DEVELOPMENT OF A PORTABLE ELECTROLUMINSENCE MEASUREMENT SYSTEM – 2024S1

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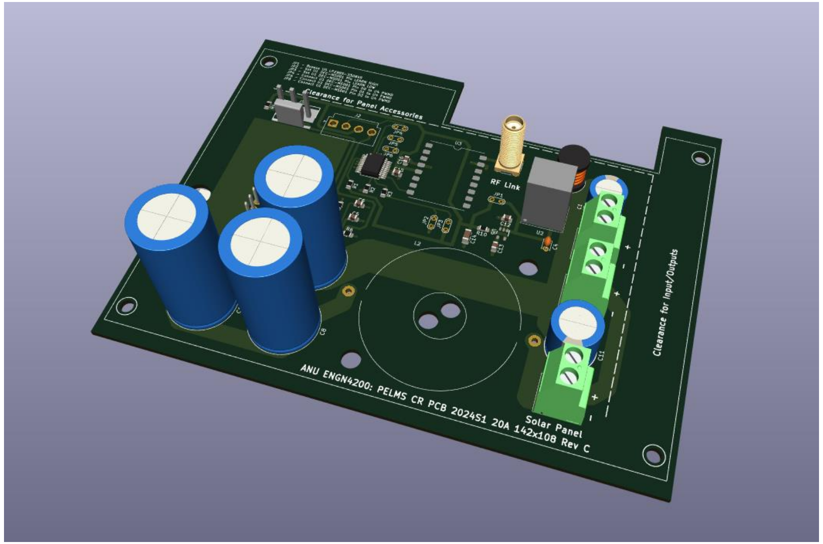


Australian National University

Contents

Design Project

Overview

Overview

The goal of my project was to continue the development work of a Portable Electroluminescence Measurement System (PELMS) that had previously been completed by the ENGN8170 Student project *Team Solar* in 2023.

The Portable Electroluminescence Measurement System (PELMS) is a device that uses Electroluminescence (EL) imaging to identify defects in Photovoltaic (PV) modules. A unique modulation technique is used by the PELMS device to enhance the EL imaging system by removing external light noise.

Team Solar had developed a PELMS device that implemented this modulation technique and was capable of imaging one PV module at a time to produce EL images.

The team recommended five future area for work which became the basis for five deliverables of this project.

Design Project

Team Solar Recommendations

Team Solar Recommendations

- Improve image detail by increasing the images capture from 8-bit resolution to 12-bit resolution,
- Develop a more portable and reliable enclosure that houses components securely and prevents dust and water egress,
- Improve power management to optimise power consumption,
- Create a PCB board for the circuitry on the prototyping board, and
- Increase the current rating above 10A.

Design Project

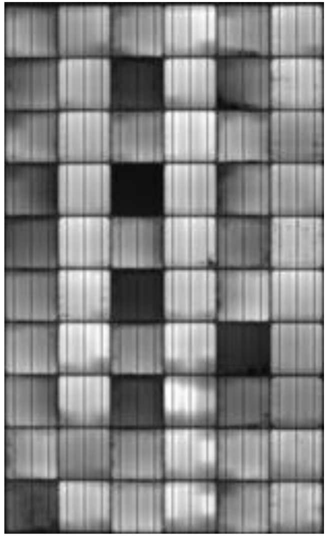
PELMS 2024S1 Project Deliverables

PELMS 2024S1 Project Deliverables

- Develop python code to handle 12-bit resolution images and redevelop/update the GUI,
- Design and construct an improved enclosure,
- Modify electrical circuitry to optimise power,
- Construction of a PCB board for the electrical circuit to replace the prototyping board, and
- Recalculate the component values of the electric circuit to handle loads above 10A.

Background

Electroluminescence(EL) Imaging and PV modules



Source: Report IEA-PVPS T13-10:2018, pp 45, Figure 2-27b

Electroluminescence (EL) Imaging and PV modules

- Luminescence is where an object emits light only not heat,
- Conventionally, PV cells absorb light, and the PV cell induces a DC electrical current to flow,
- By reciprocity, the inverse phenomena is possible i.e. a DC electrical current injected into a PV cell will cause the PV cell to emit light
- The emitted light is in the infra-red (IR) range and not detectable by humans but is detectable by digital camera
- PV module is a configuration of PV cells – an EL image of PV module is one where a DC current has been injected into the PV module and the IR light is being emitted
- The industrial application of this phenomena is to identify failures and in a PV module and is discussed in *Report IEA-PVPS T13-10:2018: Review on Infrared and Electroluminescence Imaging for PV Field Applications*

Background

PELMS Modulation Technique

PELMS Modulation Technique

- EL images are combination of visible light and IR light
- A problem with EL imaging is that the image also captures the ambient visible light (which is regarded as noise) and the emitted IR light which contains the information about the PV module.
- Ideally, we remove or reduce the visible light component in the image and enhance the IR component
- The PELMS device was designed to use unique modulation technique to remove visible light from the EL image that would enhance the images
- The technique involves capturing a base image of the PV module containing only visible light (i.e. a normal image) followed by capturing an image of the PV module with a DC current injected into it that contains the visible light and the IR light
- The images are digital so the base image can be subtracted from the EL image which leaves behind the IR image which is what contains the information of the PV module

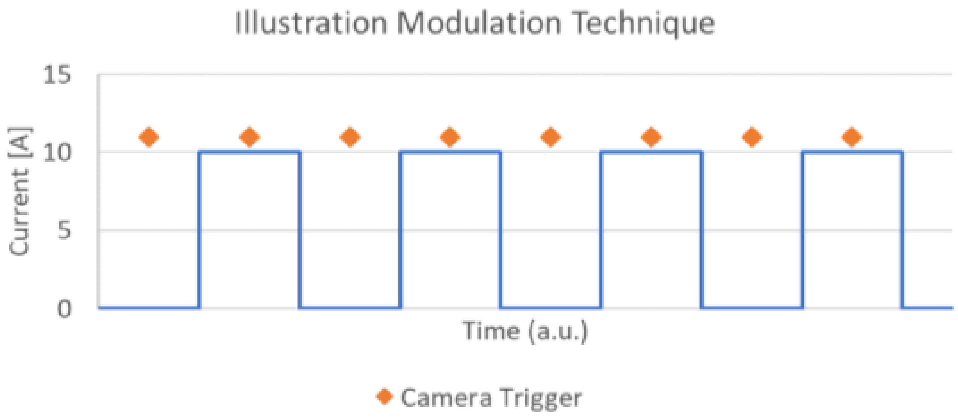
Background

PELMS Modulation Technique

PELMS Modulation Technique

- The time domain implementation of this technique is shown below where the PELMS device will inject a DC current at arbitrary time intervals (i.e. 0 or 10 A) and the unit will send a trigger to the camera at the midpoint of the interval to capture a base image when the DC current is off (i.e. 0 A) and an EL image when the DC current is on (i.e. 10A)
- The PELMS device will then subtract, sum / stack /scale the differences of the images.

