MODULAR, REALTIME POWER MONITORING SYSTEM FOR SCALABLE DATA COLLECTION

BSC307C Final Individual Project

By:

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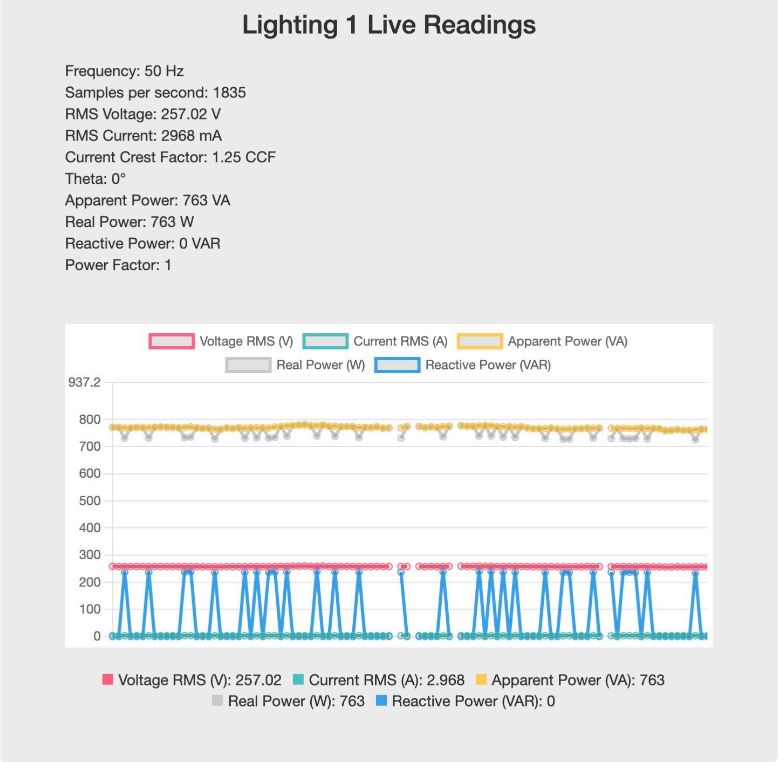
Introduction

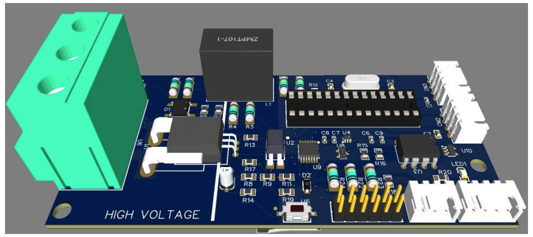
Objectives:

To research, design and manufacture a modular power monitoring system capable of measuring and logging:

- Current
- Voltage
- Frequency
- Real, Reactive & Apparent Power
- Current Crest Factor
- Power Factor
- Up to 100 circuits simultaneously

Develop a user interface to allow for graphical representation of the data

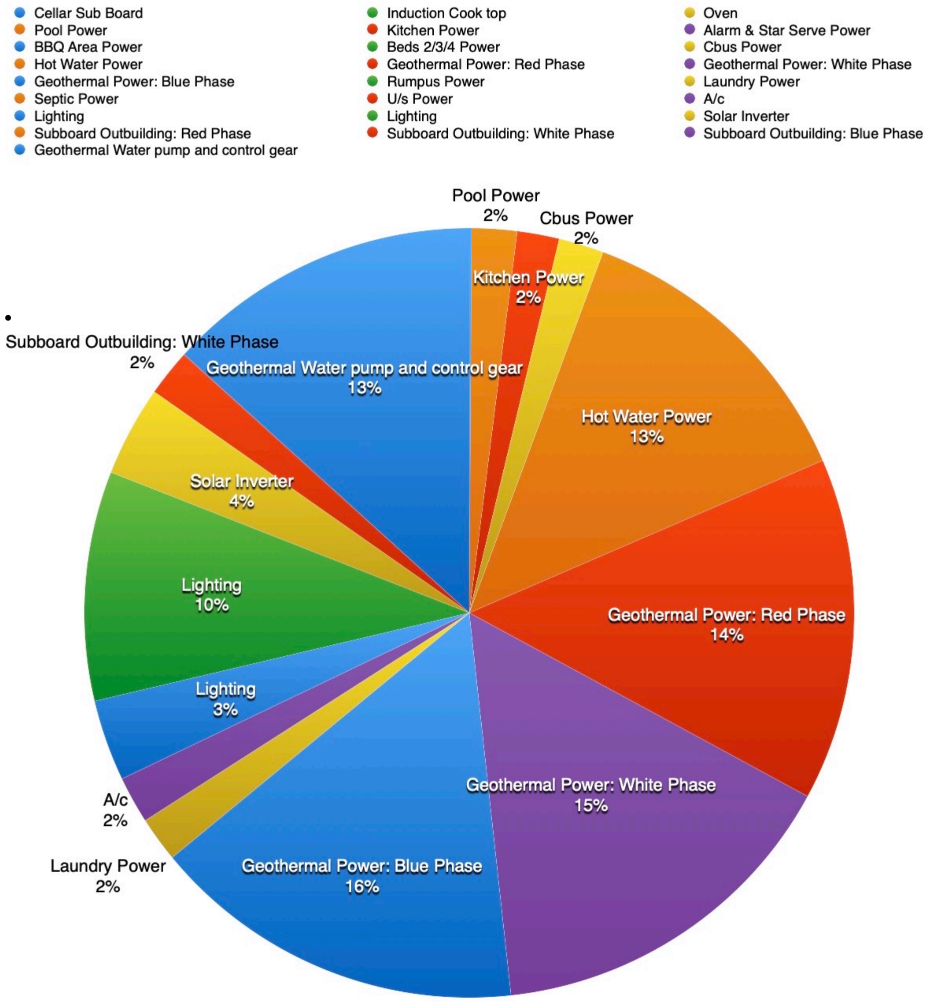




Introduction

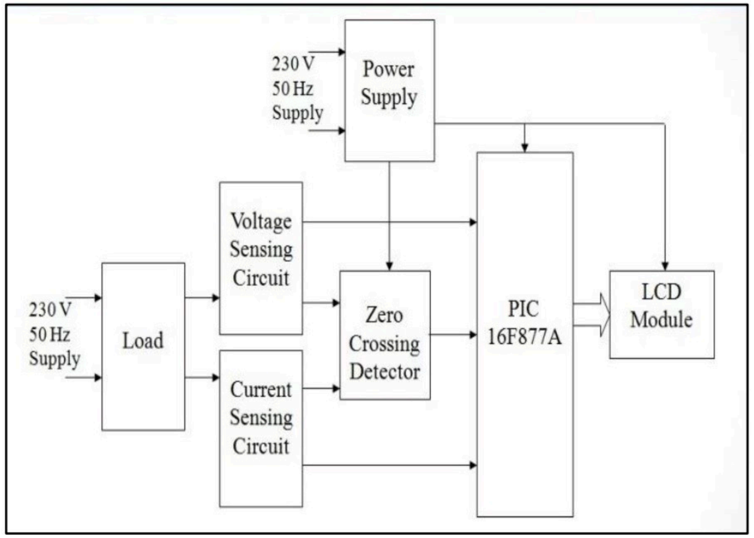
Inspiration:

- Client requests & previous work.
- Increasing power costs.
- Increasing attention to energy efficient equipment & processes.
- Detailed understanding of the state of a circuit & load.
- Opportunity to combine my passion for:
  - Problem solving,
  - Electronics,
  - PCB development,
  - Low-level and high-level programming and
  - Developing user-interfaces.



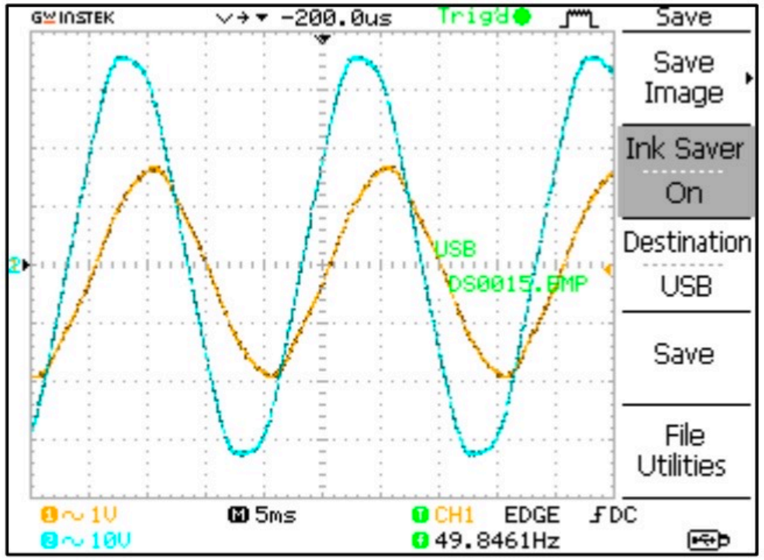
Microcontroller Based Load Monitoring System

-By I. Abed & H. Naser



Features:

- PIC-16F877A MCU w/ 5 MIPS, 14KB & 8 *10-bit ADCs.
- Zero-crossing detection.
- Voltage, Current, Power Factor, Active Power, Reactive Power & Apparent Power of a load.
- Discussion of resistive, inductive & capacitive loads.



ESP32 Microcontroller Based Smart Power Meter

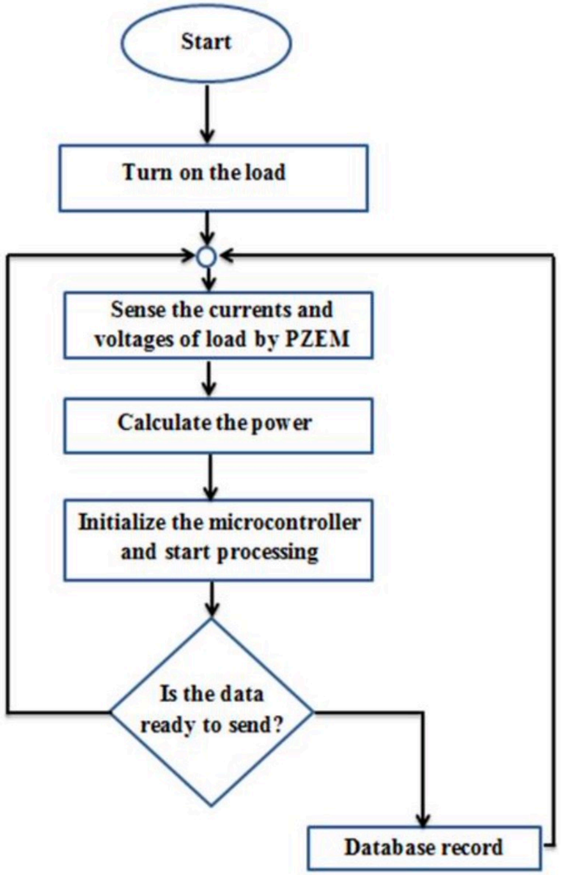
System Design and Implementation

-By I. Issa Ahmed Abed & Hayder Yasir Naser

Features:

- ESP32 MCU.
- PZEM-004T: Current, Voltage, Power, Serial Comms
- SQL Database
- Web-based user interface

PZEM-004T



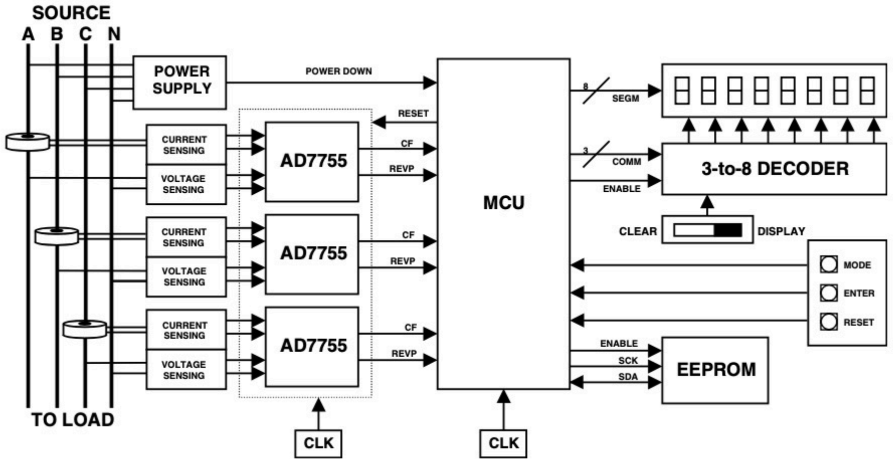
Research: Academic Literature

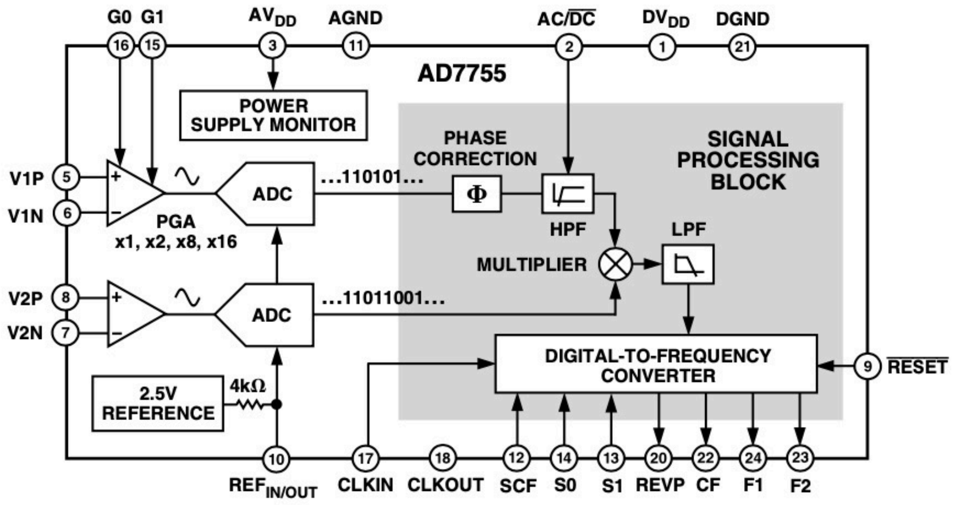
Microcontroller-Based Energy Metering using the AD7755

-By John Markow

Features:

- Purpose built IC: AD7755
- Guaranteed accuracy for IEC 687/1036
- Digital signal processor
- Low pass filtering
- Pulsed, digital-to-frequency converted output





Research: Example of Available Energy Metering ICs

Engineering Institute of Technology.

