 3.3V logic supply
- USB-C host interface (CDC class) running open ORCP protocol
- Optional CAN bus interface for multi-controller and field-bus integration
- Reference client libraries for Python and ROS 2; MATLAB integration in preparation
- Protocol-level simulator available for host-software development without hardware
- Safe-start interlock — outputs remain disabled at power-up until commanded by the host

2.2 Applications

- Indoor autonomous mobile robots (AMRs), 5–25 kg class
- Service, inspection and security robots
- Educational and university robotics platforms
- Research and experimental mobile robotics
- Internal R&D and proof-of-concept robots
- OEM differential-drive robotics platforms

3. FUNCTIONAL BLOCK DIAGRAM

Figure 1 shows the functional architecture of Motion Core. The dashed boundary marks the Motion Core PCB. Items shown outside the boundary (motors, encoders, E-stop pushbutton, charger-detect switch, host SBC, battery, auxiliary loads) are external to the board and are connected via the labelled connectors described in Section 4.

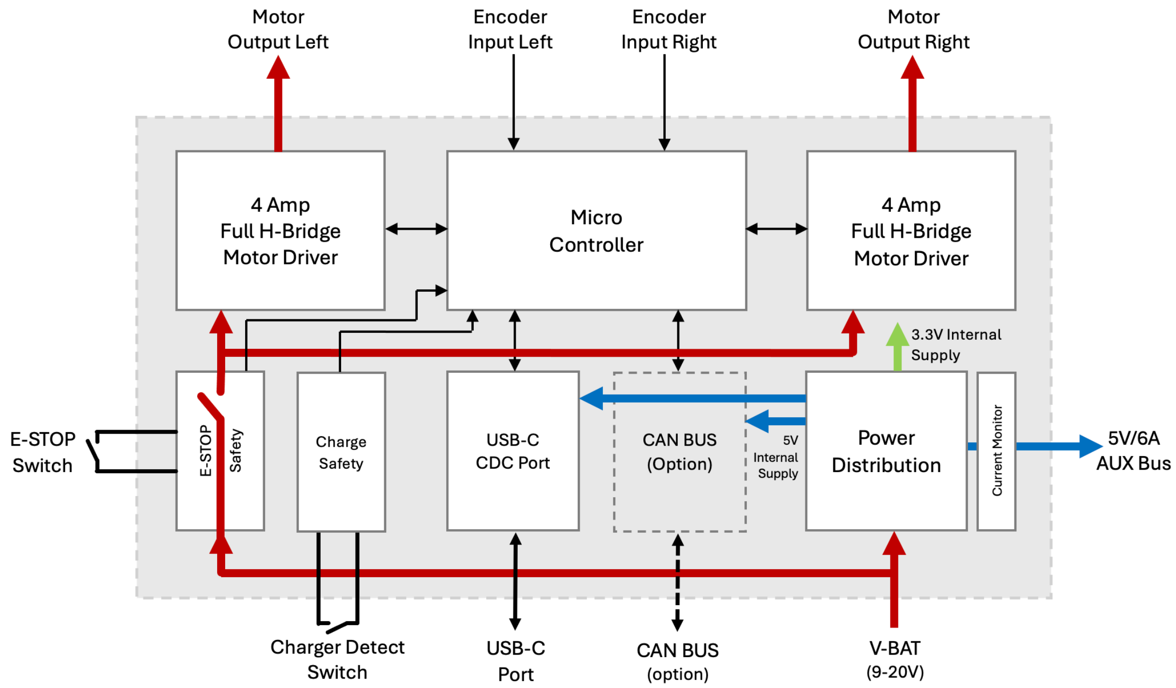

Figure 1 — Motion Core functional block diagram

NOTE

Red arrows indicate motor and battery power paths. Blue arrows indicate regulated low-voltage supplies. Black arrows indicate signal-level connections. Dashed blocks (CAN bus) are factory-fit options.

4. PIN AND CONNECTOR DESCRIPTIONS

Motion Core uses dedicated connectors for each external interface to simplify wiring and reduce the risk of misconnection during integration.

4.1 Connector Locator

Figure 2 shows the physical location of each connector on the Motion Core PCB.

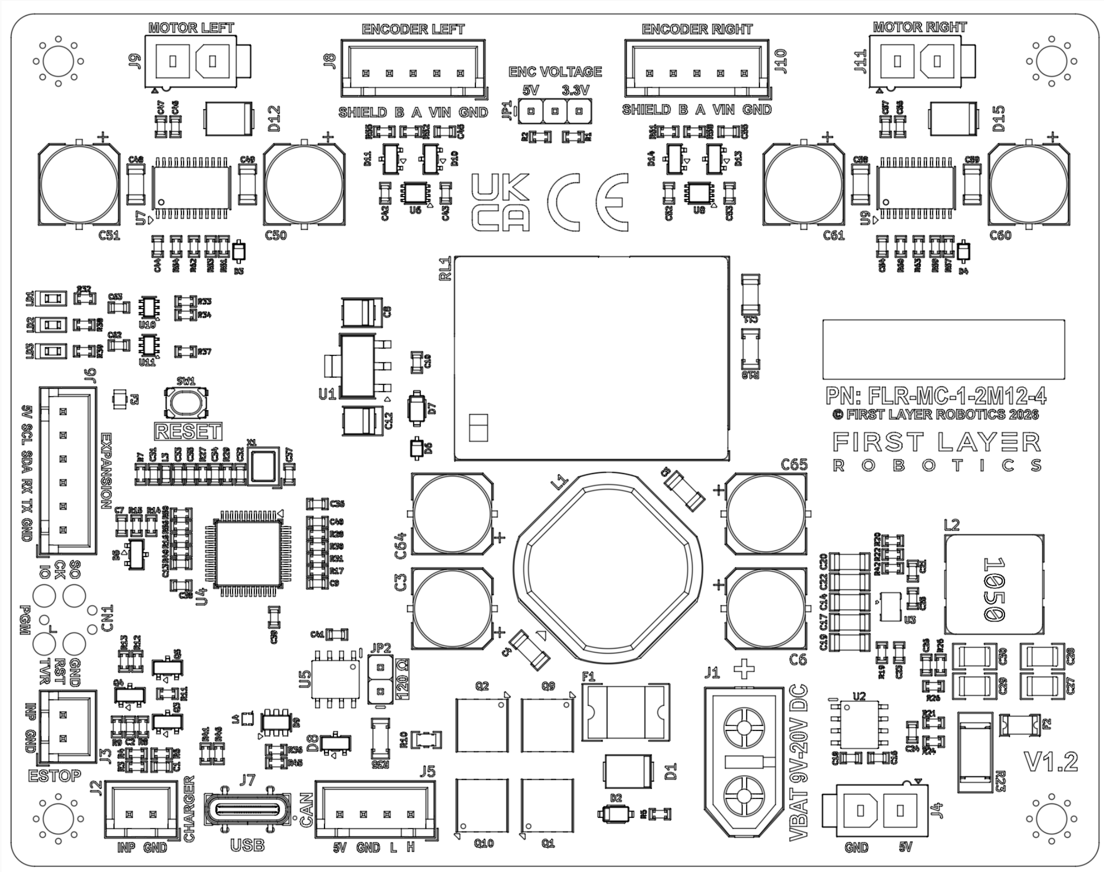

Figure 2 — Connector locator drawing (top-down view of PCB)

4.2 J1 — V-BAT Power Input (2-pin XT60 connector)

Primary battery / DC supply input. Note polarity is identified with the **+** shown on the PCB.

