ESP32-S3 ANSI Type 2 Optical Meter Coupler - Complete Build Guide

Phase 1: Component Verification & Preparation

Bill of Materials (BOM) Checklist

Power Supply:

- [ ] 1x Li-Ion battery (3.7V, ~2000mAh) with JST-PH or equivalent connector
- [ ] 1x AMS1117-3.3 voltage regulator (SOT-223 package or breakout board)
- [ ] 1x Micro slide switch (SPST, rated for 3.7V)
- [ ] 2x 10µF electrolytic capacitors (6.3V or higher)
- [ ] 1x 100µF electrolytic capacitor (6.3V or higher)
- [ ] 3x 0.1µF ceramic capacitors (decoupling)

Optical Interface - Receiver:

- [ ] 1x WP3DP3BT/BD photodiode (940nm)
- [ ] 1x OPA2333 dual op-amp IC (DIP-8 or SOIC-8)
- [ ] 1x 10M ohm resistor (1/4W, 1%)
- [ ] 1x 50pF capacitor (feedback)

Optical Interface - Transmitter:

- [ ] 1x QBED8160 IR LED (940nm, 50mA)
- [ ] 1x TLP291 optocoupler (DIP-4)
- [ ] 1x 5.1K ohm resistor (1/4W)
- [ ] 1x 1.5K ohm resistor (1/4W)
- [ ] 1x 91 ohm resistor (1/4W)

Indicators:

- [ ] 1x Green LED (3mm or 5mm)
- [ ] 1x Yellow LED (3mm or 5mm)
- [ ] 1x Red LED (3mm or 5mm)
- [ ] 3x 1K ohm resistor (power LED) (1/4W)
- [ ] 2x 470 ohm resistor (activity LEDs) (1/4W)

Microcontroller & Support:

- [ ] 2x ESP32-S3 development boards

- [ ] 1x USB-C cable (for programming/debug)

Additional Materials:

- [ ] Breadboard or perf board (for prototyping)
- [ ] Jumper wires (22 AWG recommended)
- [ ] Solder and soldering iron
- [ ] Wire strippers and cutters
- [ ] Multimeter (for testing)
- [ ] Hot glue gun or epoxy (for final assembly)

Phase 2: Prototyping on Breadboard

Step 1: Power Supply Assembly

1. **Connect battery to breadboard:**
    - Place battery connector on breadboard
    - Battery + (red) connects to one side of slide switch S1
    - Other side of S1 connects to AMS1117-3.3 VIN pin
    - Battery - (black) connects to ground rail
2. **Install voltage regulator:**
    - AMS1117-3.3 has 3 pins: VIN, GND, VOUT
    - VIN: from switch (3.7V input)
    - GND: to ground rail
    - VOUT: to +3.3V rail (use bus strip on breadboard)
3. **Add capacitors:**
    - 10µF between VIN and GND (input side)
    - 10µF between VOUT and GND (output side)
    - 100µF between VOUT and GND (bulk filtering)
    - 0.1µF ceramic caps near each IC power pin
4. **Test voltage:**
    - Flip switch ON
    - Measure voltage on +3.3V rail: should read 3.3V ±0.1V

- Measure quiescent current: should be <10mA with no load

Troubleshooting:

- If voltage is too low: Check regulator orientation and capacitor polarity
- If voltage oscillates: Add another 10µF cap on output

Step 2: LED Indicators Assembly

1. **Power LED (Green):**
   - LED anode (+, longer leg) → 1K resistor → GPIO21
   - LED cathode (-, shorter leg) → GND
   - Test: LED should light when powered on
2. **RX Activity LED (Yellow):**
   - LED anode → 470Ω resistor → GPIO8
   - LED cathode → GND
   - Test: Will blink during operation
3. **TX Activity LED (Red):**
   - LED anode → 470Ω resistor → GPIO9
   - LED cathode → GND
   - Test: Will blink during operation

LED Testing:

```
// Quick test code to verify LEDs work:
void setup() {
  pinMode(21, OUTPUT);  // Power
  pinMode(8, OUTPUT);   // RX
  pinMode(9, OUTPUT);   // TX
}

void loop() {
  digitalWrite(21, HIGH); delay(500);
  digitalWrite(21, LOW);  delay(500);

  digitalWrite(8, HIGH);  delay(100);
  digitalWrite(8, LOW);   delay(100);

  digitalWrite(9, HIGH);  delay(100);
  digitalWrite(9, LOW);   delay(100);
}
```

Step 3: IR Receiver Circuit (Meter → ESP32)

Photodiode Setup:

1. Place WP3DP3BT/BD on breadboard
2. Cathode (shorter lead) → connects to OPA2333 inverting input (−)
3. Anode (longer lead) → to ground
4. Bias the cathode through 10M resistor to ground (creates bias path for photodiode)

Transimpedance Amplifier (OPA2333 - first stage):

1. OPA2333 pin configuration (DIP-8):
   - Pin 1: Offset Null (not used, leave open or to GND)
   - Pin 2: Inverting input (-) → from photodiode cathode
   - Pin 3: Non-inverting input (+) → to GND
   - Pin 4: GND
   - Pin 5: Offset Null (not used)
   - Pin 6: Output → feedback network and Schmitt input
   - Pin 7: +3.3V

- Pin 8: +3.3V

2. **Feedback network:**
   - 10M resistor from output (pin 6) to inverting input (pin 2)
   - 50pF capacitor in parallel with 10M resistor
   - This creates the transimpedance: Vout = -Iin × R_feedback
3. **Decoupling:**
   - 0.1μF cap from pin 7 to GND
   - 0.1μF cap from pin 4 to GND

Schmitt Trigger (OPA2333 - second stage):

1. Use second half of OPA2333:
   - Pin 9: Offset Null (open or GND)
   - Pin 10: Inverting input (-) → from first stage output
   - Pin 11: Non-inverting input (+) → to GND or voltage divider (~1.6V ref)
   - Pin 12: GND
   - Pin 13: Offset Null (open)
   - Pin 14: Output → GPIO44 (UART RX)
   - Pin 15: +3.3V
   - Pin 16: +3.3V
2. **Decoupling:**
   - 0.1μF cap from pin 15 to GND
   - 0.1μF cap from pin 12 to GND

Output connection:

- Pin 14 → GPIO44 (UART RX input on ESP32-S3)

Testing receiver:

1. Shine a 940nm IR LED (or use remote control) at photodiode
2. Oscilloscope on pin 6 output: should see voltage changes
3. Oscilloscope on pin 14 output: should see clean square wave transitions

4. Serial monitor should show data when meter transmits

Step 4: IR Transmitter Circuit (ESP32 → Meter)

Optocoupler (TLP291) Setup - DIP-4 pinout:

- Pin 1: Anode of LED (connects to ESP32 GPIO43 through 1.5K resistor)
- Pin 2: Cathode of LED (connects to GND)
- Pin 3: Collector of phototransistor (connects to +3.3V through 5.1K pull-up)
- Pin 4: Emitter of phototransistor (connects to GND)

Build optocoupler circuit:

1. GPIO43 → 1.5K resistor → TLP291 pin 1 (anode)
2. TLP291 pin 2 → GND
3. +3.3V → 5.1K resistor → TLP291 pin 3 (collector)
4. TLP291 pin 3 → output to IR LED drive stage
5. TLP291 pin 4 → GND

IR LED Driver:

1. Output from optocoupler pin 3
2. Through 91Ω resistor
3. To IR LED anode
4. IR LED cathode → GND
5. This limits LED current to ~36mA (safe for 50mA rated LED)

Important: IR LED Polarity

- Anode (longer leg, flat edge marker) → 91Ω resistor
- Cathode (shorter leg) → GND

Testing transmitter:

1. Set GPIO43 high in code: should see IR LED light up (use phone camera to see IR)
2. Oscilloscope on optocoupler output: should see TTL-level signal matching GPIO43
3. Measure IR LED current: should be 30-40mA

Step 5: ESP32-S3 Board Integration

GPIO Mapping Summary:

```
GPIO21  → Power LED (green) via 1K resistor
GPIO8   → RX Activity LED (yellow) via 470Ω resistor
GPIO9   → TX Activity LED (red) via 470Ω resistor
GPIO43  → UART TX (to optocoupler)
GPIO44  → UART RX (from Schmitt trigger)
+3.3V   → All IC power pins and LED + side
GND     → All IC grounds and LED cathodes
```

Connecting to breadboard:

1. Place ESP32-S3 on breadboard with USB-C connector accessible
2. Connect GND pins (at least 2) to ground rail
3. Connect +3.3V pin to +3.3V rail from regulator
4. Connect GPIO pins as mapped above
5. Verify no shorts with multimeter before power

Phase 3: Testing & Validation

Initial Power-Up Test

1. **Without ESP32 connected:**
   - Apply power via switch
   - Measure 3.3V on all rails
   - All currents should be <100mA (mostly LED currents)
2. **With ESP32 connected:**
   - Power on
   - Green LED should blink slowly (waiting for peer)
   - Open serial monitor (115200 baud)
   - Should see startup messages

UART Loopback Test (Before Meter Connection)

1. Temporarily connect GPIO43 (TX) to GPIO44 (RX) with jumper
2. Upload test code that sends serial data
3. Serial monitor should echo data back
4. Remove jumper

