Development of Multiple Input Single Output DC-DC Converter for Cal Poly's Hybrid AC/DC House

Senior Project Presented to the Electrical Engineering Department At

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Written By:

Ryan Bailey

Miguel Carmona

Jose Velez-Lopez

Advisor:

Dr. Taufik

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ABSTRACT

Development of Multiple Input Single Output DC-DC Converter
for Cal Poly's Hybrid AC/DC House

Ryan Bailey, Miguel Carmona, Jose Velez-Lopez

This senior project report details the testing and validation of the designed DC-DC Multiple Input Single Output converter. The MISO uses four-switch buck-boost topology to output a single 48V from multiple nominal 24V inputs. The previous iteration of the MISO was plagued with an overheating mosfet that would drastically reduce the lifespan of the boards and reduce efficiency. This newest iteration includes more ground panes to combat the issues. In addition, the 200W MISO board was redesigned to utilize an edge connector for secure installment, removal, and replacement in the actual DC House system panel. The slots also have a locking mechanism for the MISOs to ensure a secure connection. Also, an LED was added to the board to indicate when the board is in operation. Results of hardware measurements on the 200W and 400W MISO converters show that the efficiency of full load is above 97.8%, line regulation of 2.5% to 5.65%, load regulation of 0.62% to 4.09% and output voltage ripple of 1.29% to 2.82%.

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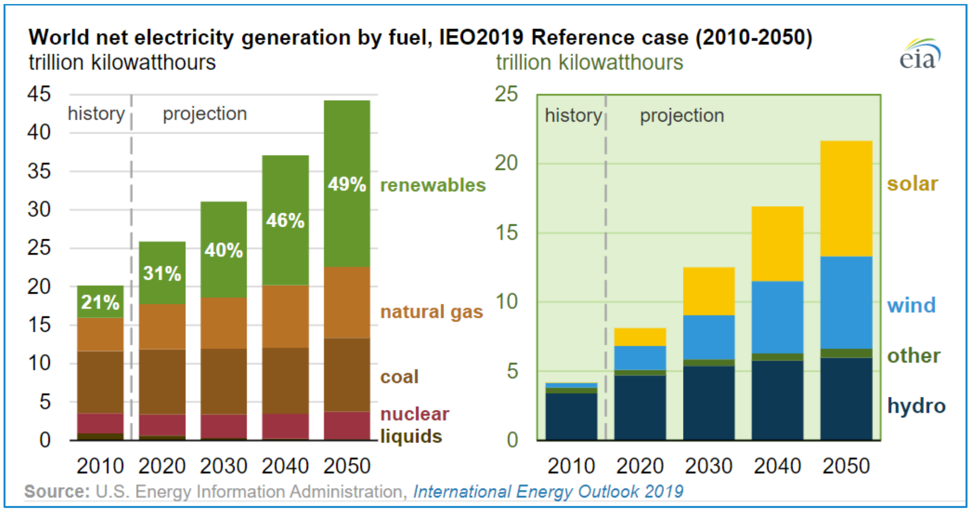
Chapter 1. Introduction

Electricity has become a necessity in the modern world and energy demand has steadily increased over the years. Energy demand is associated with both population and economic growth, with increased population growth and industrialization the energy demand is expected to grow over the coming decades. The main challenge of the future will be meeting this demand while transitioning to a sustainable low carbon energy system. Renewable energy will play a significant role in fulfilling our energy demand in the future. Advancements in energy storage and energy efficiency will also be important due to allowing for a more reliable and cost-effective solution.

Energy demand is directly correlated with population and according to a United Nations report we are on track to hit 9.7 billion people by the year 2050 [1]. As population grows more energy will be required to power their homes, transportation, and other needs. The EIA predicts that the expected energy demand will be 45 trillion kilowatt-hours by 2050 [2]. A larger population leads to more urbanization resulting in increased power requirements as more buildings need lighting, heating, cooling, and other systems. With the predicted energy demands of the future being double what they currently are, a sustainable and reliable energy solution will be in high demand.



Source: U.S. Energy Information Administration, *International Energy Outlook 2019*

Figure 1.1: Projected Energy Demand [2]

Another aspect to take into consideration is that not everyone has access to electricity, in 1994 25% of the world population did not have access to electricity. In 2014 that number reduced to 15%, this trend has and is expected to continue. Accounting for the fact that there is also a rise in world population there is a compounding effect taking place. More people are on the planet and a larger percentage of them are getting access to electricity.

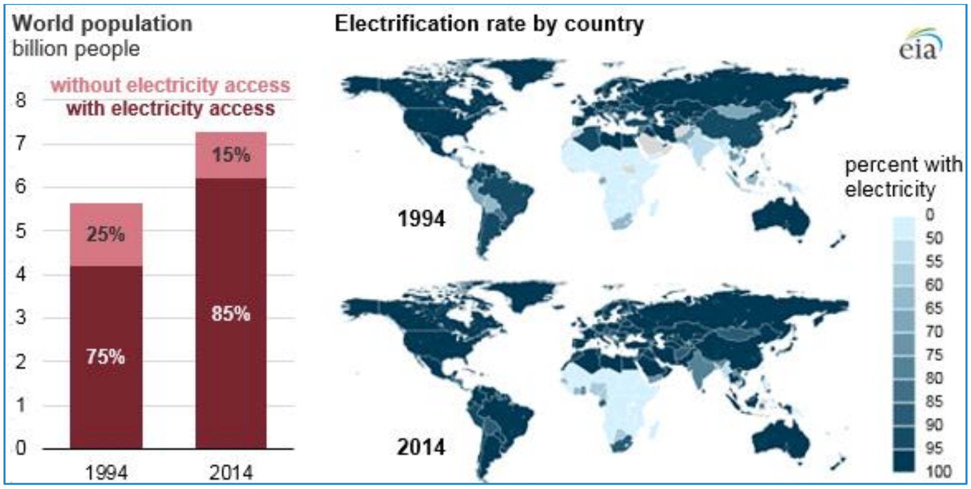


Figure 1.2: World Population with Access to Electricity [3]

Energy reliability is an issue that also needs to be considered. Planned power outages are becoming a common occurrence in many states across the country. Difficulty in providing power to our current population is a sign that we need to make changes to our current power distribution infrastructure. The Energy Information Administration has predicted that there will be a world energy consumption increase of 28% by 2040 [2]. With global warming becoming a precedented issue that threatens the sustainability of the earth, renewable energy has been of the leading solutions to this worldwide problem and as seen in Figure 1.3 renewable energy is projected to become one of the fastest growing energy sectors.

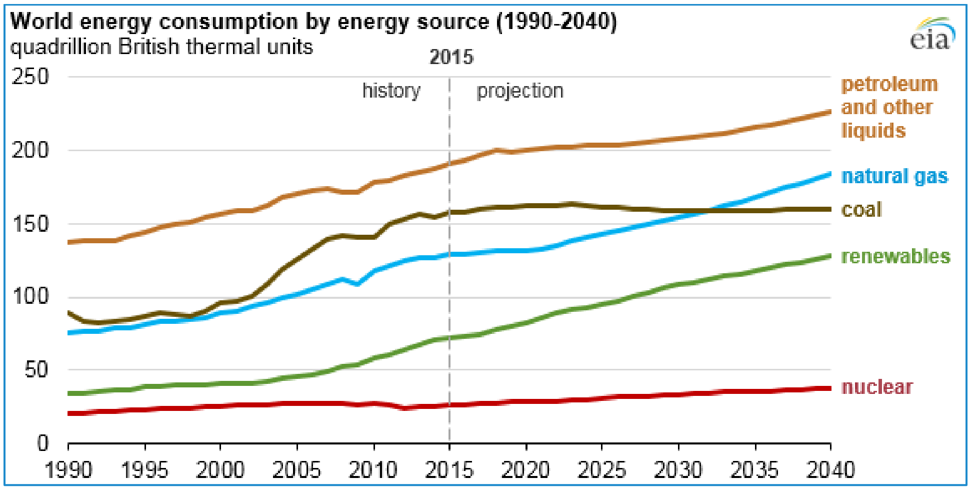


Figure 1.3: World Energy Consumption by Energy Source [4]

The issue with utility scale renewable energy is that some of them produce their power in DC form such as solar panel, fuel cells, etc. We all know that for long distance transmission AC is preferrable to minimize power losses and maintain high efficiency. Taking into consideration that most of the appliances used in a common household are DC based this results in an unnecessarily complex system. In this scenario, the power is produced in DC, inverted to AC, transmitted, and then rectified back into DC to be used in household applications. Local production of DC power would allow for the bypass of AC infrastructure that presents itself as an intermediary step.