ATM90E26

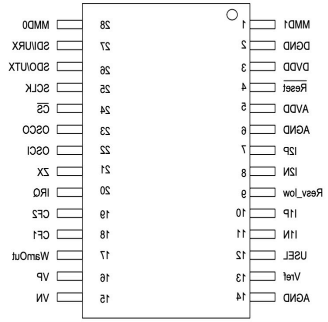
- Compliance w/ IEC62052-11, IEC62053-21 & IEC62053-23.

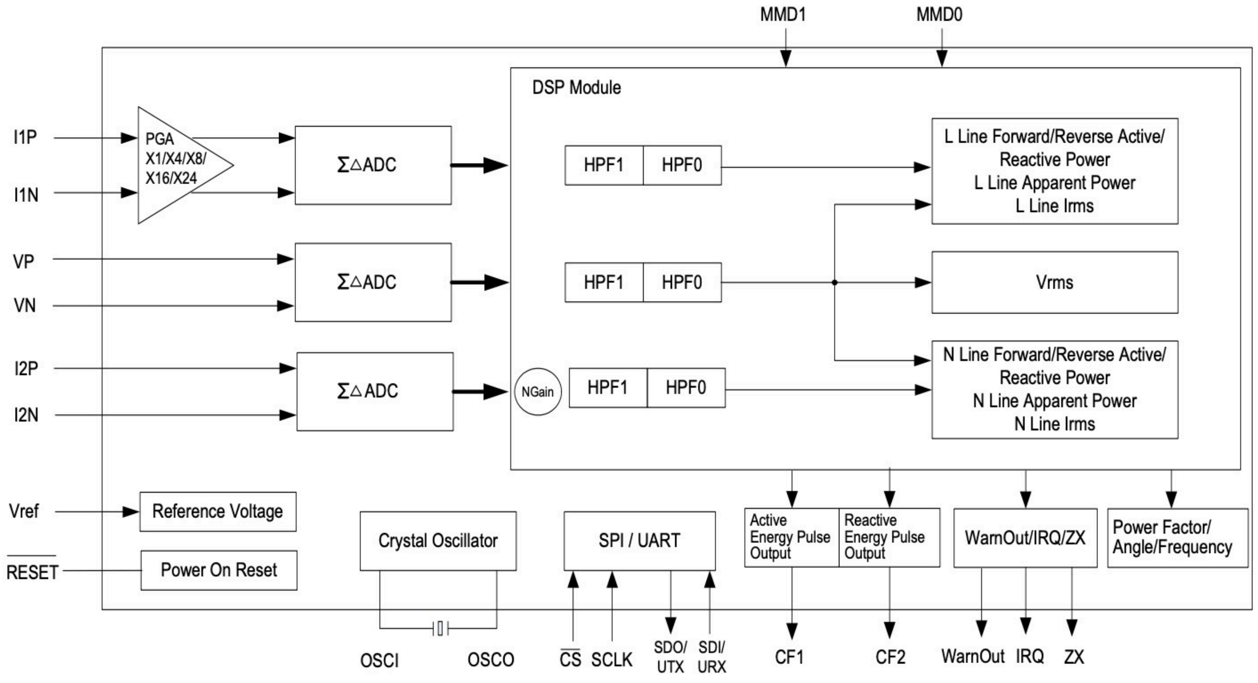
- Vrms, Irms, mean Active/ Reactive/ Apparent Power, Frequency, Power Factor and Phase Angle.

- SPI communications

- 3V system

ATM90E26

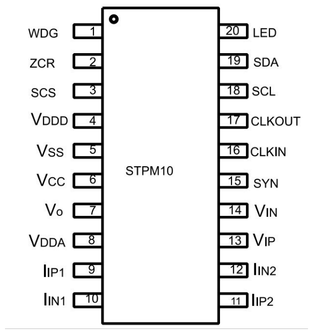


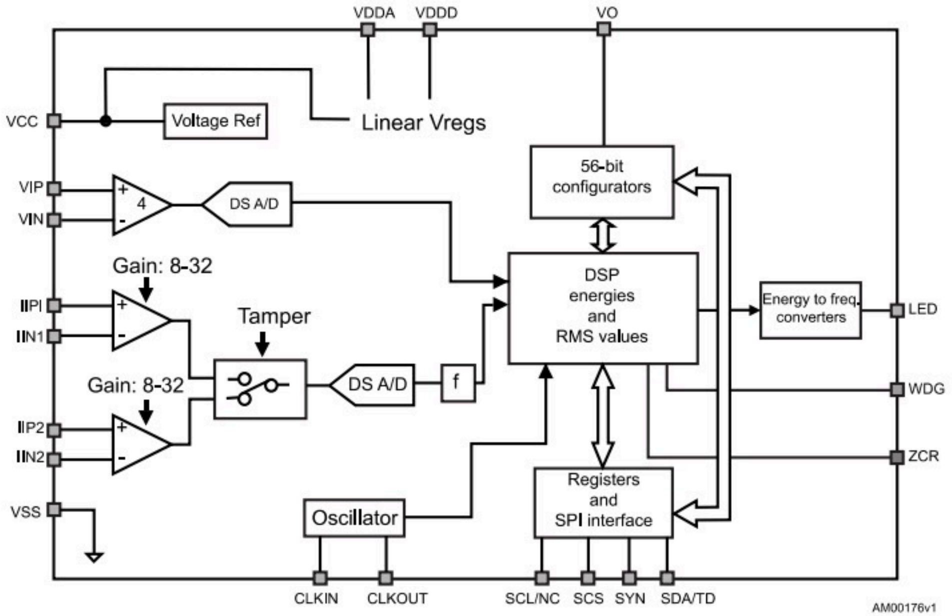


STPM10BTR

- Compliance w/ IEC62052-11, IEC62053- 2x specifications
- Vrms, Irms, mean Active/ Reactive/ Apparent Power, Frequency, Power Factor and Phase Angle.
- SPI communications
- 3V system

STPM10BTR





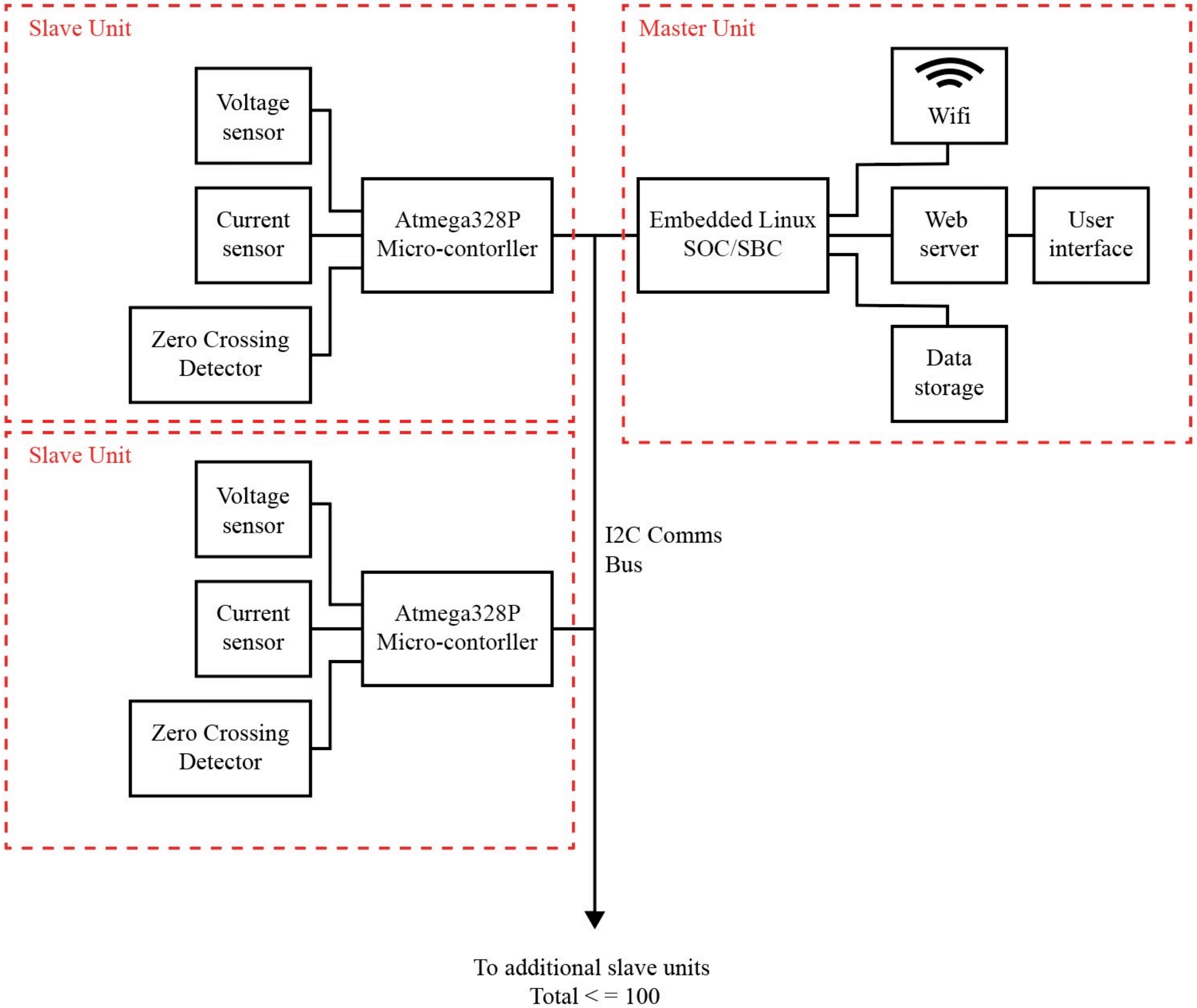
Research: Relevant Standards

- **AS 1284.11-1995 Electricity metering, Part 11: Single-phase multifunction watthour meters.**
- **AS 1284.1-2004 Electricity metering, Part 1: General purpose induction watthour meters.**
- **AS 1284.12-1995 Electricity metering, Part 12: Polyphase multifunction (non-demand) watthour meters (Class 1).**
- **AS 62052.11:2023 Electricity metering equipment (a.c.)—General requirements, tests and test conditions, Part 11: Metering equipment**
- **AS 62053.11:2023 Electricity metering equipment (a.c.)—Particular requirements, Part 11: Electromechanical meters for active energy (classes 0,5, 1 and 2)**
- **AS 62053.21:2023 Electricity metering equipment (a.c.)—Particular requirements, Part 21: Static meters for active energy (classes 1 and 2)**
- **AS IEC 62053.31:2018 Electricity metering equipment - General requirements, tests and test conditions, Part 11: Metering equipment (IEC 62052-11:2020, MOD).**

My Design:

System:

- Master / slave split role architecture
- 3 or 5V system
- I2C (I^2C) comms
- > 1000 mps/rps
- Modular & expandable
- Web-browser based UI
- Small form factor
- Reliable and accurate



My Design:

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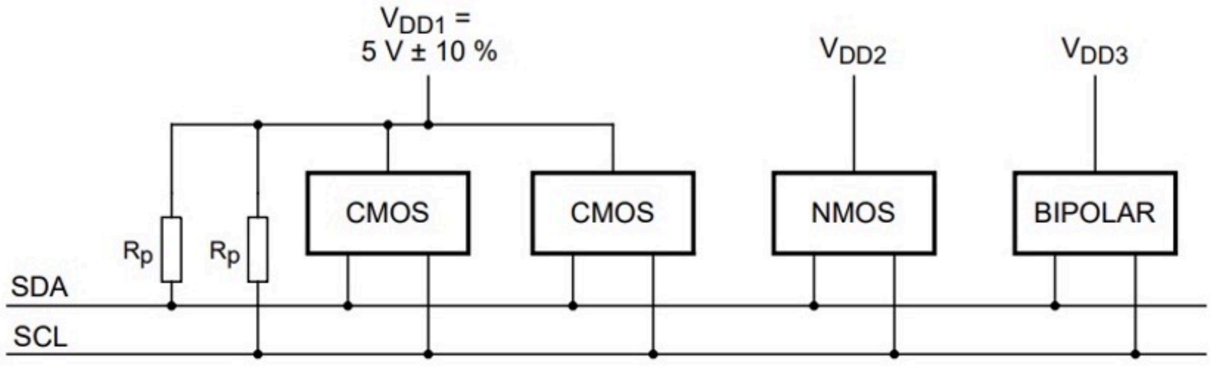
I2C Comms:

- Inter-Integrated Chip communications (I2C/ I^2C)
- 2 Wire system (SDA, SCL)
- Up to 128 devices
- Short distance communications
- Master / slave hierarchy
- Bandwidth: 100 kbit/s and 3.4 Mbit/s
- 3.3/ 5V level
- Requires pull-up resistors



