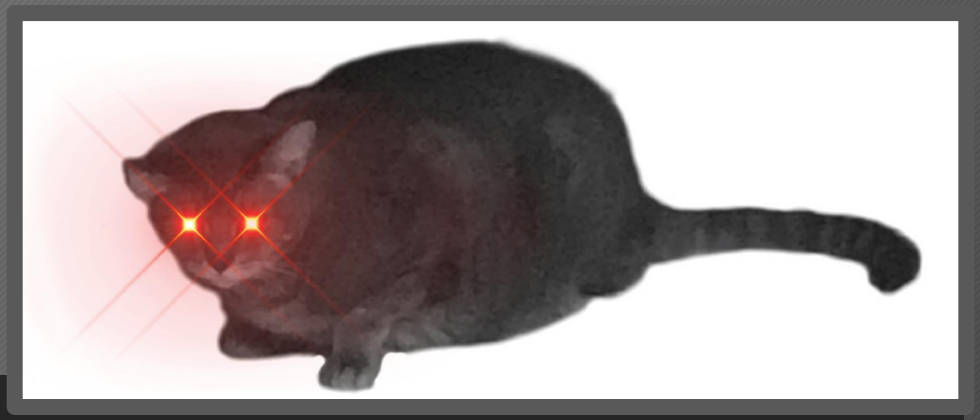


P.H.A.T.C.A.T.

Group 6

John DeFour, Daniel Hobbs, Ed Millet, & Brett Ross

What is PHATCAT?

Phasor
Harmonic
Analysis for
Transformer
Condition
Assessment &
Telemetry

Wait What?

Power Transformers need Protection

In industry, ‘Microprocessor Relays’:

- Read power system analogs
- Signal Processing & Algorithms detect faults
- Support system telemetry
- Much more!

Why PHATCAT?

- Some authors in this field
- A variety of disciplines involved
- Great need for education in this field

Objectives

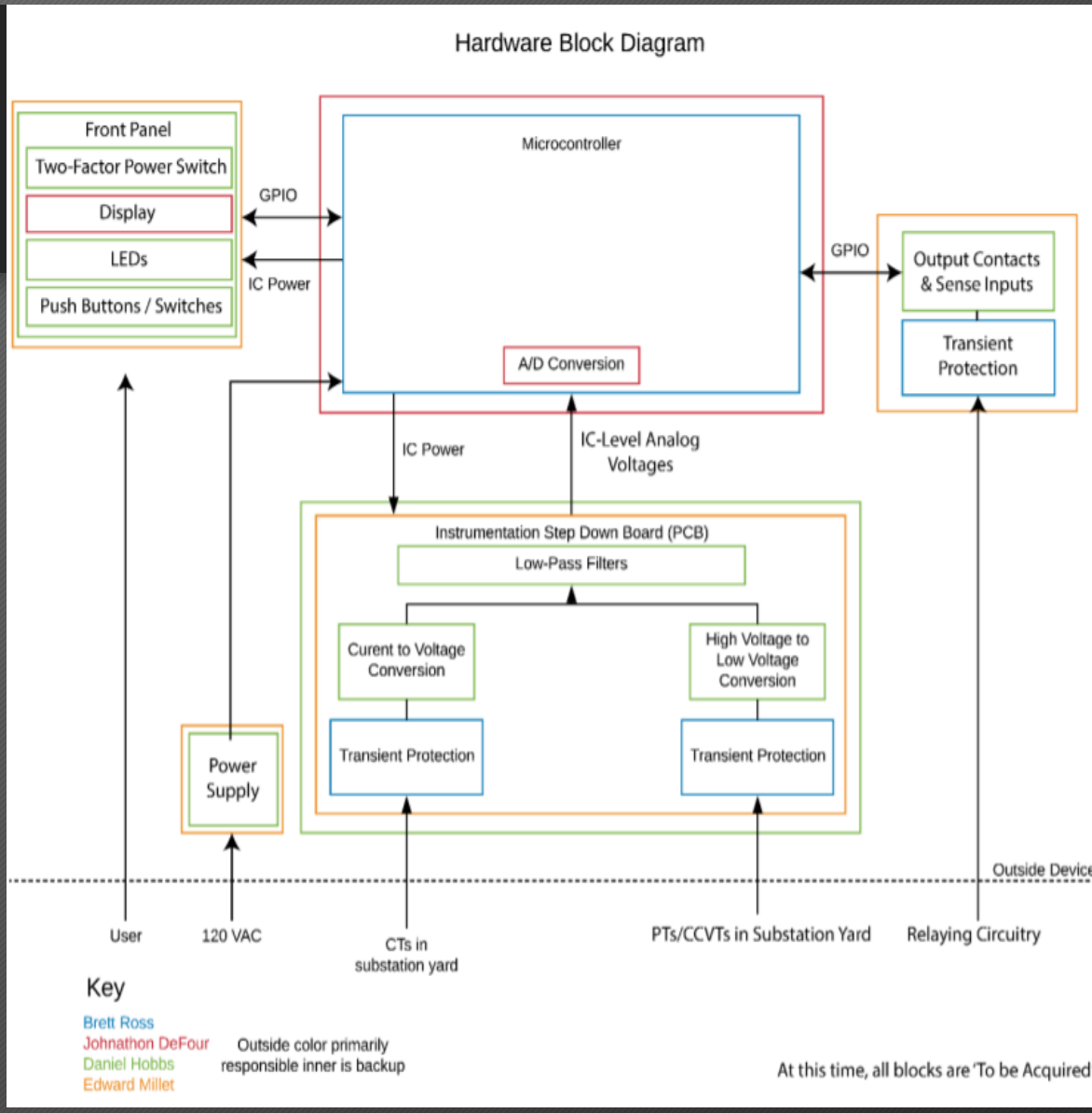
- Primary Goal: Detect Faults in the Grid
- Differentiate between different kinds, take appropriate action
- Support user Customization
- Provide user information

Key Specifications

- 5% Accuracy for Phasors
- 2 Cycle Trip Time
- For use in 45Hz to 65Hz Systems
- Measure up to 5th Harmonic
- Support standard protection functions
  - Time Overcurrents, Restrained Differential, Overexcitation, etc.
- Support external 125VDC logic circuitry

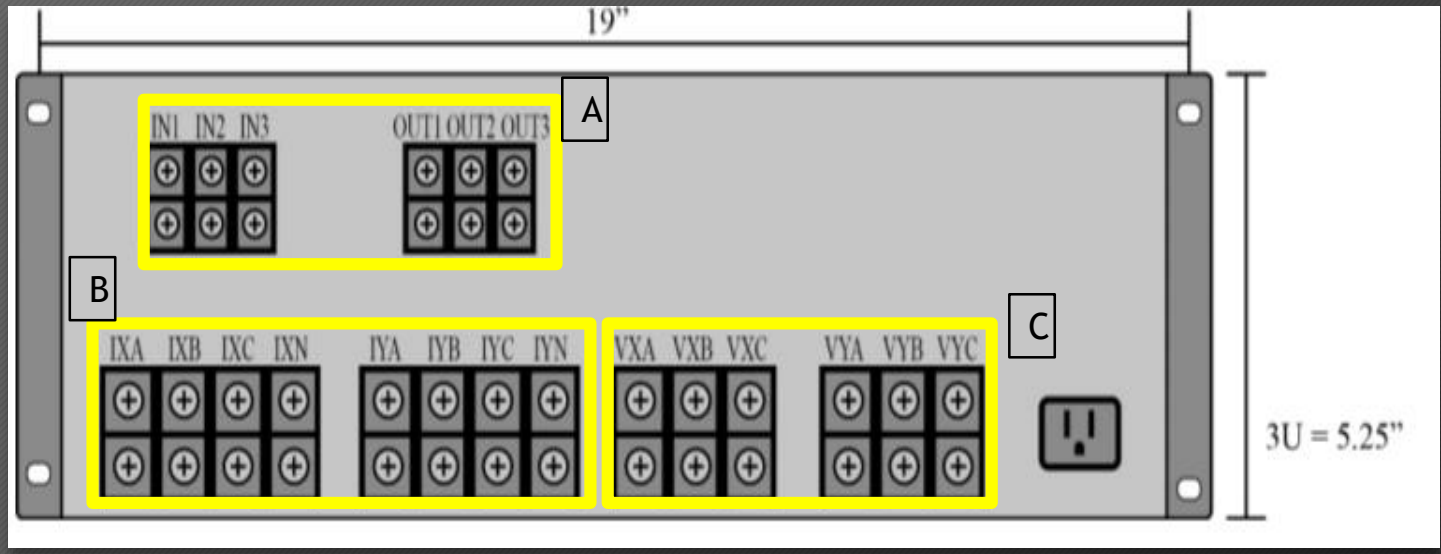
Hardware Functional Block Diagram

- Front panel with LCD display for information and LED push buttons for interaction.
- Off the shelf power supply
- Instrumentation step down board with analog inputs
- Output contacts and sense inputs
- ADC conversion and MCU



The Rear of PHATCAT

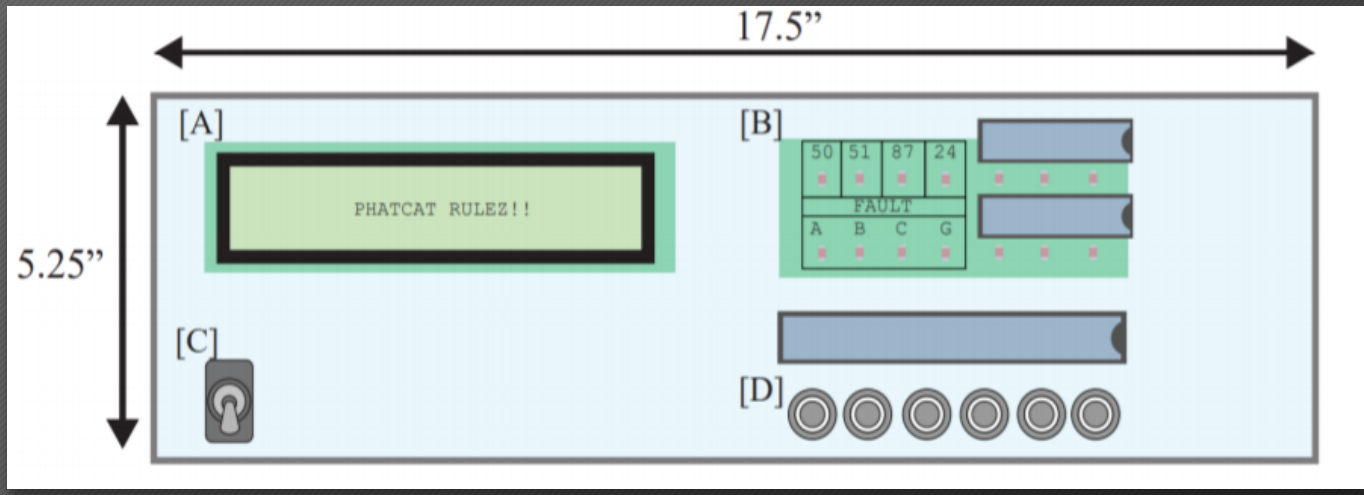
- Screw terminals for connections
- The sense inputs and output contacts
- Instrumentation step down connections for current and voltage inputs
- The main power source will also be connected



- A – Sense inputs
- B – Current inputs
- C – Voltage inputs

The Front of PHATCAT

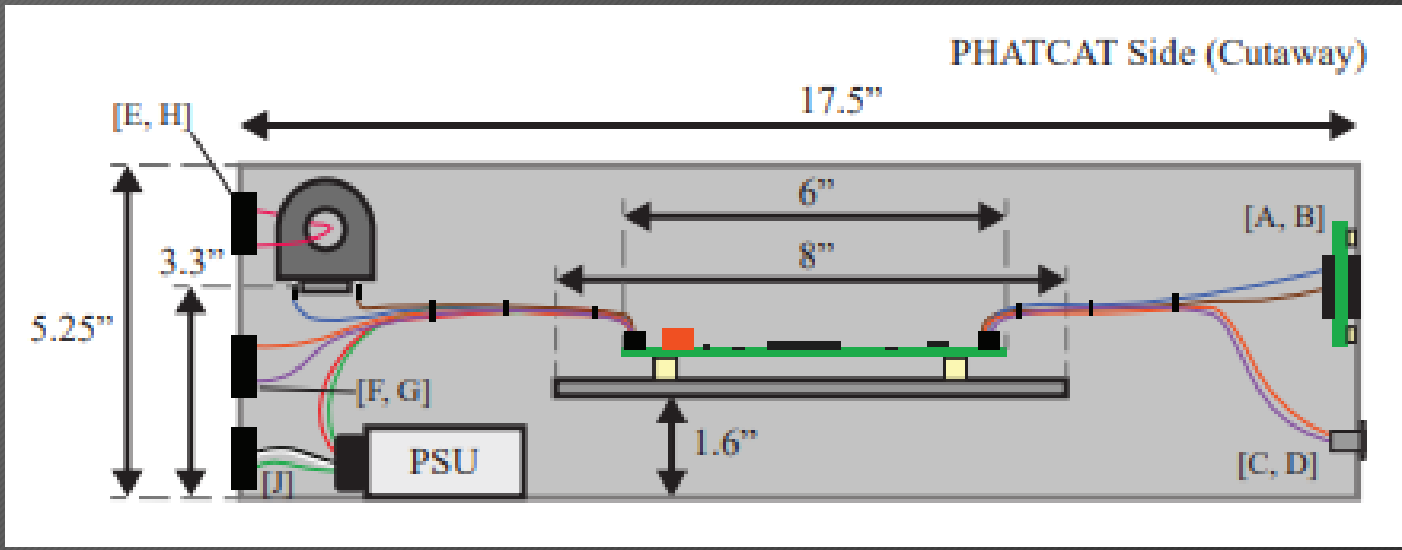
- LCD to display data outputs and values to the user.
- LEDs to allow the user to read the operating condition of the relay.
- Power switch for turning PHATCAT on/off
- User programmable push buttons to correspond to specific actions desired by the user.