It is important to address the energy concerns that will arise from developing countries because as we have discussed there is a hidden compound effect that results in there being a large energy demand. The adoption of microgrids has quickly become one of the most effective ways to electrify rural areas in developing countries. This is due primarily to the difficulty that arises when trying to connect a village to a grid. There are a variety of factors that make this a time consuming and capital-intensive effort. These include environmental, difficulty of maintaining, and distance from a central grid [5][6]. Fortunately, microgrids are mostly using renewable energy sources and take advantage of the environment to produce power and with the small footprint of a village getting the power directly to homes is not an issue that requires AC conversion.

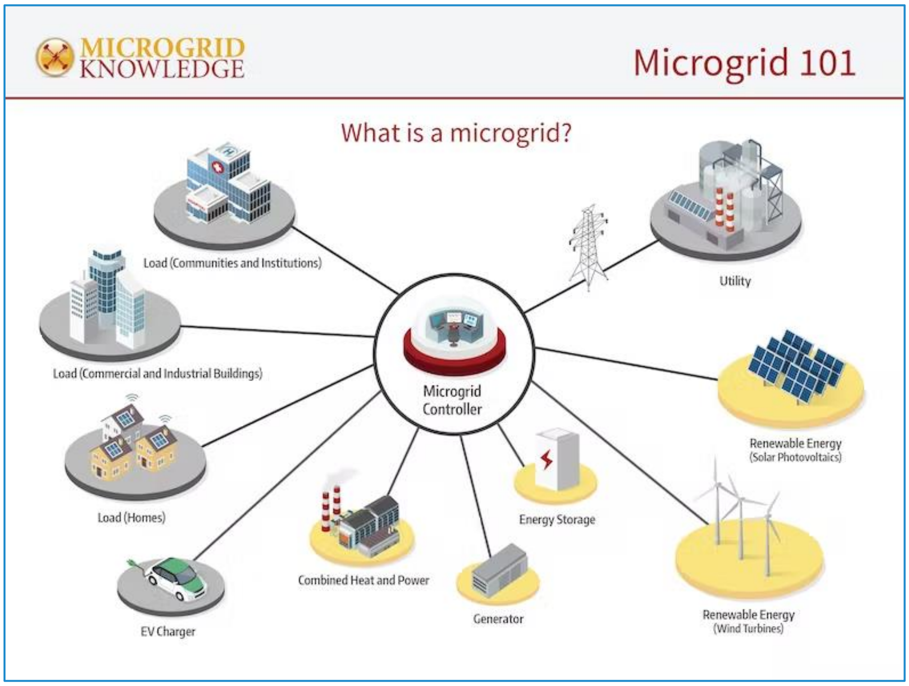


Figure 1.4: Microgrid System [6]

Microgrids are implemented in Third World countries and widespread adoption in highly developed countries. Microgrids are attractive because they reduce dependence on the main grid. As mentioned before planned power outages are becoming more common and being able to minimize the disturbance caused by them is preferable. Microgrids also help strengthen the grid overall resilience because overall load demand is less. Microgrids support a flexible and efficient electric grid by enabling the integration of growing deployment of distributed energy resources.

In inherent characteristic of a microgrid and similar technologies is the ability to take in multiple sources of electricity and be able to output a single signal. This is the definition and the topic of this senior project a Multiple Input Single Output (MISO) DC-DC Converter. The concept of the MISO converter was first introduced in the DC House project whose simplified diagram is shown in Figure 1.5 [7][8].

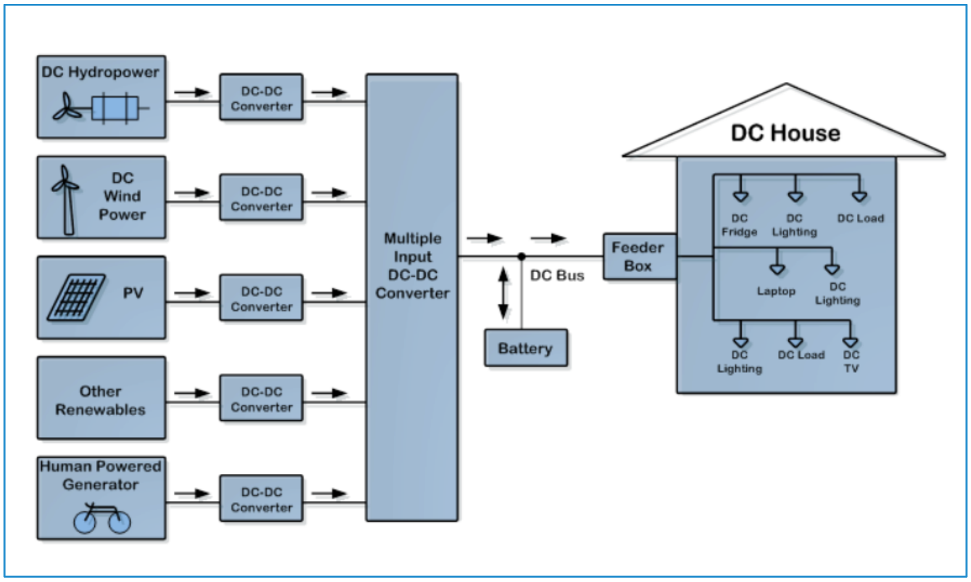


Figure 1.5: MISO Implementation [7]

The MISO is a device that will take in multiple inputs from renewable sources and output a single regulated output. This will be implemented in the AC/DC Hybrid House; this device's integration will allow the house to take input from both AC and DC sources, with the DC sources free from unnecessary and lossy conversions. The end goal is to have a highly modular MISO that will allow for easy integration of additional sources. If this can be achieved the AC/DC Hybrid House can be implemented in rural areas in developing countries and bring electricity to those that need it. Not only that, but with the use of only renewable sources, it starts cutting out the dependency on fossil fuels and non-renewable sources. In doing so, providing clean energy from an infinite energy source, and reducing negative environmental impacts from non-renewable sources.

Chapter 2. Background

The main objective of this senior project is the construction and proper operation verification of the MISO (Multiple Input Single Output). The previous model of the MISO board has an overheating MOSFET. Specifically, the low-side boost FET, which reaches a peak temperature of 109.9°C [9]. This overheating MOSFET leads to power loss, lowering efficiency and resulting in a shorter device lifespan. Reliability is an important aspect of any device and ensuring that the MISO can operate without needing to be replaced often will lead to promising device economics. To combat the overheating MOSFET issue, new ground planes have been added to this newest version of the MISO board to assist with heat transfer. Large power planes like the ones already implemented and the new ground planes will help dissipate heat more effectively due to their large surface area [10]. The board will be tested to verify that the heating issue has been resolved.

The 200W MISO board will also be updated with edge connectors, this with a motherboard, allowing for an easily adaptable power system for the AC/DC House. This card slot method will allow for easy installment, removal, and replacement of input power devices. Once connected to the motherboard, the three 200W MISO boards will allow for 600W input available to the AC/DC House. Currently the AC/DC House uses an OR Diode to intake two DC sources which is to be replaced with a MISO [11][12]. This will be accomplished through the current sharing feature of the MISO boards, communication between boards will also be updated to work through ribbon cables instead of the previous banana cable connection. In addition, having three separate MISO boards lowers the demand on any device, improving life span, and increasing redundancy [13][14]. Board size was an important design consideration for this updated version of the 200W MISO board. Ensuring that this board could be easily accessible when implemented with the AC/DC House was essential. An LED was also added to the board to indicate when the board was outputting properly to help diagnose device functionality.

Chapter 3. Design Requirements

To improve the previous board design, LED and edge connectors were incorporated. The idea to use an LED on each standalone 200W MISO originated from the need to know when the boards were in operation and if they were working properly. The LED will require 5V, provided using a voltage divider with selected resistor values. To ensure that we do not provide too much voltage to the LED resulting in burning the LED, a simulation can be used to double check calculations for the voltage divider will be used. In addition, edge connectors have been integrated in this latest design of the 200W MISO board to provide an easy to way to integrate multiple boards to provide more power to the AC/DC House.