Source: Development of a Portable Electroluminescence Measurement System for Photovoltaic Modules, Leong et al, pp 1 Fig 1.

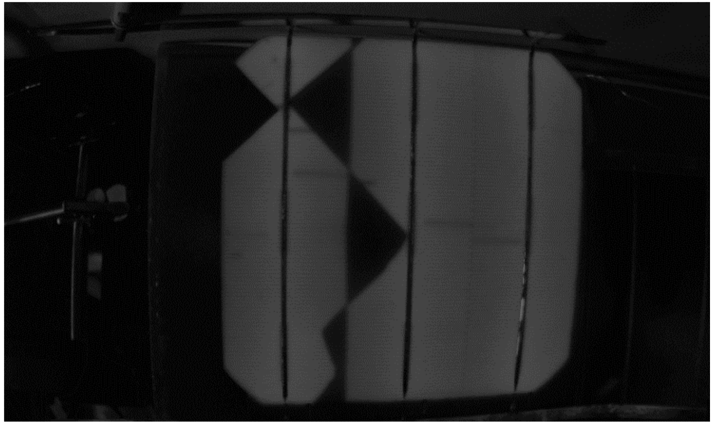


Background

2023 *Team Solar* PELMS

2023 *Team Solar* PELMS

- Team Solar was the ENGN project team who built a PELMS device in 2023 that demonstrated the modulation technique.
- The developed system imaged one solar panel and produced electroluminescence images within 5 minutes.
- The developed system was built comprising of cheaper more readily available components such as Raspberry Pi and Raspberry Pi cameras.



Source: Development of a Portable Electroluminescence Measurement System for Photovoltaic Modules, Leong et al, pp 4 Fig 8.

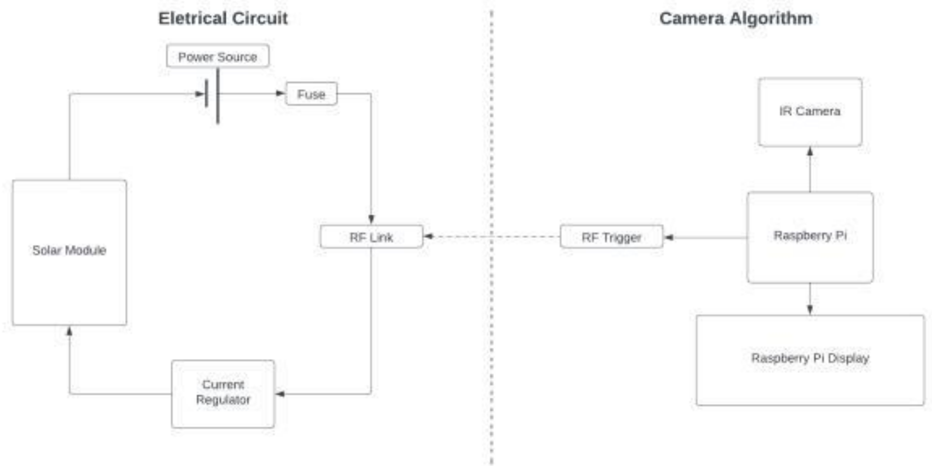
Background

2023 *Team Solar* PELMS Design

2023 *Team Solar* PELMS Design

- The device is composed of two subsystems:
  - Electrical Circuit Subsystem
  - Camera Algorithm Subsystem

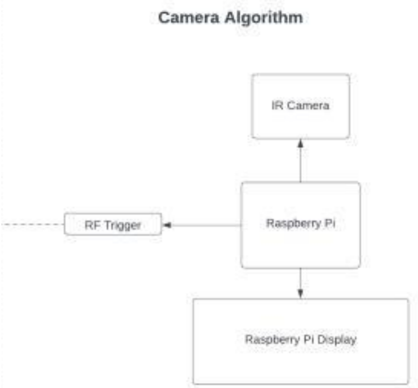
Source: Development of a Portable Electroluminescence Measurement System for Photovoltaic Modules, Leong et al, pp 2 Fig 2.



Background

2023 *Team Solar* PELMS Design

Source: Development of a Portable Electroluminescence Measurement System for Photovoltaic Modules, Leong et al, pp 2, Fig 2 and pp 5, Fig 7.



2023 *Team Solar* PELMS Design

Camera Algorithm Subsystem components:

- Raspberry Pi is the Controller/Processor of the Camera Algorithm Subsystem – which runs a GUI and processing software that is written in Python.
- Raspberry Pi Display is implemented using a Smart Pi Touch 2 Touchscreen.
- IR Camera is implemented using a Raspberry Pi HQ Camera.
- RF Trigger is implemented a Linx Technologies 433 MHz Transmitter Evaluation Board.

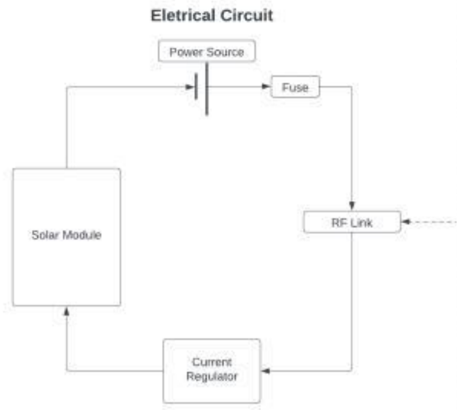
Background

2023 *Team Solar* PELMS Design

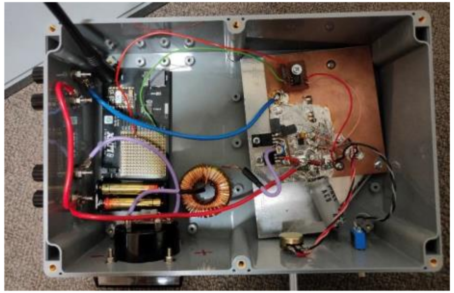
2023 *Team Solar* PELMS Design

Electrical Circuit Subsystem components:

- Solar Module is the PV Module under test.
- Power Source is implemented using 52V E-bike battery.
- RF Trigger is implemented a Linx Technologies 433 MHz Transmitter Evaluation Board.
- Current Regulator is a circuit that injects a DC current into the Solar Panel when triggered via the RF Link.