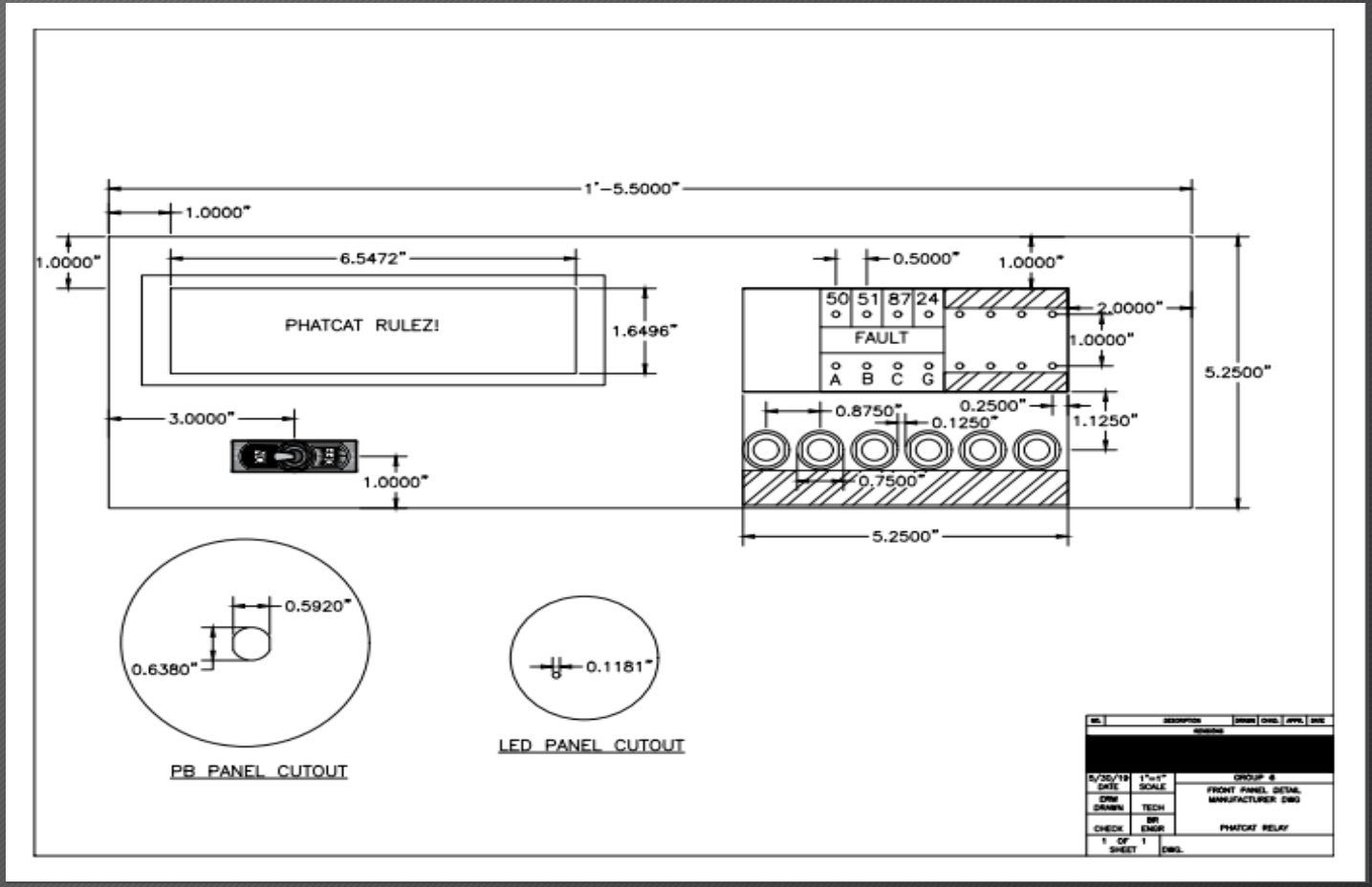
- A – LCD
- B – Fault Code Display
- C – Power Switch
- D – Push Buttons

The Internal Cutaway

- E – CURRENT & VOLTAGE SENSING INPUT
- PHASE TERMINALS
- F – SENSE INPUTS TERMINALS
- G – OUTPUT CONTACT TERMINALS
- J – POWER SUPPLY INPUT

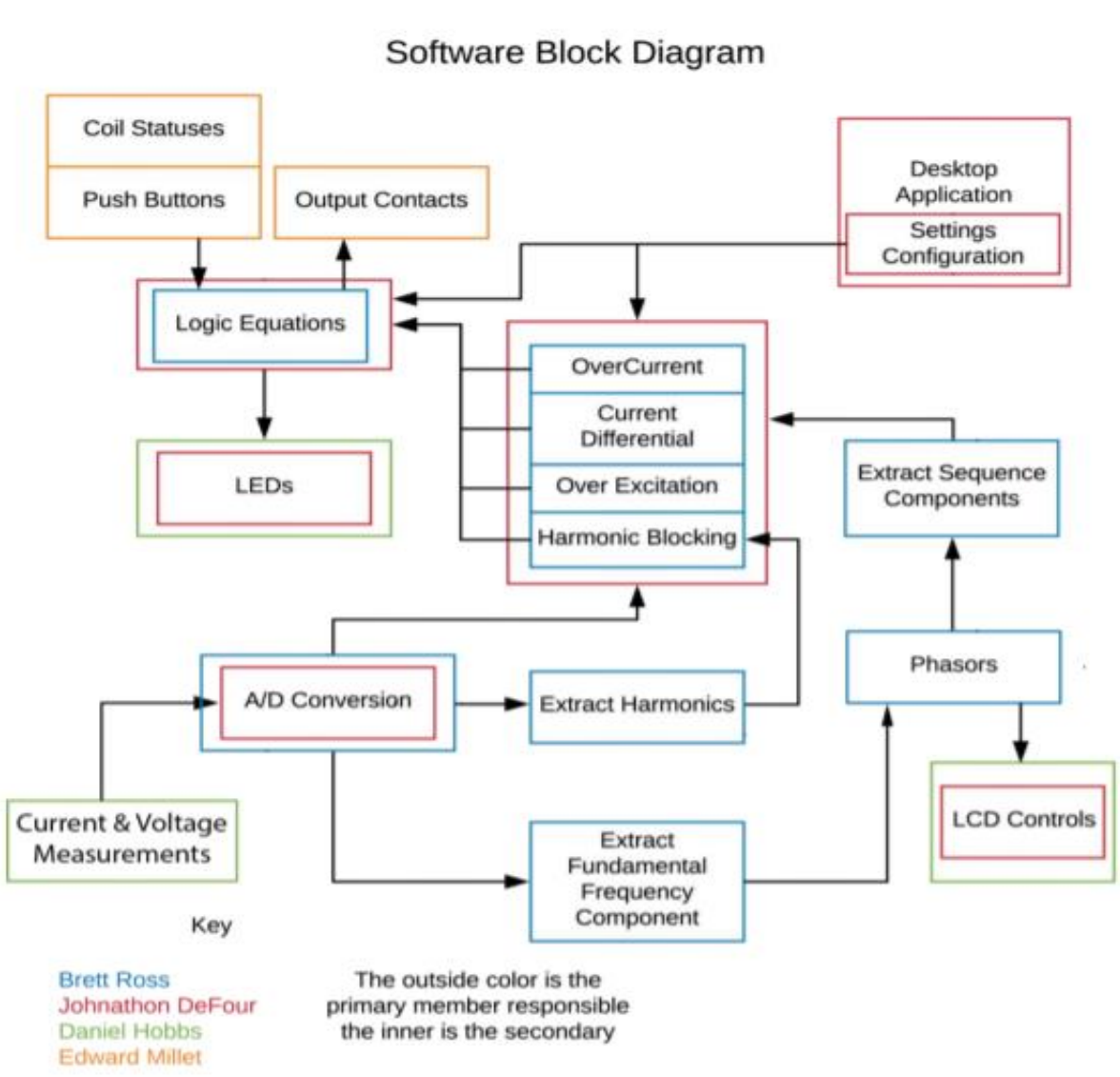


Autocad Front Panel Draft



Software Functional Block Diagram

- Analog inputs from current and voltage transformers.
- A/D conversion for software analysis
- Extracting the fundamental frequency
- Constructing phasors & displaying them
- Logic equations set by user from the desktop application
- LEDs will be programmable with a cheat-sheet to translate the link between the LED and status it represents (coil status, faults etc.)



Microcontroller Selection

~Requirements~

- Minimal 16-bit word size to accompany the external ADC
- Direct Memory Access to preform real-time processing of the ADC without interrupting the MCU.
- At least 93 GPIO pins required to preform all the tasks required
- Debugging capabilities
- We chose the MCU after the hardware selection since there are so many choices.

Table 3.14. Estimate input and output needs for microcontroller

Function	Main Component	Pin Needs	Pin Purposes
ADC	(x2) ADS8588S	2 x 32 GPIO	Parallel Interface (16 data, 3 control), Configuration (13)
Output Contacts	(x3) EE2-12NU	3 x 1 GPO	Enable optocoupler
Sense Inputs	(x3) TBD	3 x 1 GPI	Read optocoupler output
LED Indicators	MAX6979	4	Serial Interface
Push Buttons	(x6) AV1610R112R04	6 x 1 GPI	Read High/Low
Power Button	S1A	1 GPI	Read High/Low
Display	NHD-0440WH-ATFH-JT#-ND	12 x 1 GPIO	Parallel Interface (8 data, 2 control), Chip Enable (2)
Total:	**93 Pins**		

Table 3.15. Memory needed for storing user-settings

Type of Setting	Types of Needed Data	Needed Space
Push Button, LED, Output Contact, and Sense Input Logic Equations	Strings of up to 128 characters each.	16 x 128 bytes
Protection Logic Equations and Setpoints	Strings of up to 128 characters each, Floating Point Values	2 x 128 bytes, 40 x 2 bytes
Power System / Equipment Data	Strings of up to 128 characters each, Floating Point Values	10 x 128 bytes, 10 x 2 bytes

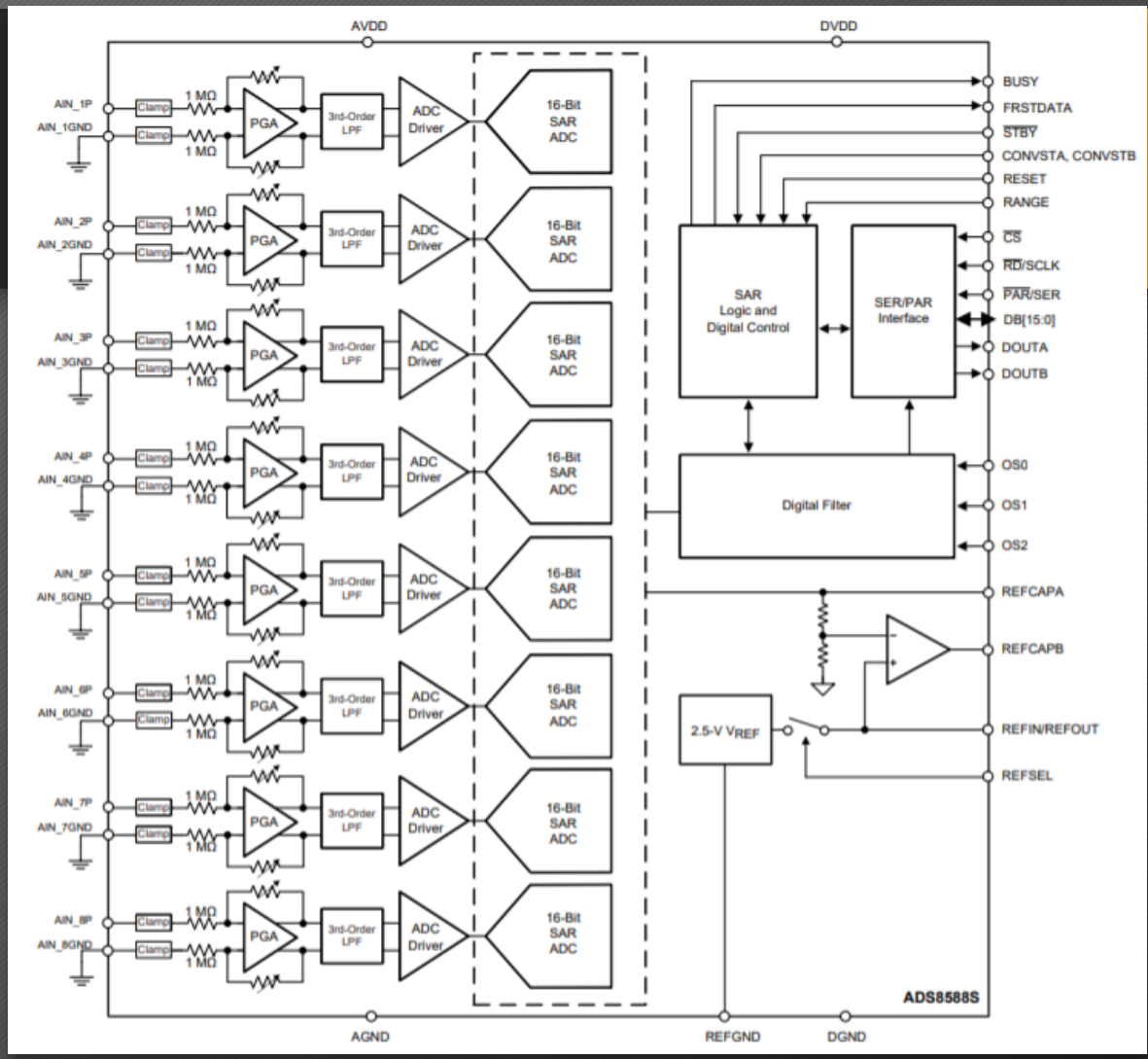
Microcontroller Selection Cont.