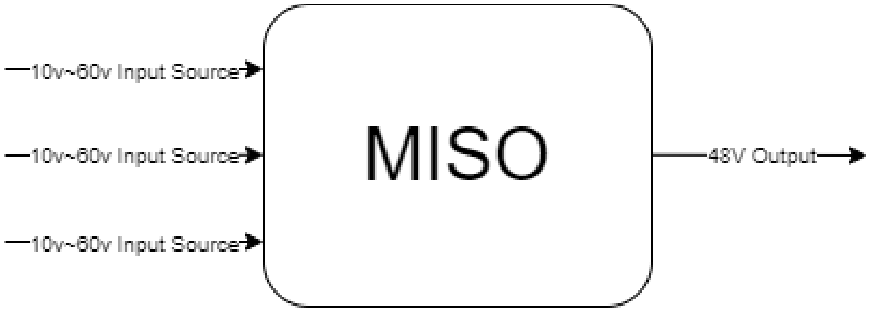


Figure 3.1: MISO Block Diagram Level 0

Figure 3.1 shows the MISO in its most general form. The MISO is represented as a black box that can take up to three inputs from different renewable sources ranging from 10V to 60V and outputs a regulated 48V to be used by loads.

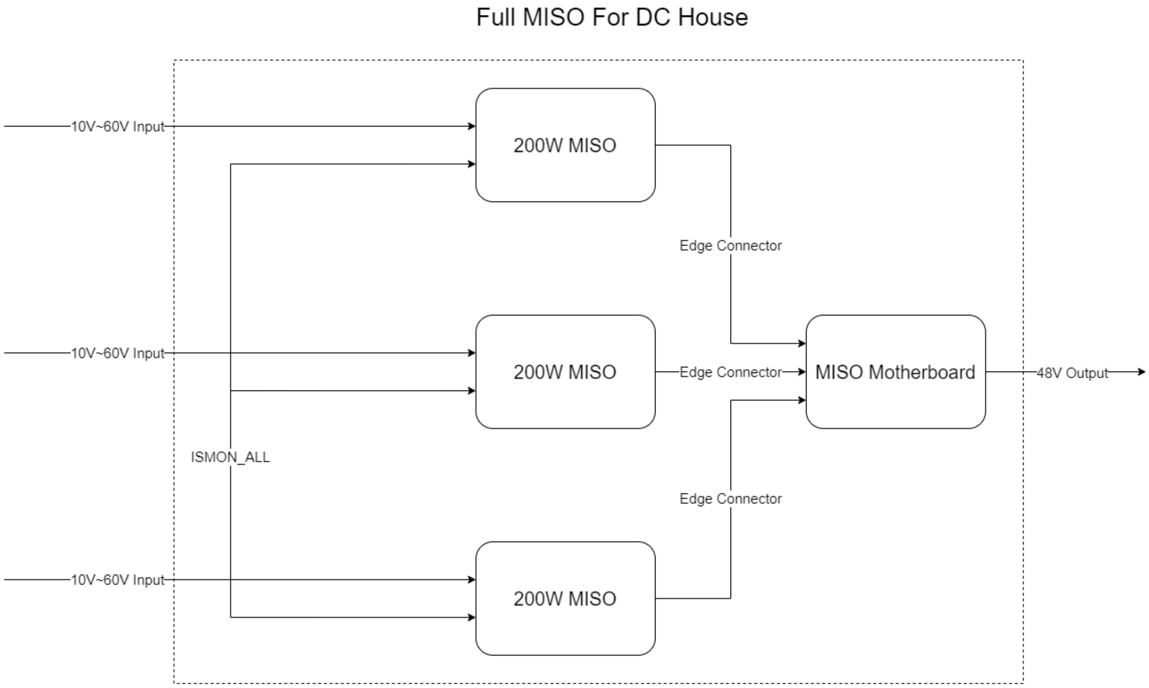


Figure 3.2: MISO Block Diagram Level 1

Level 1 block diagram of Figure 3.2 shows how each input source is connected to a separate 200W MISO board and then connected to a motherboard. The motherboard is designed to allow three 200W MISO modules to be connected, allowing for 600W input capacity. The ISMON_ALL connection is also shown in this diagram, this is a connection that allows for the separate MISO modules to communicate with each other. This connection is necessary for the current sharing feature.

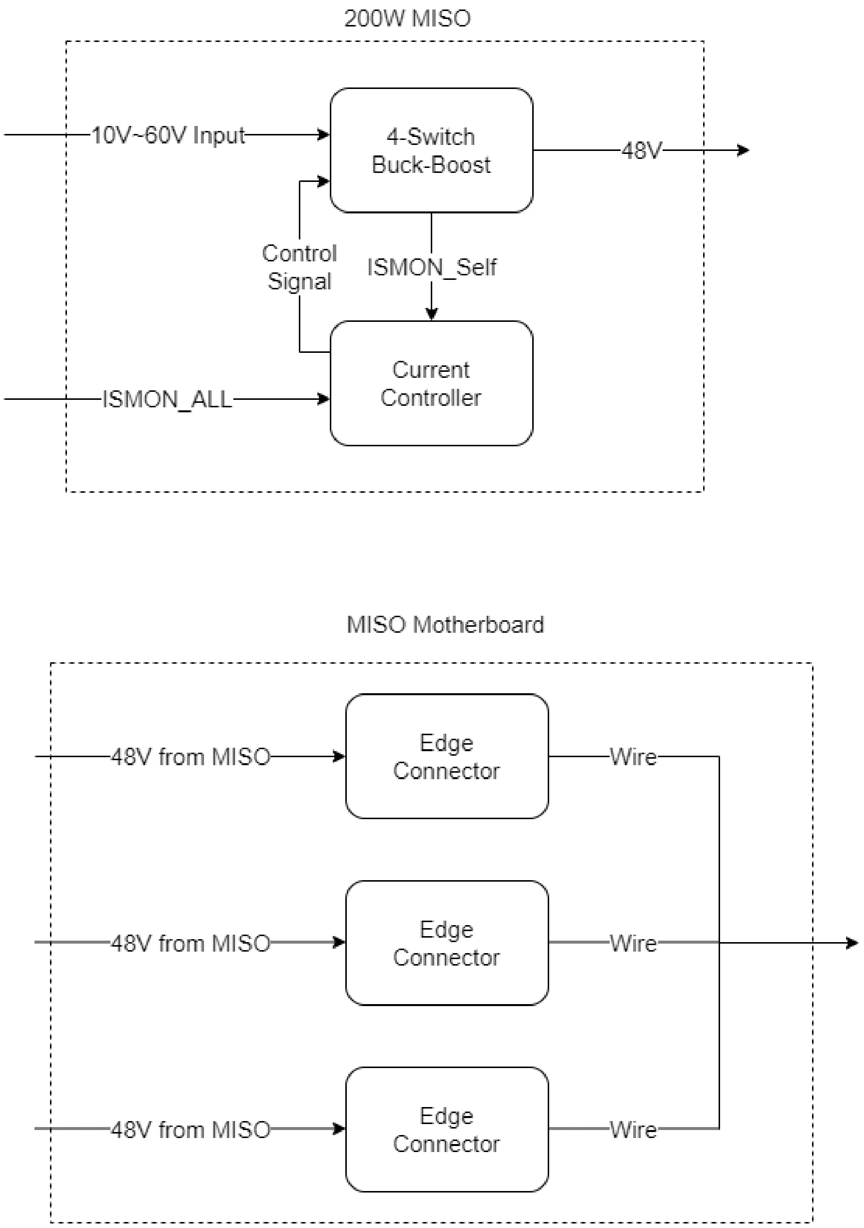


Figure 3.3: MISO Block Diagram Level 2

Figure 3.3 shows the level 2 block diagram, the top image shows the inside of an individual MISO module while the bottom represents that of the motherboard system. It shows that the MISO has a 4-switch-buck-boost in place connected to a current controller. With the continuous communication between the two, the MISO can intake 10-60V input and output 48V as mentioned earlier. The bottom image shows the outputs from the modules reaching the edge connectors, conjoining, and then powering the DC house. Table 3.1 summarizes all design specifications shown and used in this design.

Table 3.1: Design Specifications Summary

Type	Rating
Input Voltage	10V-60V, 24V nominal
Average Output Voltage	48V
Maximum Output Power	600W for 1 motherboard, Standalone 200W module
Number of Parallel Modules	3 200W modules
LEDs	5V
Efficiency	≥ 90%
Airflow	0 LFM
Line Regulation	3% with 12V – 36V input
Load Regulation	3%
Output Voltage Ripple	3%
Input and Output Connection	Edge connectors

Chapter 4. Design

This chapter discusses the design of the new iteration of the MISO, and how it was implemented. The major changes from the previous MISO 200W include: an edge connector, 600W motherboard, an “running” LED, new input/output connectors, new control signal connectors.