Source: Development of a Portable Electroluminescence Measurement System for Photovoltaic Modules, Leong et al, pp 1 Fig 1.



Methodology

Approach

Approach

- There were 5 deliverables for development work across the across the 2 subsystems of the 2023 PELMS device.
- The work for the 5 deliverables was broadly covered in 3 design fields of engineering:
  - Software Development,
  - PCB Design, and
  - Electronic Enclosure Design.

Methodology

Approach

Approach

- There were 5 recommendations across the 2 subsystems of the PELMS device

Recommendation	Deliverable	Relevant Subsystem	Relevant Design Field
Improve image detail by increasing the images capture from 8-bit resolution to 12-bit resolution	Develop python code to handle 12-bit resolution images and redevelop/update the GUI,	CAS	Software Development
Develop a more portable and reliable enclosure that houses components securely and prevents dust and water egress,	Design and construct an improved enclosure,	ECS	Enclosure Design
Improve power management to optimise power consumption,	Modify electrical circuitry to optimise power,	ECS	PCB Design
Create a PCB board for the circuitry on the prototyping board, and	Construction of a PCB board for the electrical circuit to replace the prototyping board, and	ECS	PCB Design
Increase the current rating above 10A.	Recalculate the component values of the electric circuit to handle loads above 10A.	ECS	PCB Design

Methodology

Software Development

Software Development

- Recommendation: Improve image detail by increasing the images capture from 8-bit resolution to 12-bit resolution.
- Deliverable: Develop python code to handle 12-bit resolution images and redevelop/update the GUI.

- Background and Supporting Resources
  - ENGN2219 Computing for Engineering
  - ENGN4528 Computer Vision
  - ENGN2218 Electronic Systems and Design
  - Internet resource e.g., Stackoverflow, Python library pages etc.

Methodology

Software Development

Software Development

- Python Libraries used:
  - Tkinter for the GUI
  - GPIO library for communicating with the RF Link
  - Picamera2 for capturing images
  - Opencv
  - Numpy

Methodology

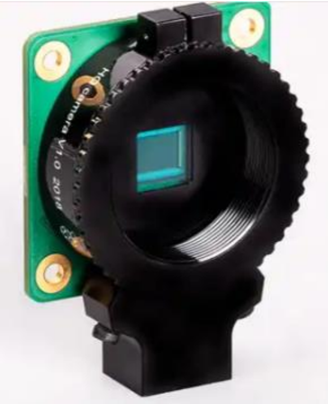
Software Development – Raspberry Pi Camera System

Software Development – Raspberry Pi Camera System

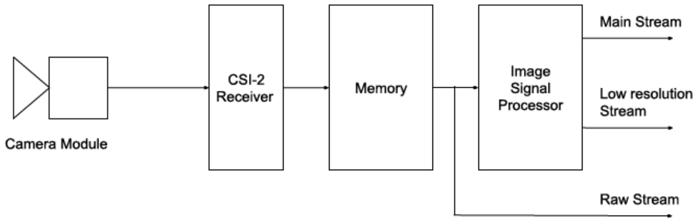
- Raspberry Pi HQ (High Quality) Camera
  - Raw 12-bit, 12.3 MP, Sony IMX477 sensor
  - Raw Capture Frame Size = 4056 x 3040 P = 12330240 P ≈ 12.3 MP

- Raspberry Pi camera system has 3 image stream outputs:
  - main – quality – RGB or YUV format, typical 8-bit, configurable frame size
  - lores – viable – YUV format, typical 8-bit, smaller frame than main image
  - raw – original – Bayer image date, 12-bit, fixed frame size

Source: Raspberry Pi website: https://www.raspberrypi.com/products/raspberry-pi-high-quality-camera/. (15/05/2024)



Source: The Picamera2 Library, 2022-2023 Raspberry Pi Ltd, pp 15., Figure 2.



Methodology

Software Development – Picamera2

Software Development – Picamera2

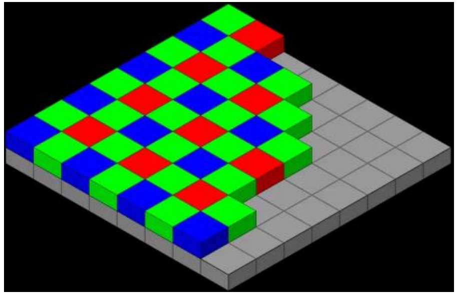
- Picamera2 is the software library that contains python software that communicates with the Raspberry Pi Camera.
- Differs to the original Picamera which was used in PELMS 2023
  - Raspi-config legacy camera is ON for Picamera to work, OFF for Picamera2 to work

- Raspberry Picamera2 has 3 configuration modes which are:
  - Still – capture that uses 4056 x 3040 raw frame for the a main, lores or raw image stream for still images
  - Video – capture that uses 4056 x 3040 raw frame for the a main or lores image stream for video
  - Preview – capture that uses 2028 x 1520 raw frame for the a main, lores or raw (still image only) image stream for still images or video

Methodology

Software Development - Raw Image Processing Algorithm

Software Development – Raw Image Processing Algorithm



Source: https://en.wikipedia.org/wiki/Bayer_filter#/media/File:Bayer_pattern_on_sensor.svg (15/05/2024)

- Convert a raw 12-bit Bayer image format to 16-bit RGB format
- Python code:

```
# Capture the VL image:
# Get a raw Bayer frame with 12-bit values packed into 16-bits.
# Convert Bayer 12-bit array to RGB 16-bit an write to file by
# doing the following steps:
#   - Convert to 12-bit value to 16-bit by shifting 4 bits
#   - Convert from Bayer format to RGB format
img_VL_Bayer_12bit = picam2.capture_array("raw").view(np.uint16)
img_VL_Bayer_16bit = img_VL_Bayer_12bit * 16
img_VL_RGB_16bit = cv2.cvtColor(img_VL_Bayer_16bit, cv2.COLOR_BAYER_RG2RGB)
```

Methodology

PCB Design

PCB Design

- Recommendation: Improve power management to optimise power consumption
- Deliverable: Modify electrical circuitry to optimise power,
- Recommendation: Create a PCB board for the circuitry on the prototyping board
- Deliverable: Construction of a PCB board for the electrical circuit to replace the prototyping board, and
- Recommendation: Increase the current rating above 10A.
- Deliverable: Recalculate the component values of the electric circuit to handle loads above 10A.