- C28X processor provides specialized cases for trig functions & complex numbers (TMU & VCU) which will be used for phasor analysis.
- The dual processor allows for PHATCAT to prioritize protection algorithms.
- Development board comparatively affordable price & has JTAG for debugging.
- Online documentation of the development CAD layout for reference.

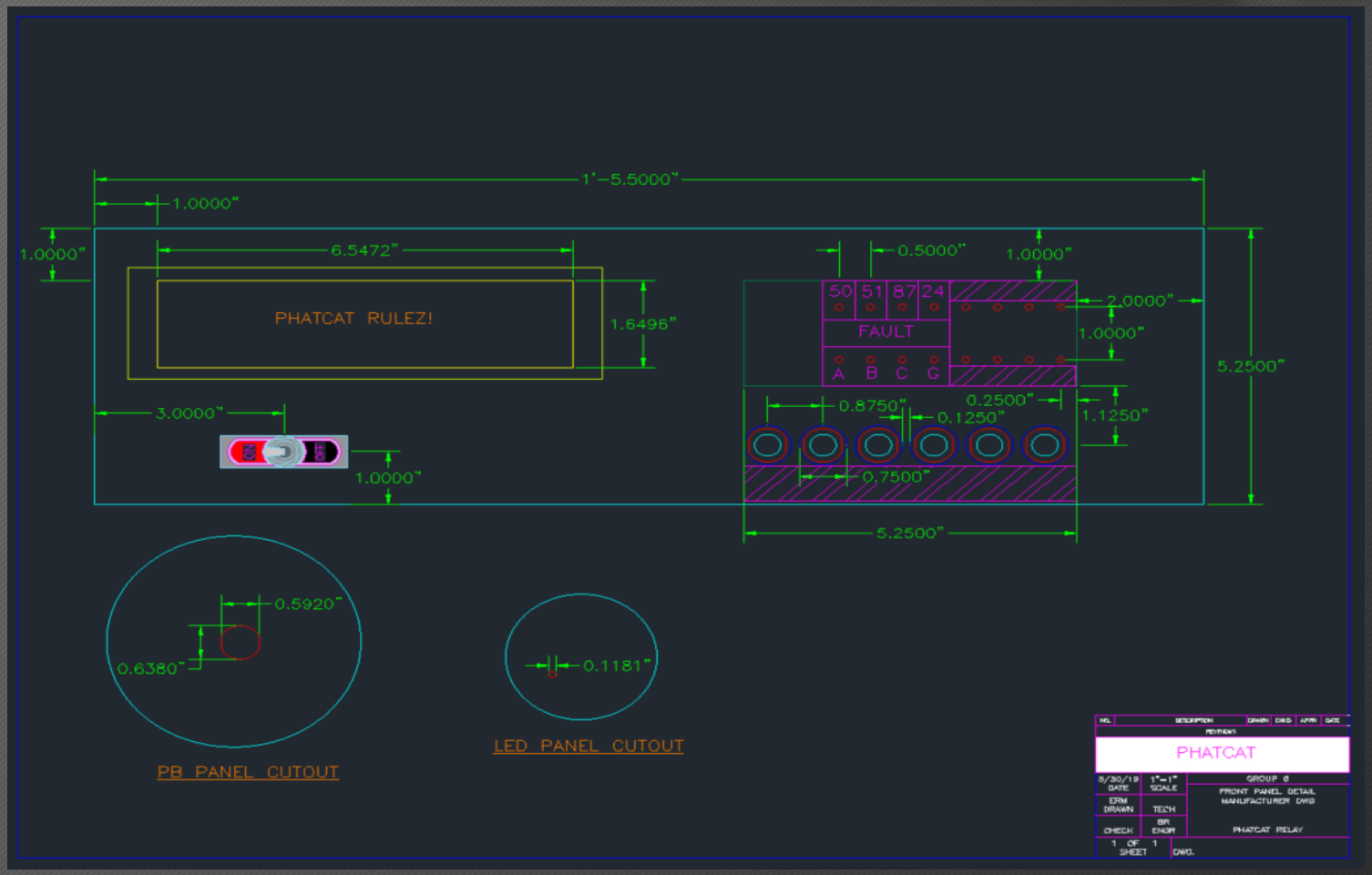
Device	ATSAME54N20A	LPC4337FET256	TMS320F28377S
Manufacturer	Microchip	NXP	Texas Instruments
Max CLK	120 MHz	204 MHz	200 MHz
Word Size	32-bit	32-bit	32-bit
Program Memory	1 MB Flash, among others	1 MB Flash, among others	1 MB Flash, among others
GPIO	81 I/O pins	164 GPIO	169 GPIO
Floating Point Unit?	Yes, 32-bit	Yes	Yes, also Trigonomic and Complex Units
DMA?	Yes, 32-channel	Yes, 8-channel	Yes, 6-channel
Dev. Board*	SAM E54 Xplained Pro, $84	OM13088: LPCXpresso4367 Development Board, $27	C2000 Delfino MCU F28379D LaunchPad™ development kit, $33.79
Communications	8 Interfaces, supports I2C, SPI, RS485, USB 2.0	USB 2.0, 1 SPI, Quad SPI, LCD controller	USB 2.0, 3 SPI, 2 I2C
Onboard Debugger?	In development board. External required otherwise.	In development board. External required otherwise.	In development board. External required otherwise.
Chip Cost	$5	$9.24	$25.36

16 Bit Analog-to-Digital Convertor

- Offers a PGA to convert single ended input signal into fully differential signal to drive the 16-bit ADC.
- Internal 3rd order lowpass Butterworth, antialiasing filter for high frequency filtering.
- Maximum 200kSPS
- Oversampling
- Bipolar input
- Differential input



Autocad Front Panel Draft



NHD-0440WH-ATFH-JT#-ND

LCD Display

Purpose: Display information

Features:

- Simple Display
- Low Cost
- FSTN Model

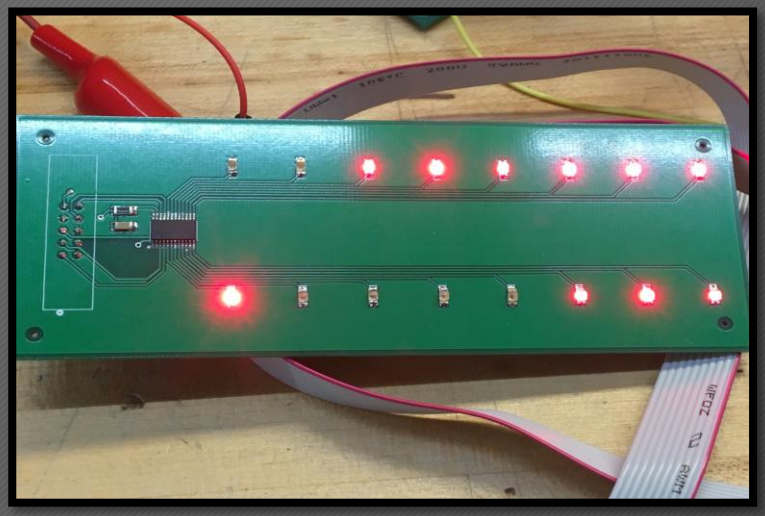
Device	NHD-0440WH-ATMI-JT#-ND	NHD-0440WH-ATFH-JT#-ND	NHD-7.0-HDMI-N-RSXN-ND
Manufacturer	Newhaven Display Intl	Newhaven Display Intl	Newhaven Display Intl
Characters*	40x4	40x4	800 x 400 pixels
Backlit	Yes (White)	Yes (White)	Yes (White)
Dimensions*	190 x 54 x 13.6 mm	190 x 54 x 13.6 mm	165 x 104 x 16.5 mm
Character Format	5 x 8 dots	5 x 8 dots	N/A
Power VDD	4.75 ~ 5.25 V	4.75 ~ 5.25 V	4.75 ~ 5.25 V
Interface	Parallel	Parallel	HDMI
Cost	$24.90	$25.20	$93.00
Pins Necessary*	18	18	N/A
Display Type	LCD	LCD	LCD
Graphics	No	No	Yes
Touch	No	No	No
Type	STN	FSTN	TFT

LED Indicator Board

MAX6979

Purpose: To indicate specific data and functions of PHATCAT

- 4 Serial Interface Inputs
- 16 Outputs
- 1- R_SET Resistor needed only



Product	MAX6979	TLC6C598-Q1
Manufacturer	MAXIM	TEXAS INSTRUMENTS
Number of Outputs	16	8
Serial Interface Inputs	4	5
Logic Supply Voltage	-0.3V to +6V	-0.3V to 8V
Logic Input Voltage Range	-0.3V to +6V	-0.3V to 8V
V_{ds} Voltage Range	-0.3V to 6.3V	-0.3V to 40V
R_{set}	360ohms	N/A
OUT Sink Current	60mA	50mA
Continuous Power Dissipation	1067mW	Not Specified
Operating Temperature Range	-40C to +125C	-40C to +125C
Cost	$8.00	$1.01

Power Electronics

Meanwell-RS-15-12
NJM7805FA
R-78E3.3-1.0

Major Component Voltage Requirements:

- Push Buttons, Relays – 12V
- LED Driver – 5V
- MCU – 3.3V

Device	Input Voltage (V)	Output Voltage (V)	Output Ripple (V_{p-p})	Output Power (W)	Cost
Meanwell RS-15-12	85-264VAC, 120 – 370 VDC	12V	120mV	15W	$9.55
NJR Corporation/NJRC NJM7805FA	7 – 35 VDC	5V	78dB Ripple Rejection	7.5W	$0.88
Recom Power R-78E3.3-1.0	6 – 24 VDC	3.3V	120mV	3.3W	$3.26

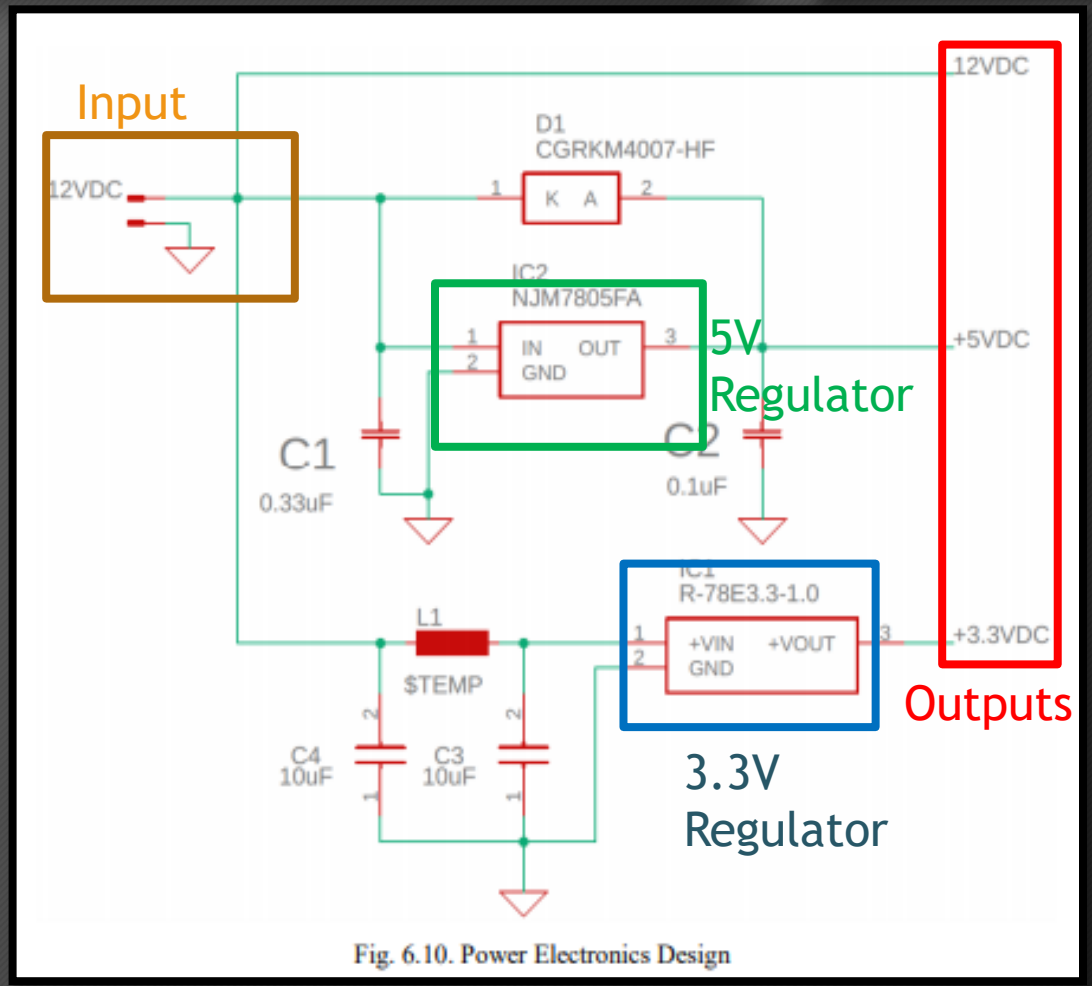


Fig. 6.10. Power Electronics Design

AV1610R112R04

Momentary Push Buttons

Purpose: To provide user programmable buttons for device versatility.

