

FET Control Box

ECEN 403

Team 16

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4/28/2025

FINAL REPORT

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FET Control Box

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CONCEPT OF OPERATIONS

CONCEPT OF OPERATIONS FOR FET Control Box

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APPROVED BY:

Project Leader _____ **Date** _____

Prof. Enjeti Date

T/A Date

Change Record

Rev	Date	Originator	Approvals	Description
1	9/15/2024	FET Control Box		Draft Release
2	12/5/2024	FET Control Box		End of Fall Semester
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1. Executive Summary

The primary purpose of the FET Control Box is for use in ECEN438, requiring ruggedness and reliability in an undergraduate lab setting. It must be easy to debug and repair, while also offering advanced performance suitable for research applications. The box contains two electrically independent pairs of Power MOSFETS and Power Diodes, and a control logic system that generates three switching modes based on PWM control. These modes include identical switching, complementary with dead-time, and alternating switching. The FET Control Box supports a range of DC-DC, DC-AC, and AC-AC converters, and can be used individually or in a master-slave configuration for more complex systems.

2. Introduction

This document describes the purpose and features of the FET Control Box, a device used to facilitate the construction and testing of power circuit topologies in a laboratory setting.

2.1. Background

Power electronics and motor drives are common subjects covered in advanced undergraduate and graduate electrical engineering curricula. However, lab experiments in power electronics require advanced knowledge and understanding of the concepts that undergraduates will not always have starting in advanced undergraduate courses. Design of systems and circuits that power electronic courses go in depth into would be very complicated and frustrating with no prior experience.

For this reason, a FET Control Box was used at the University of Illinois to abstract away certain subject areas to make hands-on power electronics instruction practical for a university course. Students can study the prebuilt subsystems in the course to start off and be able to understand the functions that each module provides without needing to design an entire system from scratch. The FET Control Box is only intended for introducing new concepts to students in power electronics and allow students to eventually create equivalent circuits that can replace each module using their own designs.

The design resulting from the proposed project is intended to replace the existing FET Control Box used in a Texas A&M University course, ECEN 438, Power Electronics. Currently, there is no replacement for broken FET Control Boxes, as they are more than 20 years old and originate from the University of Illinois.

The new design will be an updated version that replaces the currently used FET Control Box and provides an equivalent or more robust design suitable for use in lab settings. The intended lifetime of the device is to be at least 10 years, using components that can be easily replaced or last in the next decade.

2.2. Overview

This document's purpose is to describe in detail the operation, features, and limitations of the MOSFET Control Box intended to be used to complete the course ECEN 438, Power Electronics, offered by Texas A&M University.

2.3. Referenced Documents and Standards

- Robert S. Balog, Fet Control Box Redesign 2002, Ref: DD00003, Issue: 001
- Robert S. Balog, Modern Laboratory-Based Education for Power Electronics and Electric Machines

- University of Illinois at Urbana-Champaign, Document Number: SK0003, Rev: 4

3. Operating Concept

3.1. Scope

The MOSFET control box is intended to be used to complete lab assignments in the course ECEN 438, Power Electronics, where students build various switching power supplies and characterize their behavior. The FET Control Box is intended to abstract away the implementation of the switching component of power circuit topologies, so that instruction can solely be focused on power electronics design. To do this, the box contains two sets of power MOSFETS and diodes whose terminals are exposed to the student, allowing them to add components to construct various power circuit topologies. The gate of the MOSFET is driven either by an internal or external PWM signal with parameters set by the user.

3.2. Operational Description and Constraints

All MOSFET and diode terminals, except for the MOSFET gate, are exposed to the user, allowing them to construct various power circuits using the power semiconductors in the box. The gate of the MOSFET is driven by a gate driver that is controlled by a microcontroller generating a PWM signal of frequency and duty cycle specified by the user; alternatively, an external signal or duty ratio can be used instead, via BNC connectors. The two MOSFETS can be operated in three modes: matching, alternating, and complementary, where the MOSFETS operate in complement with a short dead-time specified by the user. In addition to the operating mode and switching signal parameters being adjustable via physical knobs and buttons on the box, it can also be adjusted programmatically by connecting the box to a computer via USB.

Operating conditions and system constraints are specified below:

- Power MOSFETS and diodes must have absolute maximum ratings of 400V and 20A
- Minimal component safety features
 - Overheat protection being the exception
- Operations manual is required to have following sections
 - Operation
 - Troubleshooting
 - Parts list for repairability

3.3. System Description

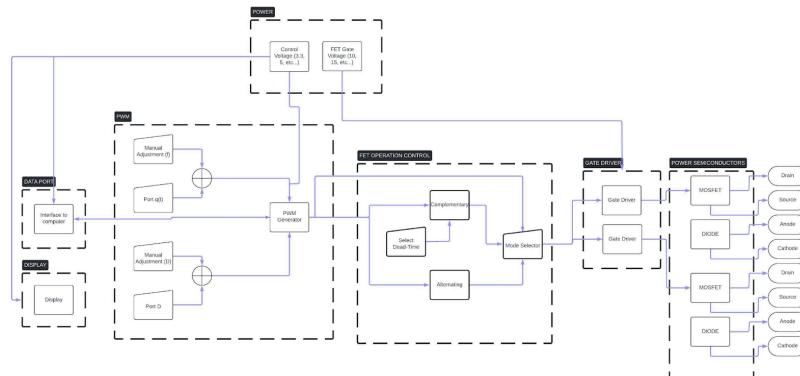


Figure 1: Subsystem Breakdown

- PWM: The PWM signal is generated by a microcontroller and can be controlled via knobs and buttons on the box, or programmatically via USB. Additionally, an external switching signal and duty ratio can be used via BNC connectors mounted on the box
- FET Operation Control: The mode of operation of the MOSFETS is specified by the user. The control logic is handled by a microcontroller.
- Data Port: The mode of operation, frequency, and duty ratio can be controlled programmatically via command line on a computer. Data is sent to and from the box via USB.

3.4. Modes of Operation

Matching: The two MOSFETS are switched using the same signal (i.e. they turn on and off at the same time).

Alternating: One MOSFET is switched on while the other is switched off. This mode would be used for implementing push-pull type circuits.

Complementary: MOSFETS are operated in complement with a short “dead-time”. This mode would be used for implementing half-bridge and synchronous-rectifier circuits among others.

3.5. Users

Students in ECEN power classes will be using this device for labs to conduct experiments. There may also be applications for graduate students and researchers to use this device. Minimal training is needed due to its simple functions and user interface, with a manual included for details and proper use.

3.6. Support

Support documentation will be available for the FET box and student lab manuals should provide basic instructions for students using the device to complete their lab assignments. The students using the FET box will have the user manual for our group's design of the FET blue box and previous user manuals that Dr. Balog has written for his version of the FET box. In addition, Dr. Balog is a current professor at the university who can further support students in the operation of the FET box if necessary. The circuits within the FET box shall be designed to allow easy replacement of circuit elements.

4. Scenario(s)

4.1. ECEN438 - Power Electronics

The FET Blue Box will be utilized in the laboratory component of ECEN 438, a course focused on the study of electric power conditioning and control, including solid-state power switches, AC power controllers, rectifiers, DC choppers, and DC-AC converters, with applications in power supplies, and airborne and spaceborne power systems. While the current control boxes used in the lab are adequate for instructional purposes, they were designed in the early 2000s, leading to a lack of available replacement parts and outdated components. The implementation of the FET Blue Box will modernize the lab equipment with updated components and enhanced features, ensuring easier maintenance and the availability of replacement parts.

5. Analysis

5.1. Summary of Proposed Improvements

The proposed improvements are the following:

- Microcontroller generated PWM signal
- PWM signal specifications can be programmatically controlled from a host computer over USB
- A display on the device will show PWM frequency and duty cycle
- Potentiometers will be replaced with encoders to allow finer control over frequency and duty cycle

5.2. Disadvantages and Limitations

Limitations of the proposed FET Control Box design include:

- Minimal component safety measures leave an opportunity for accidental damage to the device.
- Some characteristics of power circuit topologies will not be analogous to a practical implementation of them (i.e. there will be some discrepancies in power loss, noise, etc. between a topology implemented using the FET Control Box and a breadboard over a topology implemented on a PCB).
- The FET Control Box power semiconductors are rated for a maximum operating voltage and current of 400V and 20A.

5.3. Alternatives

Alternative options aside from the FET Control Box include:

- Simulation software replaces the lab component of the course.
 - Advantages:
 - i. Switching components can be sufficiently abstracted to solely focus on power electronics design.
 - Disadvantages:
 - i. Simulations of a circuit are not always a good analog to its physical counterpart
 - ii. Students lose the opportunity to gain hands-on experience building power electronics circuits
- Students build the gate drive component of their power circuits themselves.
 - Advantages:
 - i. Students gain hands on experience building power electronic circuits
 - Disadvantages:
 - i. Instruction time would be used to explain information outside the scope of the course.

5.4. Impact

This project will facilitate students and professors at the university to test power circuit topologies. Our design will improve upon the current FET box that is being used in the ECEN 438 course, giving students an easier-to-use and reliable improvement to the FET box that is currently available.

FET Control Box

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INTERFACE CONTROL DOCUMENT

INTERFACE CONTROL DOCUMENT

FOR

FET Control Box

TEAM <LUKE BETHANCOURT, JACKY CHEN, MAX GARZA, SYDNEY NADDY>

APPROVED BY:

Project Leader _____ **Date** _____

Prof. Enjeti Date

T/A Date

Change Record

Rev	Date	Originator	Approvals	Description
1	9/15/2024	FET Control Box		Draft Release
2	12/5/2024	FET Control Box		End of Fall Semester
3	4/24/2025	FET Control Box		Final

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1. OVERVIEW

This ICD—Interface Controls Document—will describe in detail: physical controls, thermal controls and electrical interfaces available to the user. Additionally, interfaces available to computers are also described in this document.

2. REFERENCES AND DEFINITIONS

Provide any references (i.e., standards documents) and definitions. Examples are shown below.

2.1. REFERENCES

IEEE 488.2

IEEE Standard Codes, Formats, Protocols, and Common Commands for Use With IEEE Std 488.1-1987, IEEE Standard Digital Interface for Programmable Instrumentation
30 Nov 1992

IEC 60320-1

IEC 60320 Appliance couplers for household and similar general purposes
27 Jul 2021

2.2. DEFINITIONS

Table 1: Definitions

FET	MOSFET
USB	Universal Serial Interface
LED	Light Emitting Diode
kHz	Kilohertz (1000 Hz)
V	Volt
AC	Alternating Current
VAC	Volts Alternating Current
A	Ampere
mA	Milliampere
OLED	Organic Light Emitting Diode
PWM	Pulse Width Modulation
USBTMC	USB Test and Measurement Class
ICD	Interface Control Document
GPIB	General Purpose Interface Bus

ESD	Electro Static Discharge
kg	Kilogram

3. PHYSICAL INTERFACE

The FET Control Box shall have the following physical specifications.

3.1. WEIGHT

The FET Control Box shall weigh no more than 15kg.

3.2. DIMENSIONS

The FET Control Box shall not have an enclosure dimension larger than 12"x10"x8".

3.2.1. DIMENSIONS OF PHYSICAL USER INTERFACE

- Power MOSFETS, power diodes, and BNC jack shall have a dimension of 6x3.5x2cm.
- Frequency and duty ratio rotary encoders shall have a dimension of 11.5x14.5 mm with a diameter of 6mm.

4. THERMAL INTERFACE

The FET Control Box power MOSFETS and diodes need to handle higher current load and dissipate heat to prevent damage to components. The components will be attached to a heatsink on the side of the enclosure, using air circulation for heat dissipation.

5. ELECTRICAL INTERFACE

5.1. PRIMARY INPUT POWER

The FET Control Box will have one Universal IEC C13 receptacle for receiving 120VAC. A power switch on the back of the box will physically switch power on or off.

5.2. SIGNAL INTERFACES

The FET Control Box will have two 6mm BNC jack connectors equipped with ESD protection for an external switching signal and duty ratio modulation.

5.3. DISPLAY INTERFACES

The FET Control Box will have an OLED screen to display the following information:

- Switching frequency
- Duty ratio
- Internal or external switching signal in use
- MOSFET operation mode

5.4. USER CONTROL INTERFACE

The FET Control Box will have the following physical controls available:

- Two rotary encoder knobs to adjust frequency and duty ratio
- Two push buttons to control switching mode and PWM operating mode

- Two sets of 6mm BNC jack connectors leading to:
 - Power MOSFET drain
 - Power MOSFET source
 - Power diode cathode
 - Power diode anode

6. COMMUNICATIONS/DEVICE INTERFACE PROTOCOLS

6.1. HOST DEVICE

The FET Control Box will have a USB-B port mounted on the front panel that is intended to be used for communication with a computer.