Methodology

PCB Design

PCB Design

- PCB Design is for the Current Regulator component of the Electrical Circuit Subsystem
- PCB Design decisions affect the Enclosure Design

- Background and Supporting Resources
  - ENGN2218 Electronic Systems and Design
  - ENGN4625 Power Systems
  - Internet vendor websites and datasheets

- Professional Engineer Support Mr. Chris Jones

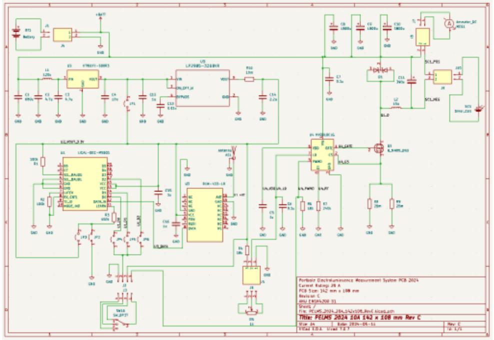
- Vendors
  - Element14, Digikey, Jaycar

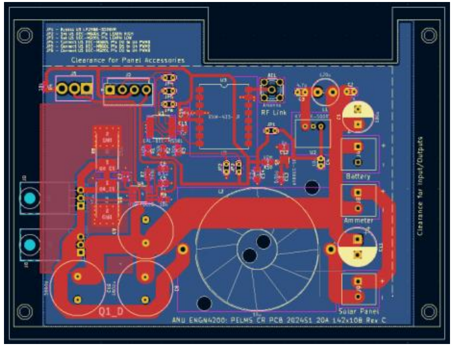
Methodology

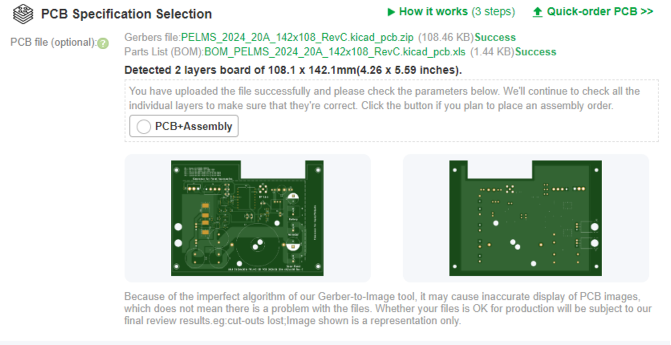
PCB Design – KiCad Development Process

PCB Design – KiCad Development Process

- KiCad is a free software suite for electronic design automation. It facilitates the design and simulation of electronic hardware for PCB manufacturing.
- Process is to edit a schematic, generate a PCB design from the schematic, generate Gerber files from the PCB design which can be passed on to a manufacturer.
- PCB Manufacturers: OSH Park (US), PCBWay (China), JLCPCB (China)





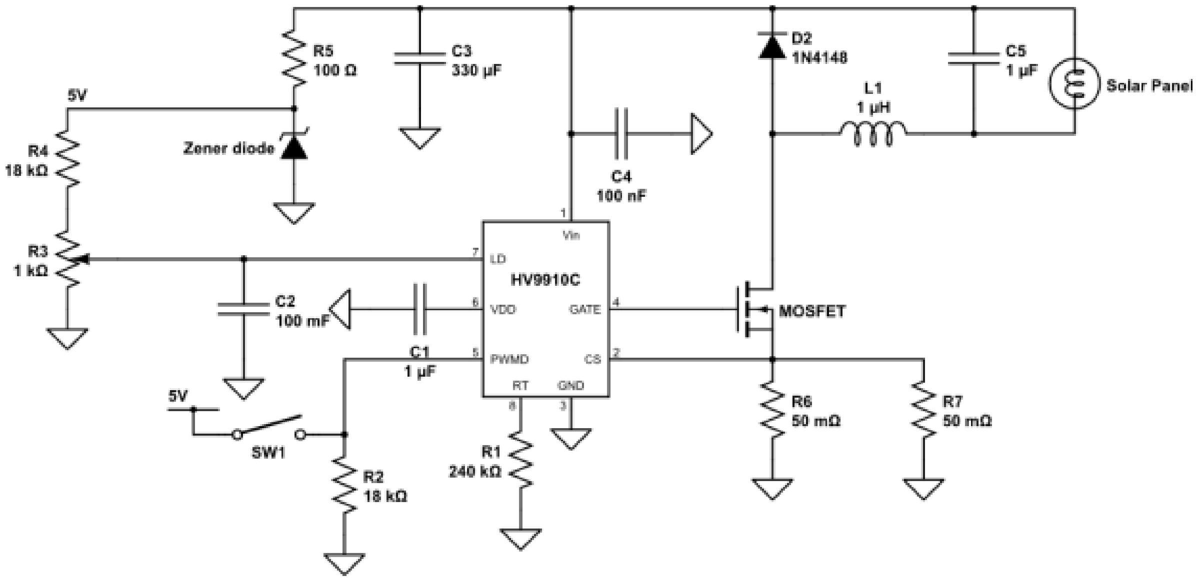


Methodology

PCB Design – Create a PCB of Prototype

PCB Design – Create a PCB of Prototype

- Documentation of original prototype was circuit schematic using HV9910C chip.