- Fun fact: They look pretty awesome, but D*** are they expensive!

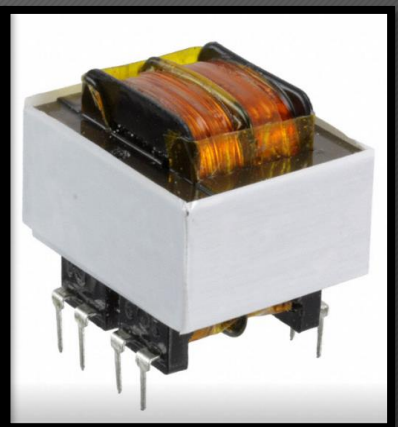
Product	PV6F240SSG-301	U16B1SW	AV1610R112R04
Manufacturer	E-Switch	Ulincos	TE Connectivity
Rated Voltage	48V	36V	36V
Rated Current	2A	2A	2A
Contact Resistance	50m-Ohm	----------	50m-Ohm
Termination Type	Solder	Screw	Solder
Packaging	Tubing	----------	Tray
Cost	$12.25	$8.89	$11.75

Current & Voltage Sensing

CR8350-2500-N
F20-055-C2

8-Current Transformers:
- 2500:1 Ratio
- Higher Saturation Level
- Longer Linear Output
- Minimal Phase Shift

6-Potential Transformers:
- Voltage Primary – 115V
- Voltage Secondary- Parallel 10V



Characteristic	Current transformer	Hall Effect Sensor
Component	CR8350-2500-N	ACS712ELCTR-30A-T
Linear output	Strong (100amps)	Medium(30amps)
Cost	$13.23	$4.50
Galvanic Isolation	Strong	Strong
Footprint	14x37mm^2	5x6 mm^2
DC offset	No	Yes
Sensitivity	Low	High
Phase Shift	Very low	Medium

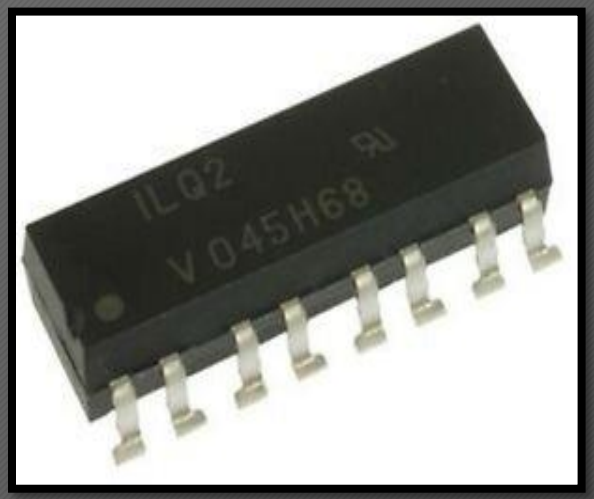
Sense Inputs

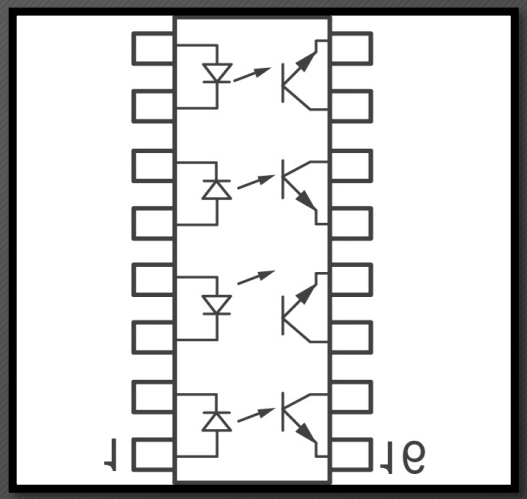
ILQ2

Purpose: To monitor equipment status in the Substation.

Features:

- Read 125VDC Input Signal
- Reduce Voltage Signal
- Isolate Input Signal





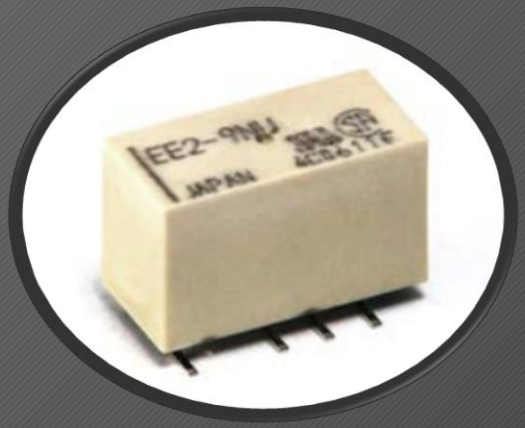
Output Contacts

EE2-12NUH-L

Purpose: To output low voltage signal for Primary circuit to energize Secondary Circuit.

Features:

- Faster Operating Time
- Lower Breaking Capacity
- Break 2A of Current
- Low Cost



Part Number	IM Relay IM06GR	Multimode Relay MT331110	Miniature Signal Relay EE2-12NU
Manufacturer	Potter & Brumfield	Potter & Brumfield	Kemet
Termination Style	Gull Wing	Plug-in, 11 Pin (Octal)	Gull Wing
Contact Arrangement	DPDT	TPDT	DPDT
Contact Form	2 form C, 2 (CO)	3 form C, 2 (CO)	2 form C, 2 (CO)
Contact Rated Voltage	220 VDC	240VAC	220 VDC
Contact Rated Current	2A	10A	2A
Switching Capacity	125VDC ≈ 0.5A	110VDC ≈ 10A	125VDC ≈ 0.48A
Operate Time	3ms	15ms	2ms
Release Time	5ms	10ms	1ms
Bounce Time	3-5ms	4/10ms	Not Specified, typ. 3-5ms
Coil Rated Voltage	12VDC	110VDC	5VDC
Coil Operate Voltage	9.6VDC	82.5VDC	3.75VDC
Coil Resistance	1.315kΩ	10kΩ	178kΩ
Rated Coil Power	140mW	1.2W	140mW
Cost	$2.33	$20.88	$1.90

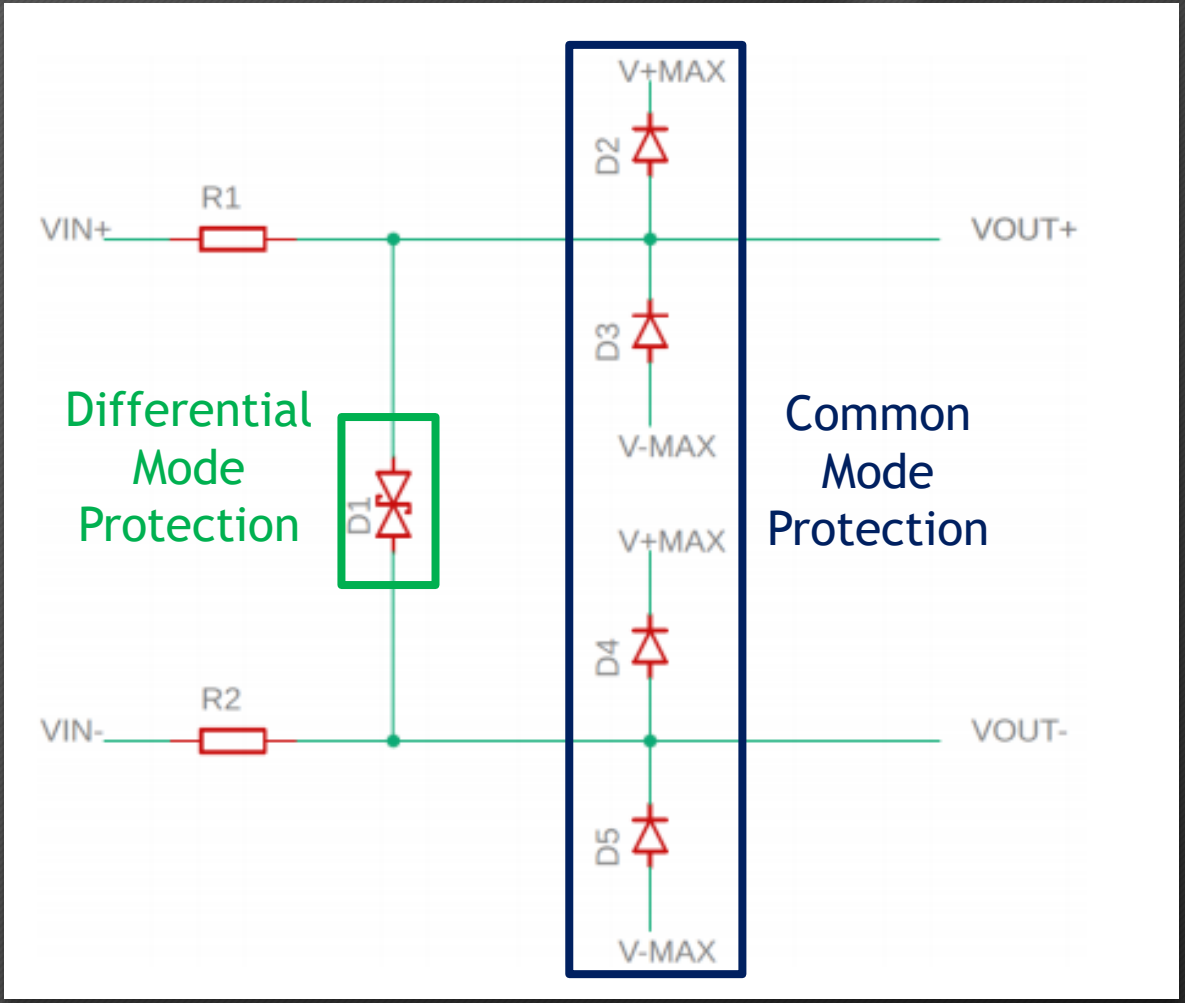
Transient Protection

Purpose:

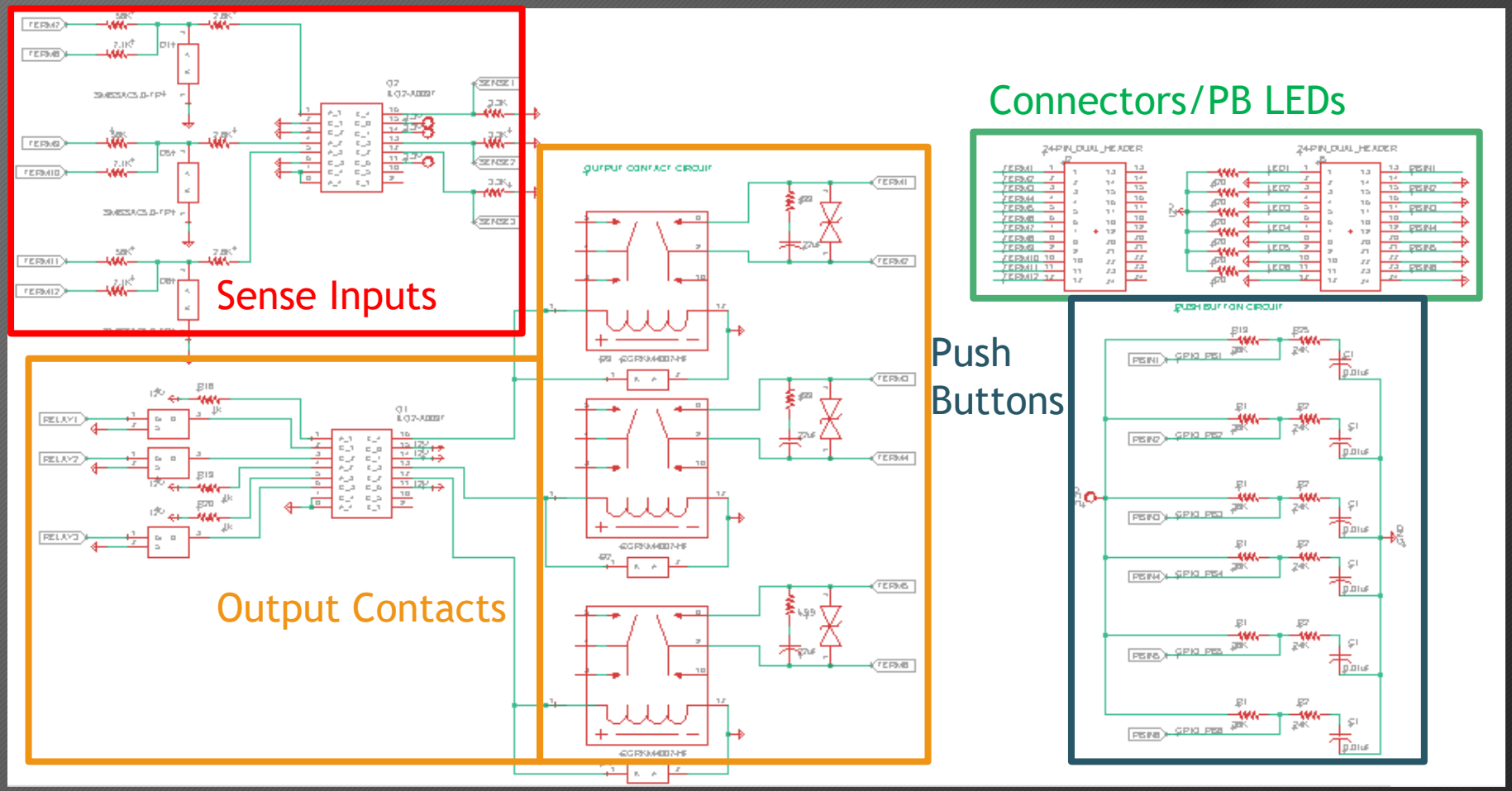
To protect electronic circuit components from ESD and Transients.

Features:

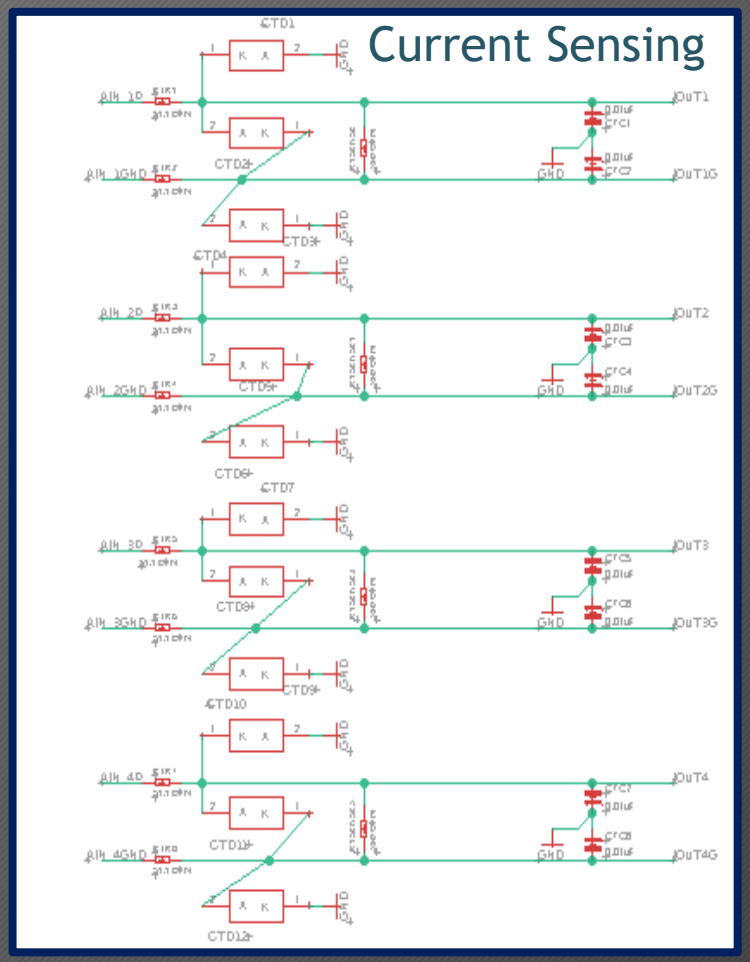
- TVS Diode (D1)
- 4-DIODES (D2,D3,D4, & D5)
- 2-RESISTOR (R1 & R2)

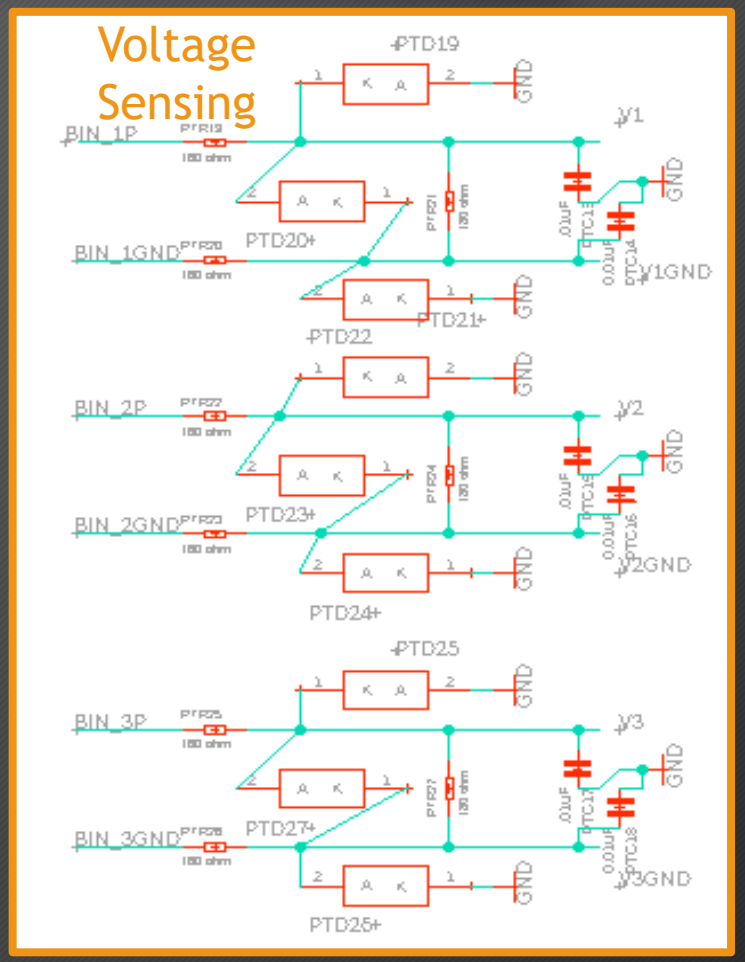


PCB Schematics

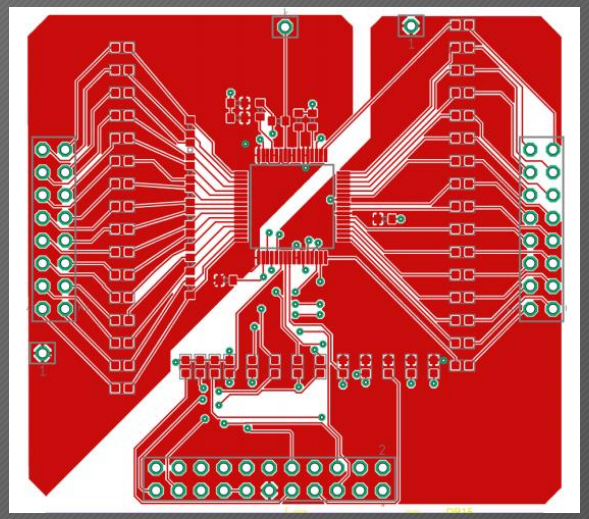


PCB Schematics Cont.





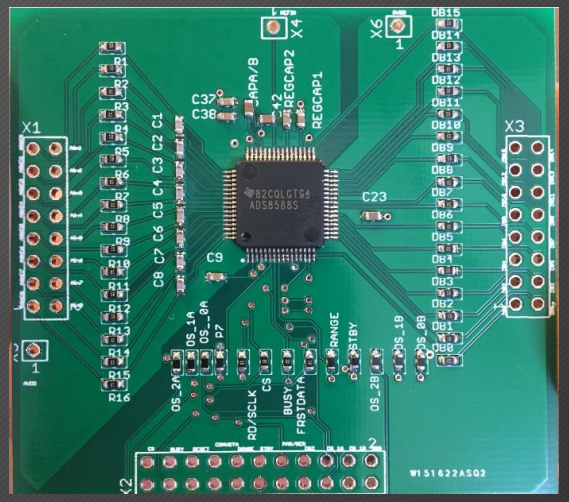
PCB Board Layout

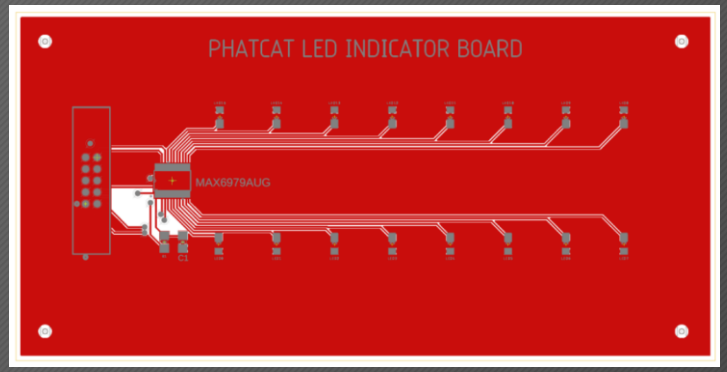


A/DC
BREAK-OUT
BOARD

62mm

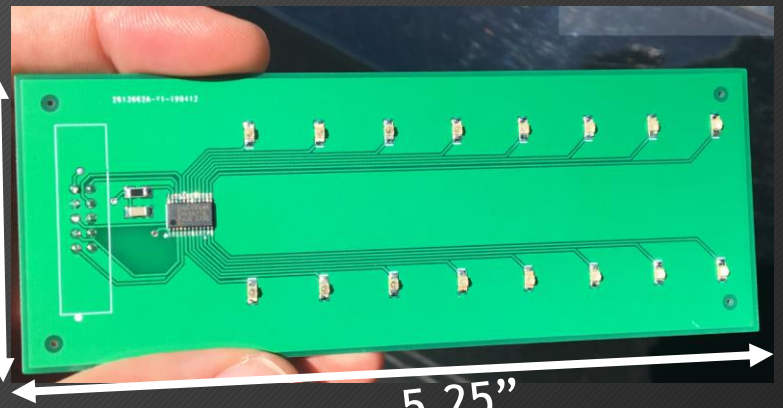
57mm





LED
INDICATOR
BOARD

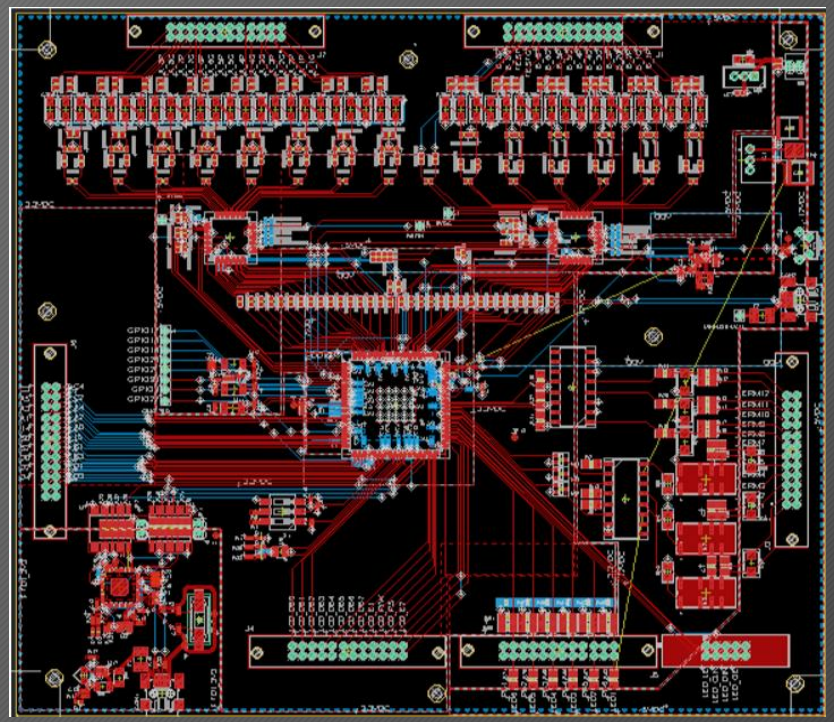
2”