PIN	SIGNAL	TYPE	DESCRIPTION
+	**V-BAT+**	Power IN	Positive battery / DC supply, 9 to 20 V DC nominal
-	**GND**	Power IN	Battery return / system ground

4.3 J2 — Charger Detect Input (2-pin JST XH Connector)

Mandatory hardware charger-detect interlock, designed for a normally-closed (NC) switch fitted to the robot's charging connector. The charger-detect circuit is integrated directly into the drive-enable logic: when the loop is open (charger connected), motor outputs cannot be enabled, independently of host commands. The same input is also sensed by the on-board controller and reported to the host via ORCP.

PIN	SIGNAL	TYPE	DESCRIPTION
1	**GND**	Power	Power supply ground
2	**CHGDET**	Digital IN	Charger-detect loop, conductor B (loop closure)

CAUTION

The charger-detect input is mandatory and must be present for the motor drive to operate. If no charger-detect switch is fitted, J2 pins 1 and 2 must be jumpered closed with a wire link. Operating Motion Core with the charger-detect loop open will hold the motor outputs disabled at hardware level regardless of host commands.

4.4 J3 — E-Stop Input (2-pin JST XH Connector)

Mandatory hardware emergency-stop input, designed for a normally-closed (NC) pushbutton. The E-stop circuit is a de-energise-to-trip relay interlock: when the loop is open, power is physically disconnected from the H-bridges. Recovery requires the loop to be closed and an explicit host ‘ENABLE ON’ command via ORCP.

PIN	SIGNAL	TYPE	DESCRIPTION
1	**GND**	Power	Power supply ground
2	**ESTOP**	Digital IN	E-stop loop, conductor B (loop closure)

CAUTION

The E-stop loop must be closed (NC contacts connected) at all times during normal operation. If no external E-stop is fitted, J3 pins 1 and 2 must be jumpered closed. Operating Motion Core with the E-stop loop open will hold the motor outputs disabled at hardware level regardless of host commands.

4.5 J4 — 5V Auxiliary Output (2-pin Molex Mini-Fit-JR)

Regulated 5V auxiliary supply for powering external sensors, SBC peripherals or other 5V loads. Total current is monitored on-board and reported to the host via ORCP status messages. Refer to Section 7.4 for detailed electrical characteristics.

PIN	SIGNAL	TYPE	DESCRIPTION
1	**+5V**	Power OUT	Regulated +5V output, 6A maximum
2	**GND**	Power	Power supply ground

4.6 J5 — **CAN Bus** (Optional, 4-pin JST XH Connector)

Optional CAN bus interface, factory-fit only. Provides high-level access to the same ORCP command surface as the USB-C interface. Useful for multi-controller installations and integration with existing CAN-based vehicle networks.

PIN	SIGNAL	TYPE	DESCRIPTION
1	**CAN_H**	Bus	CAN bus high (dominant)
2	**CAN_L**	Bus	CAN bus low (dominant)
3	**GND**	Power	Signal ground
4	**+5V**	Power OUT	Regulated +5V output, 500mA maximum

4.7 J6 — **Expansion Header (**Reserved, 6-pin JST XH Connector)

Reserved header for future Motion Core accessories and add-on modules. Firmware update required prior to use; no functionality is exposed on this connector at initial release.

PIN	SIGNAL	TYPE	DESCRIPTION
1	**GND**	Power	Signal ground
2	**TX**	Bus	UART TX / DIO
3	**RX**	Bus	UART RX / DIO
4	**SDA**	Bus	I2C SDA / DIO
5	**SCL**	Bus	I2C SCL / DIO
6	**+5V**	Power	Regulated +5V output, 500mA maximum

4.8 J7 — **USB-C Host Interface** (Standard USB-C Connector)

USB-C connector for host SBC connection. CDC (Communications Device Class) is presented to the host operating system, appearing as a serial port (e.g. /dev/ttyACM0 on Linux).

The USB-C connector is data-only: Motion Core neither draws operating current from VBUS nor sources power to a connected host, and USB Power Delivery (PD) is not implemented in either direction. Peripherals requiring a regulated 5 V rail (for example, an on-board SBC) should be powered from the Aux 5 V output described in 7.4.

PIN	SIGNAL	TYPE	DESCRIPTION
—	**USB-C**	Data	Standard USB-C receptacle. CDC class device. Host-side cable is USB-C to USB-A or USB-C as required by SBC.

4.9 J9, J11 — Motor Outputs (2-pin Molex Mini-Fit-JR)

Two independent H-bridge motor outputs. J9 = Motor Left, J11 = Motor Right. Polarity convention determines forward direction; direction can be reversed in configuration settings.

PIN	SIGNAL	TYPE	DESCRIPTION
1	**M+**	Power OUT	Motor output, positive terminal (forward direction)
2	**M−**	Power OUT	Motor output, negative terminal

4.10 J8, J10 — Encoder Inputs (5-pin JST XH Connector)

Two quadrature encoder inputs supporting A and B channels only. J8 = Encoder Left (paired with Motor Left), J10 = Encoder Right (paired with Motor Right). A/B wiring convention determines the direction of positive count; count direction can be reversed in configuration settings (see section 10.2). When a motor is reversed via configuration, the paired encoder is typically reversed to match, so that a forward command still produces positive counts. Inputs are level-shifted to support 3.3V & 5V encoders. Encoder VCC is determined by jumper JP1 (see below).

PIN	SIGNAL	TYPE	DESCRIPTION
1	**GND**	Power	Ground
2	**ENC_VCC**	Power OUT	Configurable encoder supply voltage (3.3v/5v)
3	**ENC_A**	Digital IN	Quadrature channel A, supports 3.3V or 5v logic
4	**ENC_B**	Digital IN	Quadrature channel B, supports 3.3V or 5v logic
5	**Shield**	Power	Optional ground connection for shield if used

4.11 JP1— Encoder Voltage Select (3-pin Header & Jumper)

Encoder supply voltage selector provides supports for 5v or 3.3v encoders. Note a jumper must be fitted for the encoders to function correctly.

PIN	SIGNAL	TYPE	DESCRIPTION
1	**5V**	Power	5V supply
2	**ENC_VCC**	Power OUT	Configurable supply voltage to encoder
3	**3.3V**	Power	3.3V supply

5. ABSOLUTE MAXIMUM RATINGS

CAUTION

Stresses beyond those listed below may cause permanent damage to Motion Core. Functional operation under absolute-maximum conditions is not implied; exposure to absolute-maximum-rated conditions for extended periods may affect device reliability and is not covered by warranty.