Methodology

PCB Design – Create a PCB of Prototype

PCB Design – Create a PCB of Prototype

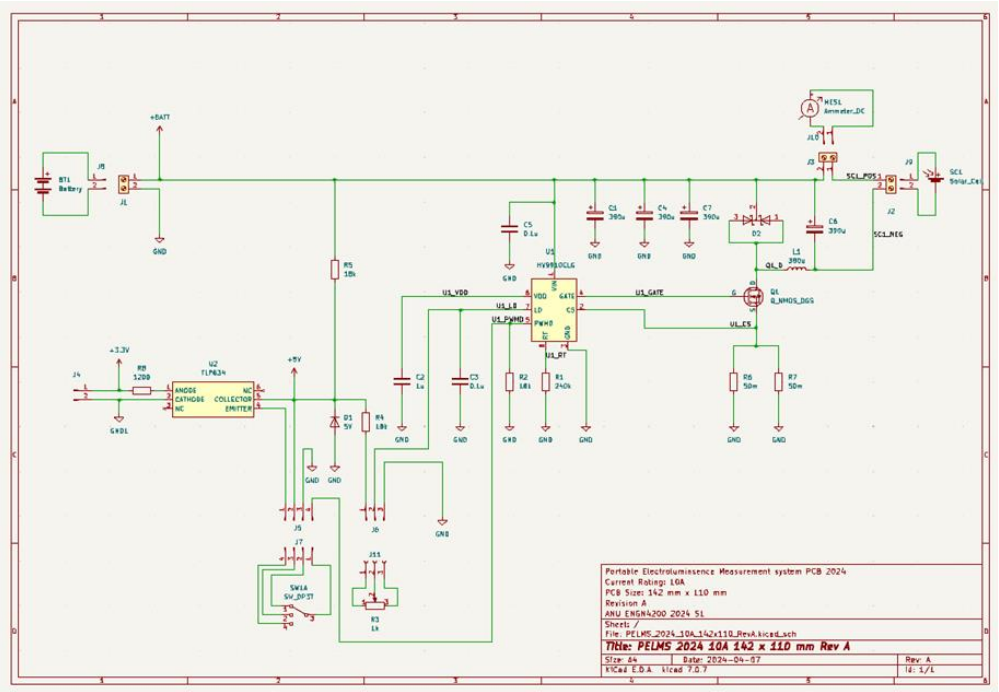
- Generated a KiCad project: PELMS 2024 10A 142x110 Rev A
  - Design was rated for the original 10 A.
  - Confirmed component values and operation.
  - Built on a reduced footprint 142 x 110 mm. This size was suitable for a reduced enclosure size of 170 mm x 120 mm rather than the original enclosure size of 240 mm x 160 mm.
  - RF Link is implemented off-board and was connected connects via an optical coupler and was powered separately i.e., using 2 x 1.5V AA batteries.
  - The track widths were modified thicker tracks were used for the heavier current loads while thinner tracks were used light current load i.e., those that were carrying signaling.
  - Transistor Q1 and Diode D1 were placed underneath the board for to attach to an Aluminum plate that could draw heat away from the circuit.