FET Control Box

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FUNCTIONAL SYSTEM REQUIREMENTS

FUNCTIONAL SYSTEM REQUIREMENTS FOR FET Control Box

TEAM <LUKE BETHANCOURT, JACKY CHEN, MAX GARZA, SYDNEY NADDY>

APPROVED BY:

Project Leader _____ **Date** _____

Prof. Enjeti Date

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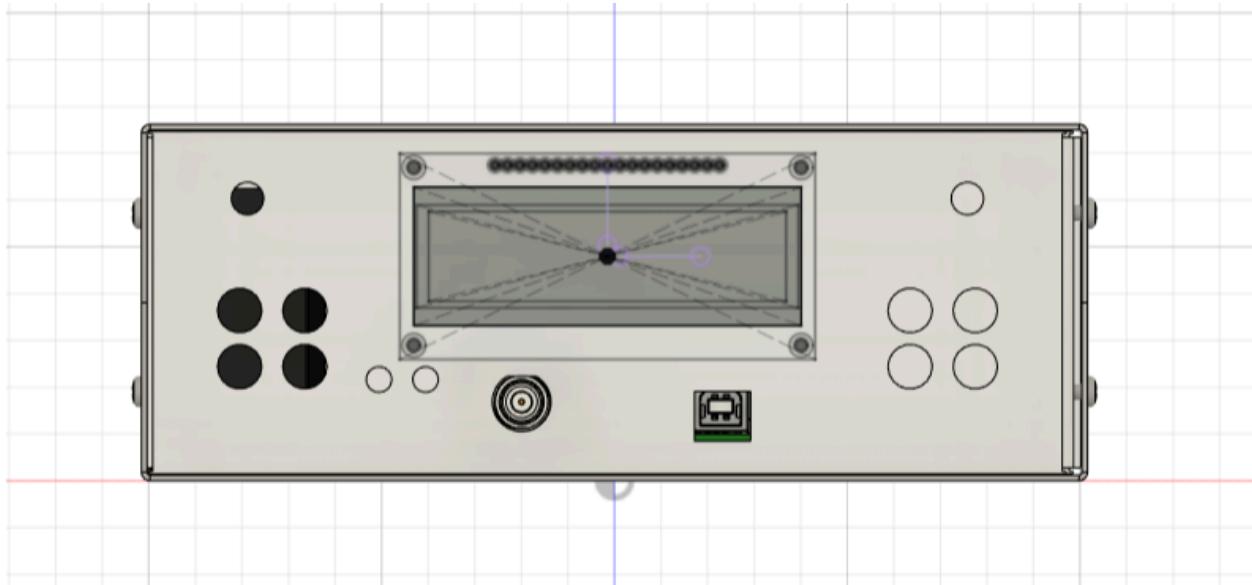
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1. INTRODUCTION

1.1. PURPOSE AND SCOPE

This specification defines the technical requirements for the development items and support subsystems delivered to the client for the FET control box. Figure 2 shows a representative integration of the project in the proposed CONOPS. The verification requirements for the project are contained in a separate Verification and Validation Plan.

Figure 2: FET Control Box Conceptual Rendering (Front)



The following definitions differentiate between requirements and other statements.

- Shall: This is the only verb used for the binding requirements.
- Should/May: These verbs are used for stating non-mandatory goals.
- Will: This verb is used for stating facts or declaration of purpose.

1.2. RESPONSIBILITY AND CHANGE AUTHORITY

The team leader Max Garza has the responsibility of making sure the project requirements are met. Furthermore, the group as a whole intends on keeping others in the group accountable for upholding the schedule and requirements of the project. The project sponsor Dr. Balog will also have authority to change the requirements of the project as he sees fit.

2. APPLICABLE AND REFERENCE DOCUMENTS

2.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title

IEEE 488.2	11/30/1992	IEEE Standard Codes, Formats, Protocols, and Common Commands for Use With IEEE Std 488.1-1987, IEEE Standard Digital Interface for Programmable Instrumentation
IEC 60320	07/27/2021	Appliance couplers for household and similar general purposes

2.2. REFERENCE DOCUMENTS

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
DD00003	9/15/2004	FET Control Box Redesign 2002
0885-8950	5/2/2005	Modern Laboratory-Based Education for Power Electronics and Electric Machines
	Version 1.4B – 8/2014	ECEN 438 – Power Electronics Laboratory – Laboratory Manual

2.3. ORDER OF PRECEDENCE

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

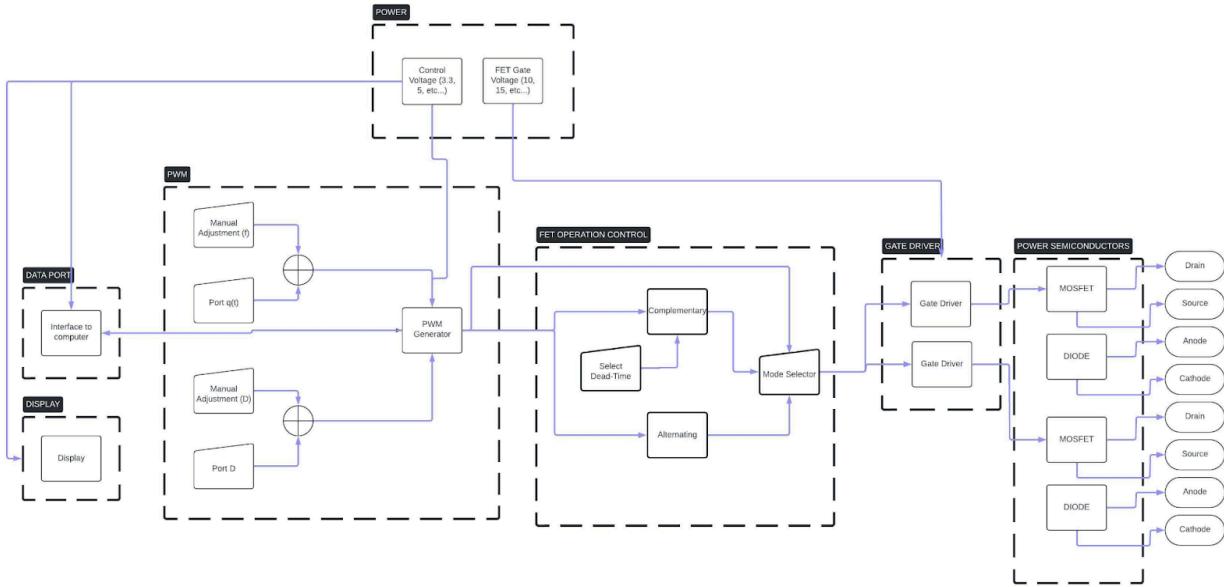
3. REQUIREMENTS

This section defines the minimum requirements that the development item(s) must meet. The requirements and constraints that apply to performance, design, interoperability, reliability, etc., of the system, are covered.

3.1. SYSTEM DEFINITION

This document describes the purpose and features of the FET Control Box, a device used to facilitate the construction and testing of power circuit topologies in a laboratory setting. The FET box controls the frequency and duty cycle of a PWM signal that is used to switch two power MOSFETS.

Figure 3: Block Diagram of System



There are four subsystems for the FET control box. The power semiconductors, gate drivers, and power supply is a subsystem; Jacky Chen will be responsible for implementing this subsystem. The microcontroller PWM generation and FET operation control logic is a subsystem; Luke Bethancourt will be responsible for implementing this subsystem. The OLED display, push buttons, and rotary encoder input is a subsystem; Max Garza will be responsible for implementing this subsystem. The PCB design for the microcontroller will be a responsibility shared between Max Garza and Luke Bethancourt, and Jacky will be responsible for the PCB design of the power electronics and power supply. Finally, the last subsystem is a computer application which uses SCPI commands to interface with the FET control box as a subsystem; Sydney Naddy will be responsible for this subsystem.

3.1.1. POWER SUPPLY

The power supply shall have the following requirements:

- Power from wall outlet shall be provided from an IEC power cord and receptacle
- Power supplied to the entire unit shall be isolated from mains power.
- Power supplied to the power MOSFETS and their gate drivers shall be isolated from control circuitry.
- The unit shall have a “Power On” LED, indicating that the unit is receiving power.
- Control circuitry shall be referenced to ground.
- The voltage range that it can take as an input

3.1.2. FET OPERATION CONTROL

The two MOSFETS shall have the following three modes of operation:

- Matching – The two MOSFETS are switched on and off at the same time.
- Alternating – The two MOSFETS are switched on and off opposite to each other (i.e. while one is on the other is off and vice versa).
- Complementary – The two MOSFETS are switched on and off opposite to each other, with a short dead-time between switching.

3.1.3. PWM GENERATION

The signal used to switch the power MOSFETS will be a PWM signal generated internally or an externally generated signal. The PWM generation system shall have the following requirements:

- Adjustable frequencies range from 1kHz to 300kHz.
- Adjustable duty ratio ranges from 5% to 95%.
- BNC connector, “q”, to allow for external switching signals.
- Switch to toggle between the internal or an external switching signal.
- Push button to toggle between three MOSFET modes of operation (*Section 3.3*).

3.1.4. APPLICATION

The FET Box shall be able to be controlled from a MATLAB application installed on a computer. The host computer shall interface with the FET Box over a USB-B port mounted on the FET Box. The application should be able to take user input concerning PWM generation and FET operation control and relay it to the FET Box.

3.1.5. DISPLAY

- PWM signal parameters shall be displayed on the OLED display mounted on the unit.
- Current FET operation mode shall be displayed on the OLED display mounted on the unit.
- Internal or external signal status (i.e. which signal is being used) shall be displayed on the OLED display mounted on the unit.

3.2. CHARACTERISTICS

3.2.1. FUNCTIONAL/PERFORMANCE REQUIREMENTS

3.2.1.1. POWER MOSFET SPECIFICATIONS

The two power MOSFETS shall have the following characteristics:

- Absolute maximum drain-source voltage of at least 800V
- Continuous drain current of at least 20A @ 25°C
- Acceptable packages:
 - TO-247
 - TO-220

3.2.1.2. POWER DIODE SPECIFICATIONS

The two power diodes shall have the following characteristics:

- Absolute maximum DC reverse voltage of at least 800V
- Average rectified current of at least 20A
- Acceptable packages:
 - TO-220-3
 - TO-247-3

3.2.1.3. POWER SEMICONDUCTOR MOUNTING

The power semiconductors shall be mounted using screw terminal blocks that have the following specifications:

- Single level
- Three positions
- Pitch greater than 3.50mm
- Voltage rating of at least 800V

- Current rating of at least 20A

3.2.2. PHYSICAL CHARACTERISTICS

3.2.2.1. MASS

The mass of the FET control box shall be less than or equal to 15 kg.

Rationale: Students and lab workers should be able to carry and lift the box without high risk of dropping them or hurting themselves.

3.2.2.2. VOLUME ENVELOPE

The volume envelope of the FET control box should be able to fit on a shelf with other equipment in a lab table.

Rationale: The intended use in a lab setting where it will be placed among other equipment, such as an oscilloscope and bench power supply.

3.2.2.3. INPUTS

The presence or absence of any combination of the input signals in accordance with ICD specifications applied in any sequence shall not damage the FET Control Box, reduce its life expectancy, or cause any malfunction, either when the unit is powered or when it is not.

No sequence of command shall damage the FET Control Box, reduce its life expectancy, or cause any malfunction.

Rationale: By design, should limit the chance of damage or malfunction by user/technician error.

3.2.2.3.1. POWER CONSUMPTION

The maximum peak power of the system shall not exceed 16000 watts.

Rationale: To limit the risk of damaging components, the maximum peak power that the components can handle is 800V and 20A. The device is designed to be operated at maximum 400V and 10A.

3.2.2.3.2. INPUT VOLTAGE LEVEL

The input voltage level for the FET Control Box shall be 265VAC to 85VAC.

Rationale: The FET Control Box will be plugged into the wall with Universal IEC connectors.

3.2.2.3.3. ISOLATION

The FET Control Box shall not interfere with the components being used in experiments (i.e. the power MOSFETS and diodes)

Rationale: The power given to the MOSFET gate driver circuit, in addition to the switching signal applied must be electrically isolated.

3.2.2.3.4. EXTERNAL COMMANDS

The FET Control Box shall document all external commands in the appropriate ICD.

Rationale: The ICD will capture all interface details from the low level electrical to the high-level packet format.

3.2.2.4. OUTPUTS

3.2.2.4.1. SIGNAL INPUT/OUTPUT

The FET Control Box has a BNC jack available to allow for the use of an external switching signal over the internally generated one.

Rationale: This was a key feature of the first iteration and will be preserved in the new design.

3.2.2.4.2. DATA TRANSFER

The FET Control Box shall receive commands over USBTMC in compliance with IEEE 488.2.

Rationale: IEEE 488.2 provides a standardized way for devices on a GPIB bus to communicate and interact, making it easier to build and control instrument systems.

3.2.2.4.3. CONNECTORS

The FET Control Box shall use external connectors in accordance with IEC 60320-1.

Rationale: The IEC 60320-1 international standard defines power supply connectors and inlets used in electrical and electronic equipment, including laboratory equipment like the FET Control Box.