PARAMETER	SYMBOL	MIN	MAX	UNIT	NOTES
Supply voltage	V_BAT_MAX	−0.3	24.0	V	Single-fault tolerant; verify against final regulator and protection ratings
Supply voltage, reverse polarity	V_BAT_REV	−24.0	—	V	Protected. Reversed V-BAT applied without damage
Motor output current, peak	I_OUT_PK	—	8.0	A	Pulse duration 5 seconds, protected by onboard firmware
5 V AUX output current	I_AUX	—	6.0	A	Short-circuit protected — see Section 7.4
Encoder input voltage	V_ENC	−0.3	5.5	V	Relative to GND
E-stop input voltage	V_ESTOP	−0.3	3.6	V	Dry-contact input
Charger-detect input voltage	V_CHG	−0.3	3.6	V	Dry-contact input
USB-C VBUS voltage	V_USB	−0.3	5.5	V	Data-only; VBUS not used for board power
Storage temperature	T_STG	−40	85	°C	
Junction temperature (any IC)	T_J	—	150	°C	Lowest T_J(max) across fitted devices; internal thermal shutdown intervenes below this
ESD, human body model (HBM)	V_ESD_HBM	—	TBC	V	All exposed pins, TBD per JEDEC JS-001
ESD, contact discharge (IEC)	V_ESD_IEC	—	TBC	kV	USB-C, encoder, e-stop, charger-detect inputs, TBC per IEC 61000-4-2

All voltages referenced to GND unless otherwise specified.

6. RECOMMENDED OPERATING CONDITIONS

The conditions tabulated below define the parameter envelope within which Motion Core meets all electrical characteristics in Section 7. Operating outside this envelope is not destructive but may result in degraded performance, reduced lifetime, or non-compliance with the specified electrical characteristics.

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	CONDITIONS / NOTES
Supply voltage	V_BAT	9	12	20	V	Multi-chemistry battery support
Operating ambient	T_A	0	25	40	°C	Full-rated motor output
Motor output current, continuous	I_OUT	—	—	4	A	Per channel, at 40 °C ambient
Motor output current, peak	I_OUT_PK	—	—	8	A	Per channel, pulse duration ≤ 5 s
5 V AUX output current	I_AUX	0	—	6	A	Combined external load
Encoder input frequency	f_ENC	0	—	100	kHz	Per channel input frequency, channels A and B. Corresponds to 400 kHz maximum decoded count rate (×4 quadrature decoding) — see Section 7.3
USB cable length	L_USB	—	—	3	m	USB 2.0 specification limit
CAN bus data rate (option)	f_CAN	—	—	1	Mbit/s	ISO 11898-2

7. ELECTRICAL CHARACTERISTICS

Unless otherwise noted, all values are specified at V_BAT = 12V, T_A = 25°C, with motor outputs unloaded and no external load on the 5V AUX output. Min/Max values are guaranteed by design and characterisation; Typical values are nominal and not guaranteed.

7.1 Supply and Quiescent

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	CONDITIONS / NOTES
Supply current, idle	I_Q	—	35	—	mA	Outputs disabled, no AUX load
Supply current, active	I_ACT	—	120	—	mA	Outputs enabled, no motor load
Supply rejection ratio	PSRR	TBC	—	—	dB	Low-frequency, AUX output
Under-voltage lockout	V_UVLO	—	9.6	—	V	Factory default, configurable with batt.critical_v setting
Under-voltage lockout hysteresis	V_UVLO_HYS	—	0.2	—	V	Factory default, configurable with batt.hyst_v setting

7.2 Motor Drive Subsystem

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	CONDITIONS / NOTES
Continuous drive current	I_cont	—	4.0	—	A	Per channel, T_A ≤ 40 °C, PWM
Peak drive current	I_peak	—	8.0	—	A	Per channel, transient
PWM frequency	f_PWM	—	20	—	kHz	
Current sense accuracy	ε_I	—	±5	±10	%	Full-scale, 0–40 °C, after factory calibration. Each board is individually calibrated against a reference load and its calibration values recorded in the board's manufacturing record.
Overcurrent trip threshold	I_trip	0	5.0	20.0	A	Per channel configurable. *motor.i_fault* . ! FAULT OVERCURRENT_* after debounce.
Overcurrent debounce time	t_trip	100	500	30,000	ms	Configurable *motor.i_max_time_ms*
Duty slew rate	dD/dt	0	5.0	100	s-1	*motor.max_duty_accel* bounds inrush on *WHEEL mode=DUTY*. 0 = step response (disabled).
Motor Voltage Cap	V_max	0	12.0	30.0	V	*motor.v_max*. Effective duty clamped so mean motor voltage ≤ V_max regardless of Vbat.

7.3 Encoder Inputs

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	CONDITIONS / NOTES
Logic high threshold	V_IH	2.0	—	5.6	V	
Logic low threshold	V_IL	−0.3	—	0.8	V	
Maximum count frequency	f_ENC	—	—	400	kHz	×4 decoding of per-channel input

7.4 Auxiliary 5 V Output

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	CONDITIONS / NOTES
Output voltage	V_AUX	4.8	5.0	5.2	V	Full load range, full temperature
Output current	I_AUX	0	—	6.0	A	Continuous, T_A ≤ 40 °C. Regulator device rating is 8 A, providing margin above the specified maximum
Line regulation	ΔV_LINE	—	5	15	mV	V_BAT = 9 to 20 V, I_AUX = 2.5 A
Load regulation	ΔV_LOAD	—	20	50	mV	I_AUX = 0 to 5 A
Output ripple	V_RIPPLE	—	25	50	mV_p-p	20 MHz bandwidth, I_AUX = 5 A
Current monitor accuracy	ε_I_AUX	—	± 2	± 5	%	Full-scale, 0–40 °C ambient
Overcurrent warning threshold	I_WARN	0	4.8	20.0	A	*aux5v.i_warn*, configurable. Emits: *! WARN AUX5V state=warn* when exceeded. Default is 80 % of the specified 6 A maximum
Undervoltage warning threshold	V_WARN	0	4.7	6.0	V	*aux5v.v_warn*, configurable. Emits: *! WARN AUX5V state=warn* when exceeded.
Soft-start time	t_SS	—	1	1	ms	0 to 5 V, no load

NOTE: The auxiliary current monitor's measurement range is set by the aux5v.i_max configuration parameter, which defaults to the 6 A specified maximum. Applications requiring measurement resolution optimised for a narrower load range may reduce this value; readings above the configured range are clamped.

7.5 Digital Inputs (E-Stop, Charger Detect)

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	CONDITIONS / NOTES
Logic high threshold	V_IH	2.0	—	—	V	Guaranteed logic high; dry contact, internal pull-up to 3.3 V
Logic low threshold	V_IL	—	—	0.8	V	Guaranteed logic low; dry contact, internal pull-up to 3.3 V
Internal pull-up	R_PU	30	40	50	kΩ	Weak pull-up to 3.3 V
E-stop response time	t_ESTOP	40	45	50	ms	Loop-open → duty=0 & DRV8873H nSLEEP driven low. Includes 50 ms software debounce (fixed, 5 × 10 ms poll ticks); disable then dispatches within the same tick.

7.6 USB Interface

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	CONDITIONS / NOTES
USB enumeration time	t_USB_ENUM	—	500	1500	ms	Cold-plug to CDC endpoint ready; host & driver dependent
USB data rate	f_USB	—	12	—	Mbit/s	USB 2.0 full-speed signaling rate on the wire

7.6.1 Host Interface Virtual Serial Port Configuration

On the host, Motion Core enumerates as a USB CDC (Communications Device Class) virtual serial port. Because CDC transports the data as a USB byte stream, the classical serial-line parameters (baud rate, data bits, parity, stop bits, hardware flow control) do not affect the physical link and are not enforced by the device. However, most host serial libraries and terminal applications require the port to be opened with a valid configuration before I/O is permitted. The recommended values are:

SETTING	VALUE
Baud rate	115200 (Nominal; value is ignored by device)
Data bits	8
Parity	None
Stop bits	1
Flow control	None

Any standard configuration will work — these values are given simply to guarantee the port opens successfully across all common host platforms and libraries.