5.25”

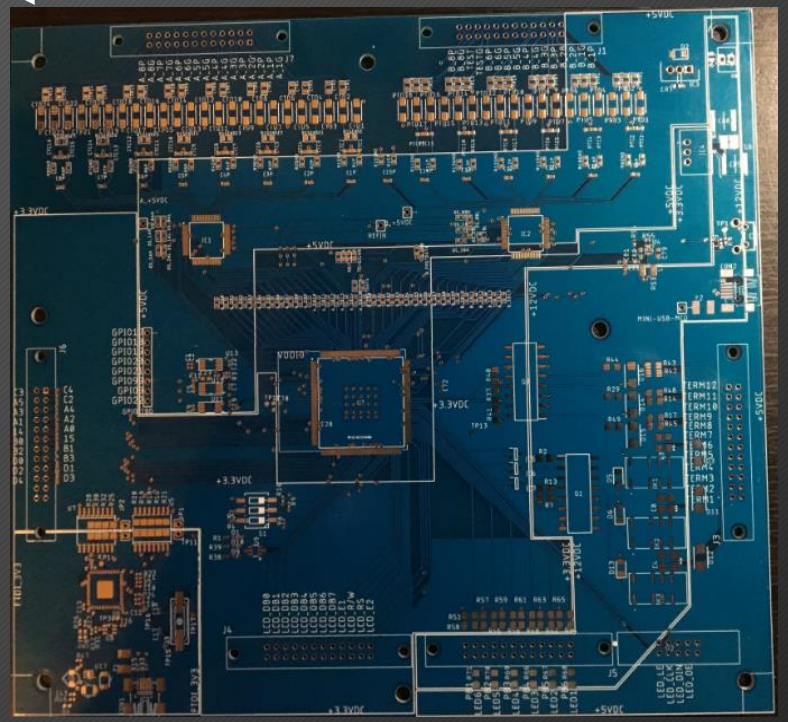
PCB Board Layout Cont.