4. SUPPORT REQUIREMENTS

4.1. OPERATIONS MANUAL

The FET Control Box shall have an operations manual explaining how to use the following features of the device:

- PWM frequency adjustment
- Duty ratio adjustment
- Setting MOSFET operation mode
- Using an external switching signal
- Modulation of duty ratio
- Automation using USB commands

4.2. CONSTRUCTION MANUAL

The FET Control Box shall have a construction manual explaining step-by-step how to put together the device.

4.3. COMPUTER INTERFACE REQUIREMENTS

4.3.1. WINDOWS

To control the FET Control Box over USB on a Windows computer, the following requirements must be met:

- Installation of the MATLAB Runtime associated with the application
- 1 USB port available (USB-B to USB-A connection)

- Installation of appropriate serial drivers (if not already available)

4.3.2. LINUX

To control the FET Control Box over USB on a Linux computer, the following requirements must be met:

- Installation of the MATLAB Runtime associated with the application
- 1 USB port available (USB-B to USB-A connection)

FET Control Box

Luke Bethancourt

Jacky Chen

Max Garza

Sydney Naddy

EXECUTION PLAN

Execution Plan for FET Control Box

	1/13/25	1/20/25	1/27/25	2/3/25	2/10/25	2/17/25	2/24/25	3/3/25	3/10/25	3/17/25	3/24/25	3/31/25	4/7/25	4/14/25	4/21/25	4/28/25	5/5/25
PIC32 PCB Repair																	
PIC32 Firmware Integration																	
Create a Standalone Executable																	
Status Update 1 (01/29)																	
Final PCB Design																	
PCB Ordered																	
Parts Ordered																	
Finalize Additional App Features																	
Status Update 2 (02/3)																	
Housing construction plan																	
Housing labels																	
Final PCB Assembly																	
Heatsink mounting plans																	
Status Update 3 (02/24)																	
Front Plate and PCB Mounting Design																	
Box Assembly																	
Integrate UI with Box																	
Status Update 4 (03/19)																	
Final testing with full integration																	
Status Update 5 (4/2)																	
Final Testing Criterion Met																	
Final Design Presentation (04/16)*																	
Final Demo (4/26)*																	
Final Report (4/28)																	
Project Showcase (05/02)																	

1. Performance on Execution Plan

The execution plan was mostly completed; however, several aspects of the project remained unfinished. The main incomplete tasks were the final assembly of the FET Box enclosure and full system validation. The I/O subsystem was not fully completed or successfully integrated with the rest of the system, which prevented the project from functioning as originally intended. As a result, the project was not fully complete by the time of the system demonstration, and full system validation could not be performed. The FET Box enclosure was also left incomplete. Much of the time originally allocated for enclosure construction was redirected toward troubleshooting and attempting to fix issues with the I/O subsystem. This led to a mostly assembled enclosure, but it was not finished to a level that could be considered complete.

FET Control Box

Luke Bethancourt

Jacky Chen

Max Garza

Sydney Naddy

VALIDATION PLAN

Validation Plan for FET Control Box

Paragraph #	Test Name	Success Criteria	Methodology	TESTED (incomplete)	Responsible Engineer(s)
3.1.1	Power Supply	The power supply draws 120VAC and outputs 12VDC and 1A through an AC/DC converter.	Use a multimeter to validate DC output.	TESTED (success)	Jacky
3.1.2	FET Operation Control	The two MOSFETS have 3 modes: Matching, alternating, and complimentary.	Test the system output signal for each mode using an oscilloscope or data analysis.	TESTED (success)	Luke
3.1.3	PWM Generation	Adjustable frequency range (1kHz to 300kHz) and duty ratio (5% to 95%). The signal can be toggled between an internal and external switching signal and allow toggling between the three MOSFET modes.	Test the system output signal for each mode using an oscilloscope or data analysis.	TESTED (success)	Luke
3.1.4	Web Application	Users shall be able to control the FET control box's PWM generation and control the power MOSFET modes via the web application.	Use Web application to adjust internal FET Box PWM, and use application to switch to each MOSFET mode of operation.	TESTED (success)	Sydney
3.1.5	OLED Display	The screen shows the MOSFET mode, the set duty ratio, and the set frequency.	Visually inspect screen while adjusting frequency, duty cycle, toggling mosfet mode, and internal/external button. Measure switching PWM at the gates of the 2 mosfets to verify that the information on screen accurately reflects frequency, duty cycle, and operation mode.	TESTED (success)	Max
3.1.6	Rotary Encoders	The two rotary encoders turn clockwise and counterclockwise and update the frequency and duty cycle respectively. Turning the knob quickly changes frequency or duty cycle in large increments and turning it slowly changes frequency or duty cycle in small increments	Physically turn knob. Measure the switching PWM waveform with an oscilloscope to ensure that the two rotary encoders change the frequency and duty correctly and proportional to the amount and speed turned.	TESTED (Failed)	Max

3.1.7	External PWM Capture	The microcontroller is able to replicate an input PWM signal's frequency and duty ratio	Connect the output of a function generator with the minimum frequency and duty cycle to the FET Box's BNC port. Then increment the signal's frequency and duty ratio until the maximum supported parameters are reached. Verify that the output PWM of the FETBox matches the function generator's .	TESTED (Failed)	Max
3.2.1.2	Power Diodes	Maximum rectified current of 10A, maximum VDC = 200V from MOSFET drain to source.	Test signal at 10A sent through power diodes. 200V reverse test signal sent at power diodes.	UNTESTED	Jacky
3.2.1.3	Power Semiconductor Mounting	Power semiconductors shall be mounted according to design requirements.	Movement of the box to determine if the parts are mounted properly.	TESTED (Success)	Jacky
3.2.2.1	Mass	The FET box is less than or equal to 15 kg.	Measure the box using a weight measuring scale.	TESTED (Success)	Max
3.2.2.3	Volume Envelope	FET box volume should be a reasonable fit on a lab table/shelf with other lab equipment.	Confirm that the box fits on the lab table/shelf alongside other standard lab equipment without issue.	TESTED (Success)	Max
3.2.2.4.1	Inputs	No absence, combination, or series of inputs in accordance with ICD specifications damage the FET control box, cause malfunction, or harm its life expectancy.	(1) Adjust frequency, duty cycle, mosfet operating mode, and use internal and external PWM modes while measuring gate drive output, mosfet drain-source voltage, diode cathode-anode voltage. Measure power semiconductor temperature.	TESTED (Success)	Sydney
3.2.2.4.2	Power Consumption	Maximum power draw should be no more than 12 watts.	Use a multimeter to measure power draw of FET control box	TESTED (success)	Jacky
3.2.2.4.3	Input Voltage	Input voltage shall be 120 VAC using a IEC 320 C13 receptacle	Use a multimeter to measure input voltage to FET control box	TESTED (success)	Jacky
3.2.2.4.4	Isolation	Input signals and MOSFETs are electrically isolated within their own circuit to prevent EMI.	Confirm that the output signal does not have significant noise or differ from expected when measuring it through an	TESTED (success)	Jacky

			oscilloscope.		
	PWM signal drive	PWM signals are isolated through the optocouplers and driven to the MOSFET at a higher current.	Oscilloscope probe the optocoupler output and gate driver output/MOSFET gate input. PWM signals should keep the frequency and duty ratio for both.	TESTED (success)	Jacky
	Buck-boost test	The power semiconductors output the correct voltage when connected to an external buck boost circuit.	External circuits connected to a MOSFET and an auxiliary diode get the voltage across the load resistor. 20V power supply from external power supply and 9-10V at the load resistor. AC components from the PWM should be present with matching frequency and around 50mV amplitude.	TESTED (Failed)	Jacky
3.2.2.5.2	Data Transfer	FET Control Box frequency, duty cycle, operation mode, and internal/external PWM mode is able to be adjusted over USB using serial communication	Send commands to adjust internal PWM frequency and duty cycle. Send commands to cycle through mosfet operating modes. Send commands to toggle between internal/external PWM mode	TESTED (success)	Luke
3.1.4 & 3.2.2.6.2	Serial Port Connection	Data from the web application should be transferred from a computer to the FET box microcontroller by USB-A.	Web application sends information to the microcontroller that will indicate that information has been received.	TESTED (success)	Sydney
N/A	Full System Demo	A user can use the FET box for AC-DC, DC-DC, and DC-AC power supply topologies with the use of the analog and digital interfaces provided	Use of the web application and analog controls to demonstrate the ability to alter the PWM frequency and duty cycle, switching MOSFET modes of operation, and show the usability of the power MOSFETs and diodes.	TESTED (Failed)	Full Team

1. Performance on Validation Plan

Due to the incomplete execution of the task plan, some aspects of the project failed validation. While most subsystems were successfully tested, several components could not be fully validated by the end of the semester. The power diodes were not tested at their rated 10A and 200V conditions to avoid risking system damage. Buck-boost testing failed because the inductor used could not handle the necessary current. Additionally, failures in the rotary encoders and external PWM capture led to an unsuccessful full system demonstration.

FET Control Box

Luke Bethancourt

Jacky Chen

Max Garza

Sydney Naddy

SUBSYSTEM REPORTS

SUBSYSTEM REPORTS

FOR

FET Control Box

TEAM <LUKE BETHANCOURT, JACKY CHEN, MAX GARZA, SYDNEY NADDY>

APPROVED BY:

Project Leader _____ **Date** _____

Prof. Enjeti Date

T/A Date

Change Record

Rev	Date	Originator	Approvals	Description
1	9/15/2024	FET Control Box		Draft Release
2	12/5/2024	FET Control Box		End of Fall Semester
3	4/24/2025	FET Control Box		Final

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1. INTRODUCTION

The FET control box is a system that will allow multiple different power circuit topologies to be created for use in a lab setting. The system's behavior is controlled by the analog or digital inputs that are provided to the FET control box. The system is broken down into the microcontroller, UI and application, I/O, and Power supply subsystem. In the subsystem report each group member will report the validation and progress that they accomplished with their subsystem. The FSR and validation plan will provide the requirements and specifications for each subsystem to be seen as completed.

2. MICROCONTROLLER SUBSYSTEM REPORT

2.1. SUBSYSTEM INTRODUCTION

The purpose of the microcontroller subsystem was to generate two PWM signals that can be changed based on the frequency, duty cycle, operational mode, and external signal parameters. The input parameters can come from the microcontroller's communication with a PC using serial communication, or through the I/O subsystem which sets these parameters within the microcontroller. Another part of the subsystem was the creation of the PCB for the microcontroller, in which I co-authored the schematic and layout of the design.

2.2. SUBSYSTEM DETAILS

The microcontroller subsystem mainly focuses on three things, the generation of the PWM signal, reading and executing the commands, and the PCB. The PWM signal and reading and executing commands is the firmware for the microcontroller. Where the PCB design is the hardware for the subsystem.

2.2.1. SOFTWARE

The code for this project was written for a PIC32 microcontroller, so it was written in the MPLAB IDE. It consists of multiple functions that allow for the PIC32 to generate the necessary signals and process the commands sent to it. Listed below are some of the key functions and their descriptions.

Table 1: Microcontroller Subsystem Key Functions

Function	Description
Matching	Generates two identical PWM signals for the set frequency and duty cycle.
Alternating	Generates two identical PWM signals for the set frequency and duty cycle.
Complementary	Generates two identical PWM signals for the set frequency and duty cycle.
PWMGEN	Calls the matching, alternating, or complementary functions based upon the set operating mode that is set for the microcontroller.
UART_Task	Reads the data sent to the microcontroller,

	determines if the data is a command and sends it to be processed.
ProcessCommand	Gets the command received from UART_Task ready to be sent to SplitCommand. Receives the two strings from SplitCommand and determines what command is to be executed and implements the necessary changes
SplitCommand	Takes the command given from ProccesCommand and separates it into two strings. The two strings are the number sent in the command and the word that specifies the command. Then these two strings are sent to be executed
main	First initializes the system. Then it loops through UART_Task and checks if the PWM signals need to be updated, if so it updates the signals.

The combination of these functions allows the microcontroller to produce the correct PWM signal for any mode, frequency, duty cycle within the specified requirements that is given as an input to the system.

2.2.2. HARDWARE

The hardware for this subsystem primarily consists of a PIC32MZ2048EMF144 microcontroller, a voltage regulator, a USB connector, a USB-to-serial IC, and an OLED display connector. The microcontroller receives inputs from various sources, processes them, and generates the appropriate PWM signals to drive the gate drivers. The voltage regulator steps down a 5V input from the power supply to 3.3V, which is the operating voltage required by the microcontroller. The USB connector and USB-to-serial IC handle data sent via USB-B, converting it into a serial format usable by the microcontroller. The OLED connector facilitates communication between the microcontroller and the display. Additionally, external circuits are used to condition signals from encoders and buttons, ensuring they are suitable for microcontroller inputs. Finally, several LEDs provide visual feedback of the system's operation.