7.7 CAN Interface (where fitted)

Optional CAN 2.0B interface. Fitted only on the CAN variant board; the standard (USB) variant leaves the CAN transceiver, connector, and termination unpopulated, and the two variants are mutually exclusive. On CAN variant boards the current firmware build initialises the CAN peripheral in place of the USB CDC interface.

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	CONDITIONS / NOTES
CAN bit rate	f_CAN	25	500	1000	kbit/s	
Dominant, CAN_H	V_DOM(H)	2.75	3.5	4.5	V	Into 60Ω differential load, per ISO 11898-2
Dominant, CAN_L	V_DOM(L)	0.5	1.5	2.25	V	Into 60Ω differential load, per ISO 11898-2
Recessive	V_REC	2.0	2.5	3.0	V	Both lines, unloaded
Bus termination	R_TERM	—	120	—	Ω	Jumper-selectable; fit jumper when board sits at end-of-bus, omit when mid-bus

8. THERMAL CHARACTERISTICS

Motion Core is rated for 4A continuous per motor channel across the full 0–40 °C ambient range without forced airflow. The peak rating of 8A per channel is intended for short-duration acceleration events; prolonged operation at peak current may invoke thermal shutdown of the motor driver subsystem.

The board is designed for natural convection cooling with no enclosure restriction. Installation within a sealed enclosure or with elevated ambient temperature may require de-rating of the motor output current; contact First Layer Robotics for guidance in these operating conditions.

8.1 Thermal Characteristics Table

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	CONDITIONS / NOTES
Operating ambient, full-rated	T_A	0	25	40	°C	4 A continuous per channel, natural convection
Motor driver T_J(max)	T_J_DRV	—	—	150	°C	Internal thermal shutdown protects driver above this threshold
AUX regulator T_J(max)	T_J_AUX	—	—	150	°C	Internal thermal shutdown protects regulator above this threshold
Recommended PCB mounting	—	—	—	—	—	Standoff mounting; both sides of PCB clear for airflow

9. TIMING CHARACTERISTICS

This section summarises the key system-level timing parameters relevant to integration. Detailed timing waveforms for individual signals are not provided; consult First Layer Robotics Applications support for application-specific timing analysis.

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	CONDITIONS / NOTES
Power-on to ready	t_POR	—	1500	2500	ms	V_BAT applied to USB CDC enumerated
Safe-start interlock	t_SAFE	—	—	—	—	Motor outputs remain disabled until host issues ENABLE ON then a motion command; state-based, no timing
USB enumeration	t_USB_ENUM	—	500	1500	ms	Cold-plug of USB cable to CDC endpoint ready (board already powered)
E-stop response (hardware)	t_ESTOP_HW	40	45	50	ms	Loop-open to motor outputs disconnected; includes 50 ms software debounce
E-stop response (software)	t_ESTOP_SW	45	55	100	ms	Loop-open to host notification (!FAULT ESTOP) received; adds USB CDC transit and host stack latency to t_ESTOP_HW
E-stop recovery	t_ESTOP_REC	N/A	N/A	N/A	N/A	State-based: requires the E-stop loop to be closed, followed by an explicit ENABLE ON from the host. ENABLE ON both clears the latched fault and re-enables the drive; it is refused while the underlying condition persists.
Command-to-output latency	t_CMD	—	5	15	ms	CMD_VEL received on USB to PWM duty register updated
Odometry sample rate	f_SAMP	—	100	—	Hz	Encoder counter read rate; sets odometry resolution limit
Telemetry streaming rate	f_STREAM	1	10	50	Hz	Configurable via *stream.rate*; carries odom + status in a single line

10. FUNCTIONAL DESCRIPTION

This section describes the operation of each major subsystem on Motion Core. Refer to Section 3 for the functional block diagram and Section 4 for connector and pin definitions.

10.1 Motor Drive Subsystem

Motion Core provides two independent fully protected H-bridge motor drivers, each capable of 4A continuous and 8A peak output current at supply voltages between 9V and 20V DC. Each H-bridge supports bidirectional operation with PH/EN-style control internally; the host interface abstracts this to signed velocity commands.

Drive PWM is generated by the on-board motor controller. Current sense is integrated into the H-bridge devices and is used both for over-current protection (hardware) and for telemetry (reported to the host as part of ORCP status messages). Over-current events disable the affected output and are reported to the host; automatic re-enable is suppressed pending host acknowledgement.

Configuration settings for each motor channel include drive polarity (normal or reversed) and software current, velocity and acceleration limits. Drive polarity is typically set to align the motor's forward direction with the mechanical convention of the robot and is paired with the corresponding encoder polarity (see Section 10.2) so that a forward command produces forward motion and positive encoder counts. Settings are persisted on-board and applied at power-up. Configuration is set via ORCP; refer to Appendix A for the relevant commands.

10.2 Encoder Acquisition

Two quadrature encoder inputs are sampled directly by the on-board motor controller, with no external decoding required. Inputs are level-shifted to accept 3.3V or 5V encoders (encoder supply voltage selected by jumper JP1 — see Section 4.11) and accept encoders with open-collector or push-pull outputs.

Encoder counts are integrated to wheel velocities (rad/s) on-board and reported to the host as ORCP telemetry at a configurable rate (default 10 Hz, range 1–50 Hz, set by stream.rate). The internal encoder sampling rate is 100 Hz, independent of the reporting rate. Sign convention follows the motor-output convention: a forward-direction motor command produces increasing encoder counts. Direction can be inverted in software for installations where mechanical convention differs.

Configuration settings for each encoder channel include count direction (normal or reversed), counts per revolution, and wheel geometry (radius and track width) used for velocity and odometry integration. These settings are saved on-board and applied at power-up.

When a motor is reversed in configuration, the paired encoder is typically reversed to match, so that a forward command continues to produce positive counts. Configuration is set via ORCP; refer to Appendix A for the relevant commands.

10.3 Power Architecture

V-BAT (9–20V DC) is the sole supply input for normal operation. From V-BAT, Motion Core generates two internal supplies (5V for the auxiliary output and internal analog circuitry, and 3.3V for logic). USB-C VBUS is data-only and is not used to power the board.

The auxiliary 5V output is a regulated step-down converter specified for 6A continuous, with on-board current monitoring. The regulator device itself is rated at 8A, providing margin above the specified maximum. The current monitor is reported to the host via ORCP status messages, allowing host software to detect overload, sensor faults, or unexpected loads.

Battery voltage is monitored continuously and reported to the host. Battery state is also classified into discrete bands (FULL / LOW / CRITICAL) suitable for higher-level robot battery-state reasoning; the band thresholds are configurable via ORCP to match the connected battery chemistry.

10.4 Safety Subsystem

Motion Core implements a hardware-level emergency-stop chain. The E-stop input (J3) drives a de-energise-to-trip relay that physically disconnects the H-bridge motor outputs from the motor terminals when the loop is open. This is independent of, and overrides, the motor controller and any host commands. If the E-stop function is not required, (J3 pins 1 and 2) must be jumpered closed for the motor outputs to be enabled.