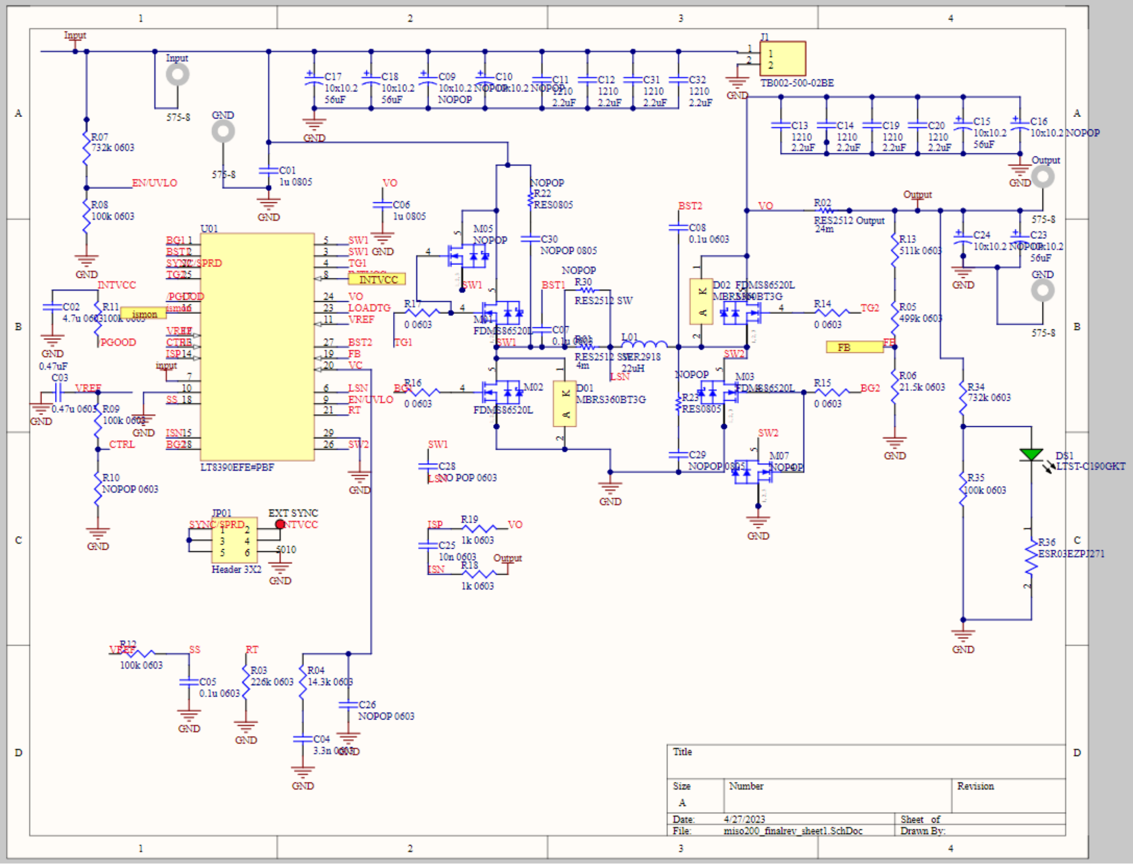


Figure 4.1: 200W MISO Circuit Schematic

The current circuit was not changed much from the previous MISO [9], however the LED circuit was added. One of the purposes of the project is to validate whether adding two plane layers helped reduce the overheating problem.

The addition of an edge connector to the 200W MISO board was one of the focuses of this senior project. Having an edge connector will allow the boards to be easily installed and removed. The TE Connectivity AMP Connectors 5145432-2 was selected due to the amp specifications, the length of the connector, and the latches.

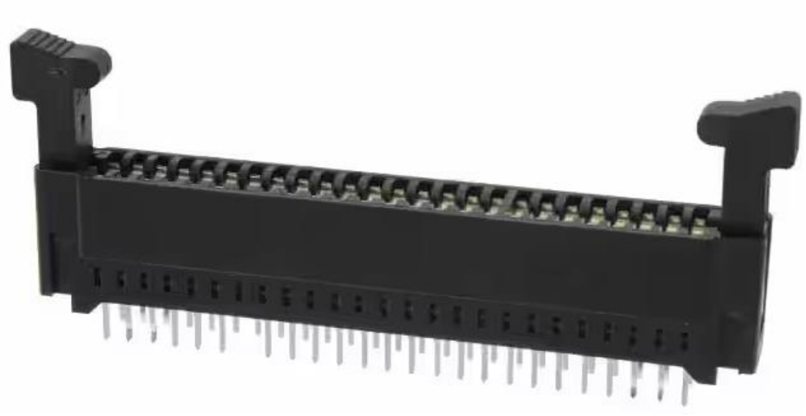


Figure 4.2: TE 5145432-2 Connector

Each pad of the connector is rated for 3 amps with 25 pads, this should allow for plenty of headroom for the output. The connector's length needed to be close to the length of the board. The latches should both secure the MISO, and make sure it is plugged all the way in; the connector is also designed so it is not possible to install the board incorrectly. For the edge connector on the board, the mate must be created from the engineering drawing [15][16].

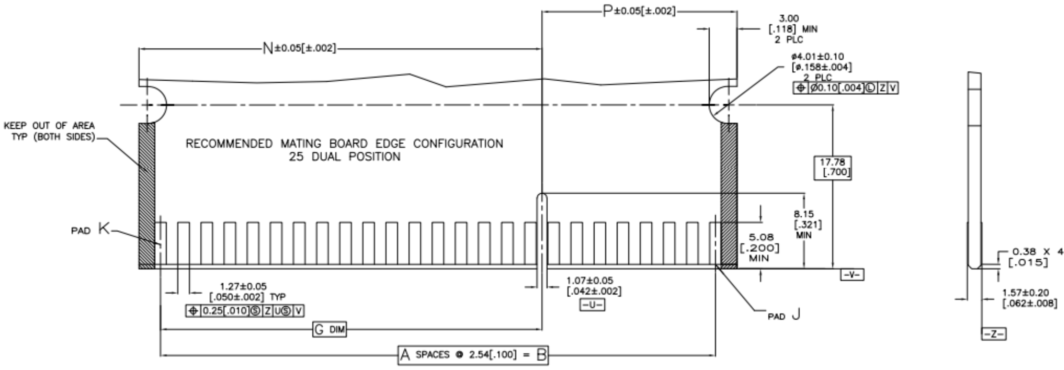


Figure 4.3: Section of Connector Mate

The female connector’s PCB footprint, and its schematic symbol was easy to import into Altium using “Altium Library Loader V2.2” extension [17]. However, the mate for the connector had to be created in the software. The engineering drawing has centerlines on pads, because having a contact be in the center of the pad. It does make placing the pads more difficult with having one unevenly spaced division. The solder mask should be removed around the pad connectors, and most edge connectors also recommend a chamfer. Altium does provide extensive design help under their “Altium Academy” [17] that were heavily referenced to complete the mate.

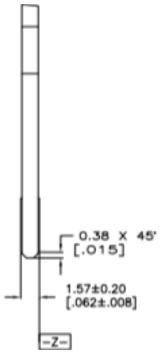


Figure 4.4: Chamfer Engineering Drawing

It needs to be noted that JLC PCB, the company that printed the boards, could not do 45-degree so a 30-degree chamfer was done instead.

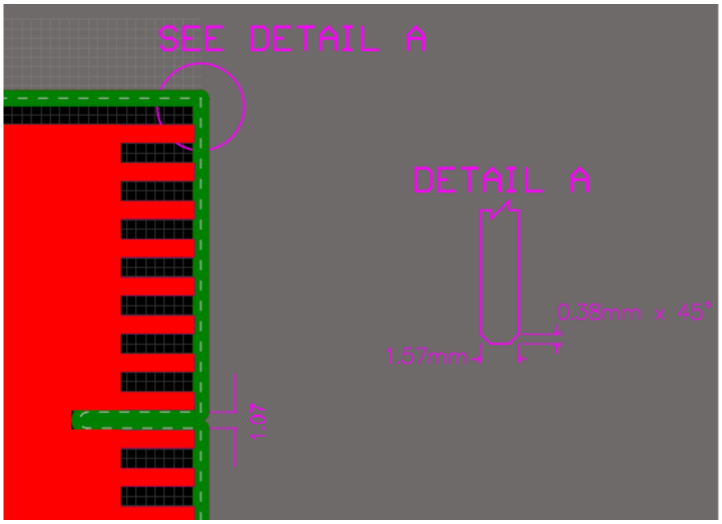


Figure 4.5: Chamfer Description in Altium

The chamfer specifications should be included on a mechanical layer, or on a separate document. It is good to include any different spacing on that mechanical layer in there are divisions on the edge connector. The board's shape should be reshaped to include the mate's dimensions.