MAIN BOARD

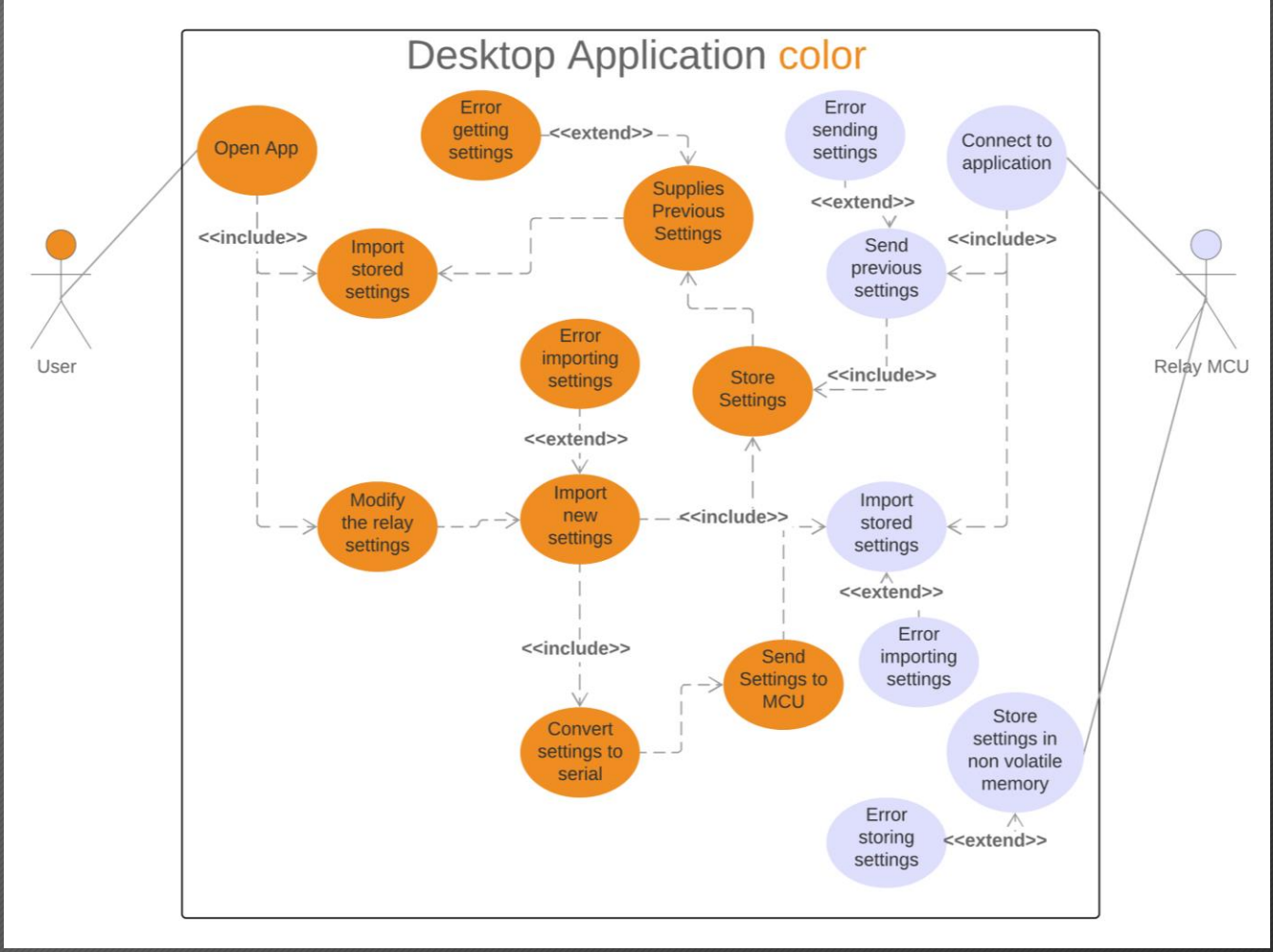


205mm

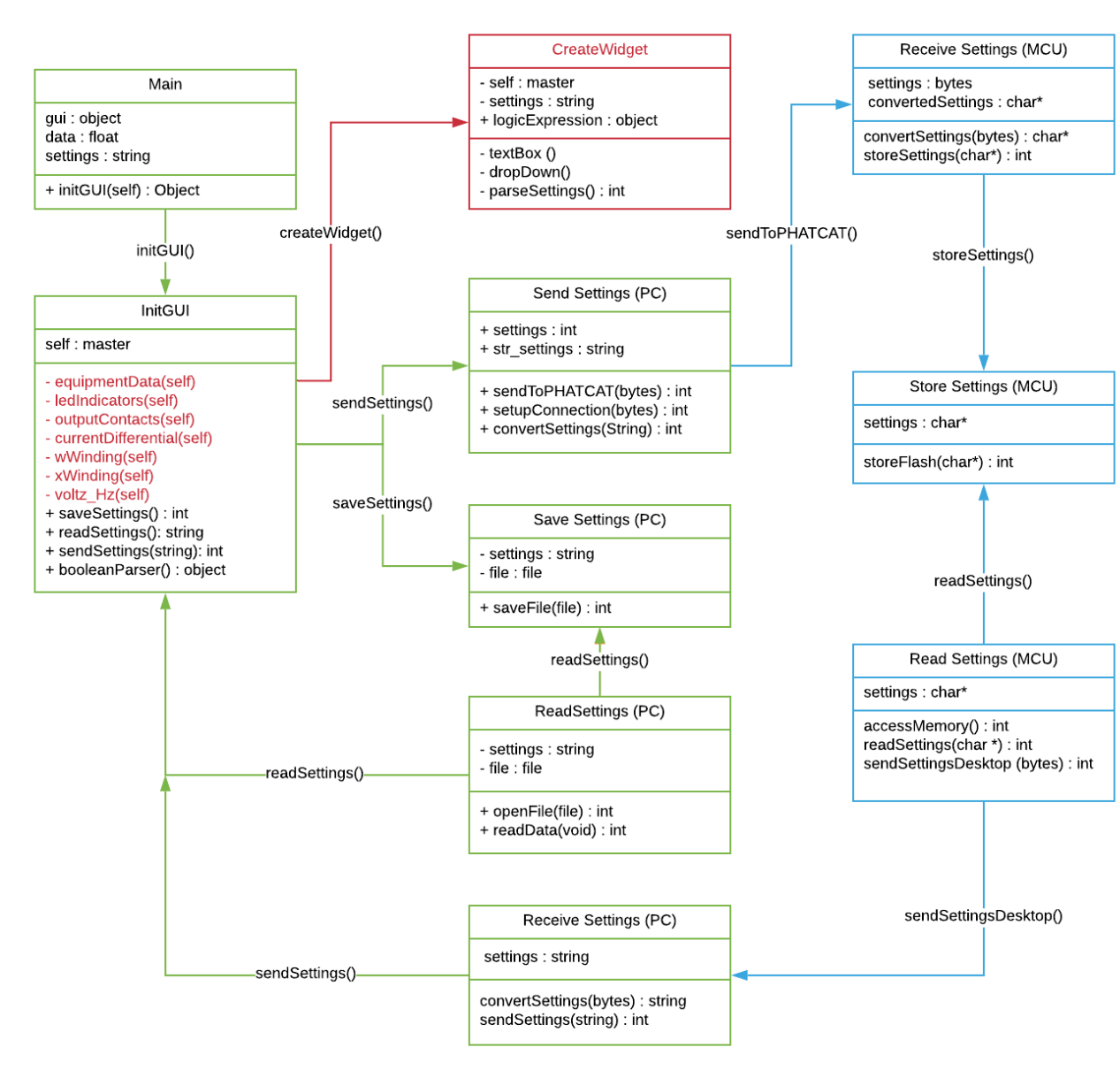
181mm



Use Case Diagram

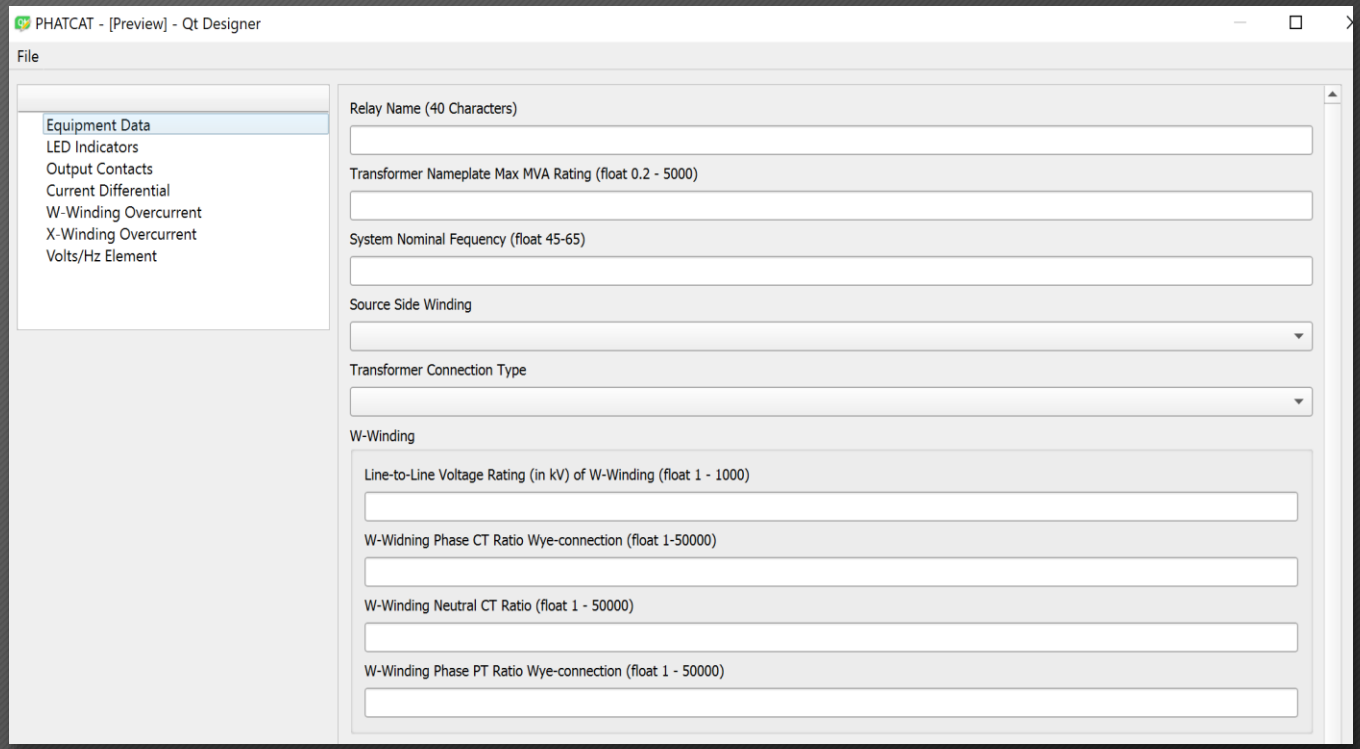


Desktop Class Diagram



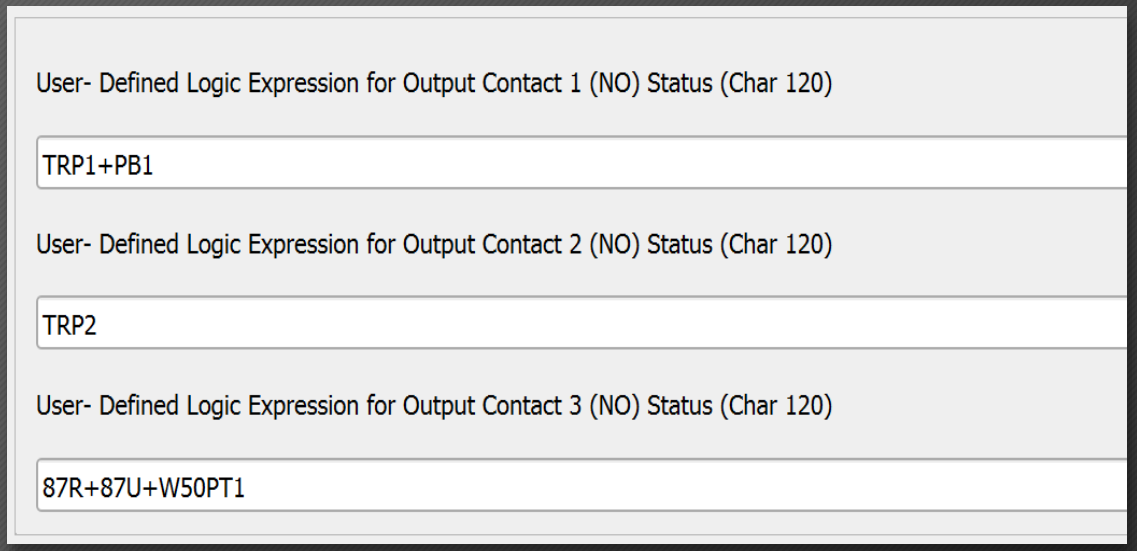
Desktop Application Mock Up

- User facing component
- Used to relay settings to device
- User can customize various options that can be sent to PHATCAT to alter how it behaves

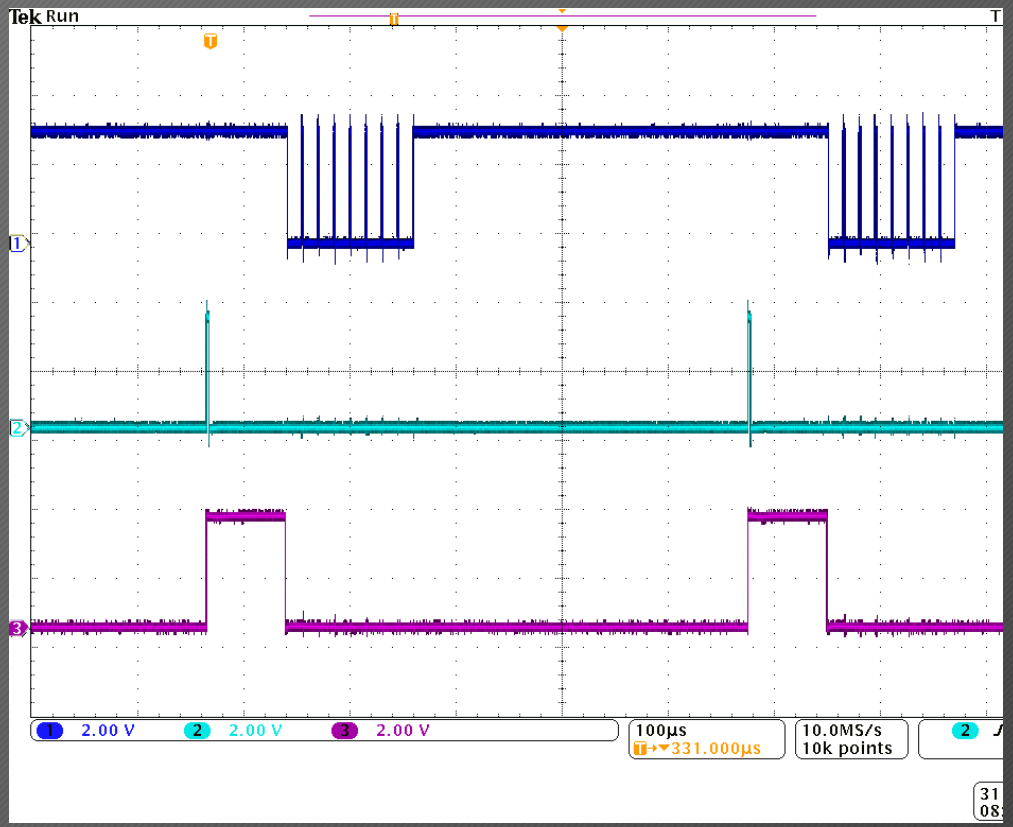


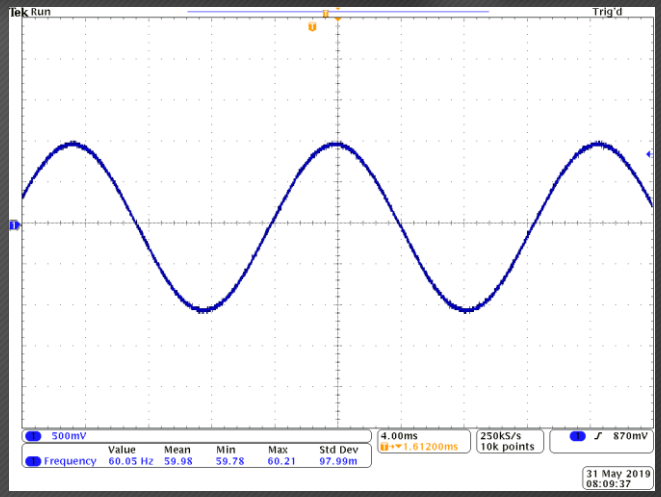
Boolean Logic Parser

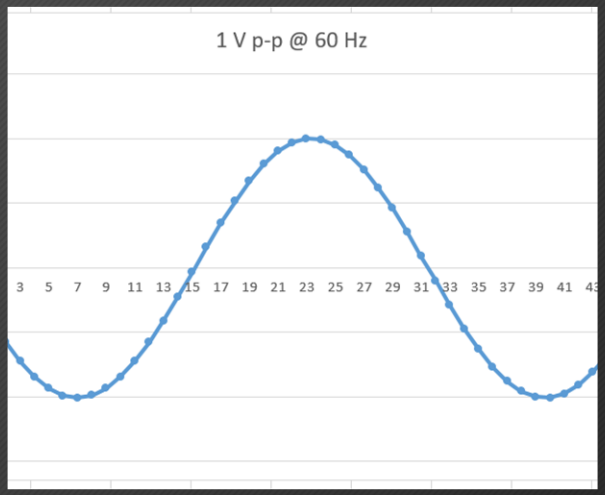
- User defined Logic expressions that will be parsed to configure the device.
- Can be used to control components and peripherals i.e. Push Buttons, LEDs



Analog to Digital Conversion (ADC)

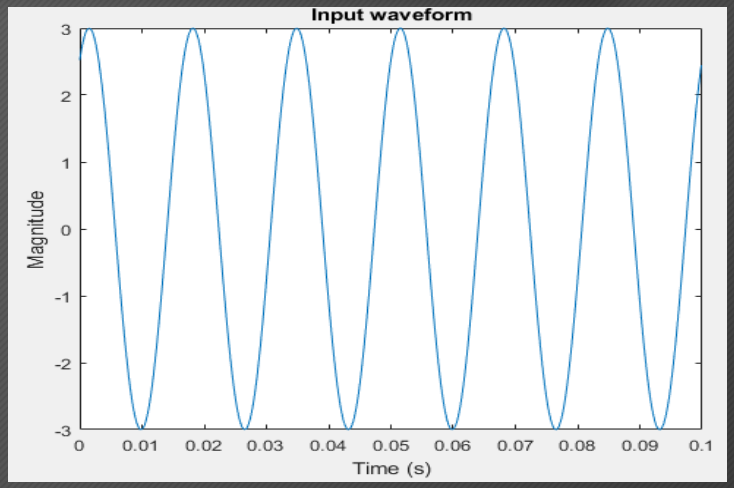


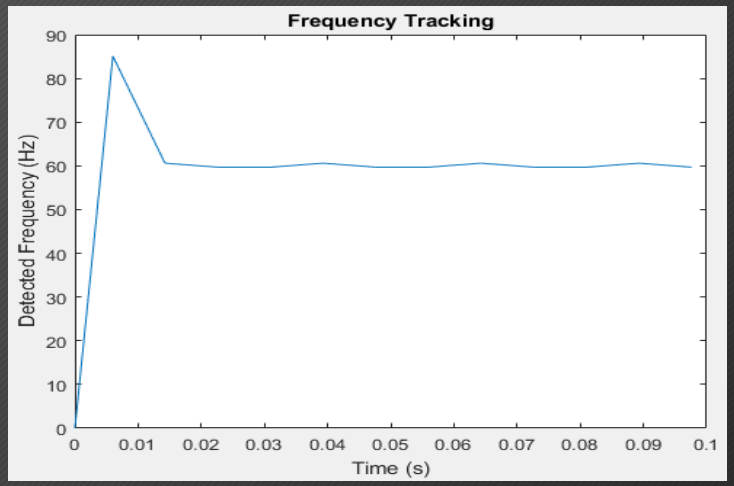




Zero Crossing Detection (ZCD)

- Used to find the frequency
- Not computationally intensive
- Important for fast computations





Fast Fourier Transform (FFT)

- Signals composed of composition of many waves
- The FFT is used to find the coefficients of those composition waves
- This gives us the spectral content, magnitude and phase of all the signals
- Will be explained further by Brett Ross later in presentation

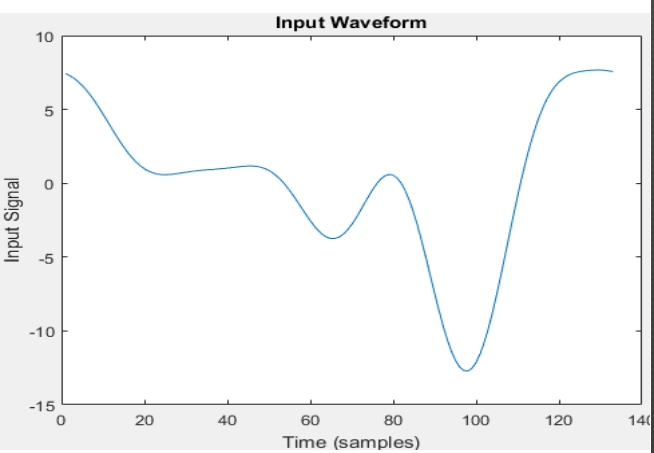


Figure 3.X. Input waveform for 16.67ms

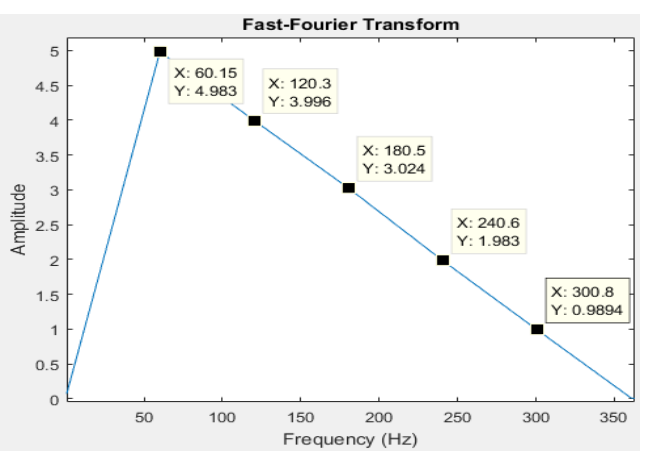
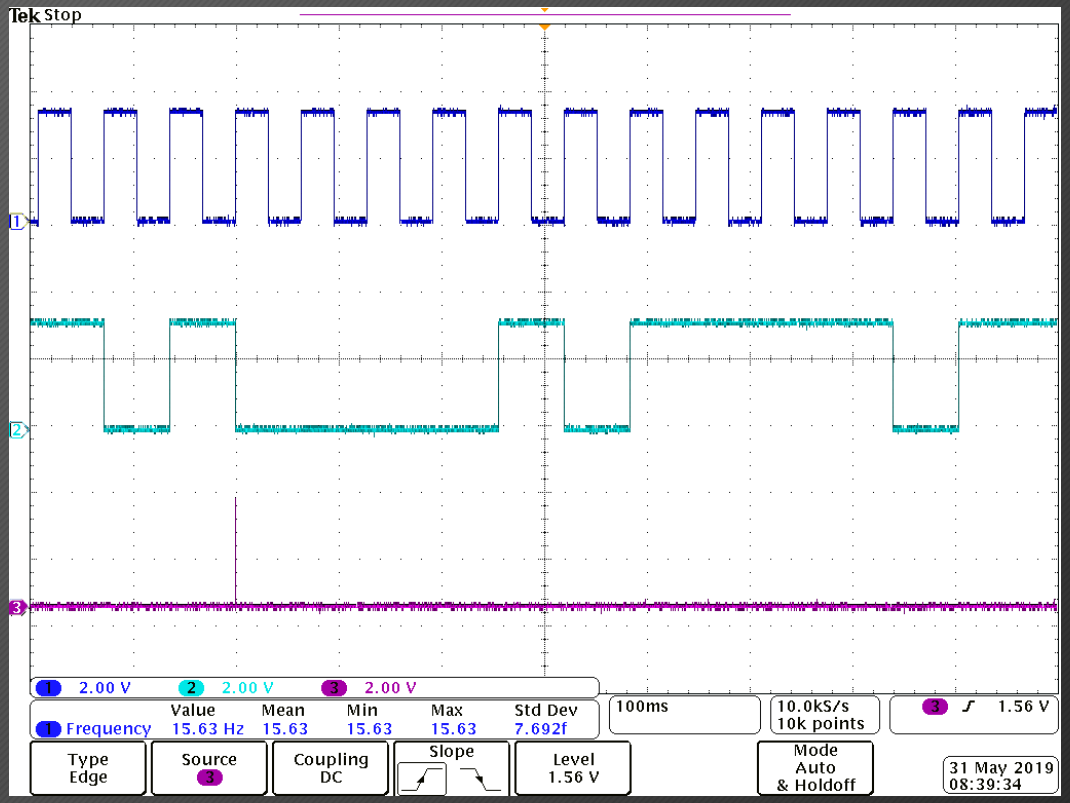