Figure 4: Microcontroller Schematic

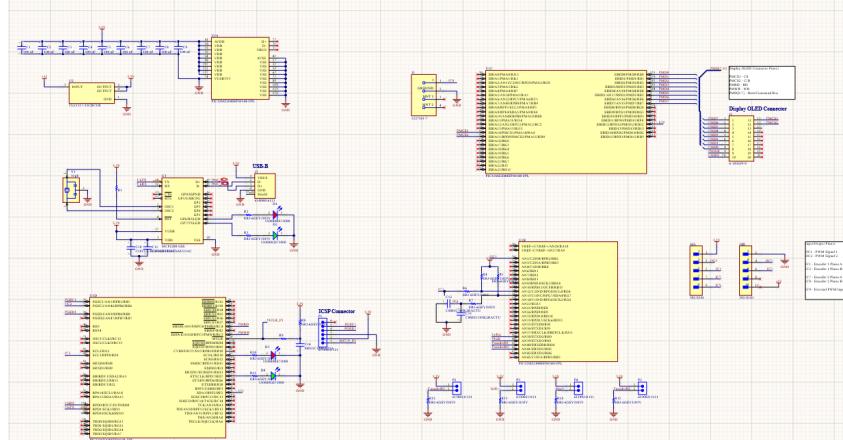


Figure 5: Microcontroller Layout

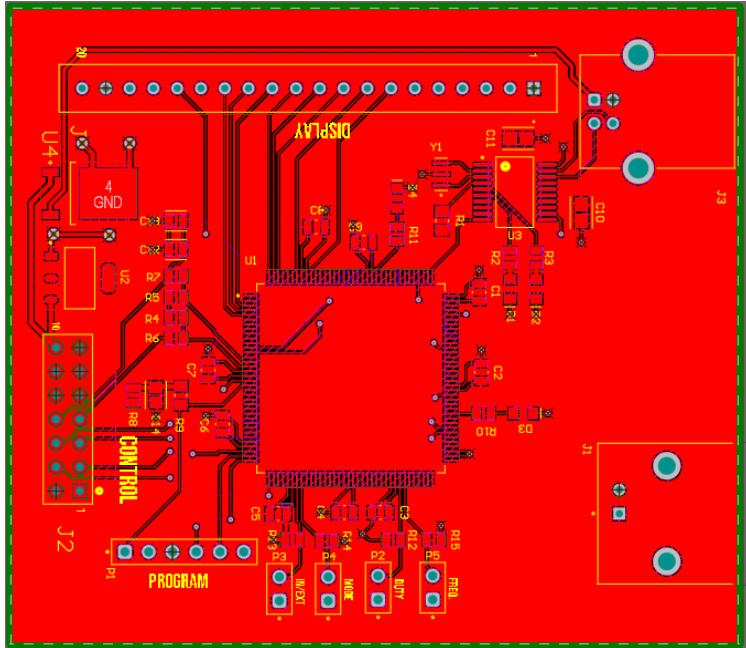
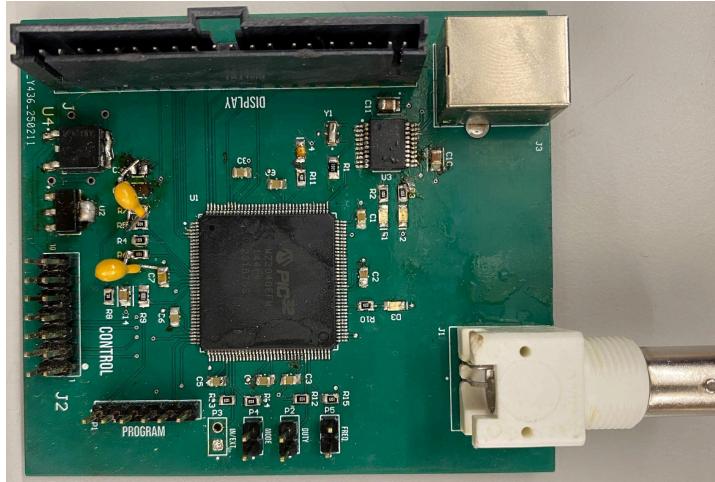


Figure 6: Microcontroller PCB



The microcontroller PCB was completed shortly after the spring semester started and has been in use for most of the duration of ECEN 404 for testing and validation.

2.3. SUBSYSTEM VALIDATION

There are three different validation tests that need to be completed for my subsystem to be complete in its entirety. The subsystem must execute PWM generation, FET operation control, and Data transfer test successfully meeting the specifications laid out in the Validation Plan.

2.3.1. PWM GENERATION

For my subsystem to successfully meet the requirements set for PWM generation for the microcontroller subsystem the signal generated must have an adjustable frequency range (1kHz to 300kHz) and duty ratio (5% to 95%). For testing of the PWM generation I have put together data that shows generated signals at the edge of and within the set frequency and duty cycle ranges.

2.3.1.1. FREQUENCY TEST

The PWM mode is set to matching and the duty cycle to 50%, changing only the frequency to multiple values at and between the range of 1kHz - 300 kHz. In the figures below are the generated signals for the stated frequencies that the microcontroller was set to produce.

Figure 7: PWM Signal (1kHz)

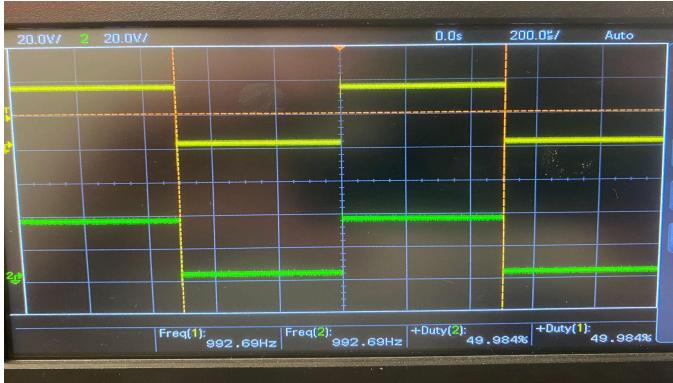


Figure 8: PWM Signal (10kHz)

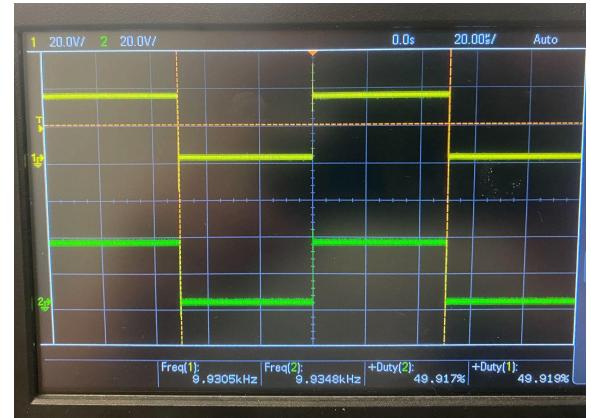
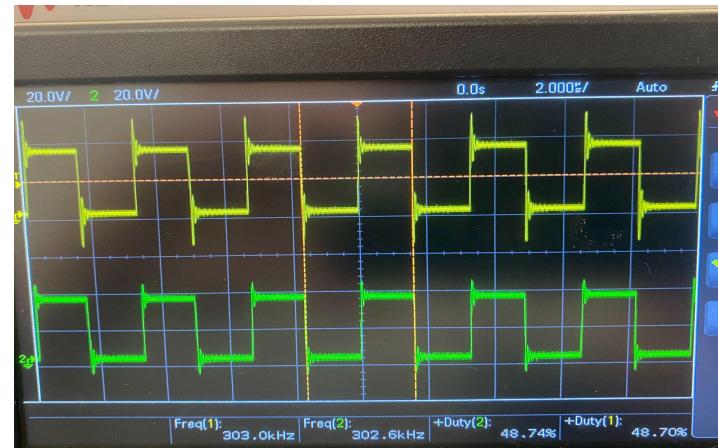


Figure 9: PWM Signal (100kHz)



Figure 10: PWM Signal (300kHz)



The PWM signals generated by the microcontroller are adjustable between the specified frequencies. The waveforms generated in figure 7-10 show that the signals can be generated at 1kHz, go as high as 300kHz, and be set at frequencies in between this range.

2.3.1.2. DUTY CYCLE TEST

The PWM mode is set to matching and the frequency of 10kHz for these tests, changing only the duty cycle to multiple values from 5% to 95% to see if the generated signals meet the specified requirements. Given below are the signals produced at the given duty cycles.

Figure 11: PWM Signal (5% Duty Cycle)

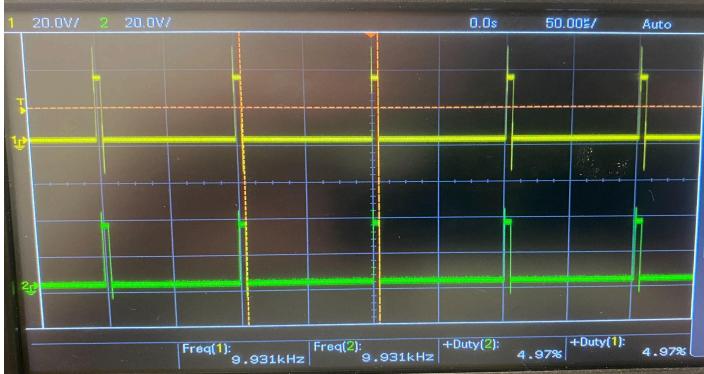


Figure 12: PWM Signal (50% Duty Cycle)

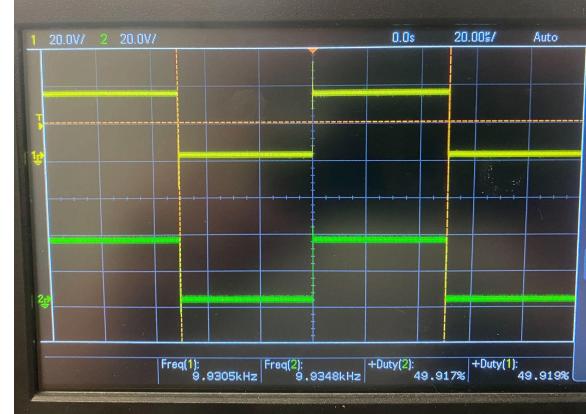
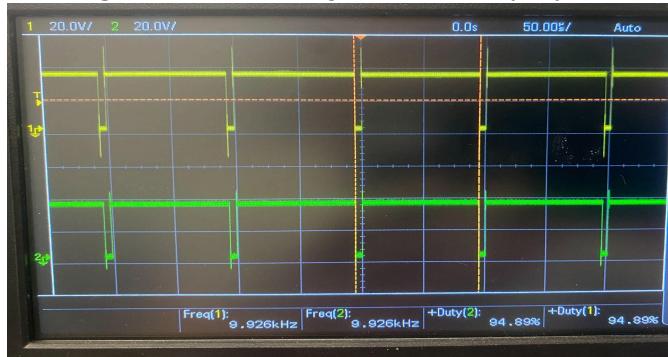


Figure 13: PWM Signal (95% Duty Cycle)



The PWM signals generated by the microcontroller are adjustable for duty cycles at or between 95% and 5%. The waveforms generated in figure 11-13 show that the signals can be generated at 5% duty cycle, 95% duty cycle, and 50%. Being able to generate at the maximum ranges allows the implication that the subsystem is able to generate signals within the specified range, the 50% duty cycle signals being an example of that.

2.3.2. FET OPERATION CONTROL

To successfully meet the requirements set for FET operation control the microcontroller should be able to generate two PWM signals that fit the behavior described in the FSR, section 3.1.2. There are three modes, and the microcontroller should be able to produce signals that are matching, alternating, and complementary to meet the requirements. The signals will be set at 10 kHz, 50% duty cycle, so that only the operating mode is changed during testing.

Figure 14: PWM Signal (Matching)

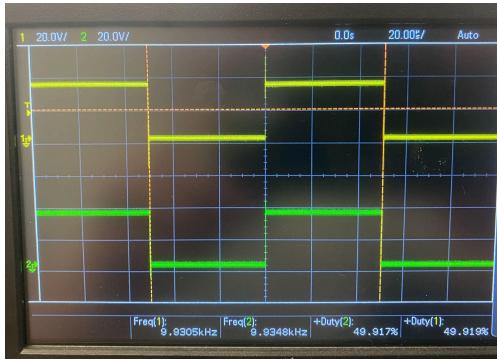


Figure 15: PWM Signal (Alternating)

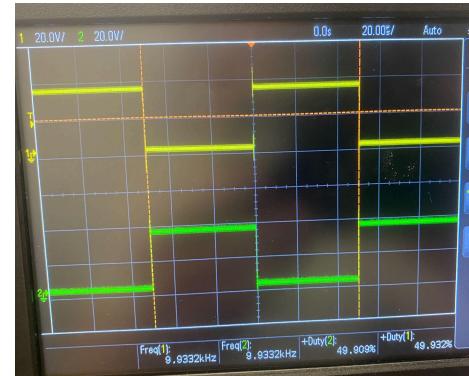
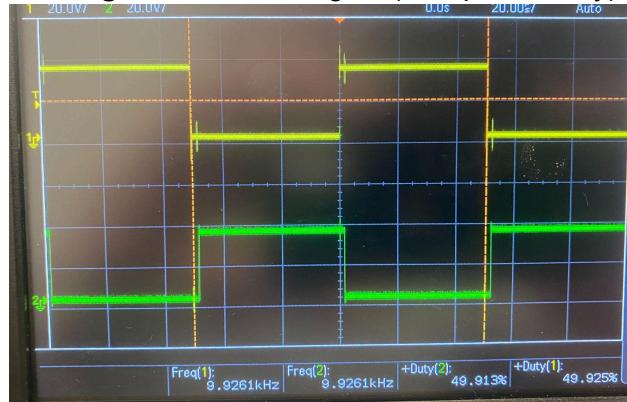


Figure 16: PWM Signal (Complementary)



Each operational mode in the validation test has matched the expected behavior. The matching mode generates two signals that are the same, the alternating mode generates two signals that are opposing, and the complementary mode generates two signals that are opposite, but have a slight delay between the signals.