Methodology

PCB Design – Create a PCB of Prototype

PCB Design – Create a PCB of Prototype

- PELMS 2024 10A 142x110 Rev A – Schematic

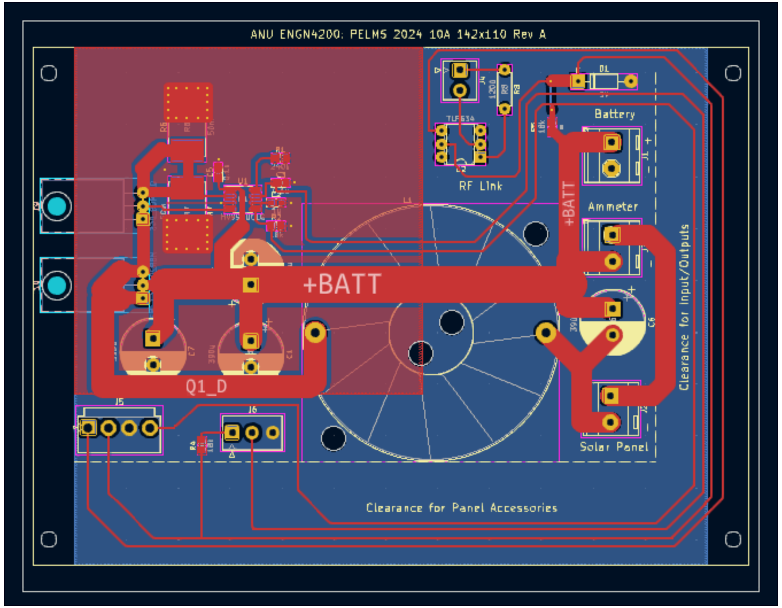


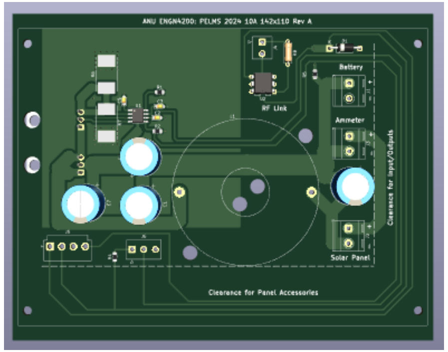
Methodology

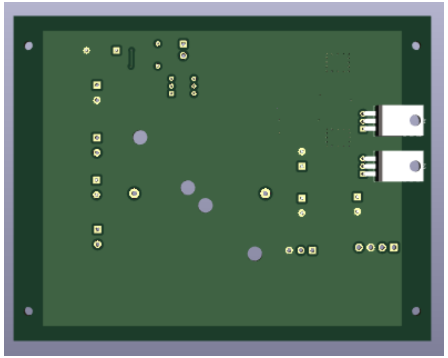
PCB Design – Create a PCB of Prototype

PCB Design – Create a PCB of Prototype

- PELMS 2024 10A 142x110 Rev A – PCB







Methodology

PCB Design – Modification to on board RF Link and RF Link power

PCB Design – Modification to on board RF Link and RF Link power

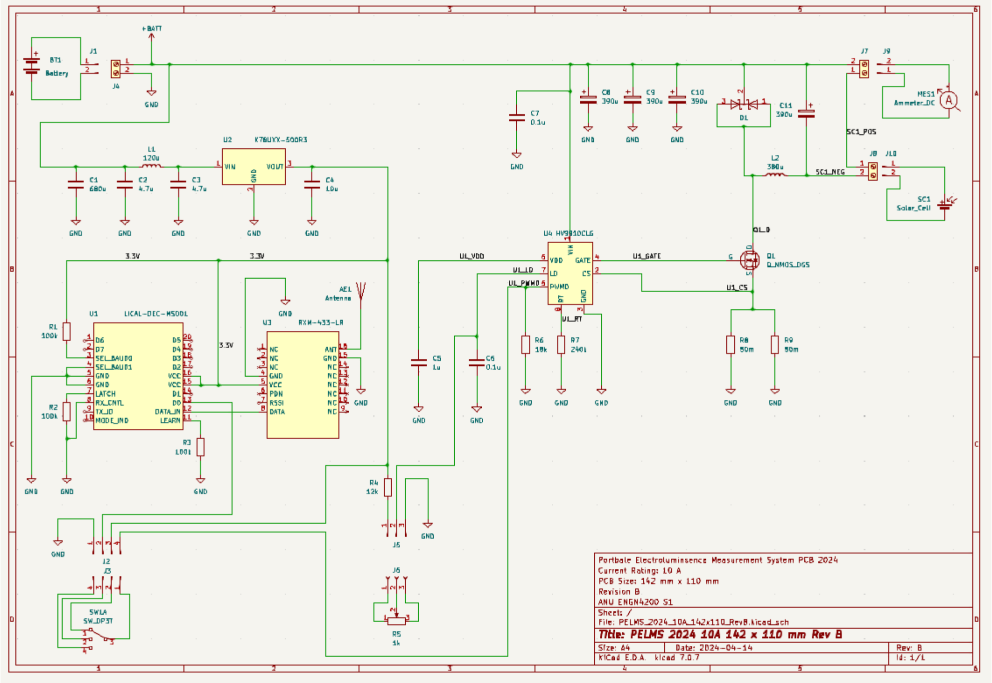
- Generated a KiCad project: PELMS 2024 10A 142x110 Rev B
  - Design was rated for the original 10 A.
  - Built on a reduced footprint 142 x 110 mm.
  - RF Link was on-boarded in this design. This required additional components including the DC/DC Converter (K78U03-500R3), RF Receiver (RXM-433-LR), decoder chip (LICAL-DEC-MS001) and Antenna mount.
  - All components in the Current Regulator were now powered off the power source (i.e., the 52 V e-bike battery).
  - There was significant increase in the signaling tracks.

Methodology

PCB Design – Modification to on board RF Link and RF Link power

PCB Design – Modification to on board RF Link and RF Link power

- PELMS 2024 10A 142x110 Rev B – Schematic

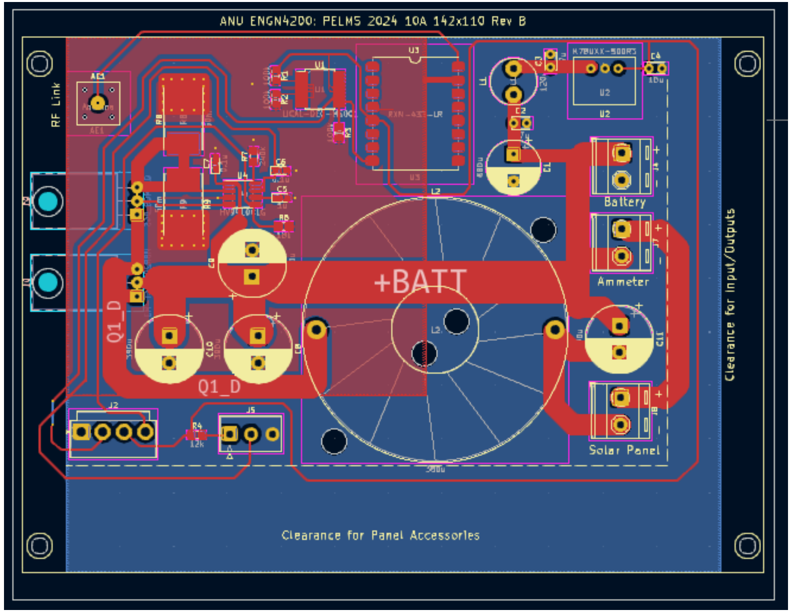


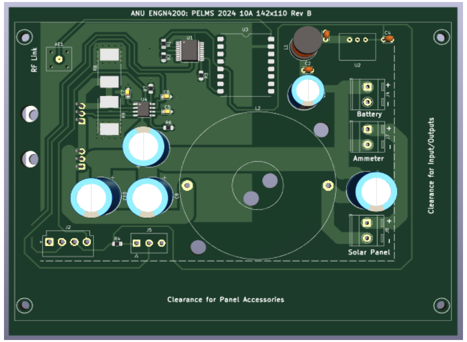
Methodology

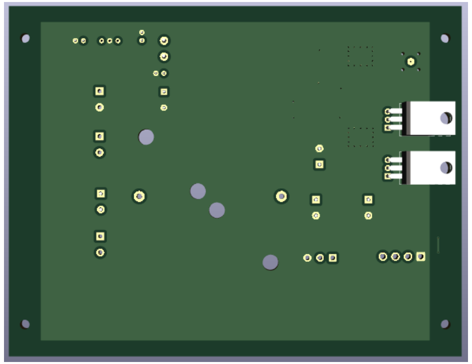
PCB Design – Modification to on board RF Link and RF Link power

