Applied ECE & Embedded Field Projects — Vol. 2 (v2)

Pure Hardware Power/Analog Builds & Full-Stack Cellular, Vision, Mains & Robotics Systems

Engineering Architecture Split: Out of your 6 field projects, **Projects 5 & 6** are solved purely in **analog/power hardware** (zero firmware, zero standby drain, maximum reliability), **Project 3** combines hardware opto-isolation/snubbers with ESP32 control, and **Projects 1, 2 & 4** leverage cellular/Wi-Fi telemetry and video streaming.

Part 1: Consolidated Incremental Shopping List (Delta Over Vol. 1 Kit)

Component	Qty	Est. INR	Target Project & ECE Selection Notes
SIM7670C / SIM7600E 4G LTE + GNSS Module	1	~₹2,000	**Project 1 (Car Tracker):** Avoid 2G SIM800L; 4G Cat-1 + integrated GNSS provides reliable HTTPS/MQTT and satellite fix.
ESP32-CAM (OV2640) + ESP32-CAM-MB Programmer	1–2	~₹550 ea	**Projects 2 & 4:** Dedicated camera nodes with snap-on USB-UART programmer for standalone CCTV and rover video.
4WD Robot Chassis + 4× BO Gear Motors	1	~₹650	**Project 4 (Rover):** Add 0.1 µF ceramic capacitors soldered directly across each DC motor's terminals to suppress brush EMI.
2× 18650 High-Drain Li-Ion + 2S Holder + 2S BMS	1 set	~₹700	**Projects 1 & 4:** 7.4V–8.4V pack with over-current/under-voltage BMS protection for rover drive and tracker backup.
LM2596 Buck Converters (3-Pack) + 1N5408 + MOV	1 set	~₹300	**Projects 1 & 4:** Steps 12V–14.4V car battery (with load-dump transient suppression) down to clean 5V.
24V 250W PMDC Motor + XL4016 CC/CV Module	1 set	~₹1,950	**Project 5 (Bicycle Charger):** High-output PMDC generator + Constant-Current/Constant-Voltage buck stage for 12V battery.
10A10 / MBR4045 Schottky Diodes + 10A Blade Fuse	1 pack	~₹100	**Projects 1 & 5:** Low-drop reverse-current blocking diode + overcurrent fuse protection.
Hi-Link HLK-PM01 (220V AC→5V DC) + PC817 + RC Snubber	1 set	~₹280	**Project 3 (Smart Switchboard):** Isolated AC-DC supply, optocoupled wall-switch sensing, and 100Ω+0.1µF X2 contact snubbers.
NC Magnetic Reed Switch + IRLZ44N + 12V/5V COB LED Strip	1 set	~₹200	**Project 6 (Almirah Light):** Pure MOSFET + reed switch hardware circuit with 0 µA standby draw.

Part 2: Pure Electrical & Power-Electronics Designs (Zero Firmware)

PURE HARDWARE PROJECT 06 • ZERO-STANDBY MOSFET SWITCHING

6. Automatic Almirah (Wardrobe) Door Light — 0 µA Quiescent Drain

- **Why Zero Firmware:** Eliminates boot latency, Wi-Fi overhead, and battery drain; draws literally **0 µA** when the door is closed.
- **Circuit Topology:** Wire a **Normally-Closed (NC) magnetic reed switch** between Gate and Source (GND) of an **IRLZ44N logic-level N-MOSFET**, with a **1 MΩ pull-up resistor** from Gate to +V (5V or 12V). Place the COB LED strip between +V and Drain.
- **Operation:** Door closed → magnet holds reed switch closed → `V_GS = 0V` (MOSFET OFF, leakage <1 µA). Door opens → reed opens → 1 MΩ resistor pulls Gate to +V → MOSFET saturates (`R_DS(on) ≈ 22mΩ`) and lights the COB strip instantly.