2.3.3. DATA TRANSFER

To successfully meet the requirements of data transfer validation, the microcontroller must take commands from a PC or laptop, process them, and execute the commands. For this test I will be sending commands to the microcontroller via matlab, the microcontroller will then write back what command it processed to the computer.

Figure 17: Frequency Command

```
uarttest.m
1 clear device; % Automatically closes the port
2 % Define the COM port and baud rate
3 comPort = 'COM3'; % Replace with the correct COM port for your system
4 baudRate = 115200; % Set the baud rate (same as the microcontroller's setting)
5
6 % Create the serial port object
7 device = serialport(comPort, baudRate);
8
9 device.Timeout = 2;
10
11
12 pause(1)
13 write(device, "setfreq:30000", "char"); %write command
14 disp("The command has been written")
15 pause(3)% wait for response
16 data = read(device, 20, "char"); % read command
17 disp("The command executed was " + data) % display data that was read
18
19 clear device;
```

Command Window

```
>> uarttest
The command has been written
The command executed was setfreq:30000
f1 >>
```

Figure 18: External Command

```
uarttest.m
1 clear device; % Automatically closes the port
2 % Define the COM port and baud rate
3 comPort = 'COM3'; % Replace with the correct COM port for your system
4 baudRate = 115200; % Set the baud rate (same as the microcontroller's setting)
5
6 % Create the serial port object
7 device = serialport(comPort, baudRate);
8
9 device.Timeout = 2;
10
11
12 pause(1)
13 write(device, "external", "char"); %write command
14 disp("The command has been written")
15 pause(3)% wait for response
16 data = read(device, 20, "char"); % read command
17 disp("The command executed was " + data) % display data that was read
18
19 clear device;
```

Command Window

```
>> uarttest
The command has been written
The command executed was external
f1 >>
```

Figure 19: Duty Cycle Command

```

1 clear device; % Automatically closes the port
2 % Define the COM port and baud rate
3 comPort = 'COM3'; % Replace with the correct COM port for your system
4 baudRate = 115200; % Set the baud rate (same as the microcontroller's setting)
5
6 % Create the serial port object
7 device = serialport(comPort, baudRate);
8
9 device.Timeout = 2;
10
11
12 pause(1)
13 write(device, "setduty:0.50", "char"); %write command
14 disp("The command has been written")
15 pause(3)% wait for response
16 data = read(device, 20, "char"); % read command
17 disp("The command executed was " + data) % display data that was read
18
19 clear device;
20

```

Command Window

```

>> uarttest
The command has been written
The command executed was setduty:0.50
f5 >>

```

Figure 20: Mode Command

```

1 clear device; % Automatically closes the port
2 % Define the COM port and baud rate
3 comPort = 'COM3'; % Replace with the correct COM port for your system
4 baudRate = 115200; % Set the baud rate (same as the microcontroller's setting)
5
6
7 % Create the serial port object
8 device = serialport(comPort, baudRate);
9
10 device.Timeout = 2;
11
12
13 pause(1)
14 write(device, "setmode:2", "char"); %write command
15 disp("The command has been written")
16 pause(3)% wait for response
17 data = read(device, 20, "char"); % read command
18 disp("The command executed was " + data) % display data that was read
19
20 clear device;
21

```

Command Window

```

>> uarttest
The command has been written
The command executed was setmode:2

```

The microcontroller is able to read commands from matlab, process them, execute them, and write back the executed command to matlab as seen in the figures provided. The read command stores the string sent to the PC from the microcontroller into the variable data and displays the string in the console. The code is able to process each type of command that is necessary to change the PWM signal generated by the microcontroller, and switch the output signal to an external signal.

2.4. SUBSYSTEM VIDEO VALIDATION

To further conclude that the subsystem is working, I have recorded a video that demonstrates the subsystem functioning at the necessary frequencies, duty cycles, and operational modes. The user interface and application subsystem is used to change values of the generated PWM signals during this test. The test starts by going through different frequencies, then duty cycles, and lasts through the three different modes. The video covers the cases presented in FET operation control and PWM generation validation. The video will be posted on Youtube and be found using the link below.

Video Link:

<https://youtu.be/CIPmD9M2FZs>

2.5. SUBSYSTEM CONCLUSION

Based on the conclusion of my validation and testing the microcontroller subsystem delivers on the generation of PWM signals is within the range of the requirements of duty cycle and frequency discussed in the FSR, it is also able to communicate with a PC/laptop using a USB-B connection. The microcontroller is able to successfully take data from the I/O subsystem, or the UI & application subsystem and generate two PWM output signals that can be used to drive the MOSFETs in the power subsystem.

3. USER INTERFACE AND APPLICATION SUBSYSTEM REPORT

3.1. SUBSYSTEM INTRODUCTION

The user interface and application subsystem modernizes interaction with the FET box for

ECEN 438 and research applications. Using MATLAB App Designer, the application replicates the box's interface and functions, allowing students to adjust parameters and send commands directly. This design enhances usability and supports hands-on learning and research in power systems.

3.2. APP COMPONENTS

3.2.1. OPERATION

The user interface is designed to replicate the functionality and appearance of the physical FET box, offering a clear and intuitive layout. Each component serves a specific purpose to facilitate user interaction. Key elements include buttons for connecting and disconnecting the device, knobs and edit fields for adjusting frequency and duty ratio, and visual indicators such as the power lamp. These components are housed in a `UIFigure`, which acts as the main application window, ensuring a seamless and organized interface for user interaction. A detailed table of components and their roles is provided below.

Table 2: MATLAB App Components

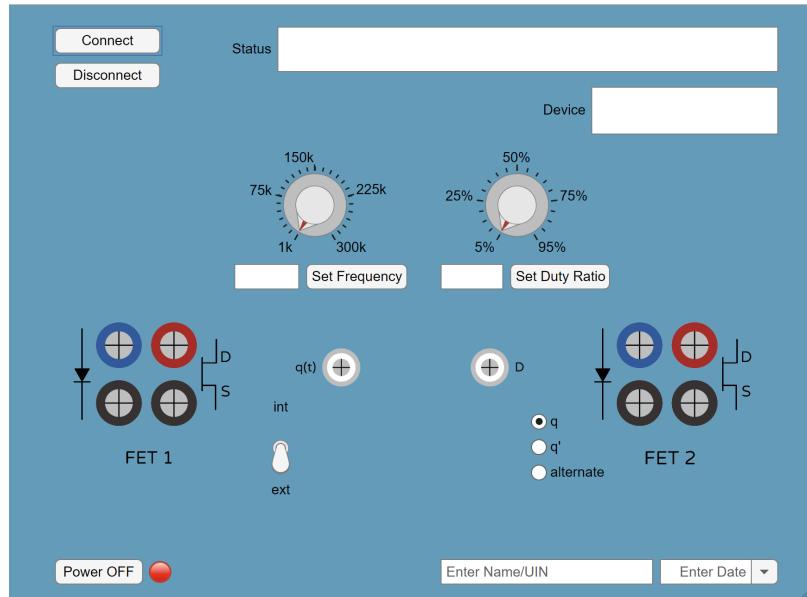
UIFigure	App that holds all the components
FET1Image FET1LabelImage	Image of BNC jacks for the anode, cathode, drain, and source for FET1
FET2Image FET2LabelImage	Image of BNC jacks for the anode, cathode, drain, and source for FET2
qtDImage	Image of BNC jacks for q(t) and D for external signals
DeviceTextArea	Text area to display available serial ports and instrument ID
DeviceTextAreaLabel	Label of DeviceTextArea
ConnButton	Button to connect to device
DisconnButton	Button to disconnect from device
PwrButton	Button to simulate power off to device
PwrLamp	Lamp to show green/red for power on/off
SetFrequencyButton	Button to send frequency value to device
FreqEditField	Edit field to type a frequency value
FreqKnob	Knob to select a frequency value
SetDutyButton	Button to send duty ratio to device
DutyEditField	Edit field to type a duty ratio value

DutyKnob	Knob to select a duty ratio value
IntExtSwitch	Switch to select internal or external signal
ModeButtonGroup matchButton compButton alternateButton	Button group to select which mode (matching, complementary, alternating)
NameEditField	Edit field to display user's name
DatePicker	Date picker to display current date

3.2.2. VALIDATION

Each component was thoroughly tested for functionality and responsiveness through real-time interaction. Error messages were implemented to enhance usability and prevent invalid actions, such as attempting to change the frequency before connecting to the device. These messages guide users to follow the correct sequence of operations. Visual elements, such as the power lamp and status messages, were also validated to ensure they accurately reflect the system's state. Below is the user interface showcasing the physical design.

Figure 21: MATLAB App Design



3.3. MATLAB CODE ARCHITECTURE

3.3.1. OPERATION

The application's functionality is closely tied to its components, with each function managing the behavior of specific interface elements. For example, the ConnButtonPushed function is associated with the connect button, enabling device connection and updating the status text area with available serial ports. The FreqKnobValueChanged and FreqEditFieldValueChanged functions ensure synchronization between the frequency knob and edit field, allowing seamless

input updates whether the value is adjusted through the knob or typed into the field. This structured approach ensures that each component operates reliably and interacts cohesively with the rest of the interface. A detailed table of functions and their associated components is provided below.

Table 3: MATLAB App Functions

ConnButtonPushed	Display available serial ports, assign port and baud rate, check if assigned port is available, create serial object
DisconnectButtonPushed	Clear the serial object to close the connection
PwrButtonPushed	Update lamp color, button text, and status message to power on or off
FreqKnobValueChanged	Update frequency edit field to the user input's knob value
FreqEditFieldValueChanged	Update frequency knob to the user input's edit field value and check boundaries
SetFrequencyButtonPushed	Retrieve the frequency value from edit field, send frequency command to device
DutyKnobValueChanged	Update duty ratio edit field to the user input's knob value
DutyEditFieldValueChanged	Update duty ratio knob to the user input's edit field value and check boundaries
SetDutyButtonPushed	Retrieve the duty ratio value from edit field, send duty ratio command to device
ModeButtonGroupSelectionChanged	Retrieve which button was pushed, send mode selection command to device
IntExtSwitchValueChanged	Retrieve the switch value, send command if switch selection is external

3.3.2. VALIDATION

The integration of functions with interface components was thoroughly tested to ensure smooth operation. Boundary checking was implemented to guide user inputs; for example, if the user enters a frequency below the minimum allowed value, such as 500 Hz, the system automatically adjusts it to the minimum of 1 kHz. Additionally, students are required to enter their name and select the current date before proceeding with any operations, ensuring proper identification. These validations, along with error handling for invalid actions, ensure all components and functions work together seamlessly, providing a consistent and user-friendly experience. Below is a screenshot of a sample MATLAB code snippet illustrating the implementation of synchronous updates between the knob and edit field, as well as boundary checking.

Figure 22: Sample MATLAB Code for App Components

```
% Value changed function: FreqEditField
function FreqEditFieldValueChanged(app, event)
    % Check if NameEditField and DatePicker are filled
    if ~app.checkRequiredFields()
        return; % Exit the function if fields are not filled
    end

    % Update knob to edit field value and check boundaries
    value = string(app.FreqEditField.Value);
    value = double(value);
    if (value < 1000) % Minimum value of 1kHz
        value = 1000;
    end
    if (value > 300000) % Maximum value of 300kHz
        value = 300000;
    end
    app.FreqKnob.Value = value;
    app.FreqEditField.Value = string(round(value));
end
```

3.4. COMMUNICATION COMMANDS

3.4.1. OPERATION

The application communicates with the FET box by sending commands that configure and control the device. These commands are triggered by user interactions, such as adjusting parameters or selecting modes, and are formatted to match the FET box's communication protocol. For instance, changing the frequency sends a command like "setfreq:5000*" to set the frequency to 5 kHz. Similarly, mode selection commands like "setmode:1*" allow the user to configure the FET settings. This structured communication ensures precise and reliable operation. A table of commands and their functions is provided below.