The charger-detect input (J2) is a parallel hardware interlock, designed for a normally-closed switch typically fitted to the charging connector. The charger-detect circuit is integrated into the drive-enable logic, and motor outputs cannot be enabled while the loop is open (charger detected), independently of host commands. The same state is sensed by the on-board controller and reported to the host via ORCP, allowing host software to coordinate charging behaviour and battery-state reasoning. As with the E-stop loop, an unused charger-detect input must be jumpered closed (J2 pins 1 and 2) for the drive to be enabled.

Motion Core implements safe-start behaviour: motor outputs are held disabled at power-up regardless of any state on the host side, and no motion can occur until the host establishes a connection and commands it. This prevents unexpected motion on power-up, after a fault, or following a reboot.

The precise requirement depends on the active safety preset. In the NORMAL preset the host must issue an explicit ENABLE ON before any motion command is accepted, and must additionally maintain a periodic heartbeat. In the SLOW preset, intended for bring-up and teaching use, a motion command alone is sufficient and the output duty is limited to a reduced ceiling. Both presets hold the outputs disabled until commanded. See Appendix A for the PRESET and ENABLE commands.

> **CAUTION**
>
> **NOTE** The E-stop and charger-detect interlocks provide a hardware means of removing drive power, independently of the on-board controller and the host. They have **not** been assessed to EN ISO 13849-1 or IEC 62061 and no Performance Level or Safety Integrity Level is claimed. They must not be relied upon as the safety-related control function of the integrator's machine. Responsibility for the machine-level safety function, its risk assessment and its validation rests with the integrator.

10.5 Host Communication

The primary host interface is USB-C, presented to the host operating system as a USB CDC (Communications Device Class) serial port. The protocol carried over this interface is ORCP (Open Robot Control Protocol) — see Section 11 and Appendix A.

The optional CAN bus interface (factory-fit) provides the same ORCP command surface, allowing Motion Core to be integrated into multi-controller installations or existing CAN-based vehicle networks. Host software does not need to be aware of which physical interface is in use; both interfaces present the identical ORCP command set.

11. ORCP COMMUNICATION PROTOCOL

ORCP (Open Robot Control Protocol) is a line-based, plain-text protocol designed specifically for robotic motion control. It is published as an open specification at github.com/orcp-protocol/orcp and is implemented by Motion Core's firmware. This section summarises the protocol; refer to the ORCP v1.1 specification for complete details.

11.1 Message Format

ORCP messages are ASCII text terminated by a newline character. There are three message types:

- **Commands** (host → device): an action verb, optionally followed by key=value parameters or positional arguments, e.g. CMD_VEL v=0.5 w=0.0
- **Responses** (device → host): OK or ERR, optionally with parameters, in reply to a command
- **Push messages** (device → host): asynchronous updates beginning with !, e.g. ! STREAM vl=4.2 vr=4.2 vbat=12.4

11.2 Key Commands

A representative subset of ORCP commands implemented by Motion Core is listed below. The complete command reference is in Appendix A.

COMMAND	DESCRIPTION
PING	Connectivity check; device replies OK PONG
CMD_VEL	Body-frame velocity command; sets target linear (m/s) and angular (rad/s) velocities
WHEEL	Per-wheel velocity command; sets target left and right wheel velocities (rad/s)
STOP	Stop both motors. Default is BRAKE (COAST is optional)
STREAM	Configure telemetry streaming rate (Hz)
INFO	Query firmware version, hardware revision and capabilities

11.3 Response Format

All responses take one of three forms — success, error, or asynchronous push. The complete response grammar, the full error-code list and the push-message types are given in Appendix A.

12. SOFTWARE INTEGRATION

Reference client libraries are provided to simplify host-side integration. Source for all libraries is hosted at github.com/orcp-protocol.

12.1 Python Client Library

A reference Python client library is available via pip:

pip install orcp

The library provides a high-level API for connection, command issuing and asynchronous push-message handling. Typical use:

```
import time
from orcp import ORCP, ConnectionError

# Device path: /dev/ttyACM0 on Linux, /dev/cu.usbmodem* on macOS
# COMx on Windows. See 7.6 for host interface settings.

with ORCP('/dev/ttyACM0') as robot:
    try:
       robot.ping()              # verify link
    except ConnectionError:
       raise SystemExit('Motion Core not responding — check USB cable')

    robot.preset('SLOW')          # SLOW preset — no ENABLE or heartbeat needed
    robot.cmd_vel(v=0.2, w=0.0)   # 0.2 m/s forward
    time.sleep(2)
    robot.stop()
```

12.2 ROS 2 Driver

A ROS 2 driver node is provided which subscribes to /cmd_vel (geometry_msgs/Twist) and publishes /odom (nav_msgs/Odometry) and /diagnostics (diagnostic_msgs/DiagnosticArray). The driver wraps the Python client library and handles unit conversions between SI velocities and Motion Core's ORCP wheel-velocity command format.

The driver is developed and verified on ROS 2 Jazzy (Ubuntu 24.04 LTS). Other ROS 2 distributions are expected to work without modification but are not currently verified.

12.3 MATLAB Integration

MATLAB can drive Motion Core today through the Python client library via MATLAB's pyenv interface, giving direct access to the full ORCP command surface from MATLAB code. A reference MATLAB live script demonstrating velocity control, odometry plotting and diagnostic streaming is in preparation — contact First Layer Robotics for current availability.

The integration is suited to algorithm development and offline robotics workflows; for real-time control, the Python or ROS 2 paths are recommended.

12.4 Protocol Simulator

orcp-sim is an open-source simulator that presents the complete Motion Core ORCP command surface over a virtual serial port or WebSocket, without hardware:

```
pip install orcp-sim
orcp-sim --profile mc1
```

The simulator implements Motion Core's full configuration-parameter set, safety presets and telemetry, allowing host software, ROS 2 nodes and integration tests to be developed and run before hardware is available. Source and profiles are at github.com/orcp-protocol/orcp-sim.

12.5 Operating System Support

The USB CDC interface is supported natively on Linux (kernel ≥ 3.0, no driver installation required), macOS (10.15 and later), and Windows (10 and later). Linux installations on Raspberry Pi OS and Ubuntu have been verified; other distributions are expected to work without modification.

13. APPLICATION INFORMATION

13.1 Typical Application

In a typical application, Motion Core is integrated into a small differential-drive AMR. The host SBC (Raspberry Pi or Jetson) communicates with Motion Core over a single USB-C cable. The battery powers Motion Core via V-BAT; the SBC can be powered from the 5V AUX output (subject to current budget) or from a separate supply.

13.2 Wiring Recommendations

- Use copper conductors sized for the expected motor current with appropriate derating headroom. Wire gauge sizing is the integrator's responsibility based on cable run length and the actual current draw of the chosen motors.
- Observe V-BAT polarity at J1. The board incorporates reverse-polarity protection and has been verified to withstand reversed supply connection without damage, but reversed polarity will prevent operation and should be corrected before use.
- Twist motor pairs (M+ / M−) to reduce radiated EMI. For installations near sensitive electronics, consider shielded motor cables with shield bonded to chassis ground.
- In noisy electrical environments, encoder cables should be twisted-pair with shield, particularly for cable runs longer than 0.5 m.
- The E-stop loop wiring should be physically separated from motor wiring and routed through any required external safety circuits before reaching Motion Core's J3.
- USB-C cable should be USB 2.0 rated or better. For cable runs longer than 1 m, use a cable with active or passive signal conditioning.