My Design: Slave Device

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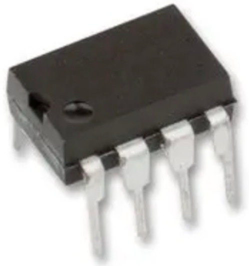
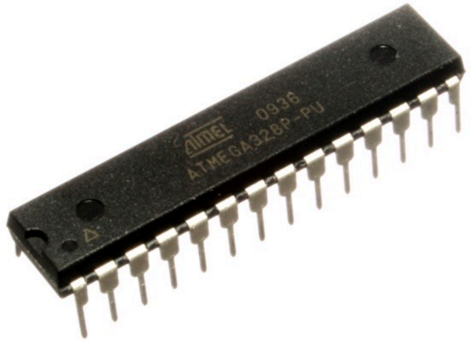
MCU Requirements:

- ADCs to measure AC current & Voltage.
- Digital I/Os for zero-crossing detection & hardware interrupts
- I2C Communication inbuilt
- Existing I2C library
- Sufficient speed (MHz) for 1000 readings/sec
- Sufficient memory for code
- Familiar, easy to use
- Accessible, cheap, well know & reliable
- Removeable package for flashing/programming

ATTiny85

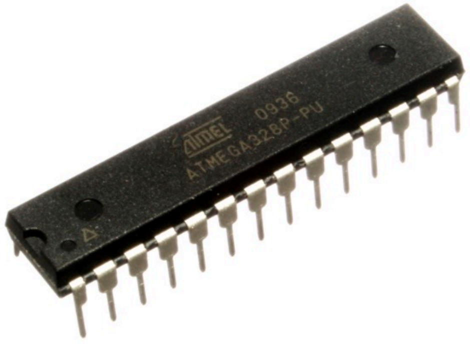


ATMEGA328P

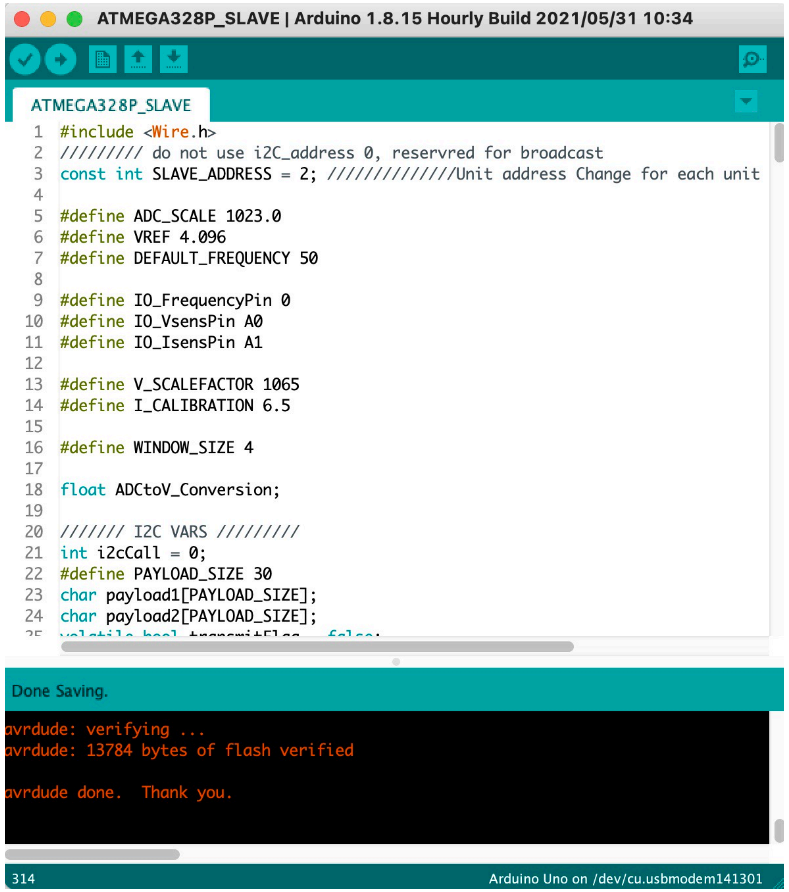


ATMEGA328P:

- CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture
- 32 KB ISP flash memory
- 1 KB EEPROM
- 2 KB SRAM
- 14 Digital I/O pins
- 6 Analogue I/O pins
- Three timer/counters
- 2 External H/W interrupts
- Serial UART
- I2C
- SPI
- 6-channel 10-bit ADC
- Operating voltage range of between 1.8V to 5.5V
- Arduino compatible



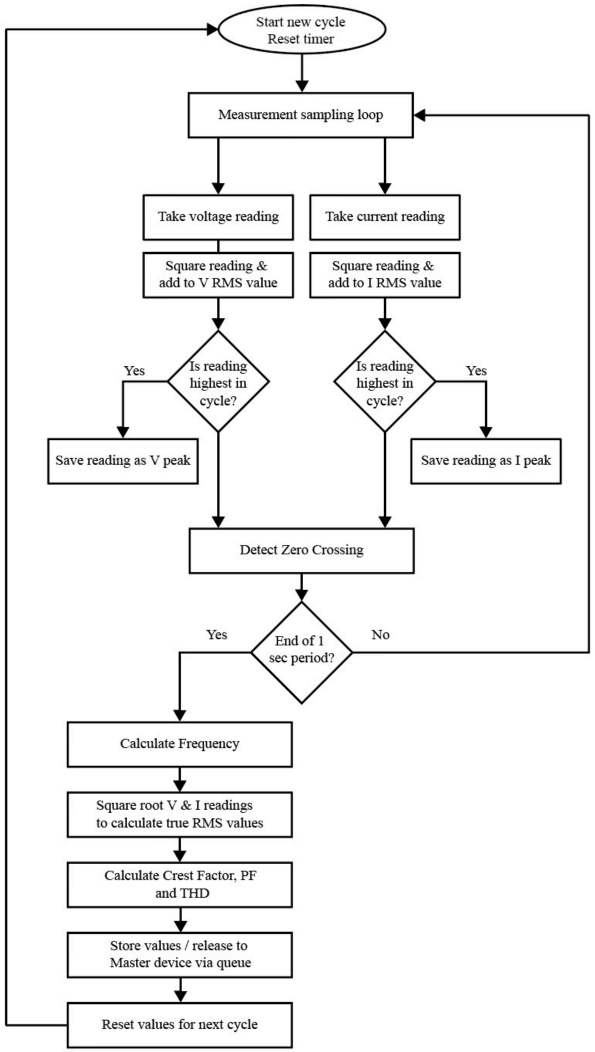
ATMEGA328P



Arduino IDE

My Design: Slave Device

Simplified Measurement Process Flow Chart



Process Requirements:

- Zero crossing detection
- Voltage measurement
- Current measurement
- Calculate Frequency, Vrms, Irms, Active/ Reactive/ Apparent Power, Power Factor, Current Crest Factor and Phase Angle.
- Potentially calculate THD
- Transmit values

My Design: Slave Device

Process Requirements:

- Zero crossing detection
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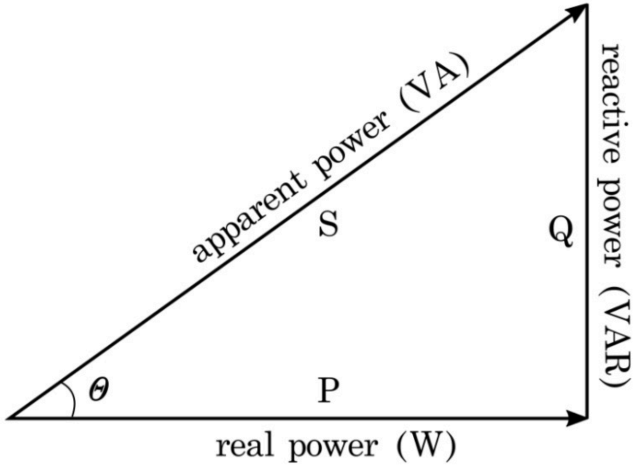
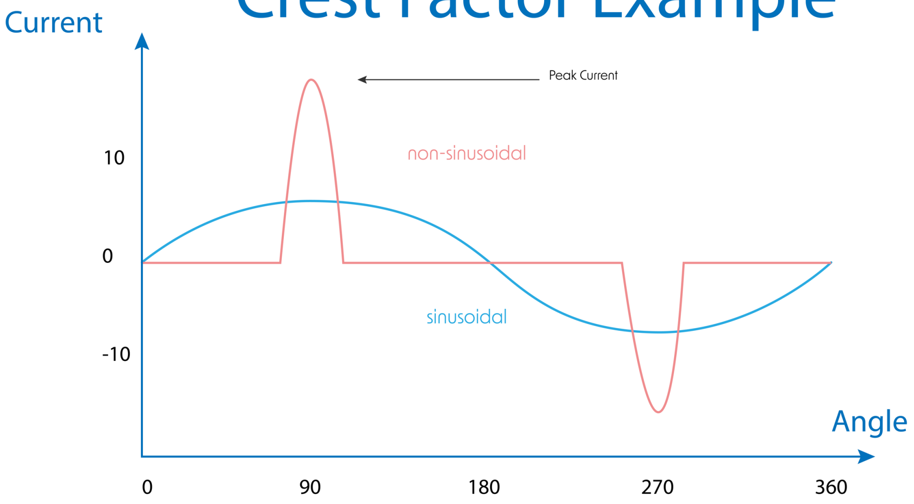


$$\cos\theta = \frac{P}{S}$$

$$\sin\theta = \frac{Q}{S}$$

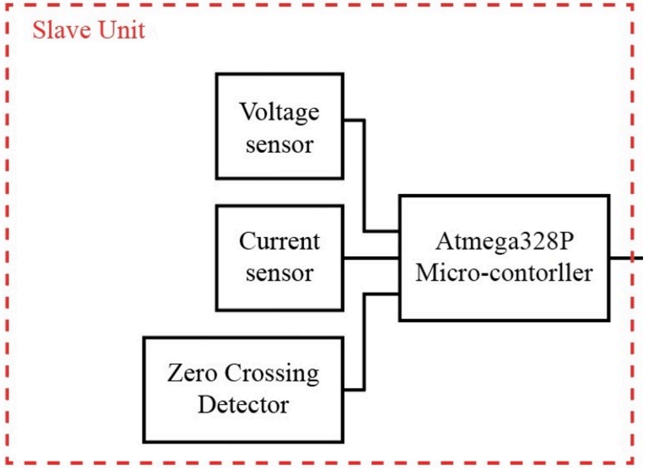
$$\tan\theta = \frac{Q}{P}$$

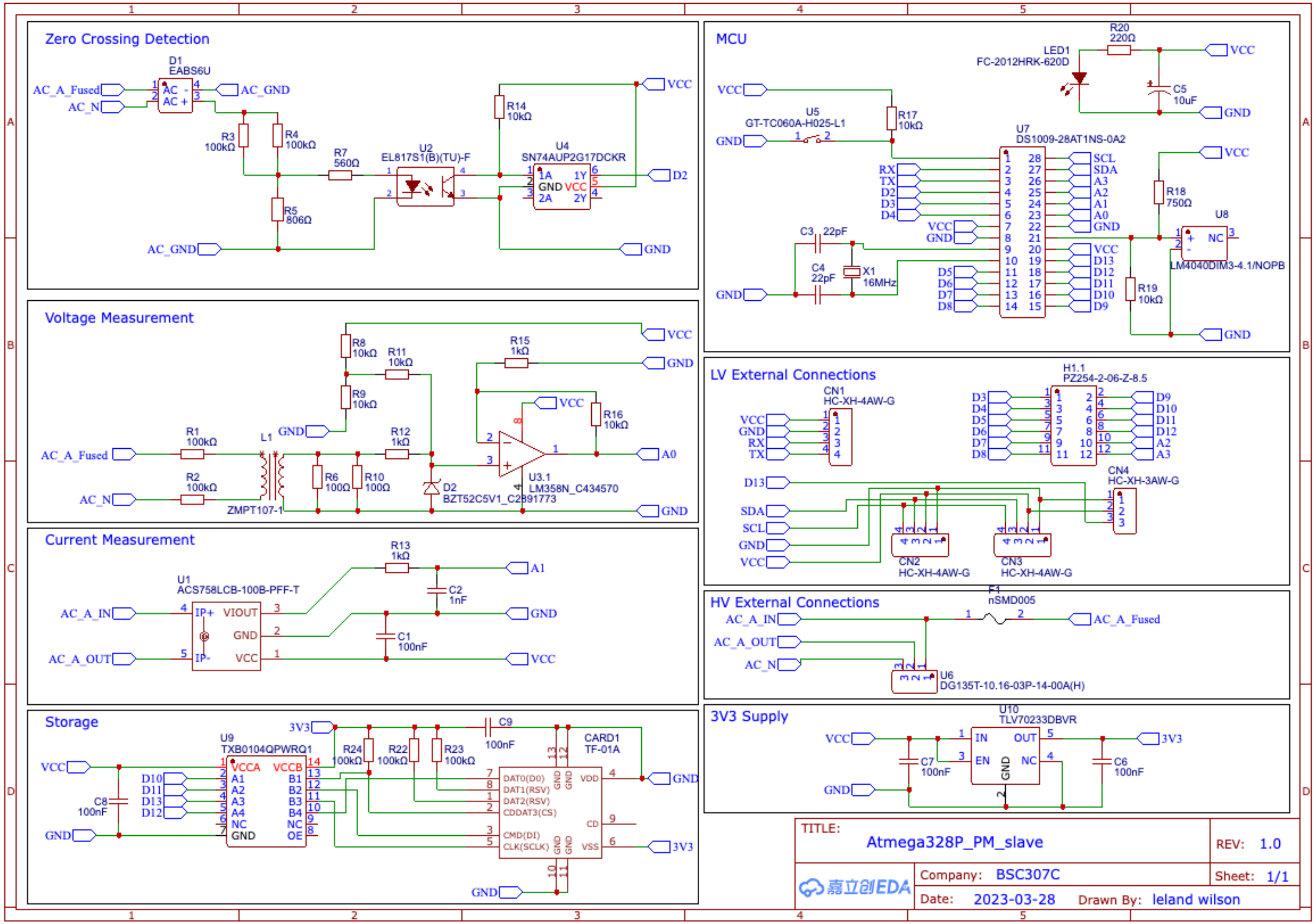
Crest Factor Example



My Design: Slave Device

Circuit Design:

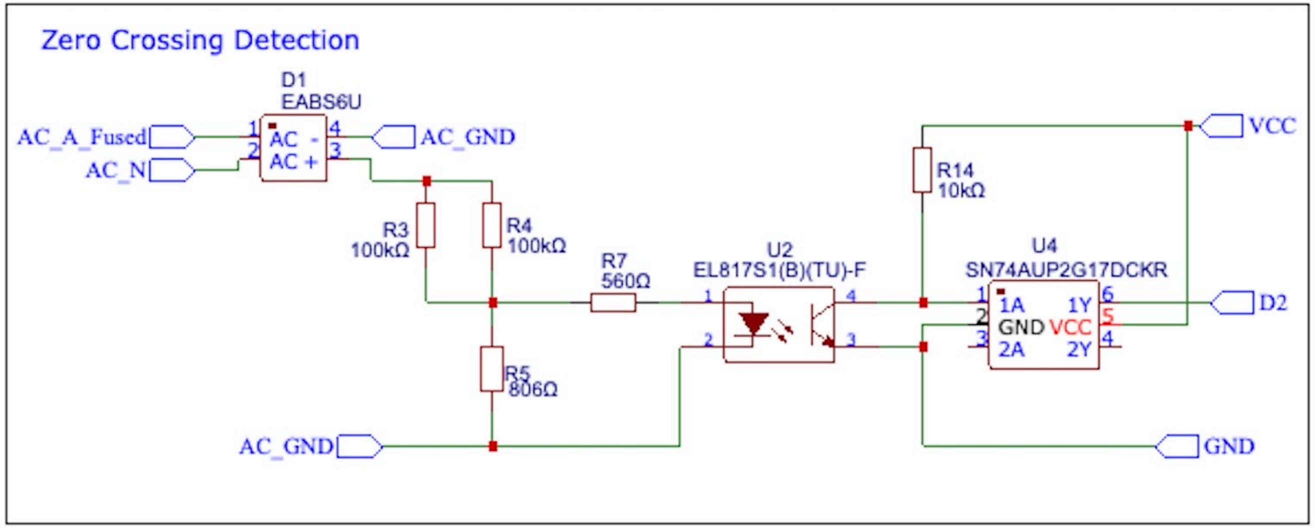


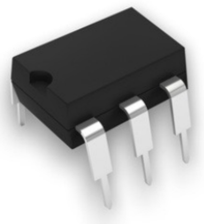


My Design: Slave Device

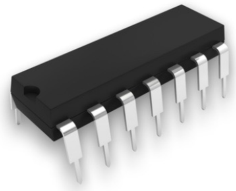
Zero-crossing detection circuit:

- Bridge rectifier
- Optocoupler
- Schmitt Trigger

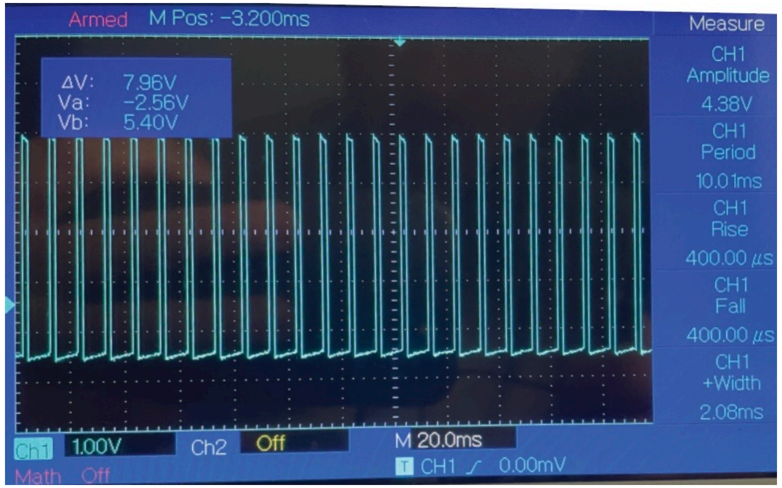


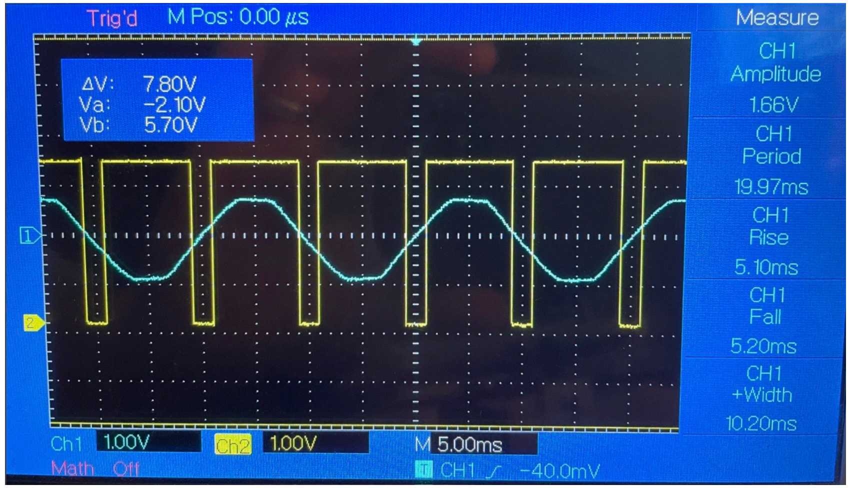


4N25 Optocoupler



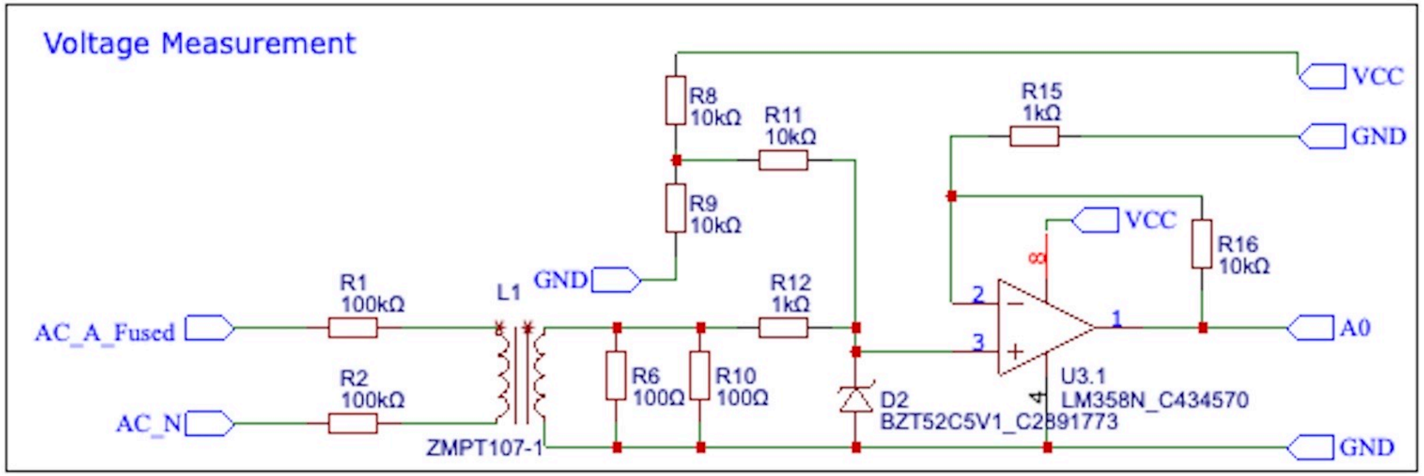
74C14 Schmitt-Trigger



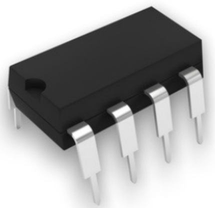


Voltage measurement circuit:

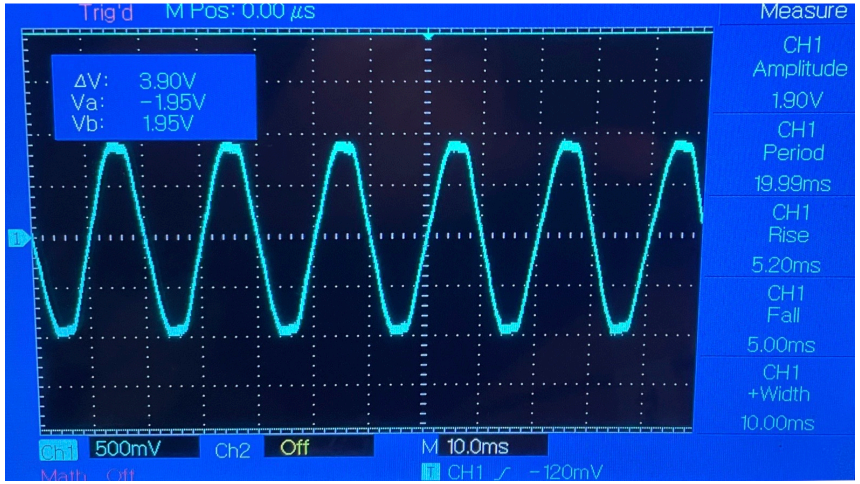
- Voltage CT (<2mA)
- Summing OPAMP



ZMPT1071-B



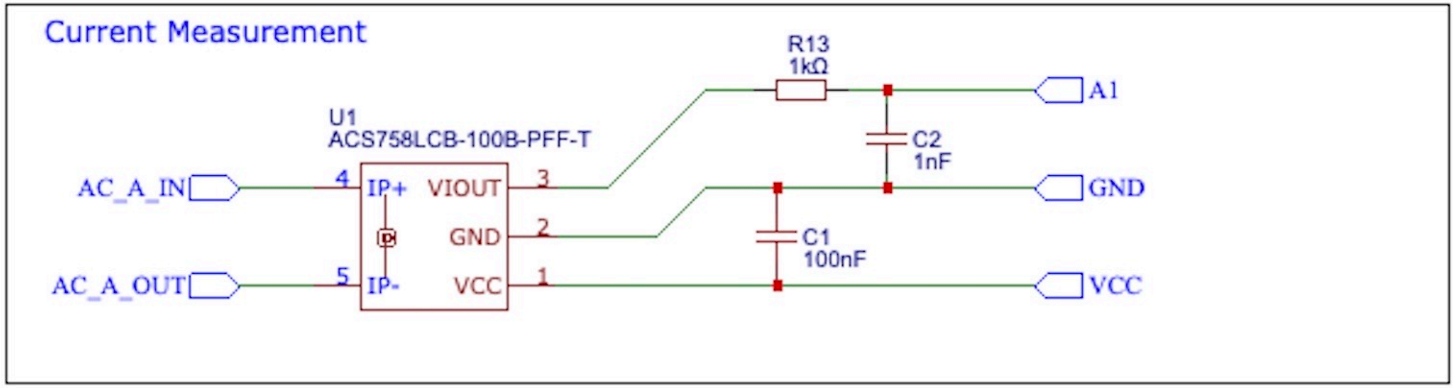
LM358 OPAMP



My Design: Slave Device

Current measurement circuit:

- ACS758 Current hall effect IC
- Bypass caps



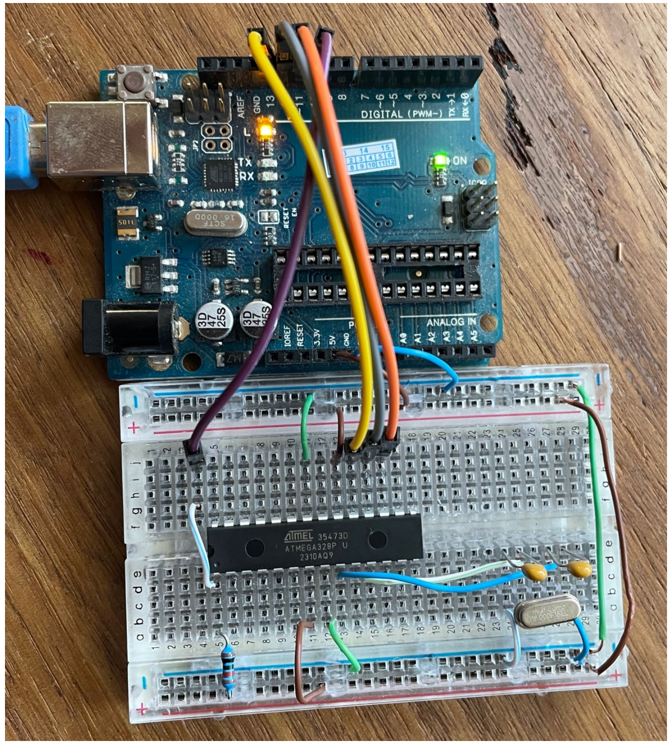
ACS758-LCB-050B

Selection Guide

Part Number [1]	Package		Primary Sampled Current, I_P (A)	Sensitivity Sens (Typ.) (mV/A)	Current Directionality	T_{OP} (°C)	Packing
	Terminals	Signal Pins					
ACS758LCB-050B-PFF-T	Formed	Formed	±50	40	Bidirectional		
ACS758LCB-050U-PFF-T	Formed	Formed	50	60	Unidirectional		
ACS758LCB-100B-PFF-T	Formed	Formed	±100	20	Bidirectional	–40 to 150	
ACS758LCB-100B-PSF-T	Straight	Formed	±100	20	Bidirectional		
ACS758LCB-100U-PFF-T	Formed	Formed	100	40	Unidirectional		
ACS758KCB-150B-PFF-T	Formed	Formed	±150	13.3	Bidirectional		
ACS758KCB-150B-PSF-T	Straight	Formed	±150	13.3	Bidrectional		
ACS758KCB-150B-PSS-T	Straight	Straight	±150	13.3	Bidirectional	–40 to 125	34 pieces per tube
ACS758KCB-150U-PFF-T	Formed	Formed	150	26.7	Unidirectional		
ACS758KCB-150U-PSF-T	Straight	Formed	150	26.7	Unidirectional		
ACS758ECB-200B-PFF-T	Formed	Formed	±200	10	Bidirectional		
ACS758ECB-200B-PSF-T	Straight	Formed	±200	10	Bidirectional		
ACS758ECB-200B-PSS-T	Straight	Straight	±200	10	Bidirectional	–40 to 85	
ACS758ECB-200U-PFF-T	Formed	Formed	200	20	Unidirectional		
ACS758ECB-200U-PSF-T	Straight	Formed	200	20	Unidirectional		