Table 4: Communication Protocol Functions

"setfreq:5000*"	Set frequency value to 5kHz (Range: 1kHz-300kHz)
"setduty:0.25*"	Set duty ratio to 25% (Range: 5%-95%)
"setmode:1*"	Set FET2 configuration to match FET1
"setmode:2*"	Set FET2 configuration to alternate FET1
"setmode:3*"	Set FET2 configuration to complement FET1
"External*"	Set system to receive an external signal

3.4.2. VALIDATION

The command system was validated to ensure proper formatting and successful transmission to the FET box. Each command was tested individually to confirm the device responded as expected, such as correctly setting the frequency, duty ratio, or mode. Additional validation was performed to ensure the application could handle invalid or out-of-bound commands gracefully, providing error messages to inform the user. Below is a screenshot of a sample MATLAB code snippet demonstrating how commands are formatted and sent to the device.

Figure 23: Sample MATLAB Code for Communication Commands

```
% Button pushed function: SetFrequencyButton
function SetFrequencyButtonPushed(app, event)
    % Check if NameEditField and DatePicker are filled
    if ~app.checkRequiredFields()
        return; % Exit the function if fields are not filled
    end

    % Retrieve the frequency value from the edit field
    frequencyValue = string(app.FreqEditField.Value);

    % Verify that the serial connection exists and is valid
    if isempty(app.serialObj) || ~isValid(app.serialObj)
        app.StatusTextArea.Value = 'Please connect to the device before setting the frequency.';
        app.FreqEditField.Value = 'Failed';
        msgbox('Please connect to the device before setting the frequency.', 'Connection Required', 'warn');
        return;
    end

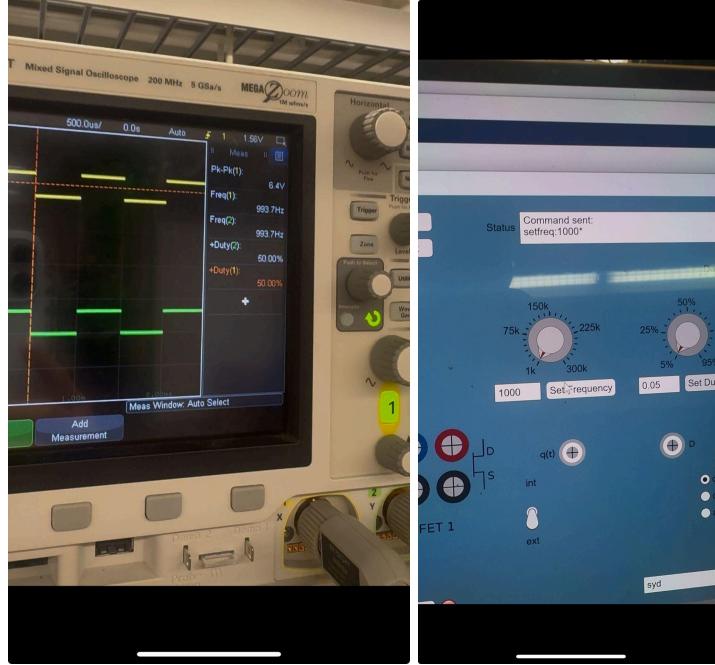
    try
        % Format the command to set the frequency
        command = 'setfreq:' + frequencyValue + '*';

        % Send the command to set the frequency
        write(app.serialObj, command, 'char');
        app.StatusTextArea.Value = ['Command sent: ', command];

        % Confirm the frequency has been set
        app.FreqEditField.Value = sprintf(frequencyValue);

    catch ME
        % Display error message if command fails
        app.FreqEditField.Value = 'Failed';
        msgbox(['Failed to set frequency: ', ME.message], 'Frequency Failed', 'warn');
    end
end
```

Figure 24: Sample Oscilloscope Validation



3.5. SUBSYSTEM CONCLUSION

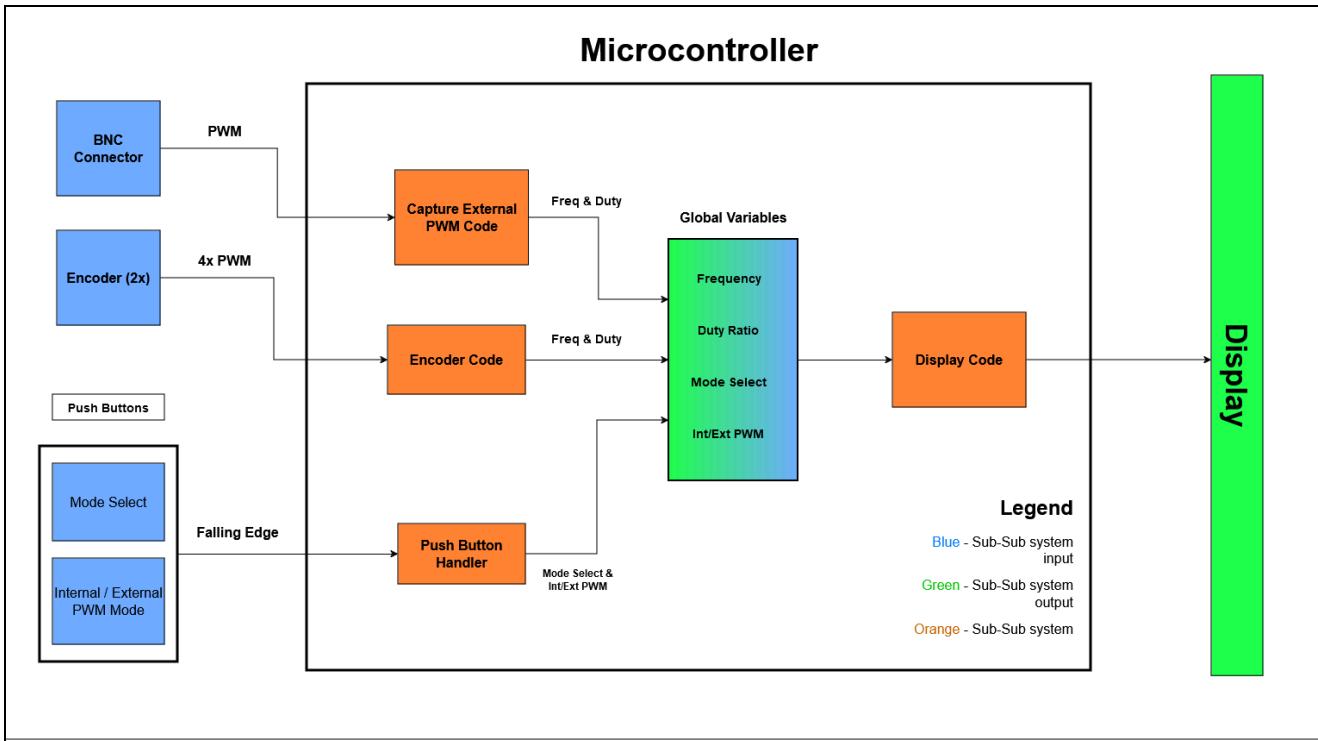
The user interface and application subsystem successfully modernizes the interaction with the FET box, enhancing both functionality and user experience. By replicating the physical interface digitally and integrating robust command and validation mechanisms, the subsystem provides a seamless platform for controlling and configuring the device. The use of MATLAB App Designer ensures flexibility and scalability, while error handling and boundary checking promote reliable operation. This subsystem not only meets the requirements of ECEN 438 and research applications but also sets a strong foundation for future enhancements and integration into modernized power systems laboratories.

4. I/O SUBSYSTEM REPORT

4.1. SUBSYSTEM INTRODUCTION

The I/O Subsystem handles—with the exception of the USB port—all interfaces that the user physically needs to operate the device (i.e. buttons, switches, displays). Through this subsystem, the user is able to emulate an external PWM signal; cycle through operation modes and toggle between internal or external PWM signals to drive the switching MOSFETS; adjust the internal PWM frequency and duty ratio; and be able to visually tell what mode, frequency, and duty ratio the device is operating at. The I/O Subsystem consists of 4 main components: External PWM Capture, Encoder Control, Push Button Control, and Display.

Figure 25: I/O Subsystem Block Diagram

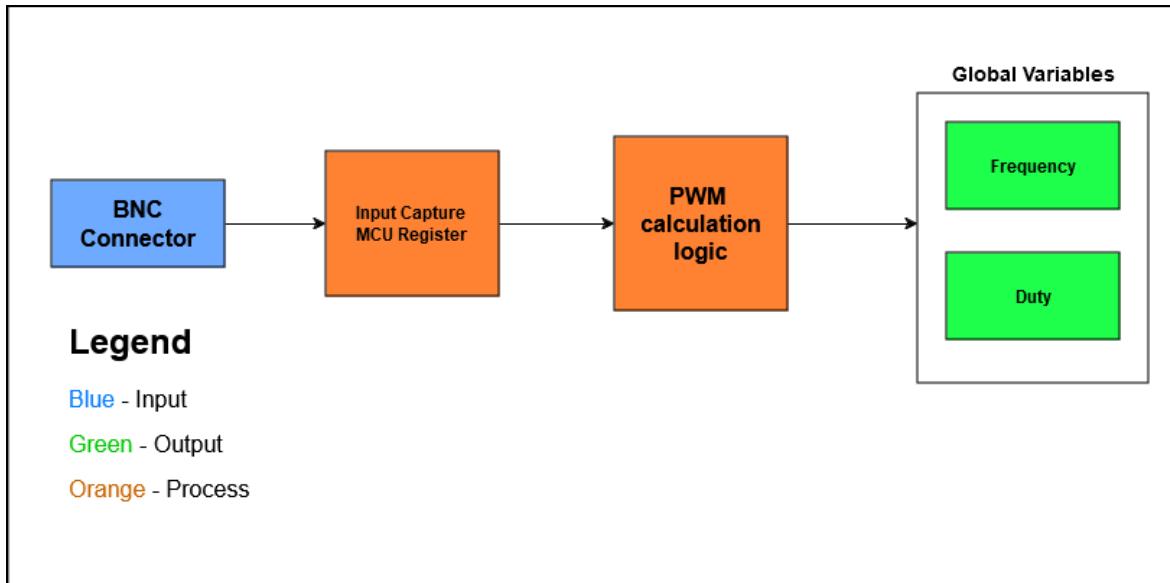


4.2. SUBSYSTEM DETAILS

4.2.1. EXTERNAL PWM CAPTURE

The I/O Subsystem is tasked with capturing an external PWM signal and emulating it on the MOSFET gate drivers using the embedded microcontroller (MCU) on the hardware. In order to use a particular external PWM signal, it is fed through a male BNC jack mounted on the hardware. If the device's mode is set to "External PWM", the MCU is used to sense the incoming signal, calculate its frequency and duty cycle, and update the MCU's output gate driver PWM signals' parameters accordingly. An overview of this subsystem feature is shown in Figure 26.

Figure 26: External PWM Capture Overview



The PWM is calculated using 3 values sampled from an integrated timer on the MCU when the pin connected to the BNC jack encounters a rising or falling edge. After a 3rd value is sampled from the timer, a function with the PWM calculation logic is called. The external PWM's frequency is calculated by subtracting the 3rd sampled value from the 1st and the duty ratio is calculated by subtracting the 2nd sampled value from the 1st then dividing over the inverse of the calculated frequency. It should be noted that the timer values are always sampled in the following order of conditions: rising edge, falling edge, and rising edge; this is done to ensure that the calculated duty ratio always denotes the time the output pin is logic-level high.

4.2.2. ENCODER CONTROL

There are two quadrature encoders that control the frequency and duty cycle respectively. The user is able to control the operating frequency and duty cycle either at 1kHz / 1% precision or 10kHz / 5% precision depending on the speed the encoders are rotated at. This design decision was made since a more complex incrementation/decrementation method was deemed unnecessary for this use case.

The turned encoder's direction and speed turned are calculated in the MCU code. Because the encoders are polled at 1kHz, a turning speed of an encoder can be approximated and used to increment either frequency/duty ratio at 10kHz/5% or 1kHz/1% increments. Since the encoder code increments/decrements the global variables directly, a check is done to make sure incrementation/decrementation will not increase frequency or duty ratio passed the limits defined in the CONOPS document (1kHz – 300kHz and 5% - 95% for frequency and duty ratio respectively).

