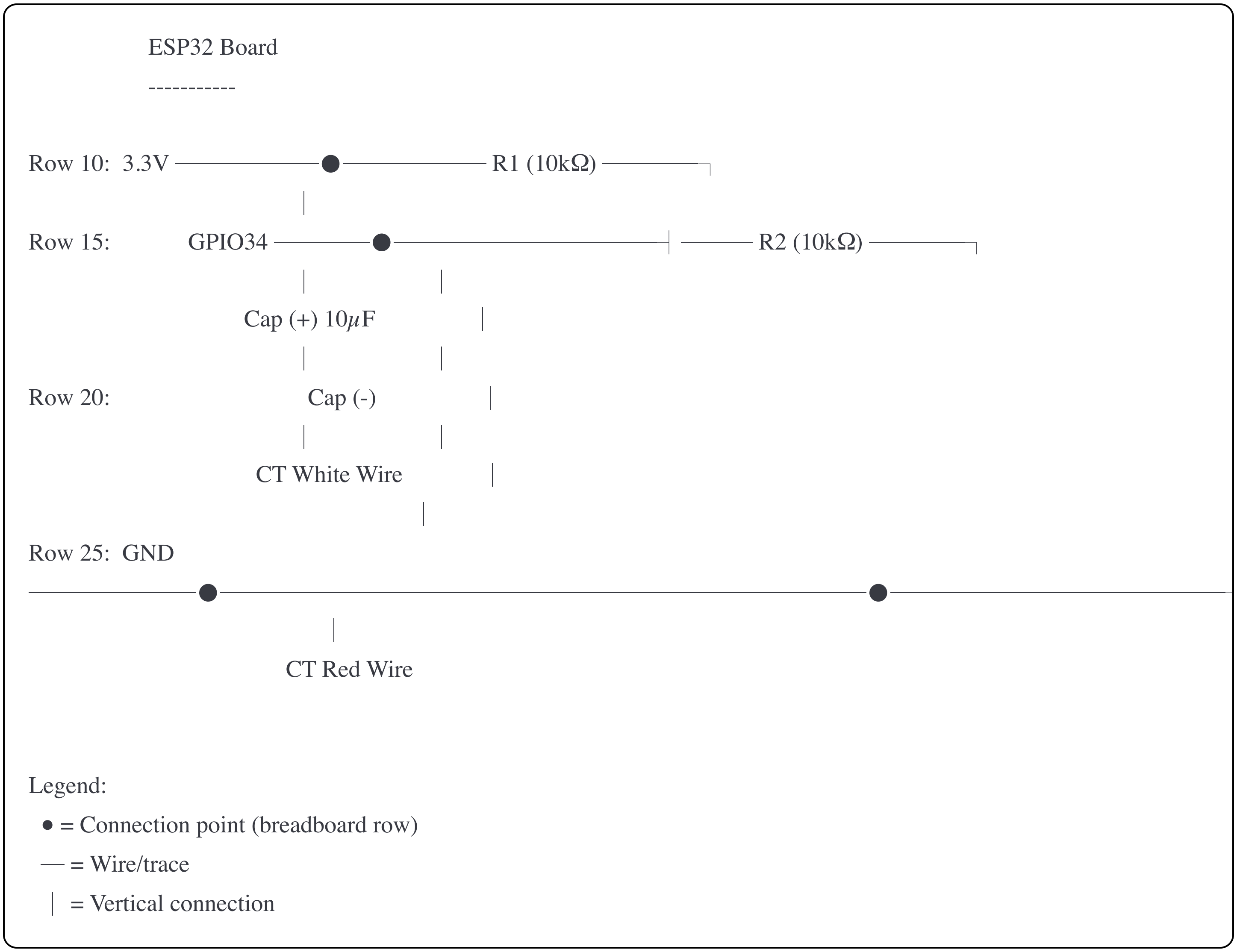
ESP32 Current Monitor - Circuit Diagram

Breadboard Layout (Prototyping)



Component Details

Resistor Network (Voltage Divider)

Creates 1.65V DC bias at ADC input:

```
  3.3V
   │
  R1 (10kΩ)    Voltage divider creates:
   │           V_mid = 3.3V × (R2 / (R1 + R2))
   ├──────── 1.65V   V_mid = 3.3V × (10k / 20k) = 1.65V
   │
  R2 (10kΩ)
   │
  GND
```

AC Coupling Capacitor

Blocks DC component, passes AC signal:

```
CT Sensor Output (AC + DC offset)
        │
     C (10μF) ───→ Blocks DC, passes AC
        │
  To ADC Pin (sees only AC riding on 1.65V bias)
```

