Mobile Base Module: Electrical & Electronics Subsystem Architecture

This document outlines the functional sub-circuits required for the mobile base's integrated PCB. Designing these as a cohesive onboard system ensures professional packaging, eliminates loose wires, and is strictly required to pass the Phase 1 Safety Check.

1 Control Panel Circuit (HMI)

This circuit manages the Human-Machine Interface directly on the robot chassis, handling physical operator inputs and providing immediate system status feedback.

- **Mode Switches:** Toggle or rotary switches to transition the state machine between Manual Teleoperation and Autonomous Mode.
- **Push Buttons:** Hardware buttons (with RC debouncing circuits) for system resets or specific execution commands.
- **Status Indicators:** LED arrays with current-limiting resistors to visually indicate Power ON, Fault States, Communication Active, and current operating mode.

2 BMS (Battery Management System) Circuit

The BMS acts as the core health monitor for the battery pack. It prevents catastrophic electrical failures and ensures the power source operates within safe margins.

- **BMS IC:** A dedicated management chip (e.g., BQ series) to monitor individual cell voltages continuously.
- **Balancing Hardware:** Cell balancing resistors and MOSFETs to ensure uniform voltage across all battery cells during charge and discharge cycles.
- **Thermal Sensors:** NTC Thermistors placed near the battery leads for real-time temperature monitoring.

- **Current Shunts:** Sense resistors to track overall power consumption and detect over-current stalls.

3 Recharging & Power Circuit

This section serves as the main power entry point, routing high current from the battery to the rest of the system while managing the mandatory safe charging approach.

- **High-Current Connectors:** Secure, polarized connectors (e.g., XT60 or XT90) bridging the battery and the main board.
- **Charge Controller:** ICs managing the safe influx of current if onboard charging is implemented.
- **Power Path Management:** Power MOSFETs configured to seamlessly and safely switch between battery power and external wall power during tethered programming or testing.

4 Regulation Circuit

Batteries provide a fluctuating voltage that drops as they discharge. This circuit steps down the raw battery voltage into the stable, clean logic levels required by the MCU, sensors, and communication chips.

- **Buck Converters (Switching Regulators):** High-efficiency circuits (comprising a control IC, inductor, diode, and smoothing capacitors) used to step down the raw battery voltage to a stable 5V for heavier logic loads.
- **LDOs (Low Dropout Regulators):** Linear regulators used to step down the 5V rail to a highly stable, low-noise 3.3V rail, which is critical for noise-sensitive components like the IMU and MCU.

5 Driver & Motor Circuit

This power electronics stage translates low-voltage logic signals from the MCU into high-current outputs to drive the omni-wheel drivechain. Similar to the rapid switching concepts used in AC motor drives, this DC circuit precisely controls speed and torque.

- **Power Switching:** H-Bridge ICs or discrete power MOSFET arrays to control the bidirectional rotation of the DC motors.
- **Gate Drivers:** ICs designed to rapidly switch the MOSFET gates, minimizing thermal switching losses.

- **Flyback Protection:** Freewheeling diodes placed across the motor outputs to protect the circuit from damaging inductive voltage spikes.
- **Decoupling:** Large electrolytic and ceramic capacitors placed physically close to the driver ICs to handle sudden, massive current spikes during rapid strafing maneuvers.

6 Safety & Protection Circuit

This is the mandatory hardware layer that acts as the ultimate failsafe for the robot. It protects the entire electronics stack from user errors, shorts, and mechanical stalls.

- **Main Fuse:** An automotive-style blade fuse correctly rated for the combined maximum current draw of the mobile base and the manipulator.
- **Emergency Stop (E-Stop):** A physical, latching mushroom button wired directly in series with the main power line to immediately cut actuation power.
- **Reverse Polarity Protection:** A P-channel MOSFET or high-current Schottky diode circuit preventing catastrophic damage if the battery is plugged in backward.
- **Transient Protection:** TVS (Transient Voltage Suppressor) diodes across power and communication lines to clamp ESD and voltage spikes.

7 Sensor & Perception Circuit

This circuit serves as the bridge between the physical environment and the main processor, conditioning signals necessary for precise odometry and autonomous visual perception.

- **Camera Interface:** A high-speed data bus (such as USB, MIPI CSI, or dedicated ribbon connector) connecting an RGB/Depth camera to handle lane detection and color classification via QR code.
- **Wheel Motor Encoders:** Dedicated headers and signal conditioning (like hardware logic level shifters or Schmitt triggers) to cleanly read high-frequency pulse trains from the quadrature encoders, essential for tracking pure X/Y translation.
- **IMU (Inertial Measurement Unit):** An onboard sensor IC (e.g., MPU6050) communicating via I^2C/SPI to provide heading stabilization and prevent unintended rotation.
- **Optional Interfaces:** Headers for extra sensors like proximity/ToF or bump sensors.

8 MCU & Communication Circuit (The Integration Layer)

This circuit houses the "brain" of the base module and the communication bus required for plug-and-play integration with the Manipulator Module.

- **Microcontroller Unit (MCU):** The primary processor (e.g., ESP32, STM32) that executes the kinematic controller, state machine, and perception pipelines.
- **Minimum System Components:** The external crystal oscillator (clock), boot configuration resistors, and reset circuitry required for the MCU to function.
- **Communication Transceivers (COM Circuit):** ICs specific to your chosen protocol (e.g., CAN transceiver like the MCP2551, or RS-485 driver) to enable a robust comms bus between the base and the arm.
- **Isolation:** Opto-isolators to electrically separate logic signals between the base and manipulator, preventing ground loops and motor noise from corrupting data.
- **Standardized Connectors:** Locking headers (e.g., Molex or JST) forming the physical standardized electrical interface for the plug-and-play requirement.