4.2.3. PUSH BUTTON CONTROL

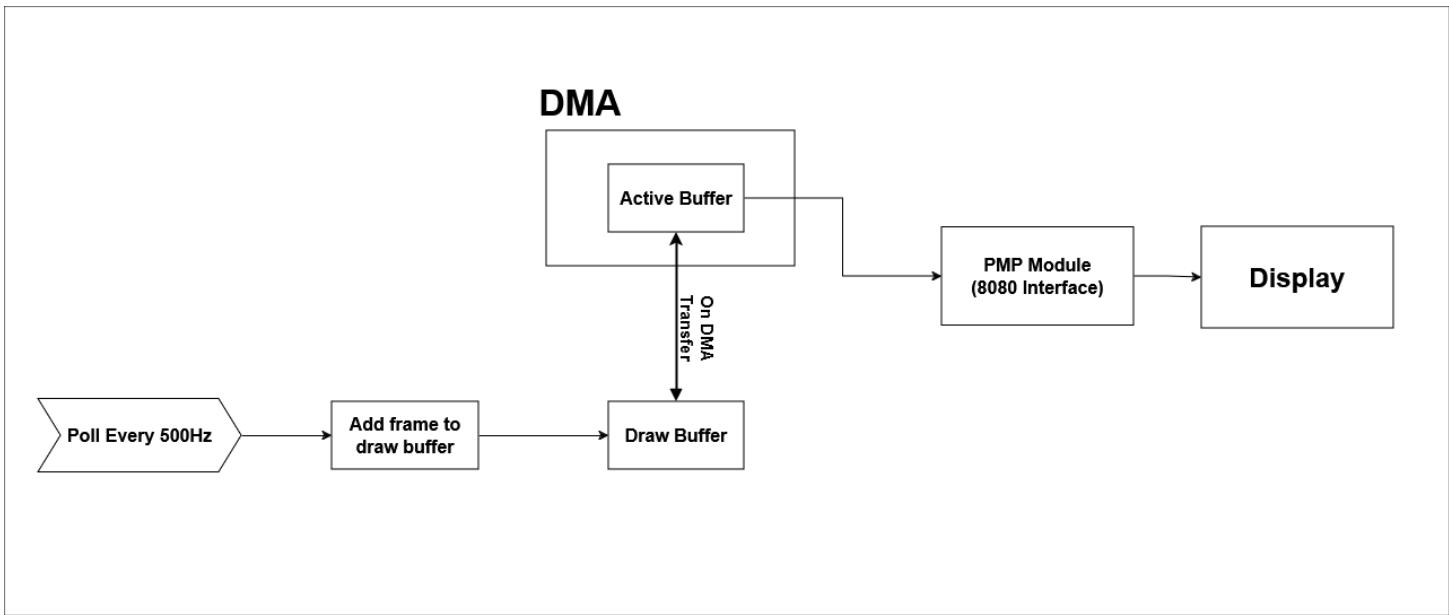
The hardware supports—via 2-pin connectors—two push buttons used to control the device's switching mode and toggle between internal/external PWM modes respectively. This was done over adding buttons directly to the hardware for testing purposes; The MCU code for the buttons denounces the input, so a custom signal simulating unintended input to the MCU GPIO was used to test this functionality.

4.2.4. DISPLAY

The display to be mounted on the front panel of the device is designated as NHD-3.12-25664UCY2, a 256x64 monochrome OLED display. This display was chosen due to its high contrast—suitable for the brightly lit laboratories this device will mostly be used in—and adequate resolution. The display is capable of displaying text and images. The font was chosen due to its simplicity.

The display already came equipped with a driver chip, designated as SSD1322, thereby freeing time to write code for the display instead of designing driver circuitry. The driver/display component supports several types of interfaces, of which 8080 parallel interface was chosen; this interface was chosen over a more conventional 3 or 4 wire interface due to the abundance of I/O on the MCU, its relative simplicity, and the integrated Parallel Master Port (PMP) module in the MCU which is purpose built for communicating with parallel devices like this display. Ultimately, the following architecture was used for the display code on the MCU.

Figure 27: Display Code Block Diagram



The display code uses a double buffer setup, with one buffer being written to the PMP module that writes to the display when its buffer is filled, and another being populated with the next frame information. The characters in the font K2D Regular were converted into a bitmap in order to load characters into the draw buffer.

4.2.5. FURTHER CONTRIBUTIONS

The microcontroller portion of the PCB was co-designed with group member Luke Bethancourt. Additionally, the PCB assembly was undertaken. Figure 28 depicts the partially-assembled PCB board.

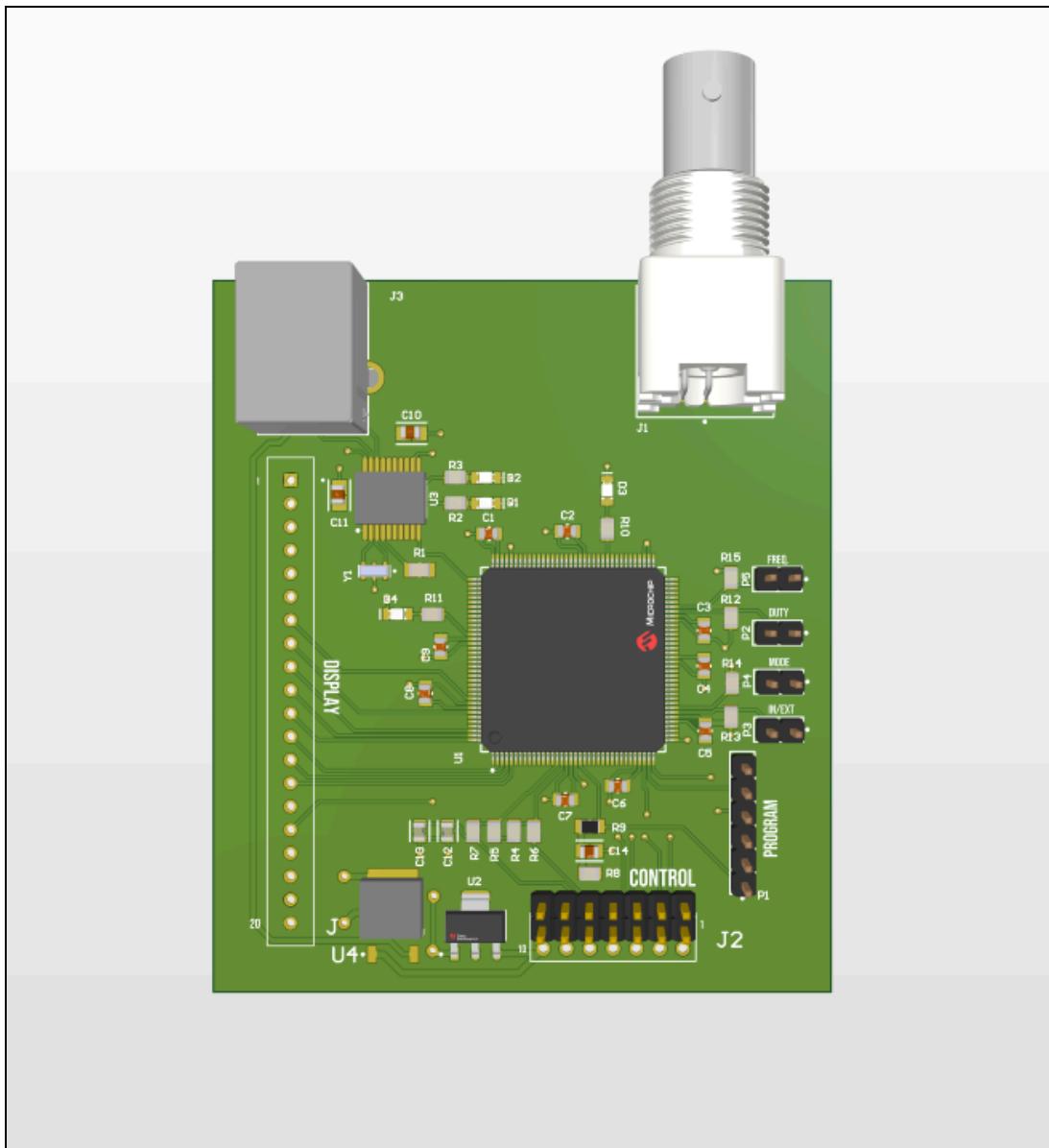


Figure 28: Altium view of MCU portion of PCB

4.3. SUBSYSTEM VALIDATION

4.3.1. EXTERNAL PWM CAPTURE

The external PWM's firmware was able to be validated via the PIC32 Curiosity Development Board (Dev Board). The test-pass condition of correctly calculating an external PWM's duty and frequency were passed. However, the final implementation on hardware could not pass validation.

4.3.2. ENCODER CONTROL

Both encoder's were verified to meet the test-pass criteria via the Dev Board. However, the final implementation on hardware could not pass validation.

4.3.3. PUSH BUTTON CONTROL

While the push button firmware was able to pass validation on the Dev Board, the final hardware implementation was not successful in passing validation.

4.3.4. DISPLAY

The display passed validation as the device's operating frequency, duty cycle, and mode were able to be shown to the user via the display.

5. POWER SUBSYSTEM

5.1. POWER SUPPLY SUBSYSTEM

5.1.1. SUBSYSTEM INTRODUCTION

The power supply provides power for all the electronic subsystems within the FET Control Box by taking in AC voltage and converting it to DC voltage. The input power comes from the wall socket power and includes circuit protection against higher voltage and current to prevent damage.

5.1.2. SUBSYSTEM DETAILS

The input port is a universal IEC style receptacle with a grounded AC line cord. An integrated fuse is built in to prevent current running higher than 250mA. A power switch controls the on/off state of the power supply, along with an LED indicating if power is on. The power supply can be powered from a range of 85-265 VAC. The power supply is an off-the-shelf AC/DC converter that converts AC power to DC power of 12V 1A.

The power supply has three electrically isolated outputs using DC-DC isolators to minimize noise and interference. Two outputs will be powering with 12V the power semiconductor subsystem and the other output is used to power with 5V to the control components (ex. optoisolators, microcontroller processor unit, LCD screen).

Figure 29: Power supply section of the PCB



5.1.3. SYSTEM VALIDATION

In order to prevent damage or injury, the power supply has been tested for shorts to prevent risk of arcing or breaking the board. Short testing used a range of low DC and AC voltages across components at all nodes to ensure that the voltages are not unintentionally shorted by design.

In order to test the intended range of AC voltage that the power supply is rated for, a variac is used to supply 85-265VAC to the power supply, which happens to supply the 12V 1A to its upper limit.

Further validation by plugging an IEC cord to the receptacle power port allows the power supply to draw power from any wall socket plug. The power supply is fully functional and powers each isolated output without a problem.

5.1.4. SUBSYSTEM CONCLUSION

As the power supply is an off-the-shelf unit, it is very simple to solder and validate as everything is already assembled. Any issues with the power supply means that it could be replaced easily.

5.2. POWER SEMICONDUCTOR SUBSYSTEM

5.2.1. SUBSYSTEM INTRODUCTION

The FETs are one of the primary components that the FET Control Box is built around. The FETs have a wide range of applications that can be used in lab experiments. The PWM signal from the PWM generation of the microcontroller will control the amount of voltage going through the MOSFET from the current sent to the MOSFET gates, which the voltage ratio is controlled by the duty cycle. One primary use case is a buck converter, where an external circuit is attached to the diodes and MOSFETs from the box and form a complete circuit without needing a complicated circuit design accounting for the MOSFETs.

5.2.2. SUBSYSTEM DETAILS

Figure 30: Schematic diagram of the power semiconductors

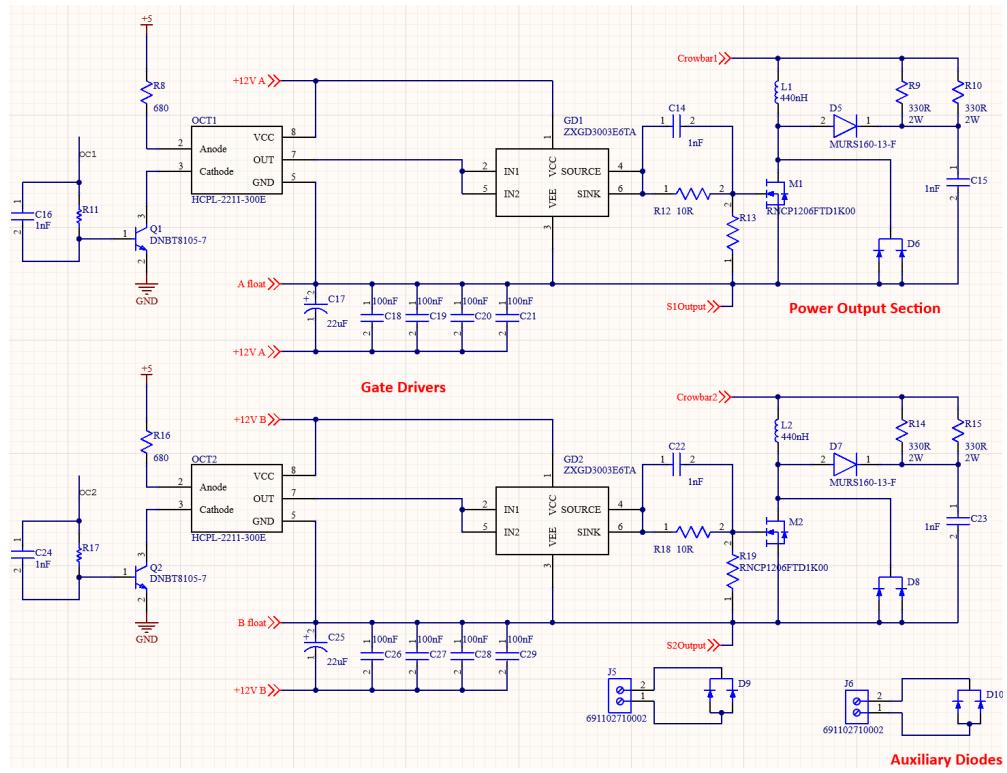
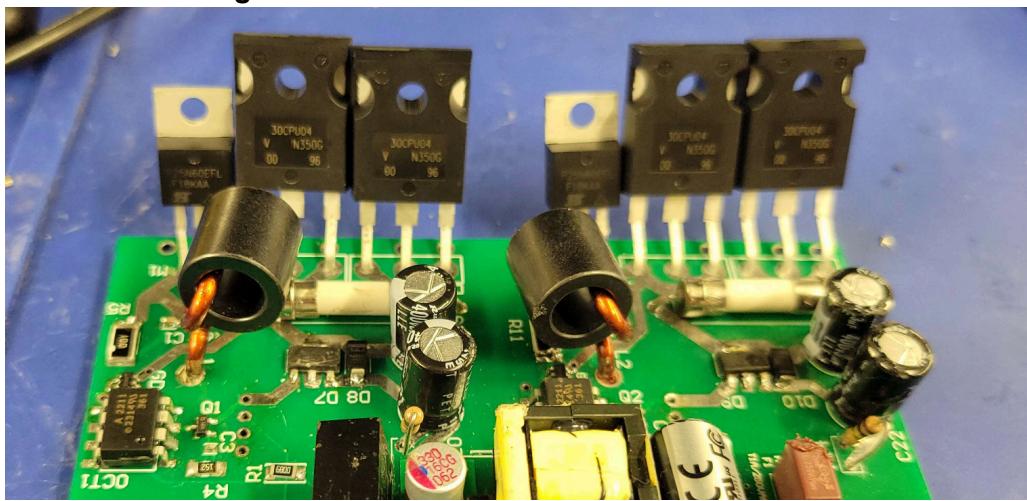