PCB Design – Modification to on board RF Link and RF Link power

- PELMS 2024 10A 142x110 Rev B – PCB







Methodology

PCB Design – Current rating upgrade to 20 A

PCB Design – Current rating upgrade to 20 A

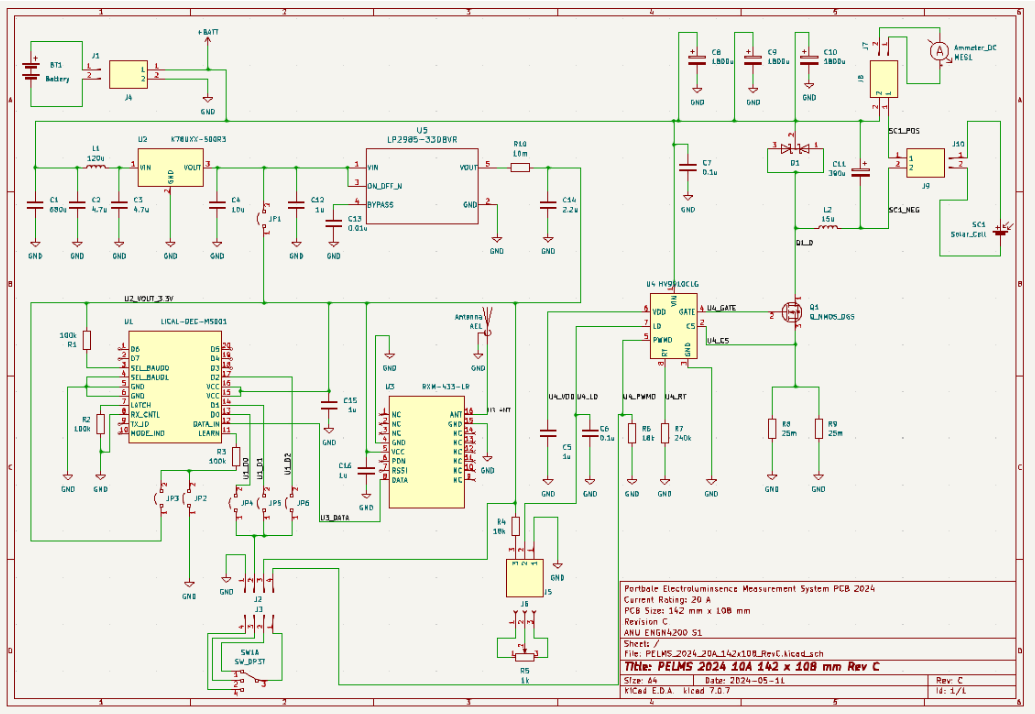
- Generated a kiCAD project: PELMS 2024 10A 142x110 Rev C
  - Design was upgraded to 20 A.
  - Recalculation was needed for current sensing resistors, components and capacitors needed to be rated to handle 20A. This also included connectors and ingress/egress wiring.
  - The footprint was slightly reduced 142 x 108 mm and some of the board was removed to clear potential space for a 20 A ammeter.
  - RF Link was on-boarded in this design.
  - All components in the Current Regulator were powered off the power source (i.e., the 52 V e-bike battery).
  - Jumper options to switch on functionality on the chip.

Methodology

PCB Design – Current rating upgrade to 20 A

PCB Design – Current rating upgrade to 20 A

- PELMS 2024 20A 142x108 Rev C – Schematic

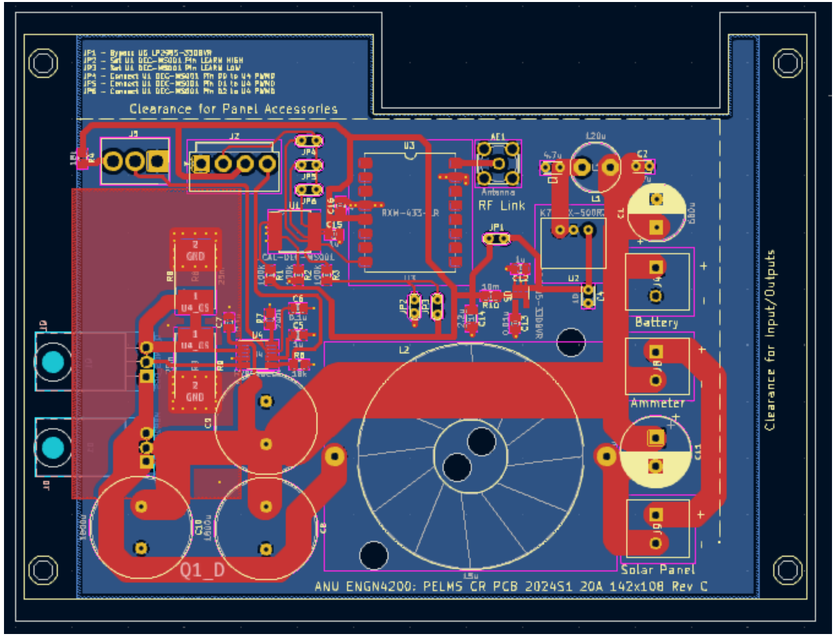


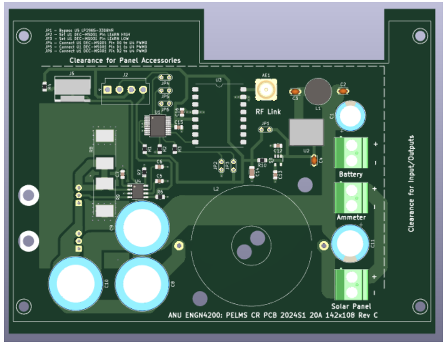
Methodology

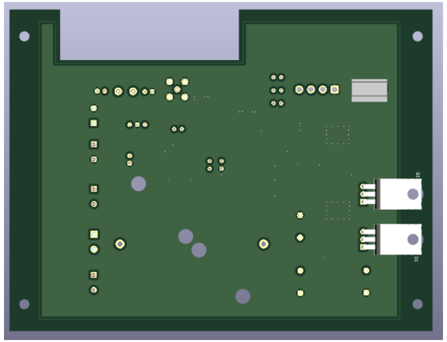
PCB Design – Current rating upgrade to 20 A

PCB Design – Current rating upgrade to 20 A

- PELMS 2024 10A 142x110 Rev C – PCB







Methodology

Enclosure Design

Source: https://www.jaycar.com.au/sealed-polycarbonate-enclosure-171-x-121-x-55-clear-lid/p/HB6248 (15/05/2024)

Enclosure Design

- Recommendation: Develop a more portable and reliable enclosure that houses components securely and prevents dust and water egress,
- Deliverable: Design and construct an improved enclosure,

- Background and Supporting Resources
  - CIT ANUQ Electronics Workshop Practices
  - Internet vendors and datasheets

- Enclosure Design was to house and reduce the footprint the Current Regulator component of the Electrical Circuit Subsystem.
- The enclosure that would house the Current Regulator was a Sealed Polycarbonate Enclosure 171 x 121 x 55 - Clear Lid
- Simplest but most costly in terms of trial and error i.e., circuits and software can be simulated but drilled holes may require a new enclosure purchase.

Methodology

Enclosure Design

Enclosure Design

- Enclosure is rated to IP65.
- IP65 rating is ingress protection code
- First digit is solid particle protection:
  - Value of 6 is Dust-tight – No ingress of dust; complete protection against contact (dust-tight).
- Second digit is liquid ingress protection:
  - Value of 5 – Water jets; Water projected by a nozzle (6.3 mm (0.25 in)) against enclosure from any direction shall have no harmful effects.