Figure 3.X. Magnitudes of frequency components by FFT

LED Communication

- Used to know notify user what is happening with PHATCAT
- Can be programmed to serve many purposes

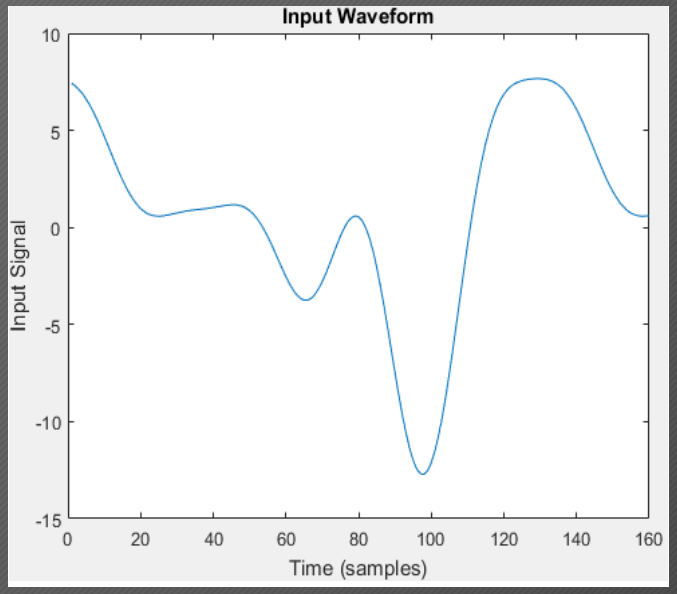


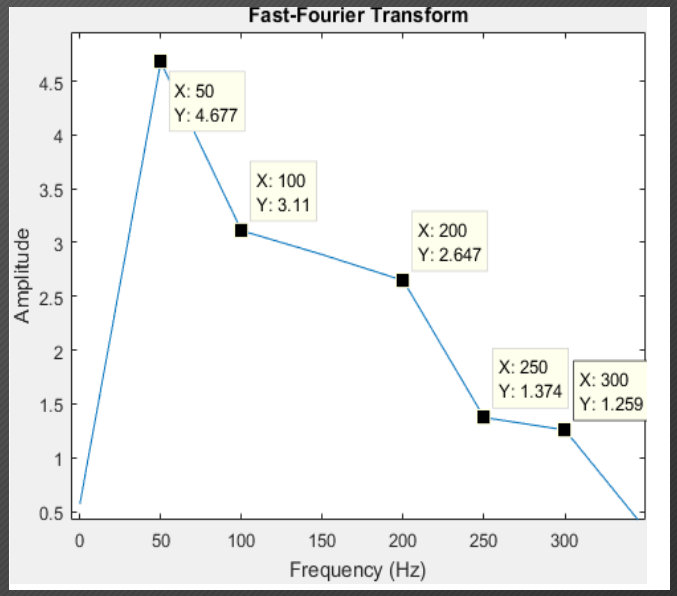
Liquid Crystal Display (LCD)

- Visualize what's happening with PHATCAT
- Will display Voltages, Currents, Power, Harmonics and Frequency

Challenge: Accurate Data *Fast*

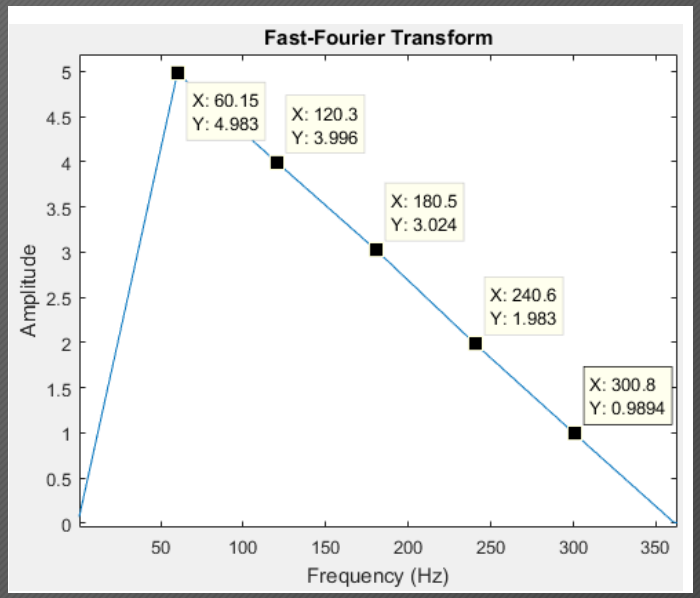
- Need to act quickly, but FFT requires a window
- Should see 5, 4, 3, 2, 1

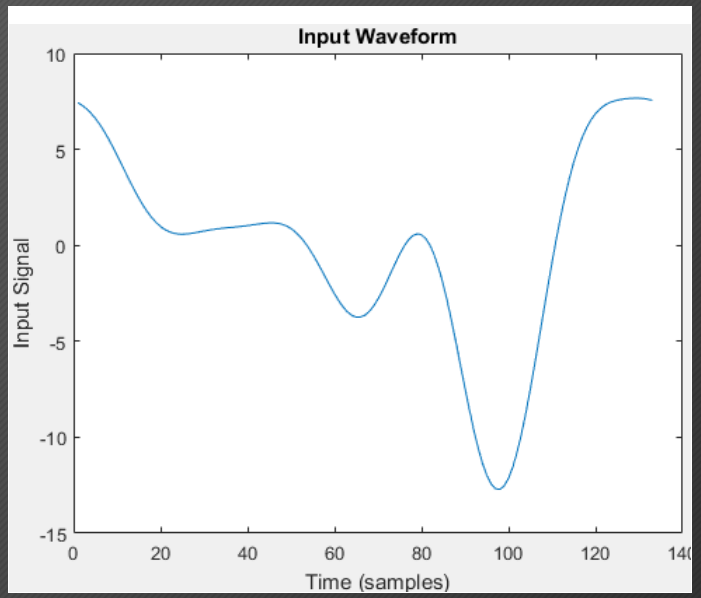




Solution: Dynamic Sampling Time

- Use ZCD Frequency to perform concurrent sampling
- Single cycle fit gives consistent binning

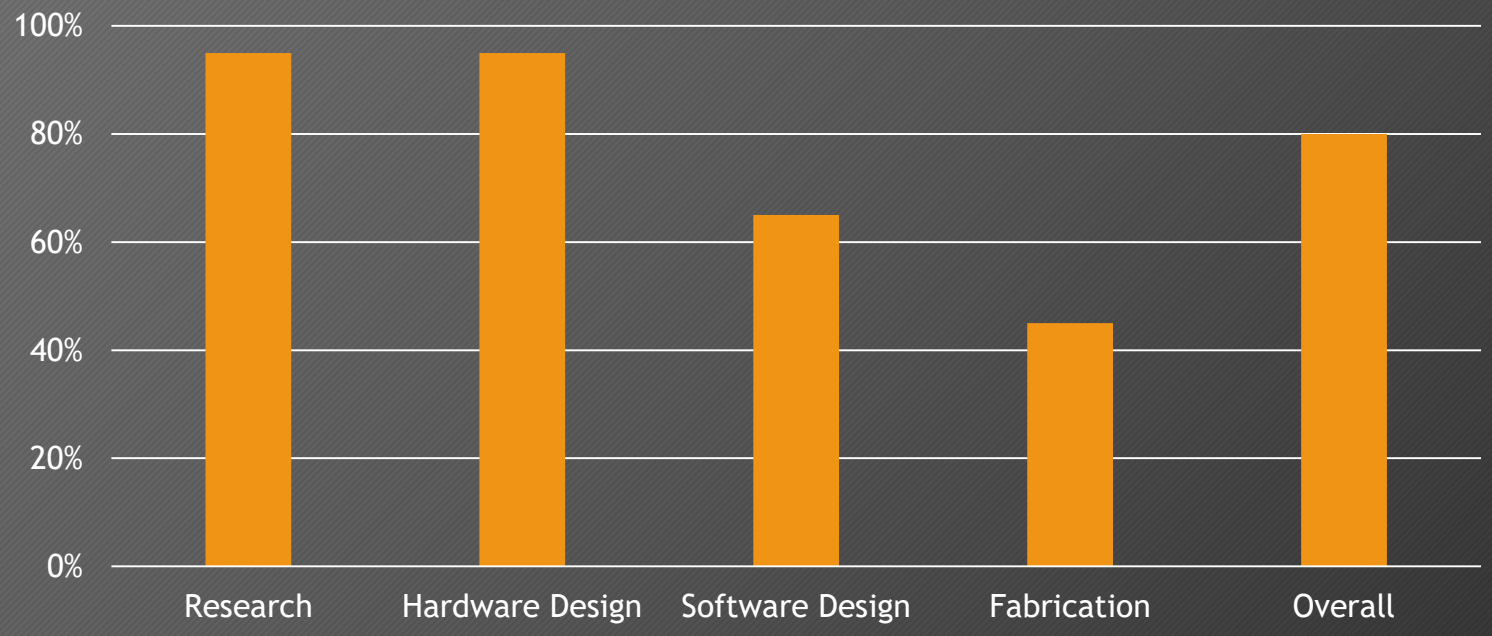




Responsibility

Brett:	John:	Ed:	Dan:
MCU ADC (HW + SW) Transient Protection Signal Processing Protective Algorithms Power Electronics	Desktop App Settings Configuration LEDs (SW) Display Logic Equations	Output Contacts Sense Inputs LED PCB Pushbuttons Final Assembly Materials	Analog Front-End ADC Breakout PCB Main PCB MAIN PCB! Enclosure
Display Desktop App Logic Equations QA - all	MCU Signal Processing Support HW Testing Protective Algorithms	Main PCB Power Electronics Analog Front End LEDs (SW)	I/O, Buttons, etc. Final Assembly ADC Transient Protection

Current Status



Budget

Feature	Quantity	Unit Cost	Total	Notes
Enclosure	1	$50.00	$50.00	Hardware, screw terminals, etc.
Display	1	$25.00	$25.00	
Power Switching	1	$15.00	$15.00	Buttons, cables, etc.
Development Board	2	$120.00	$240.00	x2 to parallel design processes
Front Panel LEDs	20	$0.30	$10.00	Extra for drivers needed
Front Panel Switches	5	$5.00	$25.00	
PCB Fabrication	N/A	$250.00	$250.00	Considers multiple iterations
Microcontroller	2	$20.00	$40.00	Chip only.
Power Supply	1	$30.00	$30.00	Considers extra converters
Current Sensing	10	$15.00	$150.00	
Voltage Sensing	10	$1.00	$10.00	
Board Protections	1	$50.00	$50.00	Used throughout board.
Output Contacts	3	$20.00	$60.00	
EMI Shields	10	$0.25	$2.50	
Soldering Wire	2	$3.50	$7.00	
Sense Inputs	5	$1.00	$5.00	
Misc. Components	N/A	$20.00	$20.00	Resistors, capacitors, diodes, etc.
ADC/DSP	2	$30.00	$60.00	
Total expected cost			$1049.50	

Agenda

Due Date	Action	Stake Holders
June 7th	Assemble PCB	Ed, Dan
June 9th	Implement FFT – Phasors on LCD	Brett
June 16th	USB Interface – Configure via Desktop	John
June 16th	Main Board Basic Testing – Done	All
June 23rd	Enclosure, Front + Back Panels, Transformers Done	Ed, Dan
June 23rd	Basic Protection Functions	Brett
June 30th	Main Board, Protections, Metering all ready	All
July 17th	Advanced Protections, User-Defined Logic	Brett, John
July 17th	Paper Edited	Ed, Dan
End of July	Show time!	All

Questions? Comments?