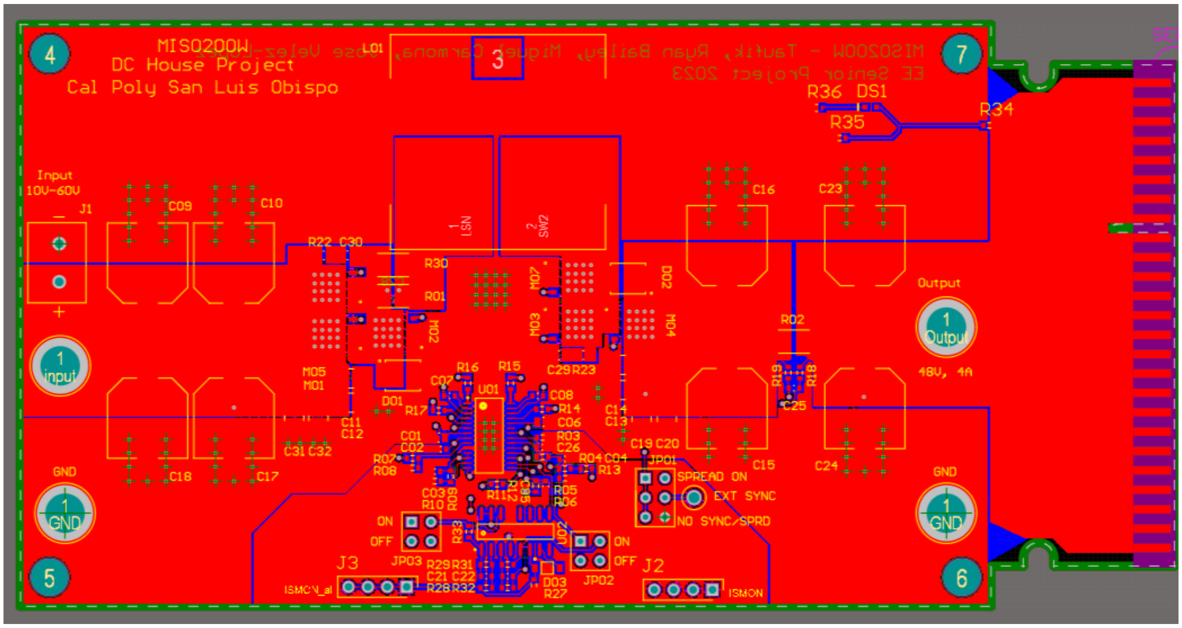


Figure 4.6: Current Iteration of the 200W MISO Board Layer View

This is the current iteration of the 200W MISO with the edge connector on the right side, and inputs on the left side of the board. The edge connector is of excellent quality and does leave room for changes. It is important to note that the drilled holes at the corners of the board are important to the testing, and the structural integrity of the system. They allow the board to be raised from the testing bench when characterizing the performance of each board.

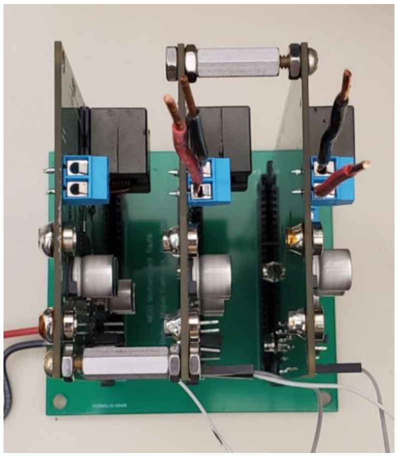


Figure 4.7: Testing Board Supports

Each MISO board raddles around even after the latches are locked in place, so to prevent damage of the connector it is recommended to add supports.

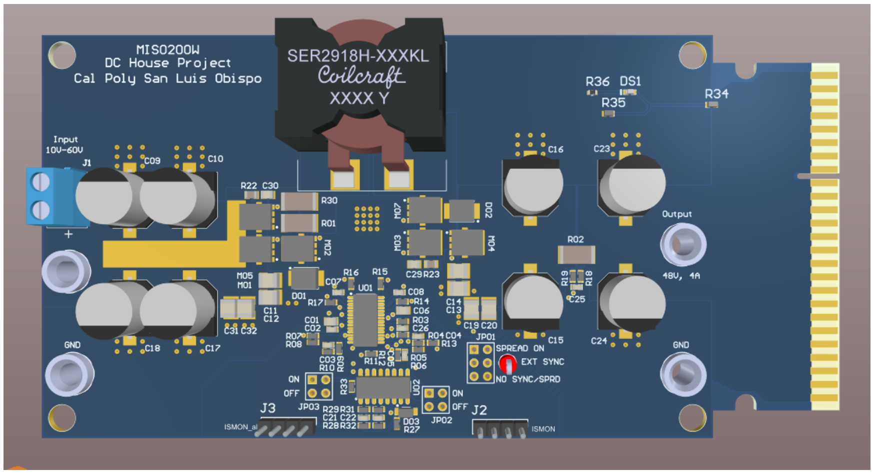


Figure 4.8: Populated 3D 200W MISO

For future iterations it be advantageous to have the input be a portion of the edge connecting and have the input of each MISO module be on the motherboard instead of each module. This would make wiring the board in the DC/AC house easier and would allow for shorter overall connections. The traces will mostly have to go on the top half of the board, but this will affect the power flow of the design. If the same connector is used a symbol and PCB footprint should be made to make the connector easier to install on future boards.

An LED circuit was added to make it easy to see if a board was outputting 48V, and act as the first step of trouble shooting without needing measuring equipment. For the MISO to be implemented into the AC/DC hybrid house the inputs and the outputs needed to be easier to hook up to electrical wire.

Figure 4.9: Input/Output Connection

A two-terminal block, CUI Devices TB002-50002BE, is serving as the input and output terminal of the motherboard. Each terminal can handle 17.5 Amps, which is enough to have a full input at 12V. This was an oversight not getting connector that can handle the theorical 20A that would be coming from the input.

The old connection for the control signal was a female banana cable connection, but that needed be changed to a smaller cable. Standard pin header was chosen due to the variable lengths, and the ease of connection them. This version of the MISO has a max of three 200W

MISO that are plugged into the newly designed motherboard. The outputs are all connected at the top plane of motherboard and the negative is connected to the lower one.

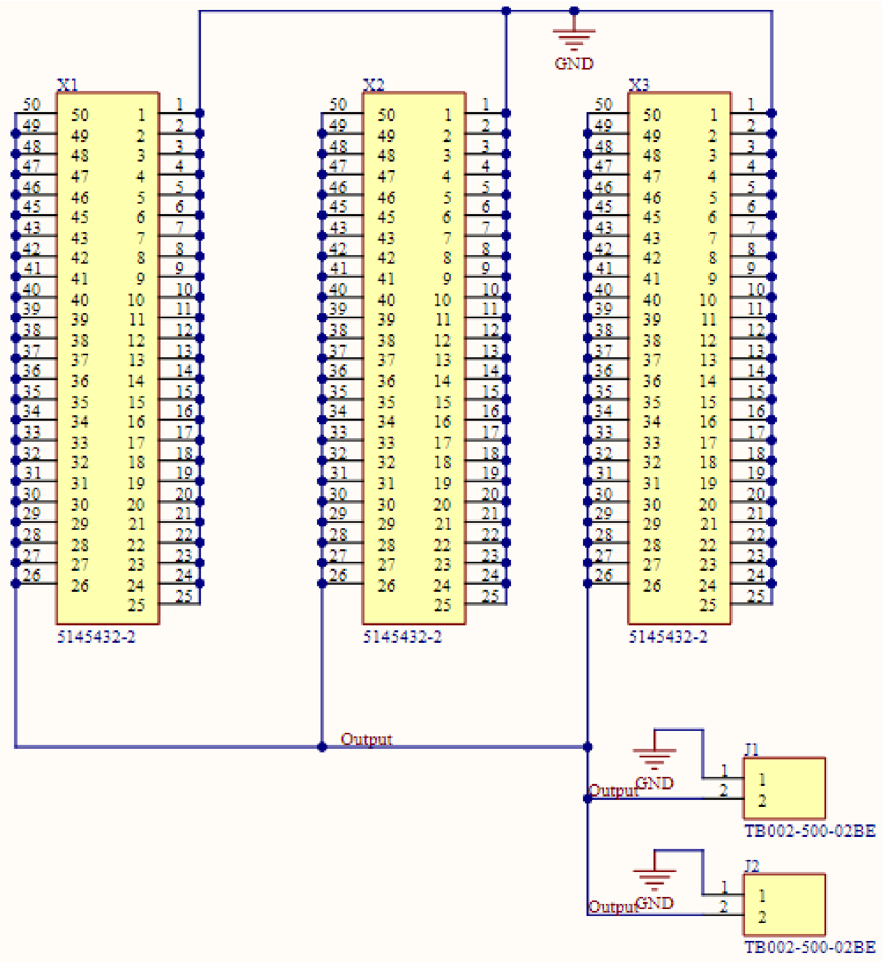


Figure 4.10: Motherboard Circuit Schematic

Currently, there are only two terminal output due to this being a prototype to be installed into the house. The current controlling current on each board is what regulates the current from each board.