13.3 Power Budget Considerations

Total system power must be budgeted against the battery capacity and Motion Core's internal regulators. Key budget contributors:

- Motor power: up to 2 × 4A × V_BAT continuous (approximately 96W at 12V V-BAT)
- 5V AUX load: up to 6A × 5V = 30 W, drawn from V_BAT through the on-board regulator
- Motion Core quiescent: approximately 35 mA at 12 V (0.4 W) with outputs disabled, rising to approximately 120 mA (1.5 W) with outputs enabled and no motor load — see Section 7.1
- Host SBC consumption (if powered from 5V AUX): typically 5–15 W for Raspberry Pi 4/5 or low-power Jetson

13.4 Grounding and EMC

Motion Core uses a single ground reference; V-BAT GND, signal grounds and shield grounds are all connected on-board. For multi-controller installations, ensure ground loops are not created via secondary connections (e.g. multiple controllers grounded to chassis at different points).

EMC performance is dependent on the integration following these wiring recommendations. Integrations that depart from them may require additional EMC mitigation at system level, and the integrator should verify the electromagnetic compatibility of the complete installation.

14. MECHANICAL INFORMATION

Mechanical drawings, board dimensions, mounting hole pattern, connector placement and PCB stack-up details will be finalised at production release. The placeholder below indicates the intended scope of the mechanical drawing package.

14.1 Board Outline and Mounting

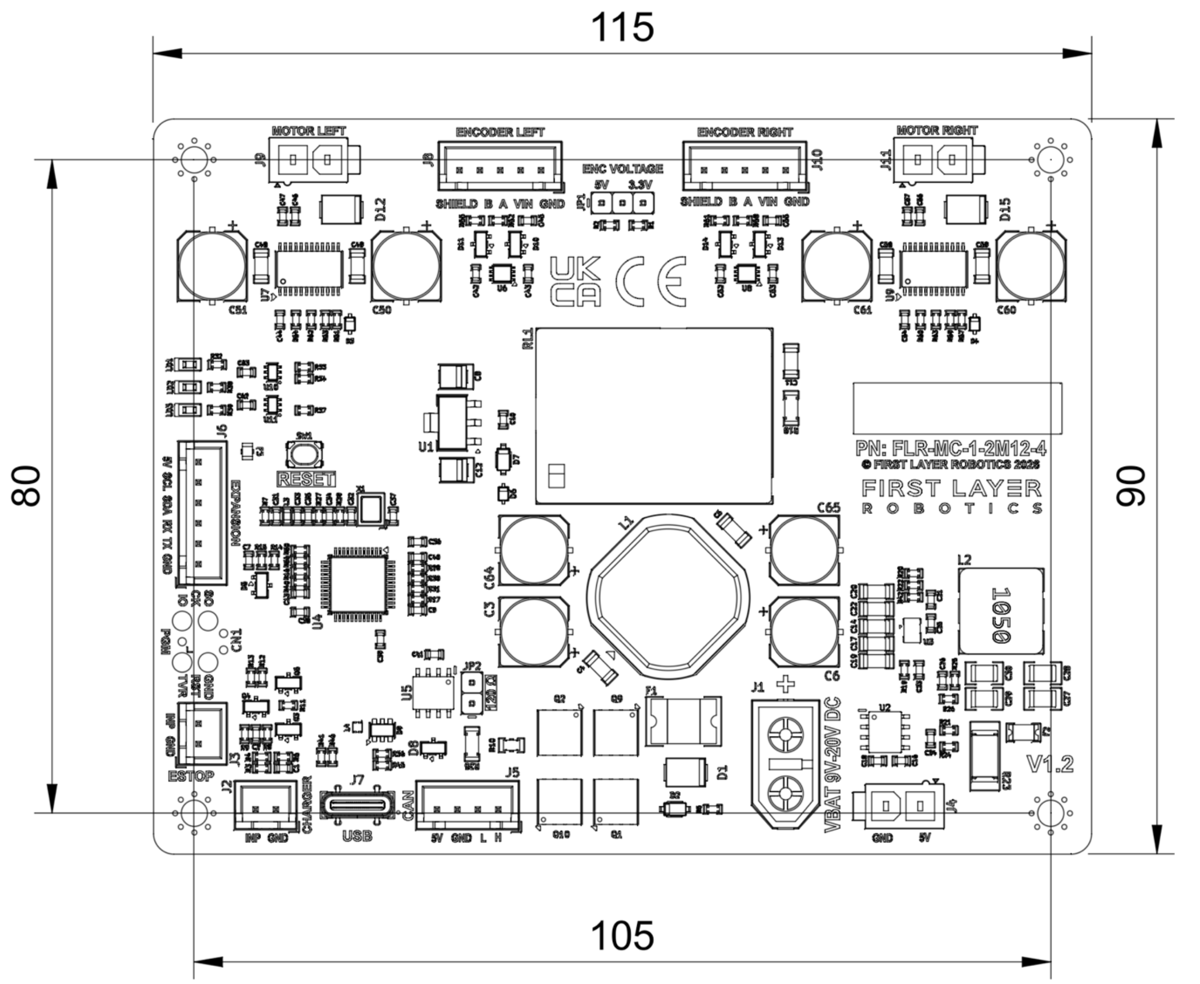

Figure 6 — Board outline and mounting hole drawing (top view, dimensioned)

14.2 Mechanical Specifications

PARAMETER	VALUE
Board outline	115.0 x 90.0 mm
PCB thickness	1.6 mm
Mounting holes	4 off, 105.0 x 80.0 mm pitch
Maximum component height, top	16mm from topside of PCB
Recommended mounting	Mounting PCB on 5mm standoffs to aid natural convection cooling

15. COMPLIANCE AND ENVIRONMENTAL

Motion Core is designed for compliance with the directives and standards listed below. Conformity assessment is in progress; a Declaration of Conformity will be issued at production release.

15.1 Conformity Marks

MARK	BASIS
CE	Electromagnetic Compatibility Directive 2014/30/EU; Restriction of Hazardous Substances Directive 2011/65/EU
UKCA	Electromagnetic Compatibility Regulations 2016 (SI 2016/1091); Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012 (SI 2012/3032)

15.2 Standards Applied

STANDARD	SCOPE
EN 61000-6-3	Electromagnetic compatibility — generic emission standard for residential, commercial and light-industrial environments
EN 61000-6-1	Electromagnetic compatibility — generic immunity standard for residential, commercial and light-industrial environments
EN 63000	Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances

15.3 Declarations

DECLARATION	SCOPE
RoHS	Directive 2011/65/EU and UK SI 2012/3032 —restricted-substances declaration
REACH	Regulation (EC) No 1907/2006 — substances of very high concern declaration

15.4 Limitations of Assessment

- Motion Core operates from a nominal 9–20 V DC supply and falls below the voltage thresholds of the Low Voltage Directive 2014/35/EU. It has not been assessed under that directive.
- Motion Core contains no intentional radio transmitter. The Radio Equipment Directive 2014/53/EU does not apply.
- The E-stop and charger-detect interlocks have not been assessed to EN ISO 13849-1 or IEC 62061, and no Performance Level or Safety Integrity Level is claimed. See Section 10.4.
- Environmental type-testing to the IEC 60068-2 series has not been performed.