Complete Signal Path

```
High Voltage AC Line
        │
    [CT Clamp] ───→ Magnetic coupling, no electrical connection
        │
    SCT013-050 Internal:
    ┌─────────────────────────────┐
    │ Current → Burden │  Built-in 62Ω burden resistor
    │ Transformer      │  Converts 50A → 1V output
    └─────────────────────────────┘
        │
    Red & White Wires (interchangeable)
        │
    ┌────────┴────────┐
    │      │
   Red    White
    │      │
   GND   Capacitor (10μF) ───→ AC couples to ADC
           │
       Bias Network (R1+R2) provides 1.65V DC
```

```
      │
    GPIO34 (ADC sees AC signal centered on 1.65V)
```

Perfboard Layout (Permanent Build)

Suggested component placement for 5x7cm perfboard:

```
[ESP32 Module]
    │ │ │ │ │
 ┌──────────┴─┴─┴─┴─┴──────────┐
 │   3V3  GND  │
 │    │    │   │
 │   R1   R2   │
 │    │    │   │
 │    └──●─────┘   │  ← Solder junction
 │       │    │
 │   [Cap 10μF] │
 │       │    │
 │   [3.5mm  ] │  ← PCB mount jack
 │   [ Jack  ] │
 │   [       ] │
 └─────────────────────────────┘
    │ │ │
To CT Sensor
```

Perfboard Soldering Guide

Step 1: Plan Layout

- Position ESP32 near one edge (or use socket for removability)
- Place 3.5mm jack near opposite edge
- Route traces efficiently

Step 2: Solder Order

1. Resistors first (easiest to solder flat)
2. 3.5mm jack (mechanical stability)
3. Capacitor (watch polarity!)
4. Wire connections to ESP32
5. Test with multimeter before connecting power

Step 3: Trace Routing

```
Top View (component side):

3V3 ──────[R1]────── Junction ──────[R2]────── GND
            │
        [Cap +]
            │
        [Cap -]────── Jack Tip

        Jack Sleeve ────── GND
```

Step 4: Strain Relief

- Use hot glue or zip ties on wires entering perfboard
- Prevents solder joints from breaking due to vibration

Multi-Channel Circuit (4 CT Sensors)

For monitoring multiple circuits:

```
          ESP32
           │ │ │ │ │
  3.3V ────────────┴─┴─┴─┴─┴──────────── GND
    │             │
    ├─── [R1a]────●────[R2a] ──────────┤  Channel 1 (GPIO34)
    │       │        │
    │   [Cap1] CT1      │
    │             │
    ├─── [R1b]────●────[R2b] ──────────┤  Channel 2 (GPIO35)
    │       │        │
    │   [Cap2] CT2      │
    │             │
    ├─── [R1c]────●────[R2c] ──────────┤  Channel 3 (GPIO36)
    │       │        │
    │   [Cap3] CT3      │
    │             │
    └─── [R1d]────●────[R2d] ──────────┘  Channel 4 (GPIO39)
          │
      [Cap4] CT4

Each channel is independent and identical to the single-channel circuit.
```

Parts Required (per additional channel):

- 2x 10kΩ resistors
- 1x 10μF capacitor
- 1x CT sensor with 3.5mm jack (optional)
- 1x PCB mount 3.5mm socket (optional)

Power Supply Options

Option 1: USB Power (Recommended for Testing)

```
USB 5V ───→ ESP32 USB Port ───→ Internal 3.3V Regulator ───→ 3.3V to circuit
```

Pros: Simple, easy to connect **Cons:** Needs USB port available, limited current

Option 2: External 5V Supply

```
5V Power Supply ───→ ESP32 VIN Pin ───→ Internal 3.3V Regulator ───→ 3.3V to circuit
                   (Also connect GND)
```

Pros: More current available, more robust **Cons:** Requires external power supply

Option 3: 12V Boat Power (Marine Installation)

```
12V Boat Power ───→ Buck Converter (12V→5V) ───→ ESP32 VIN Pin
                  (e.g., LM2596 module)
```

Pros: Uses existing boat electrical system **Cons:** Requires voltage converter, more complex

Important: Always use proper fusing (1A fuse recommended) and follow marine electrical standards.