PURE POWER ELECTRONICS PROJECT 05 • ELECTROMECHANICAL & CC/CV

5. Bicycle Generator Charging a 12V Bike Battery (with Analog LED Gauge)

- **Generator Stage:** Couple a **24V 250W PMDC motor** to the rear wheel/chain. Open-circuit EMF follows `V_emf = K_e · ω` (generating 15V–28V at normal pedaling cadence), buffered by a **4700 µF 50V electrolytic capacitor** to smooth pedal-stroke ripple.
- **Reverse-Current & CC/CV Regulation:** Pass rectified generator output through a low-`V_f` **MBR4045 Schottky diode** into an **XL4016 CC/CV converter** tuned to **14.2V CV limit** and **2.0A–3.0A CC limit** (safe C/10 charge rate for 12V lead-acid/LiFePO4), fused at 10A.
- **Pure Analog Fuel Gauge (No MCU):** Use an **LM3914 dot/bar driver IC** with a precision resistor divider across the battery terminals to illuminate a 10-LED handlebar state-of-charge bar graph.

Part 3: Hybrid & Embedded Field Systems

FIELD PROJECT 01 • AUTOMOTIVE POWER & 4G GNSS

1. Cellular Car GPS Tracker with Local SD Blackbox & Mobile App

- **Automotive Front-End Protection:** Protect the 12V–14.4V alternator input with a **2A fuse → 1N5408 reverse diode → 27V TVS diode → 1000 µF/35V cap** feeding an LM2596 buck stage, backed by a 18650 cell + TP4056 UPS path.
- **Telemetry & Storage:** ESP32-S3 reads GNSS NMEA coordinates over UART from the SIM7670C, logs every 5-second fix to MicroSD (SPI) as an offline blackbox, and pushes HTTP/MQTT payloads over 4G LTE to a self-hosted **Traccar** server with Android/iOS live map tracking.

FIELD PROJECT 02 • EDGE VISION & STREAMING

2. Cloud-Connected CCTV Camera with Mobile Monitoring

- **Hardware & Power:** ESP32-CAM (OV2640) powered via a dedicated low-ripple 5V supply with a 470 µF decoupling capacitor directly on the 5V/GND pins to prevent Wi-Fi + camera brownouts.
- **Firmware & App:** Flash **ESPHome** for seamless Home Assistant mobile app live viewing, motion alerts, and snapshots, or stream RTSP via MediaMTX to a custom web client.

FIELD PROJECT 03 • 220V AC MAINS & OPTO-ISOLATION

3. App-Based Home Appliance Control with Two-Way Physical Wall Switch Sync

- **Hardware Interlock:** Power the ESP32 from an isolated **HLK-PM01 (220V AC → 5V DC)** module. Sense physical rocker switch state safely via a **PC817 optocoupler** (with current-limiting resistor + bridge/anti-parallel diode) so physical toggles and mobile app state never conflict.
- **Inductive Load Protection:** Add an **RC snubber (100Ω + 0.1 µF X2 rated)** across relay contacts switching ceiling fans, or use a zero-cross BTA16 TRIAC dimmer for hum-free speed control.

> **220V AC Safety Mandate:** Maintain ≥6 mm creepage distance between AC mains and 3.3V tracks, place a 2A slow-blow fuse + MOV on the AC line, and house inside a flame-retardant ABS enclosure.

FIELD PROJECT 04 • WIRELESS ROBOTICS & POWER ISOLATION

4. 4-Wheeler Inspection Rover with Live Video & High-Power LED Headlights

- **Dual-Rail Power Architecture:** Drive 4× BO gear motors (arranged as left/right skid-steer banks) from a 2S 18650 pack (7.4V–8.4V) through a **TB6612FNG MOSFET driver**, while isolating the ESP32-CAM on a separate LM2596 5V buck rail so motor stall currents never reset the video stream.
- **PWM Headlights & UI:** Drive 2× 1W/3W LEDs through an **IRLZ44N MOSFET** using ESP32 hardware PWM for remote brightness dimming alongside a low-latency MJPEG + WebSocket joystick interface.