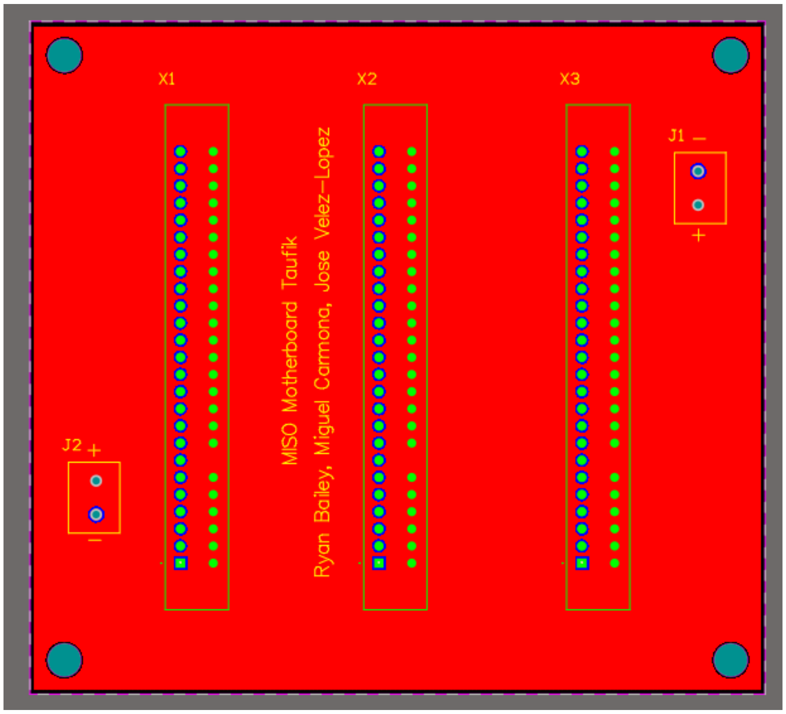


Figure 4.11: Motherboard PCB Layout

This board worked well enough to prove the concept; however, there were some oversights with the current design. The area around the mounting brackets should not have any pad connections under them and moving the output terminals to allow for better power flow.

Chapter 5. Construction and Test Results

This chapter will cover the construction, testing setup, and test results of a single 200W MISO board and the 600W MISO module. The board design was modified through Altium Designer and manufactured by JLCPCB. In addition to the board, there is also the motherboard which serves as a bus for the 200W MISO boards.

The process of soldering the components seems to have a direct connection with how well the boards can perform. A reflow oven was used to all the surface mounted components, while through hole components were hand soldered. Using a solder stencil, low melting point solder paste, and the reflow oven allow these boards to be easily assembled. The connection between this soldering method and the performance will be expanded in the next chapter.

Figure 5.1: Test Setup Diagram

To thoroughly test the board, the following devices were used: a 6032A System Power Supply, BK Precision 8510 Programmable DC Electric Load, and the RIGOL DM3052 Digital Multimeter. The digital multimeter was used at the input to ensure the input voltage was at the desired value set by the power supply, input current was measured by the power supply. A digital multimeter was also used to measure the output voltage while the output current was set by the electronic load.

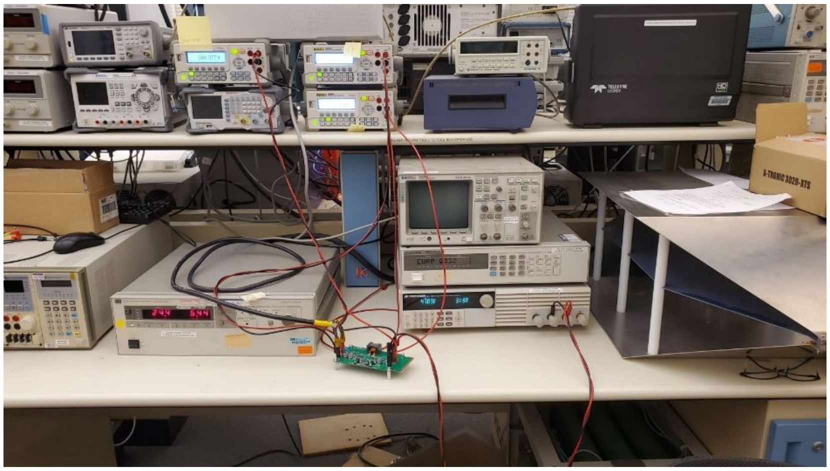


Figure 5.2: Test Setup

Each 200W MISO board was tested to ensure that the device was working as intended. The boards were tested for efficiency, line regulation, load regulation, output voltage ripple, and finally a thermal image. The performance of the MISO board will directly impact the performance of the 600W MISO device, this is because the 600W will be three 200W boards connected.

The first test done on the 200W MISO board was the efficiency test, which measures how efficient the board is converting the input voltage to the desired 48V output voltage. This is an important test because it gives insight into any internal losses that may be present. This test was performed with a nominal input voltage of 24V and had the load increased from 5% load to 100% load in steps of 5%. Efficiency is calculated by using the equation below.

$$\eta = \frac{P_o}{P_{in}} = \frac{V_o I_o}{V_{in} I_{in}} \times 100\%$$

Output current was incremented while adjusting the input to voltage to maintain nominal value, both input and output voltage and current values were recorded and tabulated. Efficiency was calculated and plotted in Figure 5.3.

Table 5.1: 200W MISO Board Efficiency Data

% Load	Po	Vin	Iin	Vo	Io	Efficiency
5	10	24	0.41	48.24	0.200	0.980
10	20	23.97	0.86	48.22	0.420	0.982
15	30	23.94	1.3	48.2	0.630	0.976
20	40	23.9	1.71	48.19	0.830	0.979
25	50	24.03	2.13	48.02	1.042	0.977
30	60	23.99	2.56	48.19	1.250	0.981
35	70	23.96	3.01	48.2	1.458	0.975
40	80	23.93	3.43	48.19	1.667	0.979
45	90	24	3.85	48.19	1.875	0.978
50	100	23.97	4.26	48.19	2.083	0.983
55	110	23.94	4.71	48.18	2.292	0.979
60	120	24.01	5.13	48.18	2.500	0.978
65	130	23.98	5.55	48.17	2.708	0.980
70	140	23.94	5.99	48.17	2.917	0.980
75	150	23.99	6.41	48.17	3.125	0.979
80	160	24	6.84	48.16	3.333	0.978
85	170	23.97	7.28	48.15	3.542	0.977
90	180	23.98	7.69	48.11	3.750	0.978
95	190	23.99	8.06	47.8	3.958	0.979
100	193.44	23.97	8.25	46.5	4.160	0.978

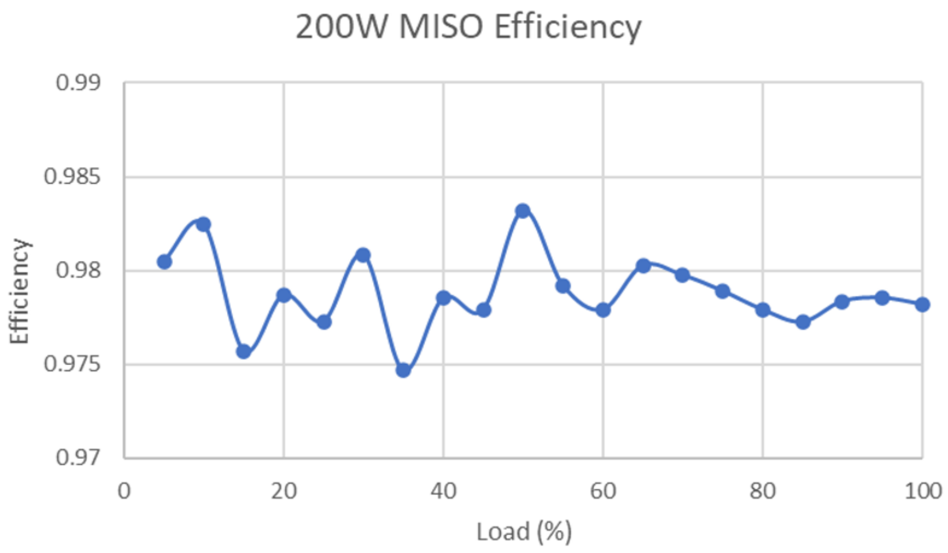


Figure 5.3: 200W MISO Board Efficiency

The 200W MISO board operates just below 98% efficiency in most load cases with nominal input voltage. This high efficiency confirms that the device has little internal losses, which leads to lower operational cost is required as less of the energy put into the system is wasted. A device with a higher performance-to-power ratio has the benefit of being both more economical and being better for the environment.