15.5 Environmental

PARAMETER	VALUE
Operating ambient temperature	0 to 40 °C (full-rated)
Storage temperature	−40 to 85 °C
Operating humidity	10 to 90 % RH, non-condensing
Operating altitude	Up to 2000 m
Pollution degree	2 (indoor use, occasional non-conductive contamination)
Ingress protection	Not rated (open-frame PCB; integrator's enclosure provides any required IP rating)

NOTE

Motion Core is intended for integration into a customer-supplied enclosure as part of a complete robotic system. End-system compliance is the responsibility of the integrator; Motion Core's component-level compliance is a necessary but not sufficient condition for end-system certification.

16. ORDERING INFORMATION

16.1 Part Number Format

Motion Core part numbers follow the format below. Variants may be added in future revisions; the current production part number is the only ordering option at this time.

FIELD	VALUE	MEANING
FLR	FLR	First Layer Robotics (manufacturer identifier)
MC	MC	Motion Core (product family)
Gen	1	Generation / hardware revision
Channels	2M	2 independent motor channels
Voltage	12	12V class (accepts 9–20 V DC input)
Current	4	4A continuous per channel

16.2 Current Variants

PART NUMBER	DESCRIPTION	CAN BUS OPTION
FLR-MC-1-2M12-4	Motion Core, Gen 1, 2 channels, 12V class, 4A /ch	Not fitted
FLR-MC-1-2M12-4-C	Motion Core, Gen 1, 2 channels, 12V class, 4A /ch	Fitted (factory option)
FLR-MC-1-2M12-4-RIK	Motion Core Rapid Integration Kit — Motion Core board supplied with matched reference motors and encoders, pre-made cable set, E-stop and charger-detect link plugs, and encoder voltage-select jumper. Supplied pre-configured for the included motors, allowing closed-loop motion on first power-up. Full kit contents at FirstLayerRobotics.com.	Not fitted

16.3 How to Order

Motion Core can be ordered directly at FirstLayerRobotics.com, where current stock and lead times are shown. Volume pricing is applied automatically at order quantities of 10 and 25 units. For larger volumes, OEM terms or evaluation samples, contact First Layer Robotics directly.

PARAMETER	VALUE
Company	First Layer Robotics Ltd
Location	United Kingdom
Web	https://FirstLayerRobotics.com
Email	hello@FirstLayerRobotics.com
Phone	+44 (0)1492 437 438

APPENDIX A — ORCP COMMAND REFERENCE

This appendix lists the complete set of ORCP commands implemented by Motion Core firmware. Command tokens are case-sensitive and uppercase. Key/value arguments use key=value with no spaces around the =. Positional bare arguments (e.g. STREAM ON) are space-separated.

Commands are sent from host to device as a single line of printable ASCII text and must be terminated with a newline character (\n, ASCII 0x0A). A carriage return (\r, 0x0D) preceding the newline is accepted but not required, allowing hosts on either UNIX or Windows conventions to send commands without conversion. A command line without a terminating newline is buffered by the device until one arrives; the device does not act on incomplete commands.

Command lines exceeding 128 characters (including the newline) are rejected with ERR TOO_LONG and the remainder of the input up to the next newline is discarded.

Responses are single lines terminated by \r\n. Hosts implementing line-based reads should treat \n as the terminator and strip any leading \r.

Responses are returned as either OK <CMD> [key=value …] or ERR <code> [<detail>].

Connectivity and Identification

COMMAND	PARAMETERS	DESCRIPTION
PING	—	Connectivity check. Response: OK PONG t=<ms>
INFO	—	Query firmware version, hardware ID, protocol level, unique device ID, build hash, serial, VBUS presence, and V_DDA
CAPS	—	Report the list of implemented commands
SERIAL	—	Query the board serial number. The serial is programmed once at manufacture and cannot be altered through normal command paths

Motion Control

COMMAND	PARAMETERS	DESCRIPTION
WHEEL	l=<value> r=<value> [mode=VEL|DUTY|CURRENT]	Per-wheel motion command. Default mode=VEL (rad/s output-shaft velocity, closed-loop). DUTY (open-loop −1.0…+1.0), CURRENT (direct current setpoint in A/side; requires cascade enabled).
CMD_VEL	v=<m/s> w=<rad/s>	Differential-drive body-frame velocity. Firmware performs the unicycle-to-wheel conversion using kin.wheel_radius and kin.track_width.
STOP	(optional) BRAKE|COAST	Stop both motors. Default is BRAKE.

Safety and System

COMMAND	PARAMETERS	DESCRIPTION
ENABLE	ON|OFF	Motor enable gate. In NORMAL preset, motors will not respond to WHEEL/CMD_VEL until enabled. ENABLE ON also attempts to clear any latched fault — succeeds if the underlying cause has cleared, otherwise responds ERR <code> enable refused: <fault>.
HB	—	Heartbeat. When the active preset requires it, HB must be sent within hb.timeout_ms (default 500 ms) or motion is halted with fault=HEARTBEAT. Required in NORMAL, not required in SLOW. The heartbeat deadline is independent of the preset's stale-command timeout (normal.timeout_ms, default 250 ms), which halts motion when no motion command has been received.
PRESET	(optional) SLOW|NORMAL	Switch or query safety preset. Response includes name, timeout, enable requirement, heartbeat requirement, and duty limit.

Telemetry and Streaming

COMMAND	PARAMETERS	DESCRIPTION
STATUS	—	One-shot state report. Response fields include preset, mode, enable state, fault code, E-stop, charger, motor and encoder fault flags, live velocities, duties, current sense, battery voltage/band, and effective duty limit.
STREAM	(optional) ON [<rate_hz>] | OFF	Control streaming telemetry. Bare STREAM reports current state. STREAM ON starts at the last configured or default rate; STREAM ON <n> starts at <n> Hz (range 1–50). STREAM OFF stops. Streamed lines are prefixed with ! and carry combined odometry + status.
ENC	(optional) RESET	Read encoder counters (wl, wr totals; dl, dr deltas; vl, vr measured velocities). ENC RESET zeroes the totals.

Configuration

COMMAND	PARAMETERS	DESCRIPTION
GET	<key> | ALL	Read a configuration parameter (or dump all as name=value pairs).
SET	<key>=<value>	Update a configuration parameter in RAM and apply immediately. Not persisted until SAVE.
SAVE	—	Persist current RAM configuration to non-volatile memory.
LOAD	—	Reload configuration from non-volatile memory, discarding un-saved RAM changes.
DEFAULTS	—	Restore factory defaults to RAM (does not save). Factory calibrated values are preserved.

Note: Full list of configuration keys, ranges, and defaults appears in Appendix B.

System

COMMAND	PARAMETERS	DESCRIPTION
BOOTLOADER	—	Reset into the bootloader for firmware update. Response is sent, then the device re-enumerates as a bootloader CDC endpoint after ~100 ms.

Response Format

All responses will be one of three forms:

- **Success**: OK <CMD> [<key>=<value> …]
- **Error**: ERR <code> [<detail>] — codes include BAD_CMD, BAD_ARG, BAD_VAL, DENIED, UNSUPPORTED, NOT_ENABLED, ESTOP, LOWBATT, HEARTBEAT, TIMEOUT, BUSY, CONFIG_CONFLICT, FLASH_ERR, NO_FEEDBACK, TOO_LONG, INTERNAL.
- **Asynchronous push**: ! <TYPE> [<key>=<value> …] — used for streamed telemetry (! STREAM …), fault notifications (! FAULT …), and warnings (! WARN …). Push lines are emitted at any time, interleaved with command responses.