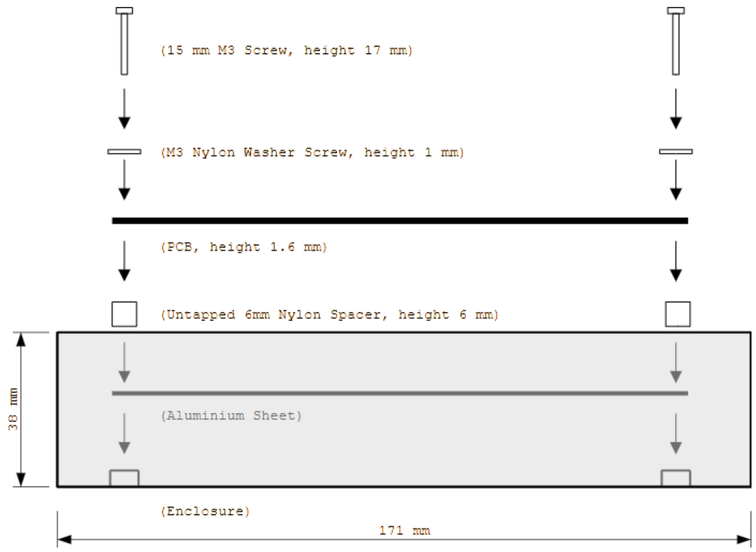
- Approach is research, measure and fit subject to two design requirements for:
  - Placement of PCB within the enclosure
  - Placement of connections and peripherals to/from the enclosure

Results

Enclosure Design – PCB Placement

Enclosure Design – PCB Placement

- PCB will sit on an Aluminum sheet as show in the side profile below.



Methodology

Enclosure Design – Peripherals and Connections

Enclosure Design – Peripherals and Connections

- Design requirements are for placement of PCB

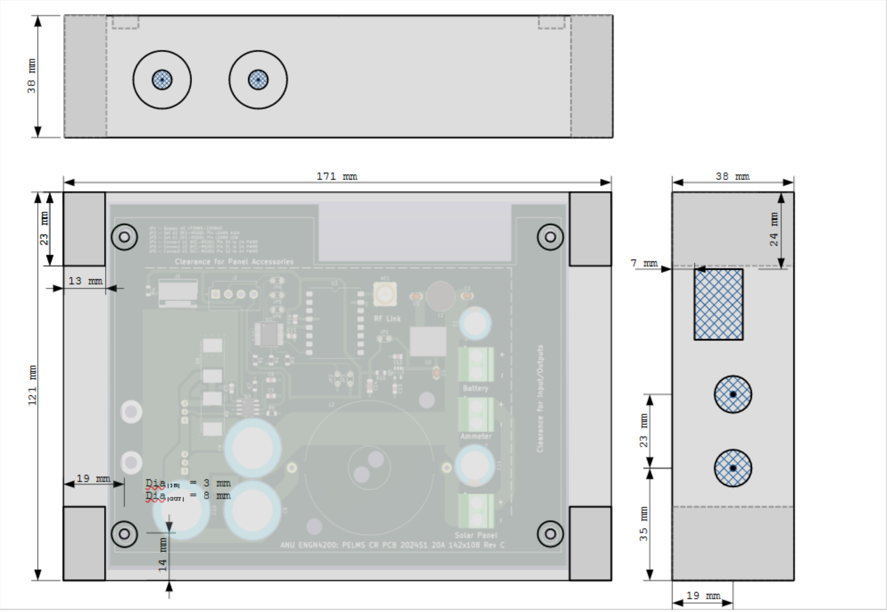
Connection/Peripheral	Designated Interface
Power Source Connection	30 A Anderson PP connectors with housing (Connecting cable is 12 AWG – rated to 25 A)
Solar Panel Connectors	Cable Glands (Connecting cable is 12 AWG – rated to 25 A)
20A Ammeter	TBC - Space (Connecting cable is 12 AWG – rated to 25 A)
Current Level Controller	Potentiometer with knob
Current Regulator Mode	Switch with knob

Methodology

Enclosure Design – Peripherals and Connections

Enclosure Design – Peripherals and Connections

- Placement in the top-down profile.



Results

Software Development

Software Development

- Achievements
  - PELMS 2024S1 GUI has been developed
  - Capable of capturing raw 12-bit images and creating gray and/or RGB files

(Deliverable)

  - Works with both 2023S1 and 2023S1 hardware i.e. because only connects to the RF Trigger

- Contribution to date
  - 12-bit resolution has produced images – but haven’t fully captured EL images

Results

Software Development

Software Development

- Still to do
  - Testing not completed
  - Ideally compare images between PELMS2023 and PELMS2024

- Challenges
  - Having some problems communicating with camera which is causing glitches. I haven’t diagnosed the problem – not sure if it is tkinter GUI or possibly some software/OS system updates based on light internet research.

Results

PCB Design

PCB Design

- Achievements
  - PCB Design completed (Deliverable)
  - PCB Design rated to 20 A in the design (Deliverable)
  - PCB RF Linx module has been on-boarded (Deliverable)

- Contribution to project
  - Main contribution is the documentation of a Current Regulator PCB and the components

- Still to do
  - PCB board is ordered, and the circuit needs to be built and tested.

Results

PCB Design

PCB Design

- Challenges
  - Most challenging of the 3 work areas
  - As the complexity of the circuit increase so does changing a part
  - Theory is not necessarily enough – there is a complex balance SWaP (Size , Weight and Power) that can start to affect costs
  - Required the guidance of an experienced Engineer
  - (Thanks Mr. Chris Jones)

Results

Enclosure Design

Enclosure Design

- Achievements
  - Enclosure footprint has been reduced.
  - Initial Design made
- Contribution to project
  - Documentation on cable egress or connecting to Power Source or Solar Panels
- Still to do
  - Placement of a 20A Ammeter
  - Tidy of documentation

Results

Enclosure Design

Enclosure Design

- Challenges
  - Changes depending on PCB design
  - Incorrect hole placement

Conclusion

Conclusion

- Still have some outstanding work to complete.
- Great project to work on very well-rounded project.
  - Software
  - Hardware
  - Electronics
  - Computer Vision theory
- Lot of work – 200 Hours vs 2 Semester.

- Extension work
  - Computer Vision a lot of detail
  - Electronics – updating RF
  - Software – lot of extra functionality

THANK YOU

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