The next test performed was for line regulation which gives insight into how the device will operate under varying input conditions. Line regulation is important in the MISO device because it is directly tied to reliability and performance. The MISO board will be taking input from a solar panel with variable supplying power depending on how much of the panel is exposed to the sun, along with other input sources supplying variable power this characteristic is important to quantify. Output voltages were measured while at full load to replicate worst case conditions and line regulation was calculated by using the equation below.

$$Line\ Regulation = \frac{V_{o,high\ input} - V_{o,low\ input}}{V_{out,nominal\ input}} * 100\%$$

Vo, high-input was measured after setting the input to 36V and determined to be 46.8V. *Vo, low-input* was measured after setting the input to 20V and determined to be 44.2V. The 200W MISO board is unable to operate properly at low input voltage when at full load, for this reason the low input voltage was set to 20V which was the lowest value that allowed near nominal output. *Vo, non-input* was determined to be 46.02V after setting the input to 24V. This resulted in a line regulation of 5.65%, meaning that the output voltage only has a 5.65% dependency on the input voltage.

The load regulation test measures how well the MISO board can maintain the desired output voltage of 48V under various load conditions. This is again important in ensuring device reliability and safety. The AC/DC House will be operating under constantly changing load conditions depending on the time of the day; lights, fans, and other various household appliances will be used demanding a different amount of power at various times of the day. Load regulation was calculated using the equation below.

$$Load\ Regulation = \frac{V_{o,no\ load} - V_{o,full\ load}}{V_{o,full\ load}} * 100\%$$

Vo at no load was measured to be 48.4V, while Vo, full load was measured to be 46.5V. Full load is at 95% of maximum load due to the board not being able to support the maximum load of 200W. The regulated output drops to 30V after a minute of operation. Reasons for this could be the inductor heating up and reaching saturation. This gave a load regulation of 4.09%. This means that the load has a 4.09% effect on the output voltage.

Voltage output ripple is a measurement that is used to quantify how well a converter is outputting a DC signal. Ideally the output signal should be flat but internal components might allow AC components to be passed through to the output. The following voltage output waveforms were taken at full load to show worst case conditions with a measured output peak to peak voltage ripple of 1.317V.

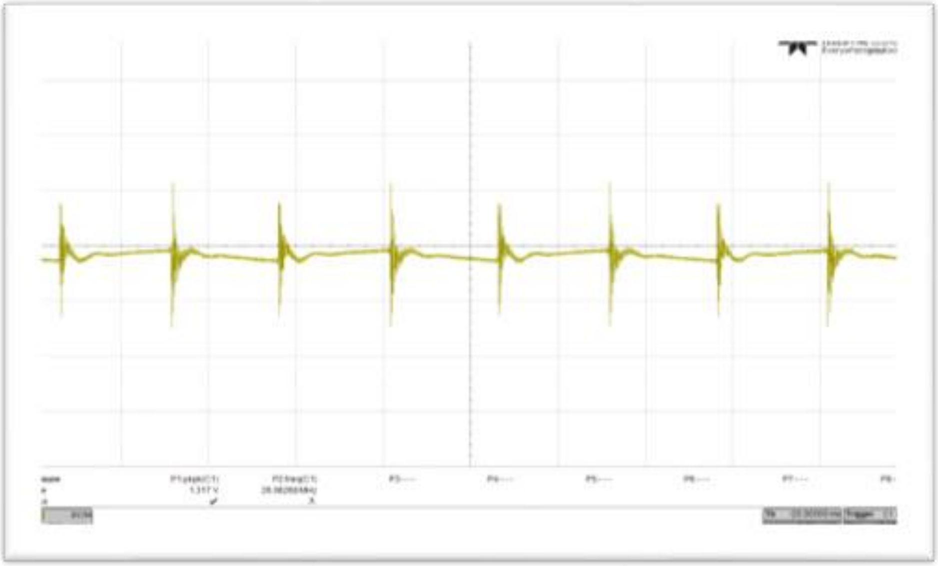


Figure 5.4: Output Voltage Waveform of 200W MISO Board.

Using 1.3117V peak to peak voltage and DC 46.5V and the below equation, the output voltage ripple was calculated to be 2.82%.

$$\%V_{o,ripple} = \frac{V_{o,ripple\ peak-peak}}{\bar{V_o}} * 100\%$$

Lastly, a heat test was performed, the previous version of this board had an issue with the M03 FET which was reaching temperatures as high as 109.9 °C. In this version of the board, which has an extra ground plane to assist with heat dissipation, the M03 FET reaches a peak temperature of 76 °C showing that there was an improvement in temperature control. This thermal image was taken after the devices had reached thermal equilibrium which is about 15 minutes at full load and nominal 24V input.

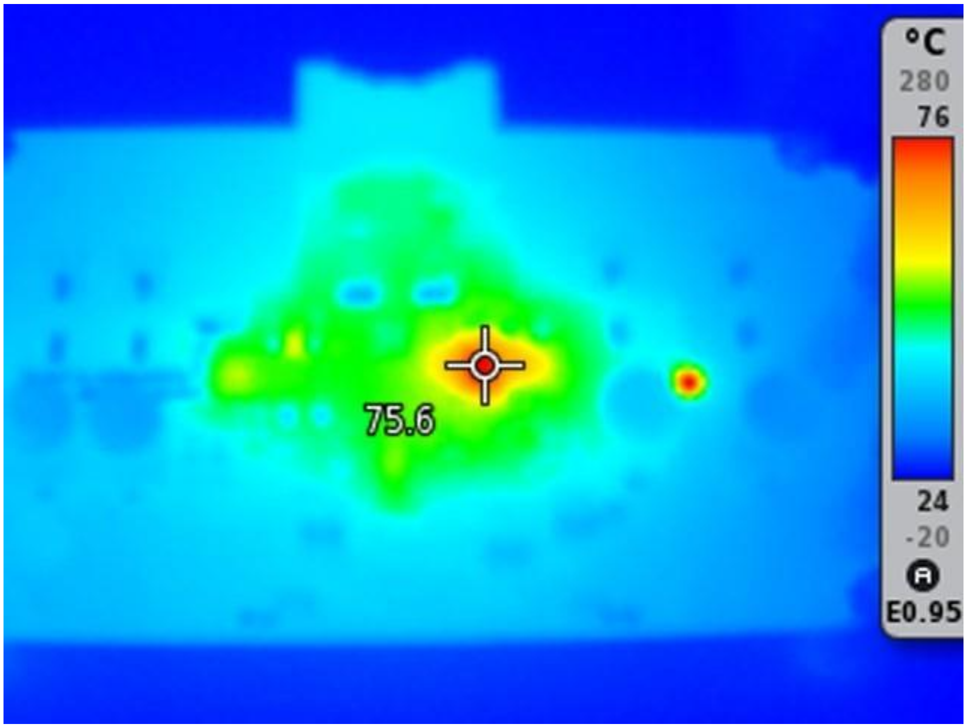


Figure 5.5: Thermal image of 200W MISO Board

The following refers to a 400W MISO configuration enabled through the connection to the designed motherboard. Although the goal of this project was to create a 600W system, the third and final board experienced elevated temperatures on the MO3 MOSFET to a noisy gate signal resulting in large losses.