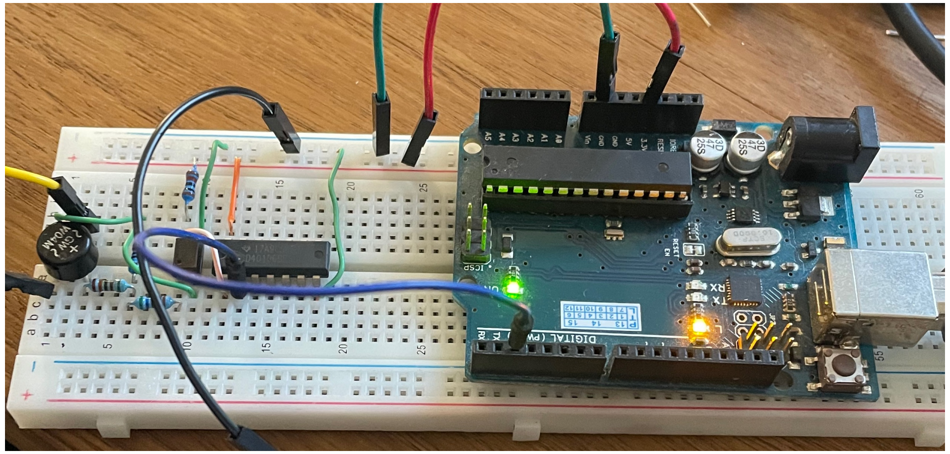
My Design: Slave Device

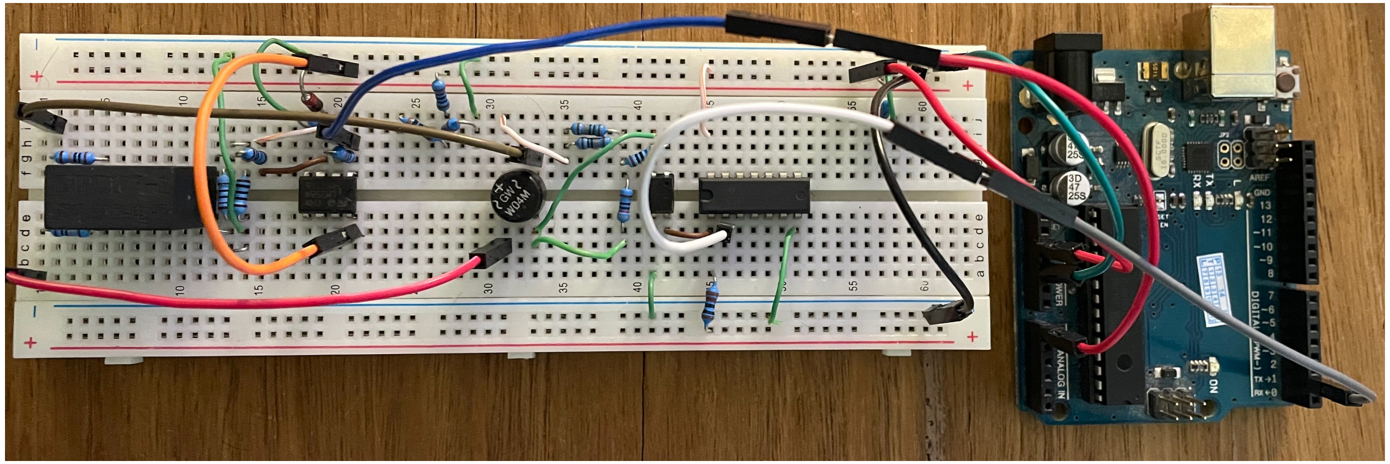
Breadboard testing:



Flashing bootloader & firmware

Voltage & Zero-crossing testing

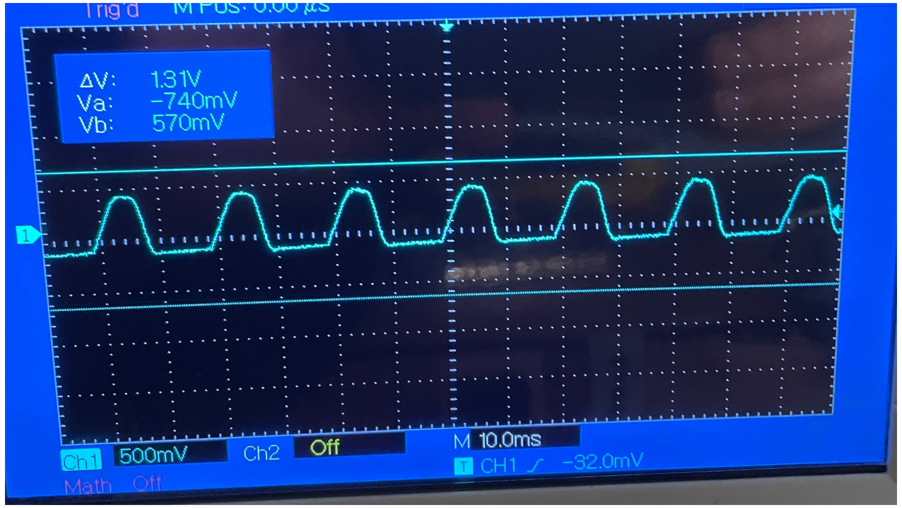


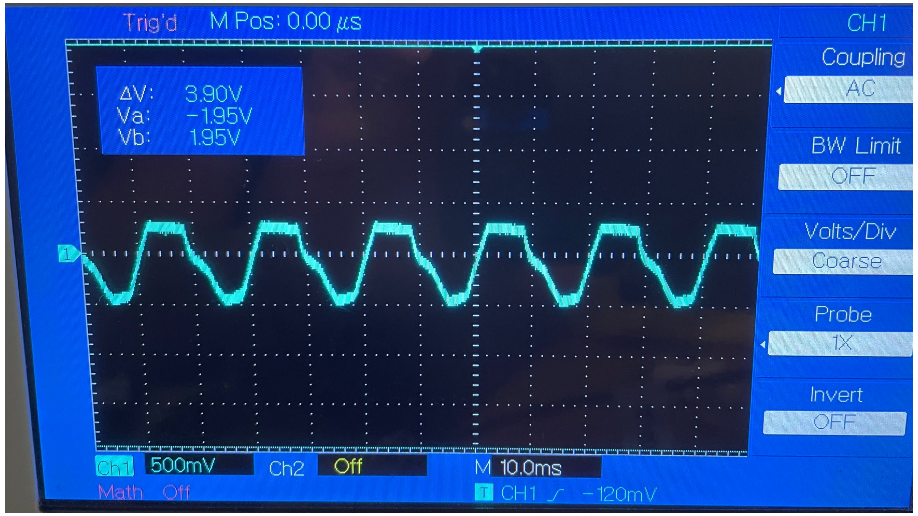


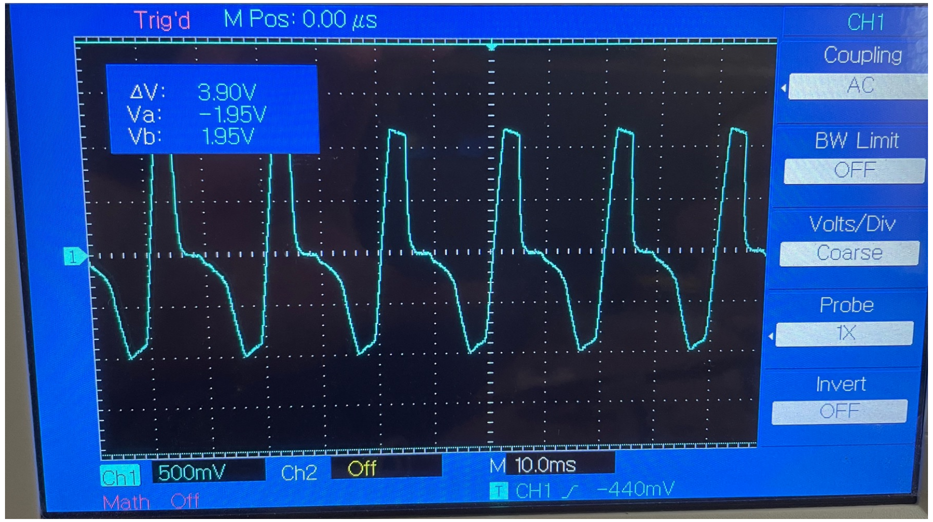
My Design: Slave Device

Engineering Institute of Technology.

Issues:

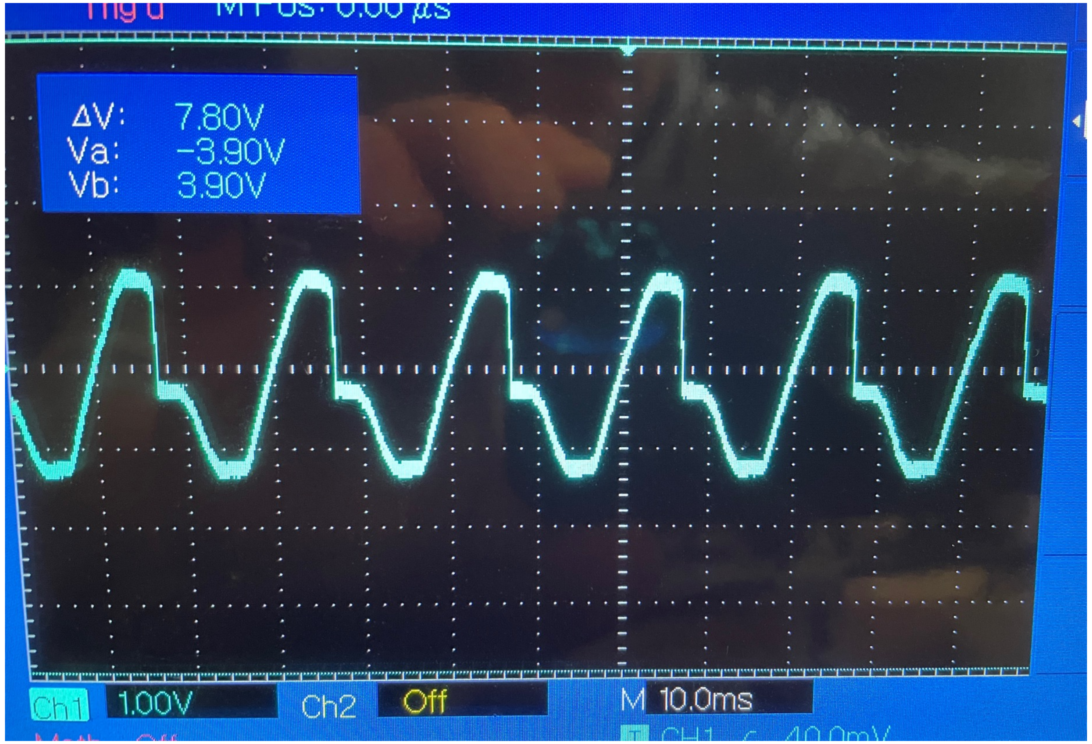




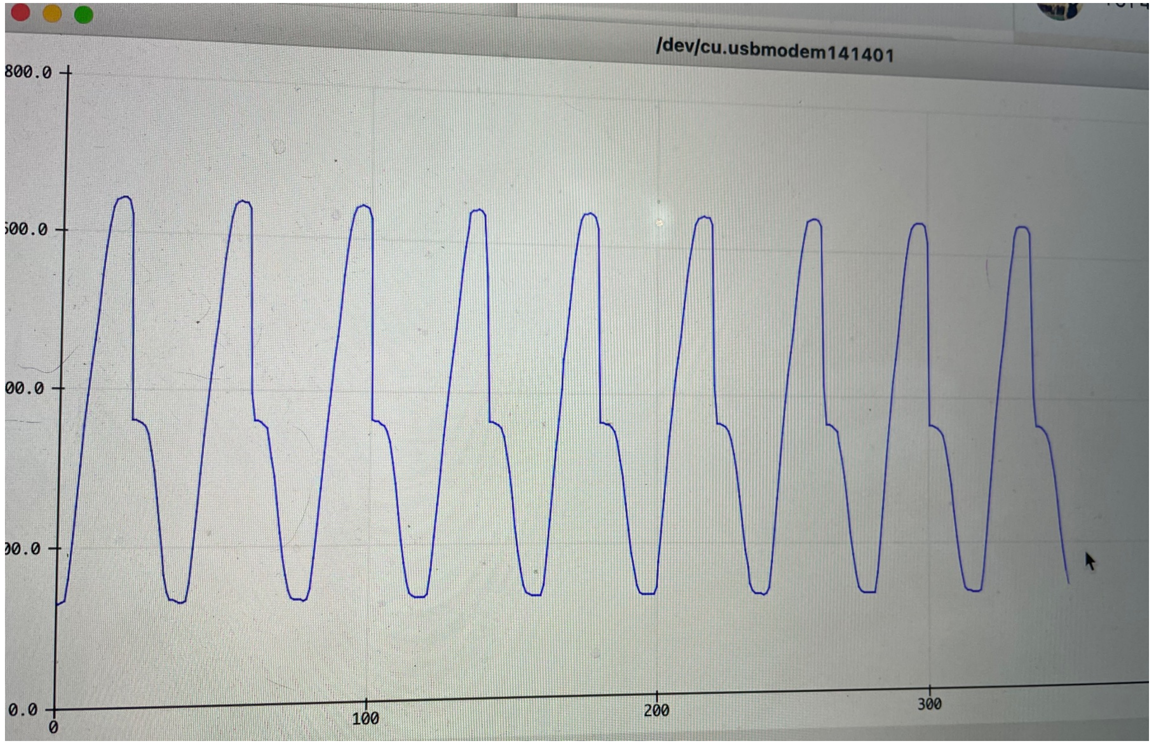


My Design: Slave Device

Issues:



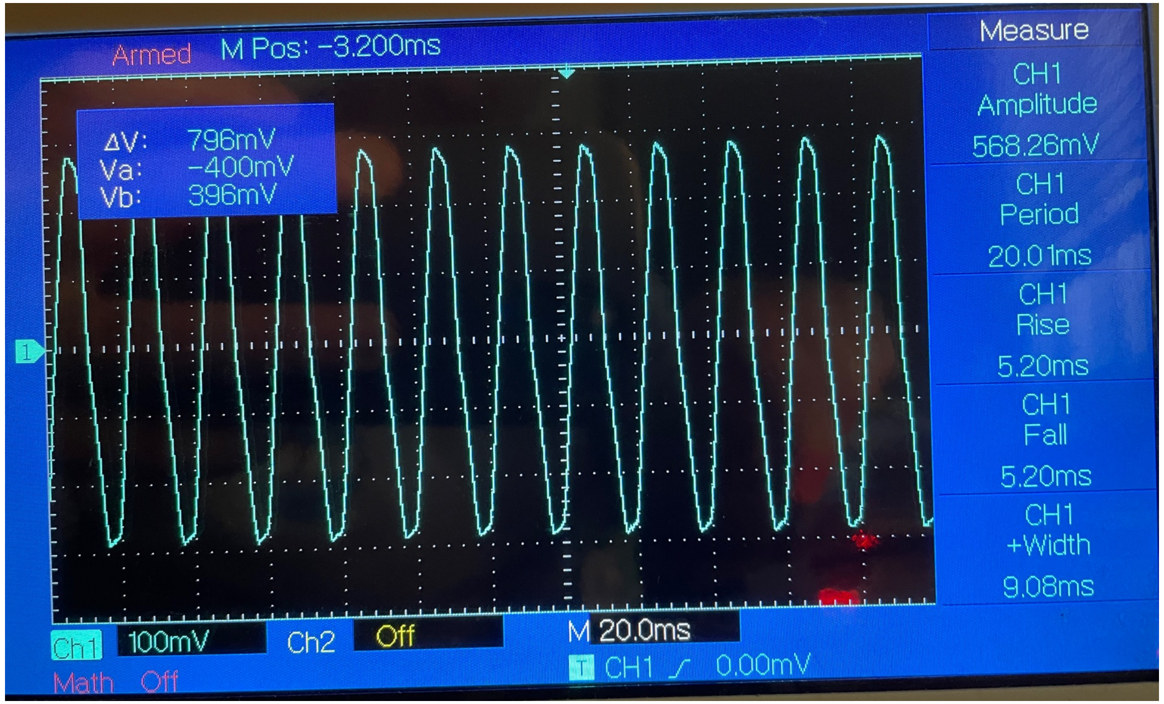
Deformed Voltage Measurement: Scope



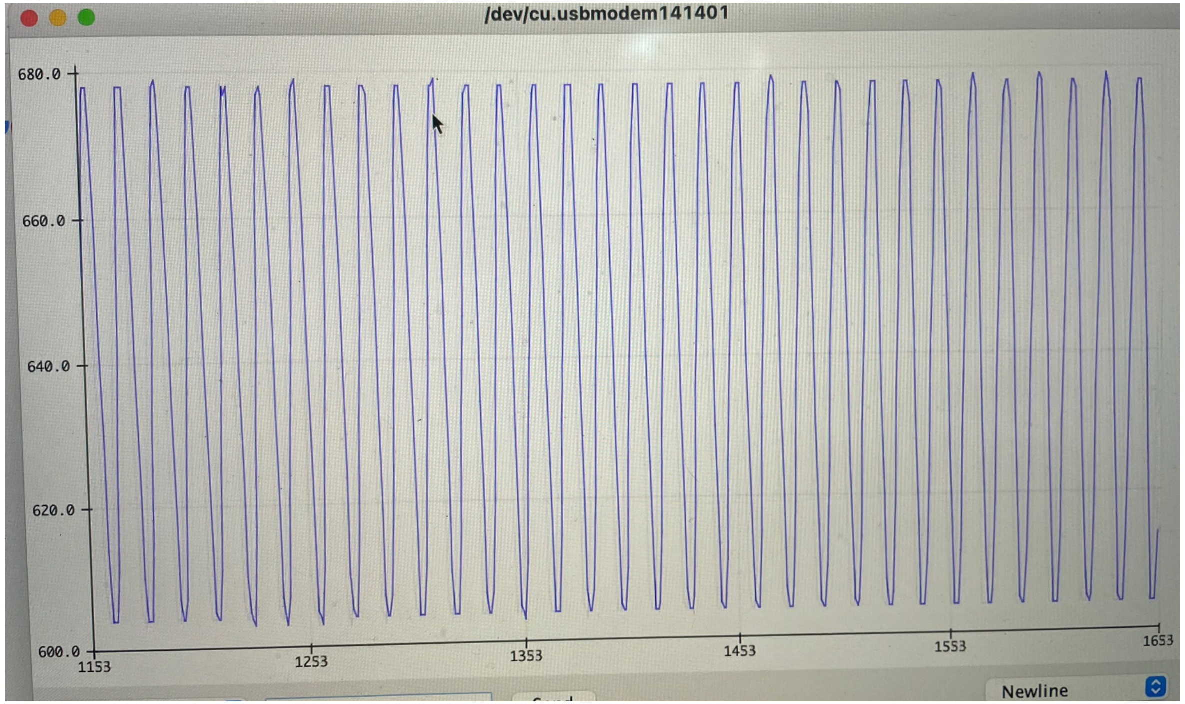
Deformed Voltage Measurement: Slave device

My Design: Slave Device

Working Output:



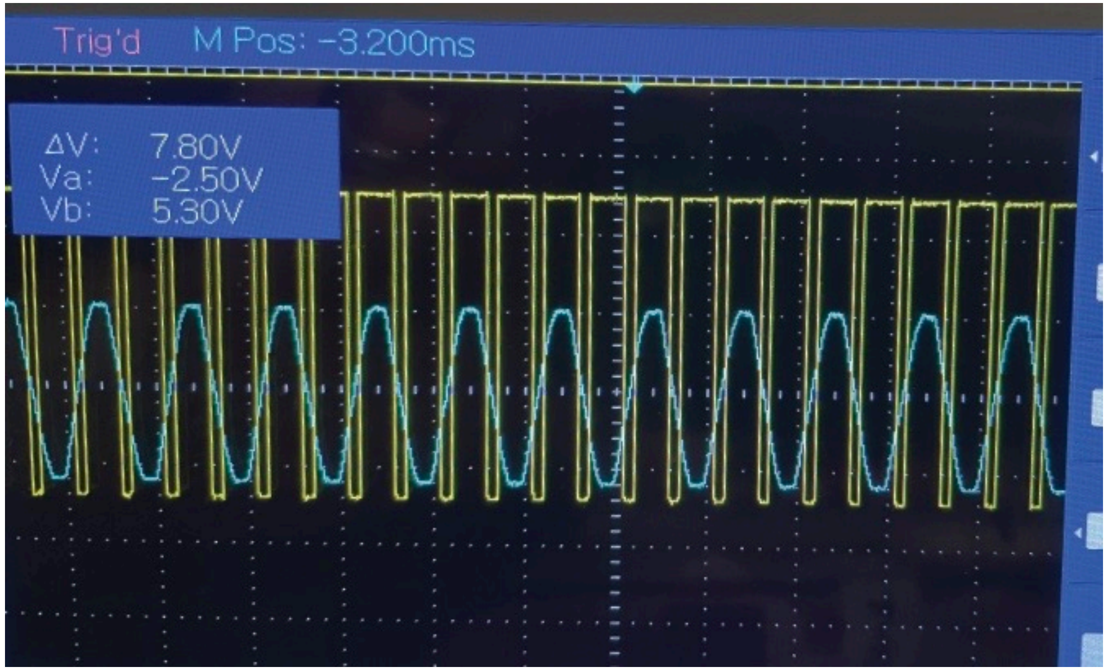
Voltage Measurement: Scope

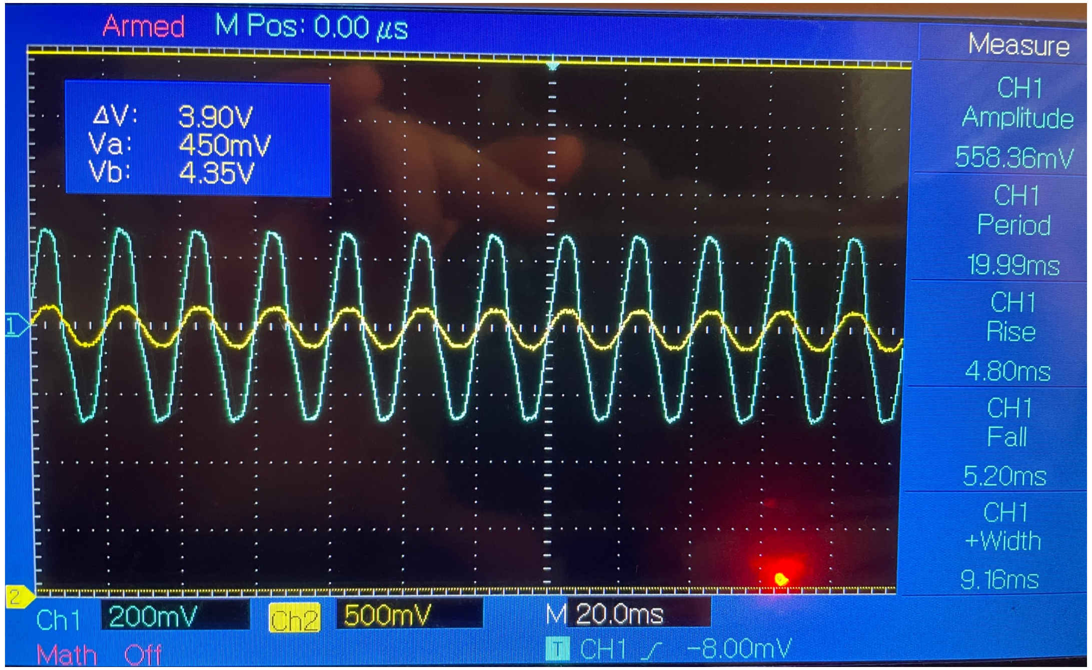


Voltage Measurement: Slave device

My Design: Slave Device

Working output: Clean & Correct



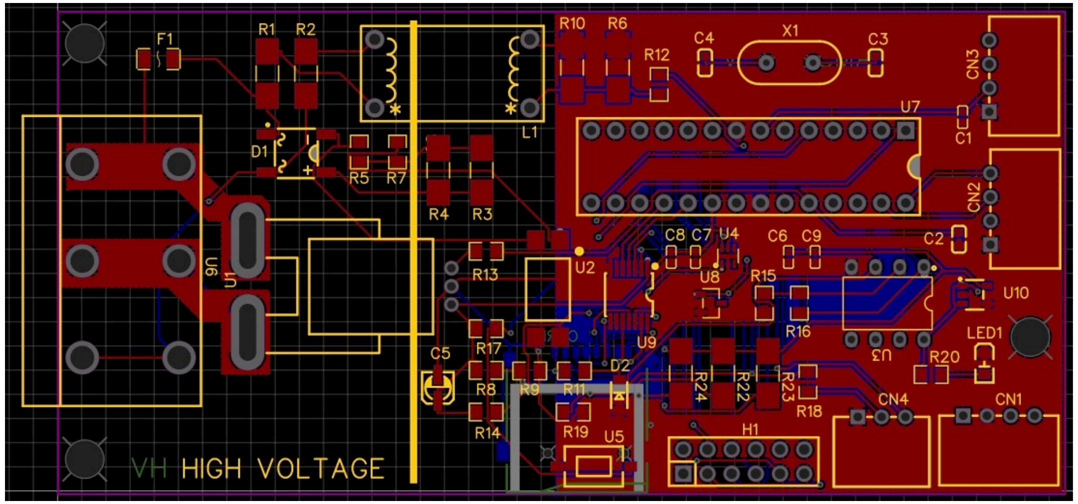


Voltage & Frequency Measurement

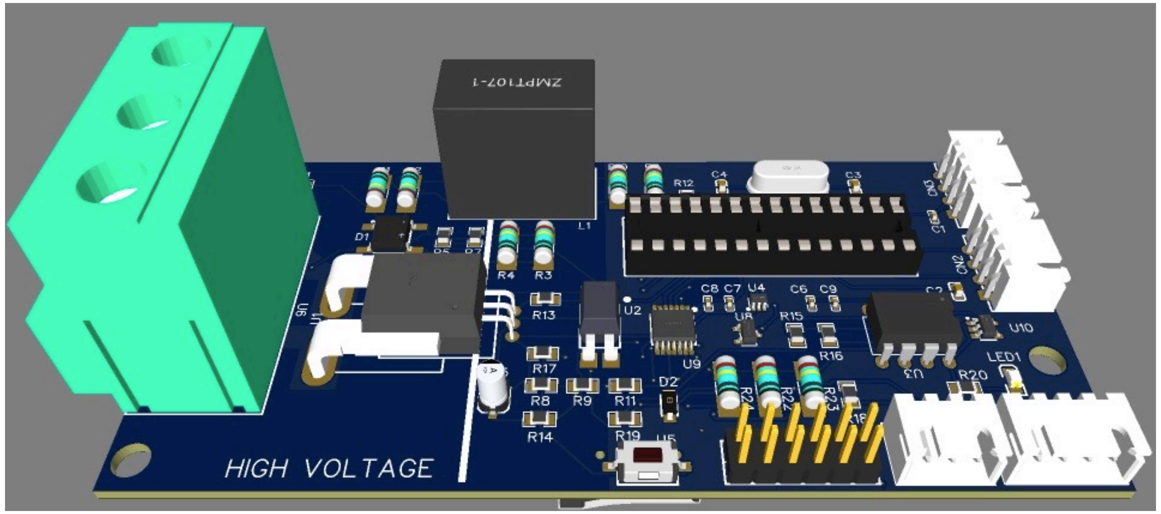
Voltage & Current Measurement

My Design: Slave Device

Slave Unit Design:



PCB Layout



3D Render

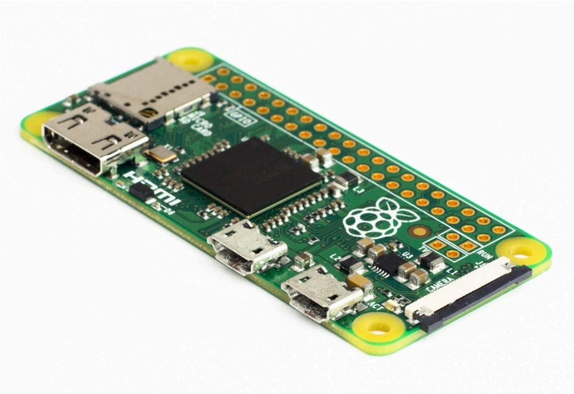
My Design: Master Device

Master Device options:

Raspberry Pi 3B:
-Linux SBC

Onion Omega 2+:
-Linux SOC

Raspberry Zero W
-Linux SBC



ESP32:
-RIOT SOC

My Design: Master Device

Master Device options:

Raspberry Pi 3B:
- Quad Core 1.2GHz Broadcom BCM2837 64bit CPU
- 1GB RAM
- BCM43438 wireless LAN
- Broadcom GPU
- Gigabit Ethernet, 2.4GHz and 5GHz Wi-Fi
- Bluetooth 4.2, Bluetooth Low Energy (BLE)
- Dimensions: 85mm x 56mm x 17mm.

Onion Omega 2+:
- Single Core 580Mhz Mediatek MT7688 MIPS CPU
- 256 MB DDR2 DRAM
- No GPU
- Wireless LAN & I/O interface for Eth LAN
- No Bluetooth
- Dimension: 73mm x 44mm

Raspberry pi Zero W:
- Single Core 1GHz ARM11 BCM2835 CPU
- 512MB of RAM
- VideoCore IV GPU
- Wireless LAN
- Bluetooth 4.1, and Bluetooth Low Energy (BLE)
- Dimensions: 65mm x 30mm x 5mm

ESP32:
- Dual Core 160Mhz Tensilica Xtensa LX6 CPU
- 520KB SRAM, 448KB ROM
- No GPU
- Wireless LAN
- Bluetooth
- Dimension 18mm x 25.5mm x 3.1mm

My Design: Master Device

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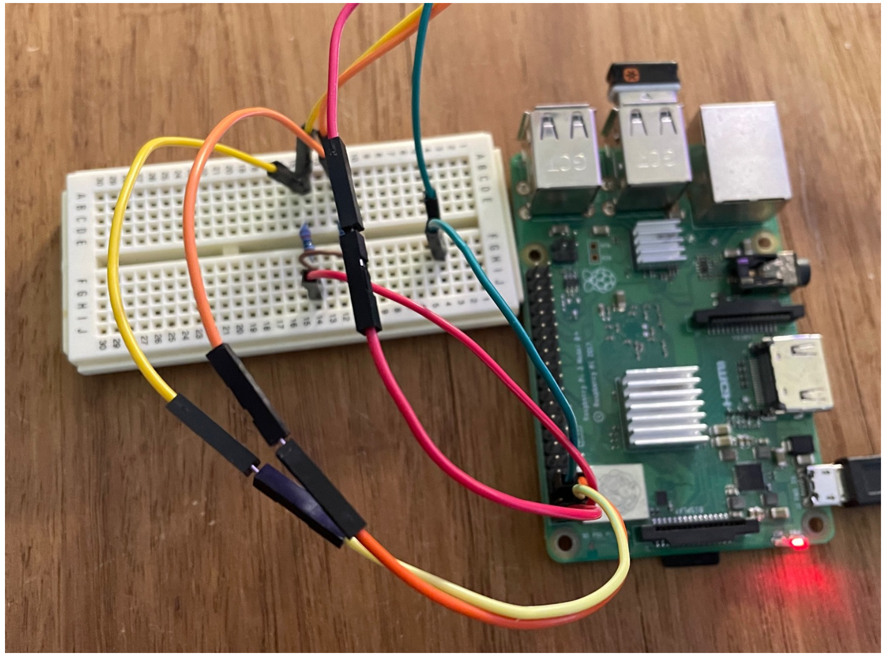
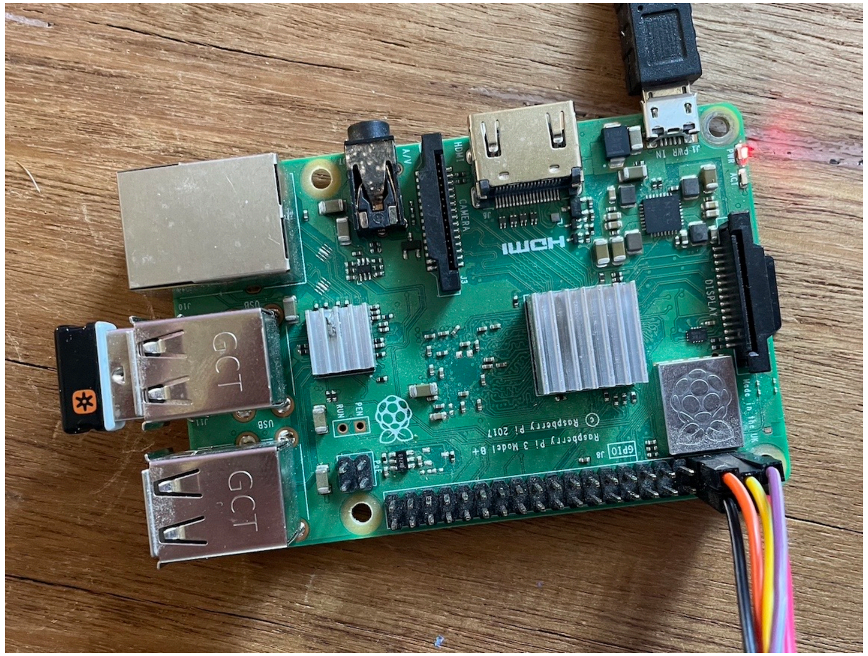
Master Device:



Raspberry Pi 3B w/ pull up resistors



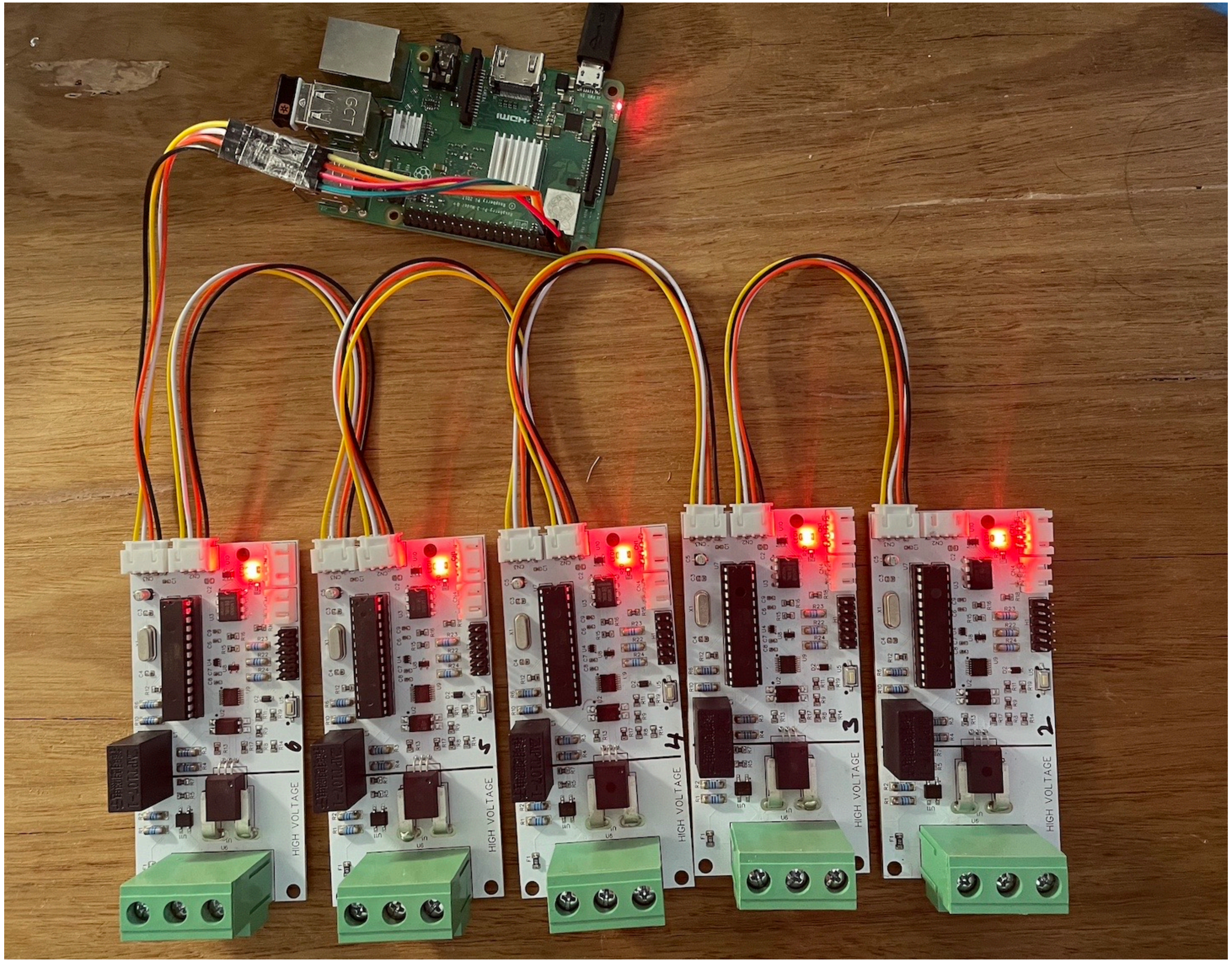
Raspberry Pi 3B inline resistors

Testing:

Completed System:

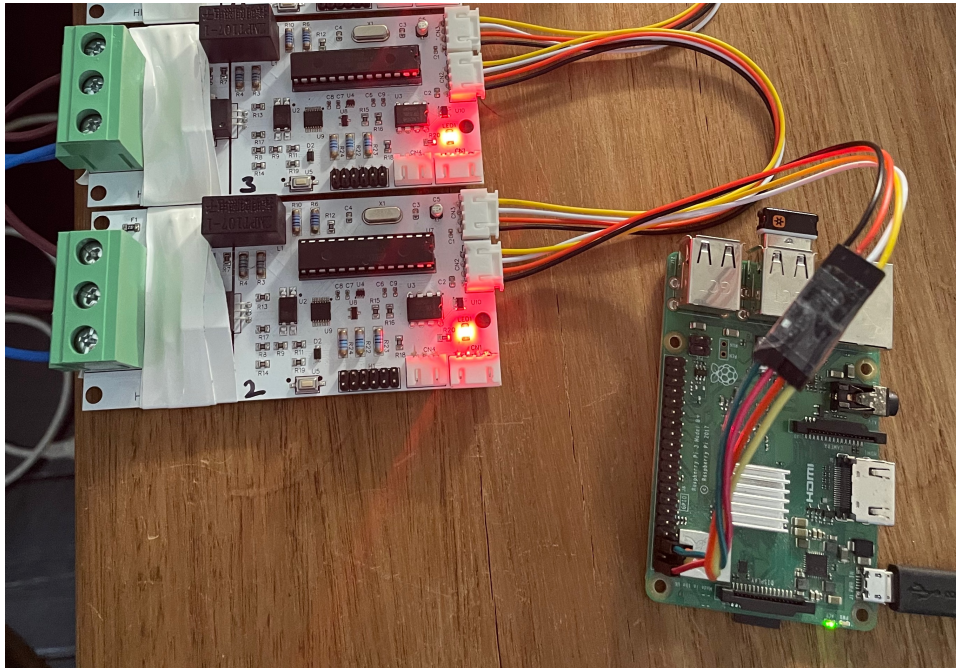
-1 Master

-5 Slaves



Testing:

Slave operation and communications:



Frequency: 50 Hz
Samples: 1825
RMS V: 281.55 V
RMS I: 2959.08 mA
CCF: 1.27
Theta: 18.00 deg
Apparent P: 833.14 VA
Real P: 792.36W
Reactive P: 257.45 VAR
PF: 0.95

<002> [50,1837,25815,03116,131,0000,0000804,0000804,0000000,100]
<003> [50,1835,25850,03086,125,1800,0000797,0000758,0000246,095]
<004> [50,1841,25949,03036,131,0000,0000787,0000787,0000000,100]
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<006> [50,1841,25835,03035,125,0000,0000784,0000784,0000000,100]

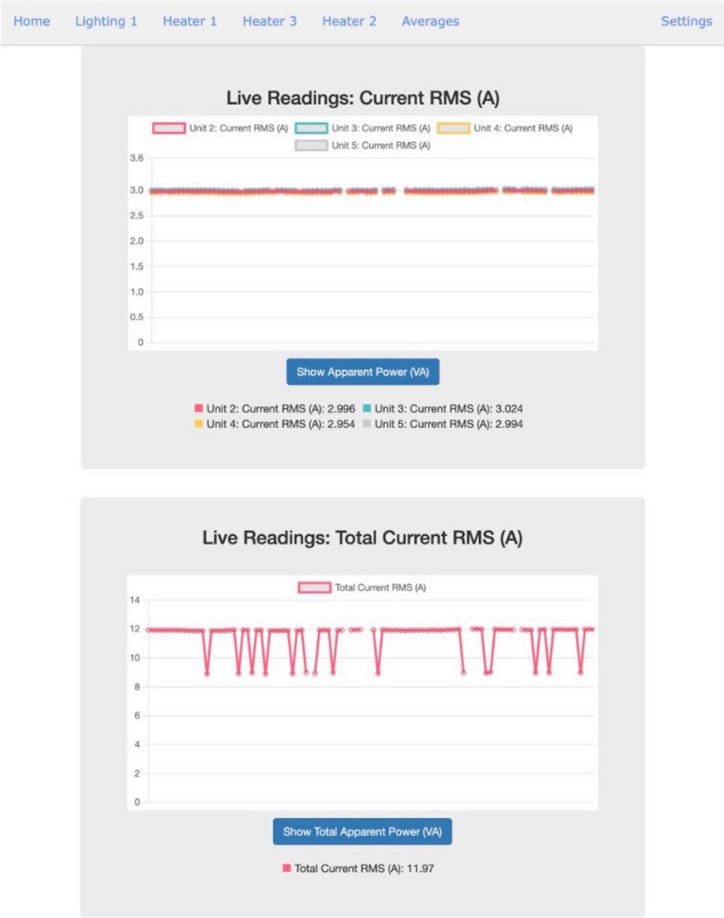
<002> [50,1840,25835,03115,131,1800,0000804,0000765,0000248,095]
<003> [50,1837,25755,03081,129,0000,0000793,0000793,0000000,100]
<004> [50,1841,25844,03033,126,-180,0000784,0000745,-000243,095]
<005> [50,1841,26105,03059,126,0000,0000798,0000798,0000000,100]
<006> [50,1843,25880,03035,122,1800,0000785,0000747,0000242,095]

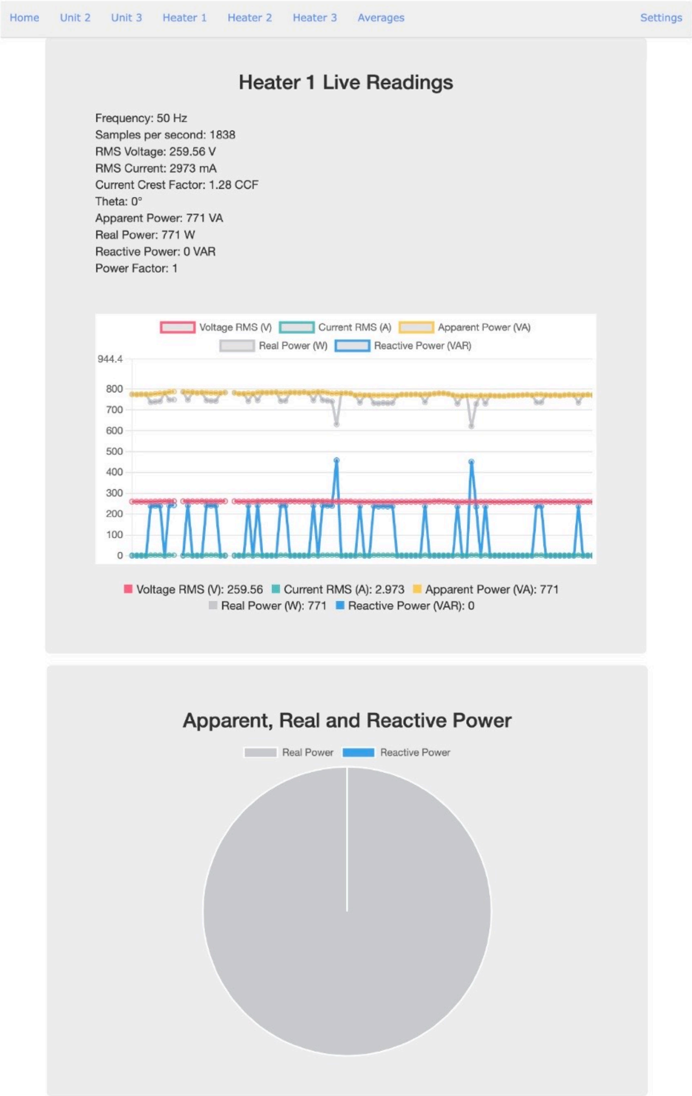
<002> [50,1838,25645,03115,125,0000,0000799,0000799,0000000,100]
<003> [50,1840,25764,03078,130,0000,0000790,0000752,0000000,100]
<004> [50,1840,25815,03029,127,0000,0000782,0000782,0000000,100]
<005> [50,1840,26058,03058,127,0000,0000796,0000796,0000000,100]
<006> [50,1839,25969,03031,124,0000,0000787,0000787,0000000,100]

<002> [50,1835,25715,03110,126,0000,0000799,0000799,0000000,100]
<003> [50,1837,25719,03074,132,1800,0000793,0000752,0000244,095]
<004> [50,1841,25904,03031,127,1800,0000785,0000746,0000242,095]
<005> [50,1840,26173,03059,127,1800,0000800,0000761,0000247,095]
<006> [50,1841,25955,03030,124,1800,0000786,0000748,0000243,095]

Testing:

User interface:



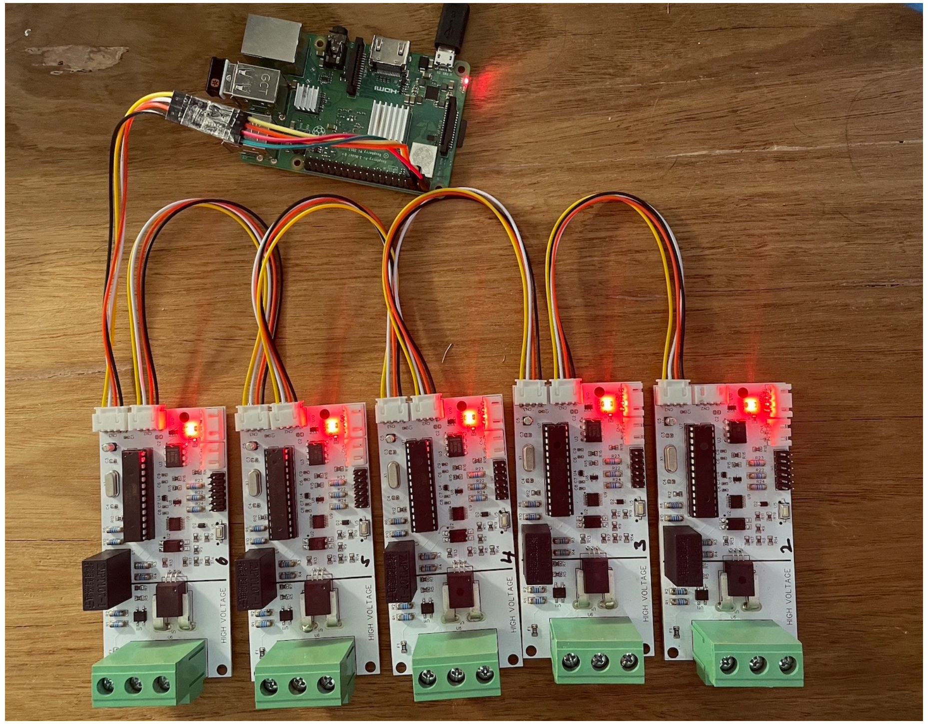


Conclusions:

Objectives:

To research, design and manufacture a modular power monitoring system capable of measuring and logging:

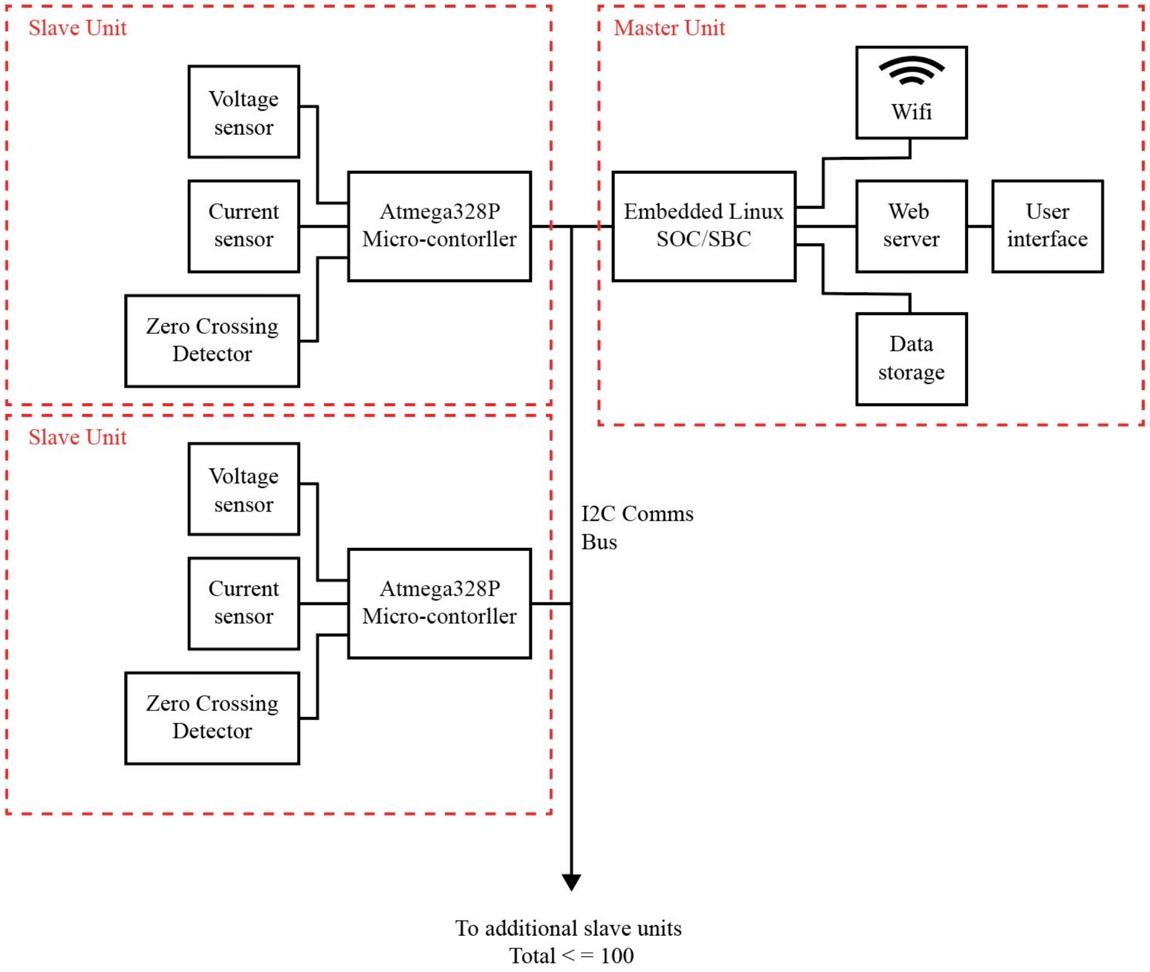
- ✅ Current
- ✅ Voltage
- ✅ Frequency
- ✅ Real, Reactive & Apparent Power
- ✅ Current Crest Factor
- ✅ Power Factor
- ? Up to 100 circuits simultaneously
- ✅ Web-based User Interface



Conclusions:

Key Lessons:

- Researching of ICs and components essential.
- Breadboard testing is important!
- Thorough testing of all functional circuits.
- Thorough testing of all functional software operations
- KISS + clear goals and timeline.
- Iterative design.
- UART Terminal output extremely helpful.
- Testing points on PCB
- Crimping JST cables is annoying!



Going Further:

Engineering Institute of Technology.

System/ Design Improvements:

- Make slave device smaller
- Design a case/ housing
- Smaller slave MCU package
- Different slave MCU w/ bigger I2C buffer
- Current zero-crossing detection circuit for h/w interrupt
- Add provision for separate voltage CT coil
- Add provision for mains supply & solar within UI
- Try different master device i.e; Onion Omega or ESP32
- Improve UI & add more features