Full System Test

1. Flash meter-side ESP32 with IS_METER_DEVICE = 1
2. Flash PC-side ESP32 with IS_METER_DEVICE = 0
3. Power both boards
4. Green LED on meter side should go from blinking to solid
5. Send test command from PC via serial terminal
6. Watch red LED on meter side flash
7. Yellow LED should flash when meter responds

Phase 4: Final Assembly

PCB Design (Optional but Recommended)

Once breadboard prototype works, design PCB with:

- Separate analog and digital ground planes
- Star-grounding for op-amp circuits
- Short traces from battery to regulator
- Filtered power supplies for sensitive circuits
- Ground plane under photodiode input traces

Enclosure Assembly

1. **Battery mounting:**
   - Use battery holder or adhesive foam pad
   - Ensure JST connector is accessible for charging
2. **PCB mounting:**
   - Use standoffs to keep PCB clear of enclosure

- Mount LEDs on enclosure front for visibility

3. **Optical interface:**
   - Mount photodiode in light-pipe or tube pointing at meter
   - Mount IR LED in separate light-pipe for transmission
   - Consider IR filter if ambient light is high
4. **Connector for meter:**
   - Mount RJ-45 or 3.5mm jack on enclosure
   - Photodiode and IR LED connect through light guides
   - Strain relief on cable

Troubleshooting Guide

Symptom	Likely Cause	Solution
No power	Battery dead or switch off	Check battery voltage; flip switch
3.3V rail low	Regulator input shorted	Check battery connections; test regulator in isolation
Green LED won't light	GPIO21 shorted or LED wrong polarity	Check LED orientation; test GPIO directly
Green LED steady but should blink	Peer not connecting	Verify ESP-NOW setup; check both boards powered
No meter data received	IR receiver not working	Test with known 940nm source; check op-amp polarity
Meter rejects commands	TX signal wrong	Check optocoupler output with scope; verify 9600 baud
Activity LEDs never flash	GPIO8/9 not toggling	Run LED test code; check GPIO connections
Serial data corrupted	Baud rate mismatch or noise	Verify 9600 baud setting; add shielding if needed

---

Safety Notes

- **Battery:** Li-Ion batteries can be dangerous if short-circuited. Never reverse polarity.
- **IR LED:** Don't stare directly into IR LED. It's invisible but can damage eyes.
- **Soldering:** Use proper ventilation. Lead-free solder is safer.

- **Voltage:** ESP32 operates at 3.3V. Never apply >3.3V to GPIO pins.

Next Steps After Build

1. **Meter Communication Testing:**
   - Connect to actual utility meter
   - Verify read/write operations
   - Log data for verification
2. **Performance Tuning:**
   - Adjust LED pulse durations if too dim/bright
   - Optimize transimpedance amp feedback if signal quality is poor
   - Test range and reliability of ESP-NOW link
3. **Production Enclosure:**
   - Design custom enclosure for field deployment
   - Add strain relief and weatherproofing
   - Consider battery charging circuit integration

Test Code for Each Component

LED Test

```cpp
```

```cpp
#define LED_POWER 21
#define LED_RX 8
#define LED_TX 9

void setup() {
  pinMode(LED_POWER, OUTPUT);
  pinMode(LED_RX, OUTPUT);
  pinMode(LED_TX, OUTPUT);
}

void loop() {
  // Test all LEDs
  digitalWrite(LED_POWER, HIGH); delay(500);
  digitalWrite(LED_RX, HIGH);    delay(500);
  digitalWrite(LED_TX, HIGH);    delay(500);
  digitalWrite(LED_POWER, LOW);  delay(500);
  digitalWrite(LED_RX, LOW);     delay(500);
  digitalWrite(LED_TX, LOW);     delay(500);
}
```

UART Loopback Test

```
cpp
```

```
#define METER_UART_BAUD 9600
#define METER_UART_TX_PIN 43
#define METER_UART_RX_PIN 44

HardwareSerial meterSerial(UART_NUM_0);

void setup() {
  Serial.begin(115200);
  meterSerial.begin(METER_UART_BAUD, SERIAL_8N1, METER_UART_RX_PIN, METER_UART_TX_PIN);
  Serial.println("UART Loopback Test - Jumper GPIO43 to GPIO44");
}

void loop() {
  if (Serial.available()) {
    uint8_t byte = Serial.read();
    meterSerial.write(byte);  // Send to meter UART
  }
  if (meterSerial.available()) {
    uint8_t byte = meterSerial.read();
    Serial.write(byte);  // Echo back to USB
  }
}
```

Good luck with your build! Document your progress and let me know if you hit any snags.