APPENDIX B — CONFIGURATION PARAMETERS

All parameters are accessed via GET <key> / SET <key>=<value> and persisted via SAVE. Ranges are the values accepted by SET; defaults are the factory-fresh values loaded by DEFAULTS. Values marked “factory calibrated” ship pre-calibrated and should not normally be changed.

The default values below are calibrated for the reference motors used during Motion Core development: a Pololu 25D 12 V brushed gearmotor with quadrature hall encoder (2249 counts/rev at the output shaft), driving 50 mm-radius wheels on a 175 mm track. Robots fitted with different motors, gearboxes, or chassis geometries will require re-tuning of the relevant parameters (particularly kin.*, motor.*, pid.*, and ff.*) via **SET**, followed by **SAVE**.

Kinematics

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
kin.track_width	m	0.05	1.0	0.175	Distance between the two driven wheels along the axle
kin.wheel_radius	m	0.01	0.5	0.05	Effective rolling radius of each driven wheel
kin.counts_per_rev	counts	0	10000	2249	Encoder counts per output-shaft revolution. Set to 0 to declare “no encoders” — closed-loop motion commands are then rejected with NO_FEEDBACK
kin.max_v	m/s	0.05	5.0	1.0	Maximum linear body velocity accepted by CMD_VEL
kin.max_w	rad/s	0.1	20.0	3.0	Maximum angular body velocity accepted by CMD_VEL
kin.max_accel	rad/s²	0.0	100.0	25.0	Wheel-side acceleration ramp limit. 0 disables ramping

Motor limits

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
motor.v_max	V	0.0	30.0	12.0	Duty is clamped so average motor voltage does not exceed this. 0 disables
motor.i_max	A	0.0	20.0	4.0	Rated continuous current per side (slow-trip threshold). 0 disables
motor.i_fault	A	0.0	20.0	5.0	Absolute hard current limit per side. 0 falls back to motor.i_max
motor.i_max_time_ms	ms	100	30000	500	Slow-trip debounce: how long current must exceed motor.i_max before fault
motor.max_duty_accel	1/s	0.0	100.0	5.0	DUTY-mode slew-rate limit (per second). 0 disables (step response)
motor.max_rads	rad/s	0.1	100.0	20.9	Per-side velocity ceiling for closed-loop commands
motor.stall_duty	1	0.0	1.0	0.20	Encoder-stall detection: minimum |duty| threshold
motor.stall_vel	rad/s	0.0	50.0	0.50	Encoder-stall detection: maximum |vel| threshold

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
motor.stall_ms	ms	0.0	10000	500	Encoder-stall detection: dwell time before ENCODER_STALL fault
motor.invert_left	0/1	0	1	0	Invert left motor direction
motor.invert_right	0/1	0	1	1	Invert right motor direction

Outer velocity PID

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
pid.kp	—	0.0	10.0	0.5	Proportional gain for direct-duty velocity loop
pid.ki	—	0.0	50.0	7.0	Integral gain for direct-duty velocity loop
pid.kd	—	0.0	1.0	0.0	Derivative gain for direct-duty velocity loop

Cascade current loop (inner + feed-forward + trim)

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
current_loop.enable	0/1	0	1	0	Master enable for the cascade current-loop architecture. When disabled, motion runs the outer velocity PID only
pid.kp_i	—	0.0	10.0	0.0	Inner current-loop proportional gain (A → duty)
pid.ki_i	—	0.0	500.0	0.0	Inner current-loop integral gain
ff.static	A·s/rad	0.0	5.0	0.03	Feed-forward: static-friction current per rad/s (sign follows velocity sign)
ff.visc	A·s/rad	0.0	2.0	0.004	Feed-forward: viscous-friction coefficient (current per unit velocity)
ff.inertia	A·s²/rad	0.0	2.0	0.0	Feed-forward: inertial coefficient (current per unit acceleration)
pid.kp_c	—	0.0	20.0	0.1	Cascade outer trim proportional gain
pid.ki_c	—	0.0	100.0	1.0	Cascade outer trim integral gain

Encoder / velocity observer

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
encoder.filter_alpha	—	0.01	1.0	0.2	Low-pass filter constant on measured velocity
encoder.invert_left	0/1	0	1	0	Invert left encoder direction
encoder.invert_right	0/1	0	1	1	Invert right encoder direction
encoder.obs_enable	0/1	0	1	0	Enable the two-state velocity observer (Layer-2 cascade)
encoder.obs_alpha	—	0.0	1.0	0.4	Observer position-error gain
encoder.obs_beta	—	0.0	1.0	0.08	Observer velocity-error gain

Battery monitoring

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
batt.full_v	V	5.0	30.0	12.6	100 % state-of-charge reference (default: 3S Li-ion / LiPo fully charged)
batt.low_v	V	5.0	30.0	10.2	LOW warning threshold. Firmware emits *! WARN BATT level=LOW* above this
batt.critical_v	V	5.0	30.0	9.6	CRITICAL fault threshold. Firmware disables motion and latches *! FAULT BATT level=CRITICAL* below this
batt.hyst_v	V	0.0	2.0	0.2	Hysteresis band on all three thresholds to prevent chatter
batt.divider_ratio	—	1.0	20.0	5.7	Factory calibrated — voltage-divider ratio for V_BAT ADC sense

Auxiliary 5 V rail monitoring

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
aux5v.i_max	A	0.1	20.0	5.0	Configures the current-monitor's full-scale range
aux5v.i_warn	A	0.0	20.0	5.0	Threshold above which the firmware emits an overcurrent warning
aux5v.v_warn	V	0.0	6.0	4.7	Threshold below which the firmware emits an undervoltage warning
aux5v.shunt_ohms	Ω	0.001	10.0	0.01	Factory calibrated — shunt resistor value for the current monitor

Safety presets

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
slow.duty_limit	—	0.05	1.0	0.30	Duty cap in SLOW preset
slow.timeout_ms	ms	0.0	60000	0	Motion command timeout in SLOW preset. 0 disables
normal.duty_limit	—	0.05	1.0	0.90	Duty cap in NORMAL preset
normal.timeout_ms	ms	10	60000	250	Motion command timeout in NORMAL preset
hb.timeout_ms	ms	10	60000	500	Heartbeat timeout in NORMAL preset

Telemetry streaming

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
stream.rate	Hz	1	50	10	Streaming telemetry rate (odometry + status combined)

Current sensing (factory calibrated)

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
current.scale	—	0.1	20.0	3.333	Motor current-sense scale factor (factory calibrated)
current.offset_left	A	−5.0	5.0	0.0	Motor current-sense zero offset, left (factory calibrated)
current.offset_right	A	−5.0	5.0	0.0	Motor current-sense zero offset, right (factory calibrated)

MCU temperature sensor calibration (factory calibrated)

KEY	UNIT	MIN	MAX	DEFAULT	DESCRIPTION
mcu.temp_v25	V	1.0	2.0	1.43	Internal temperature sensor voltage at 25 °C (factory calibrated)
mcu.temp_slope	V/°C	0.001	0.010	0.00430	Internal temperature sensor slope (factory calibrated)