Figure 31: PCB section of the MOSFET circuits



5.2.2.1. MOSFETS AND DIODES

The power semiconductors include two identical pairs of independently isolated power diodes and MOSFETs that are accessible to the user. The gate driver is driven by the $q(t)$ square wave signal from the PWM signal generator subsystem that goes through as a transistor then an optoisolator. A gate driver in each pair increases the current in the PWM signal to send to the MOSFETs.

5.2.2.2. CIRCUIT PROTECTIONS

The design of the FET Box is made to handle high power load for high voltage usage. To ensure that the components are able to handle the maximum power load sent through the MOSFETs and diodes, components are typically chosen for 400V as a minimum and 15A to withstand the intended max power load of 200V 10A. As such, caution and careful considerations have to be taken when testing as well, as the circuit ground is isolated from the chassis and power supply ground, which can reach dangerous levels of voltage.

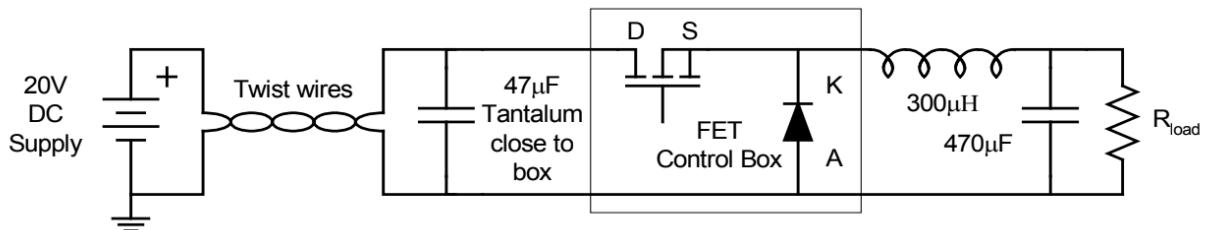
Since the max load of the subsystem is designed to be rated for 200V and 10A, minimum protection was put into the design to lessen the error margin between calculations and the results. On the old design, a lossy snubber mitigated voltage spikes from higher than rated voltages and a fast flow fuse was put at the output of D to prevent output current going over 10A (this fuse was not useful at all as the circuit would already be damaged by the time the fuse blows). In the new design, a crowbar circuit is added after the lossy snubber instead of the fuse to further protect against voltages going over 270V, as all the components are rated at a minimum of 400 volts. This way, the current and voltage are both regulated at the output of D as physical circuit protection.

5.2.3. SYSTEM VALIDATION

5.2.3.1. TEST CIRCUIT SETUP

A simple buck converter test is used here to test the operation of the FETs using an external circuit. For this specific test, only one power semiconductor circuit is needed out of the two. A perfboard is used to hold the components of the external circuit and the components are soldered to keep them in place. Originally it was planned for 20V and 1A power supply, however the components were prone to breaking at 20V, so a 10V limit was used to prevent further potential replacements of components.

Figure 32: Test circuit for a buck converter



As seen here, the external circuit needs to connect to external power supply generators. The MOSFET and diode are connected from the FET box circuit to the external circuit. The load resistor is then used to measure the voltage across it to obtain the results.

5.2.3.2. EXPECTED AND ACTUAL RESULTS

The expected DC voltages are about 45% to 50% of the voltage supplied across the load resistor. A very small AC signal is measurable using an oscilloscope probe and is dependent on the tantalum capacitor used in the external circuit. Frequency of the AC signal should be consistent with the PWM.

An external circuit was made for this sole experiment using component values shown in Figure 32. Voltage was measured to be very small when measuring the load resistor, with a 5VDC voltage supply measuring to be 0.178V max across the load resistor. Duty cycle adjustments were able to change the voltage lower or higher from 20% to 80%. Frequency of the AC signal across the load resistor matched with the PWM at roughly 210kHz.

5.2.4. SUBSYSTEM CONCLUSION

Unfortunately the inductors were made for signals and not loads that the test was intended to go through, so the results were not complete. But surprisingly the only incorrect result was the voltage, which is due to the inductors unable to send the full power through the circuit. An inductor that is made to handle these types of circuits was not accounted for unfortunately, which would have made the validation complete and successful.

FET Control Box

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SYSTEM REPORT

**SYSTEM REPORT
FOR
FET Control Box**

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Change Record

Rev	Date	Originator	Approvals	Description
1	9/15/2024	FET Control Box		Draft Release
2	12/5/2024	FET Control Box		End of Fall Semester
3	4/24/2025	FET Control Box		Final

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6. SYSTEM REPORT

6.1. OVERVIEW

Over the course of ECEN 404, the FET Box underwent subsystem integration with both successes and challenges. This report evaluates the FET Box as a fully integrated system, covering the integration process, subsystem validation, and concluding observations. The current status of the system is discussed, along with validation results for the completed aspects of the design.

6.2. INTEGRATION OF SUBSYSTEMS

6.2.1. SUBSYSTEM INTEGRATION SUCCESSES

The FET Box underwent subsystem integration throughout the course of ECEN 404. This section outlines the integration efforts and identifies the components that were successfully completed.

Integration between the microcontroller and the UI & application subsystem was successfully achieved. For this integration, the application needed to modify the PWM signals generated by the microcontroller by sending commands over a USB connection. This functionality was validated successfully.

Integration between the power subsystem and the microcontroller subsystem was also completed. In this case, the PWM output signals from the microcontroller were connected to the power PCB via jumper cables, allowing the PWM signals to drive the gates of the MOSFETs.

Firmware integration between the microcontroller and I/O subsystems was completed as well. Although the I/O subsystem code did not function exactly as intended, the firmware from both subsystems was successfully combined into a single program capable of running on the microcontroller.

6.2.2. PARTIAL INTEGRATIONS AND FAILURES

The exterior integration of the enclosure encountered several issues due to incomplete assembly and improper installation.

- The banana jack ports lacked electrical isolation from the enclosure chassis, causing all ports to short together when using the banana jacks. As a result, proper connection points were unavailable, and manual wiring was required to proceed with system validation.
- The back panel was also built without an opening for the IEC power switch port, making it impossible to fully enclose the box without affecting core functionality.
- Front panel I/O interfaces were not completed, preventing full integration and validation between the I/O subsystem and the microcontroller subsystem.

6.3. SYSTEM VALIDATION

6.3.1. PASSED TESTS

The MATLAB application successfully sent commands to the microcontroller, allowing for proper adjustment of the output PWM signals. The duty cycle, frequency, and operational modes were all correctly modified by the application. A video demonstrating this successful integration can be viewed [here](#).

The PWM signals were also successfully driven to the MOSFET gates, enabling the MOSFETs to switch according to the specified frequency and duty cycle. A video of this validation can be found [here](#).

In the external buck-converter circuit, the following tests were successfully completed:

- The voltage across the load resistor adjusted proportionally with changes in the duty cycle. A video demonstrating this can be viewed [here](#).
- The frequency measured across the load resistor matched the output PWM signal frequency.

6.3.2. FAILED TESTS

The buck converter circuit, which utilized the external test circuit along with the MOSFETs and diodes, experienced an unsuccessful setup due to the use of improperly rated inductor components. The expected voltage across the load resistor was approximately half of the supplied voltage; however, the actual measured voltage was significantly lower because of the inductors' insufficient power rating.

Additionally, the encoders and buttons could not be used in the full system demonstration. This portion of the I/O subsystem was nonfunctional due to firmware failures, which prevented the microcontroller from properly detecting the input signals from the encoders and buttons. The external signal input capture also failed to operate as intended.

6.4. CONCLUSION

6.4.1. KEY DECISIONS

Several key technical and project management decisions were made during the development of the FET Control Box:

- Each subsystem (microcontroller, application, power, and I/O) was initially developed and validated independently before attempting full system integration.
- The team decided to create a MATLAB-based application to communicate with the microcontroller over USB, allowing students to control PWM signals digitally instead of relying solely on physical adjustments.
- The team successfully implemented PWM generation and USB communication on the PIC32 microcontroller, establishing a stable foundation for subsystem integration.
- The team designed the system to use rotary encoders for both fine and coarse PWM adjustments, improving flexibility compared to the original fixed-speed controls. Full functionality is pending completion.
- As the I/O interface hardware and firmware were not fully validated in time for the final demonstration, the team decided to rely primarily on the MATLAB application for system control to ensure core functionality could still be tested and demonstrated.
- The team replaced the original output fuse with a crowbar circuit to provide faster and more reliable protection against voltage spikes.
- Due to missing mechanical cutouts and port isolation issues, the team decided to manually wire critical components during testing in order to proceed with system validation.

6.4.2. LEARNINGS

Over the course of the project, many important lessons were learned, especially as the FET Control Box was not fully completed. These experiences highlighted critical considerations for both design and integration:

- Designing circuits onto a PCB required far more consideration than expected. Schematics do not directly translate into physical layouts, and significant care had to be taken with trace routing, component placement, and minimizing signal interference.
- Adding heatsinks allowed components to handle higher currents without overheating. Key considerations included properly aligning heatsink fins vertically to maximize natural convection airflow and ensuring strong thermal contact between the device and heatsink.
- Early enclosure designs overlooked critical details such as port cutouts and component spacing, highlighting the importance of verifying mechanical layouts before fabrication.
- Early development of a stable firmware foundation for PWM generation and USB communication proved critical to successful subsystem integration and testing.
- Creating a MATLAB application for system control proved highly valuable, allowing successful adjustment of PWM signals even when physical I/O interfaces failed.
- Firmware development must be closely aligned with hardware design to ensure physical inputs (like encoders and buttons) are properly captured and processed.
- Challenges with I/O subsystem validation could have been mitigated earlier if support or troubleshooting assistance had been sought sooner.
- When mechanical or electrical issues arose, making quick decisions (such as manual wiring adjustments) allowed the project to continue progressing rather than stall.

6.4.3. SYSTEM DEFICIENCIES

A significant portion of the physical I/O, including the encoders, input capture, and mode selection switches, is nonfunctional. These problems are caused by the current hardware design, and a redesign will be necessary to achieve full functionality.

6.4.4. FUTURE WORK

Despite significant efforts, the current team was unable to meet all project objectives. Several areas of the system will require redesign in order to achieve full functionality.

Current redesign objectives include:

- Manual duty cycle and frequency input capture (physical encoders)
- Mode and external signal selection (physical push buttons)
- External signal capture (BNC input)

The project was unable to use the duty cycle and frequency encoders to adjust the PWM output signals. This failure was due to firmware issues, where input signals from the encoders were not properly detected by the microcontroller. As a result, the encoders could not be used during the system demonstration.

Similarly, the system was unable to detect changes in the push buttons used for selecting operational modes and toggling between internal and external signals. This issue also stemmed from the inability of the firmware to correctly process input signals when the buttons were pressed.

Additionally, the external signal capture feature, intended to allow a BNC input signal to mirror the output PWM signals, did not function at the time of the final demonstration. This failure was again due to problems with the input capture firmware, which was unable to correctly analyze and replicate the external signal.