Electrical Characteristics

Voltage Levels at Each Node

Node	No Load	With 8A Load	With 50A Load
3.3V Rail	3.30V DC	3.30V DC	3.30V DC
Mid Junction (bias)	1.65V DC	1.65V DC ± 0.16V AC	1.65V DC ± 1.0V AC
GPIO34 Input	1.65V DC	1.49-1.81V	0.65-2.65V
CT Output (before cap)	~0V AC	~0.16V RMS	~1.0V RMS

Current Draw

State	Current @ 5V	Current @ 12V	Power
Boot	~250mA	~100mA	1.2W
Active (WiFi ON)	~120mA	~50mA	0.6W
Idle (WiFi connected)	~80mA	~33mA	0.4W

Testing Points

When troubleshooting, measure these voltages with a multimeter:

DC Voltages (all referenced to GND):

1. **3.3V rail:** Should measure 3.25-3.35V
2. **Mid junction (GPIO34):** Should measure 1.45-1.65V DC
3. **Capacitor positive side:** Should measure 1.45-1.65V DC
4. **Capacitor negative side (CT connection):** Will vary, typically small DC offset

AC Voltages (AC mode on multimeter):

1. **Between CT wires (no load):** 0-10mV AC
2. **Between CT wires (with load):** Proportional to current (8A ≈ 160mV)
3. **GPIO34 to GND:** Small AC component (hard to measure, typically 50-200mV)

Common Wiring Mistakes

❌ Wrong: CT in Parallel with Voltage Divider

```
3.3V ──── R1 ──── GPIO34 ──── R2 ──── GND
          |
      CT Sensor
          |
        (results in 4095 ADC reading - maxed out)
```

✅ Correct: CT Through Capacitor to Biased ADC

```
3.3V ──── R1 ──── GPIO34 ──── R2 ──── GND
                    |
                  [Cap]
                    |
```

```
CT Sensor
    |
   GND
```

❌ Wrong: Capacitor Polarity Reversed

```
GPIO34 ───[Cap-]─── CT    (Cap + should go to GPIO34 side)
```

✅ Correct: Capacitor Polarity

```
GPIO34 ───[Cap+]─── CT    (Positive to high-impedance side)
```

Advanced: Understanding the Math

RMS Calculation

The ESP32 samples the AC waveform and calculates Root Mean Square current:

```
1. Sample: Read ADC 2000 times rapidly
2. Convert: ADC value → Voltage
3. Remove bias: V_signal = V_adc - 1.65V
4. Square: V² for each sample
5. Mean: Average all V² values
6. Root: √(mean) = RMS voltage
7. Scale: I_rms = V_rms × CT_RATIO
```

Why RMS? RMS (Root Mean Square) gives the equivalent DC value for AC current/voltage. For a sinusoidal AC signal, $V_{rms} = V_{peak} / \sqrt{2} \approx V_{peak} \times 0.707$

Calibration Theory

Ideal CT_RATIO calculation:

```
CT_RATIO = (Primary_Amps / Secondary_Volts) × (ADC_Voltage / ADC_Counts) × Correction_Factor

For SCT013-050:
- Primary: 50A
- Secondary: 1V
- Ideal ratio: 50

But due to component tolerances:
- Resistors: ±5%
- Capacitor: ±20%
- CT sensor: ±3%
- ESP32 ADC: ±10%

Combined tolerance: ±15-20%
Therefore calibration is required.
```

Frequency Response

The RC high-pass filter formed by the capacitor and input impedance has a cutoff frequency:

```
f_cutoff = 1 / (2π × R × C)

Where:
R = input impedance ≈ 5kΩ (parallel combination of R1 and R2)
C = 10μF

f_cutoff = 1 / (2π × 5000 × 0.00001)
f_cutoff ≈ 3.2 Hz

Since AC line frequency is 60Hz (or 50Hz), this filter easily passes the signal.
```

Bill of Materials (BOM)

Single Channel System

Qty	Component	Specification	Example Part #	Est. Cost
1	ESP32 Dev Board	ESP32-WROOM-32	ESP32-DevKitC	$8-12
1	CT Sensor	SCT013-050 (50A/1V)	YHDC SCT013-050	$12-15
2	Resistor	10kΩ ±5% 1/4W	-	$0.10
1	Capacitor	10μF 25V electrolytic	-	$0.15
1	3.5mm Jack	PCB mount, 5-pin	Tegg PJ-307	$1-2

Qty	Component	Specification	Example Part #	Est. Cost
1	Perfboard	5x7cm	-	$1-2
1	Enclosure	IP65 with cable glands	-	$10-15
1	USB Cable	Micro-USB or USB-C	-	$3-5
-	Wire	22AWG solid core	-	$2

Total Cost: ~$40-55 per channel

Four Channel System

Multiply single channel parts by 4 (except ESP32, enclosure, USB cable) **Total Cost:** ~$90-110 for 4 channels

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This circuit has been tested and validated with actual hardware. All voltage and current measurements confirmed with multimeter and Kill-A-Watt meter.