Table 5.2: 400W System Efficiency Data

% Load	Po	Vin1	Vin2	Iin1	Iin2	Vo	Io	Eff. 1	Eff. 2
5	20	23.91	23.99	0.493	0.432	48.24	0.417	0.853	0.970
10	40	23.88	24.01	0.921	0.85	48.23	0.833	0.914	0.985
15	60	23.83	24.01	1.36	1.27	48.21	1.250	0.930	0.988
20	80	23.77	24	1.79	1.7	48.21	1.667	0.944	0.985
25	100	23.73	24	2.22	2.12	48.21	2.083	0.953	0.987

30	120	23.68	24	2.66	2.56	48.19	2.500	0.956	0.980
35	140	23.63	24	3.1	2.97	48.19	2.917	0.959	0.986
40	160	23.58	23.99	3.54	3.39	48.19	3.333	0.962	0.988
45	180	23.52	23.99	3.98	3.8	48.17	3.750	0.965	0.991
50	200	23.5	24	4.41	4.23	48.17	4.167	0.968	0.989
55	220	23.48	24.04	4.86	4.67	48.16	4.583	0.967	0.983
60	240	23.4	24.01	5.31	5.1	48.16	5.000	0.969	0.983
65	260	23.04	24	5.75	5.52	48.15	5.417	0.984	0.984
70	280	23.34	24	6.2	5.95	48.15	5.833	0.970	0.983
75	300	23.27	24	6.67	6.38	48.14	6.250	0.969	0.982
80	320	23.23	24	7.12	6.83	48.13	6.667	0.970	0.979
85	340	23.22	24	7.56	7.25	48.13	7.083	0.971	0.980
90	360	23.18	24	8.04	7.66	48.05	7.500	0.967	0.980
95	380	23.13	24	8.4	8.04	47.8	7.917	0.974	0.981
100	400	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

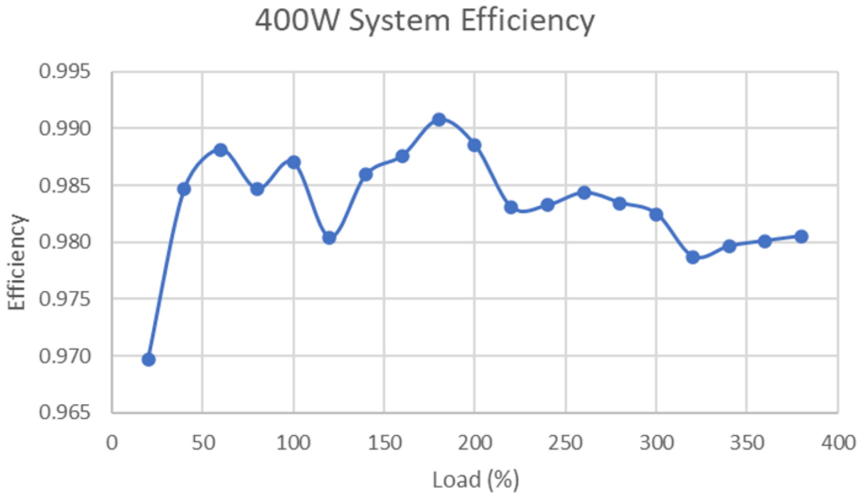


Figure 5.6: 400W System Efficiency Plot

The system was overall slightly more efficient than a single board with an average efficiency of about 98.5%. This increase in efficiency means that the system is overall more reliable throughout its lifetime, saving both energy and money.

The first test performed was the line regulation test which was calculated to be 2.5%. *Vo, high-input* was measured after setting the input to 36V and determined to be 48.11V. *Vo, low-input* was measured after setting the input to 20V and determined to be 46.91V. Like the 200W board, the 400W MISO system cannot operate properly at low input voltage when at full load, so the low input voltage was set to 20V, the lowest value allowed near nominal output. *Vo, non-input* was determined to be 48.05V after setting the input to 24V.

The second test performed was load regulation which was calculated to be 0.62%. Vo, no load was measured to be 48.37V, while Vo, full load was measured to be 48.07V. Reflecting the characteristics of the 200W board the 400W system is unable to reach the maximum of 400W and instead full load is chosen to be at 90%.

The output voltage of the 400W system is shown in Figure 5.7 and was taken at full load to show worst case scenario and has a measured output peak to peak voltage ripple of 618.4mV which means that this system has a percent voltage ripple of 1.29%.

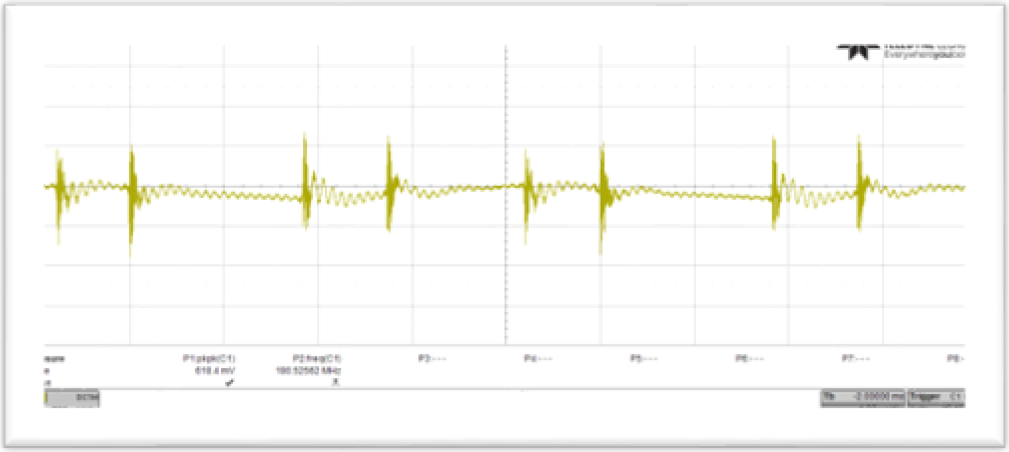


Figure 5.7: Output Voltage Waveform for 400W Configuration

The final test done on the 400W MISO system is the thermal test that was done under full load conditions to simulate worst case scenario. This image shows that the hottest part of the board is still the MO3 MOSFET with a peak temperature of 61°C which is lower than the operating temperature of a single board and can be explained by the fact that the load is being shared between the two boards resulting in each individual board having to deal with less of a load.

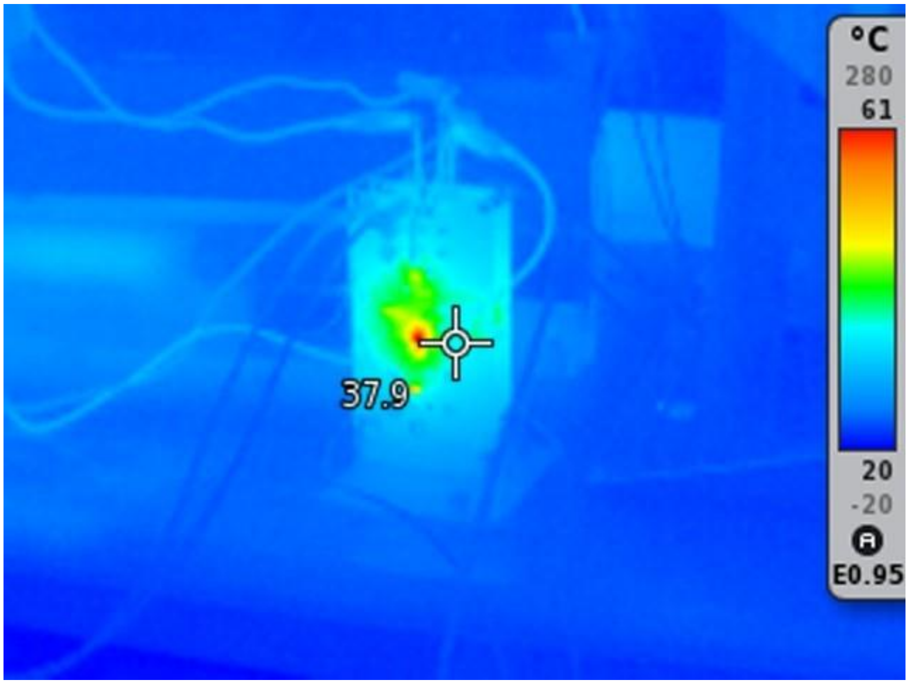


Figure 5.8: 200W MISO Board Thermal Image

The current theory of why the MOSFET is overheating is the ringing at the gate terminal of MO3. The MOSFET needs a clear square wave to turn on and off; however, it does not seem to be getting that. Testing with board 3 shows that at the MOSFET terminal there is a lot of high frequency, high amplitude noise. This explains why MO3 has been getting hotter, than it should by forcing the MOSFET to switch when it should be.

The cause of noise is still unknown; the most promising possibilities are the solder quality attaching the MOSFET, resistor before MOSFET is too small, or the trace needs to be rerouted in some way. M03 on board 1 and 2 full load operation runs 30 °C cooler than board 3; which was the only one that had its M03 changed after its initial run through the reflow oven. It is believed that the previous version of the MISO that had an overheating problem was not done in a reflow oven. With the current layout of the 200W MISO it is essential to at least place M03 using a reflow oven. However, this does not fix the ringing problem, but does help mitigate its effects.

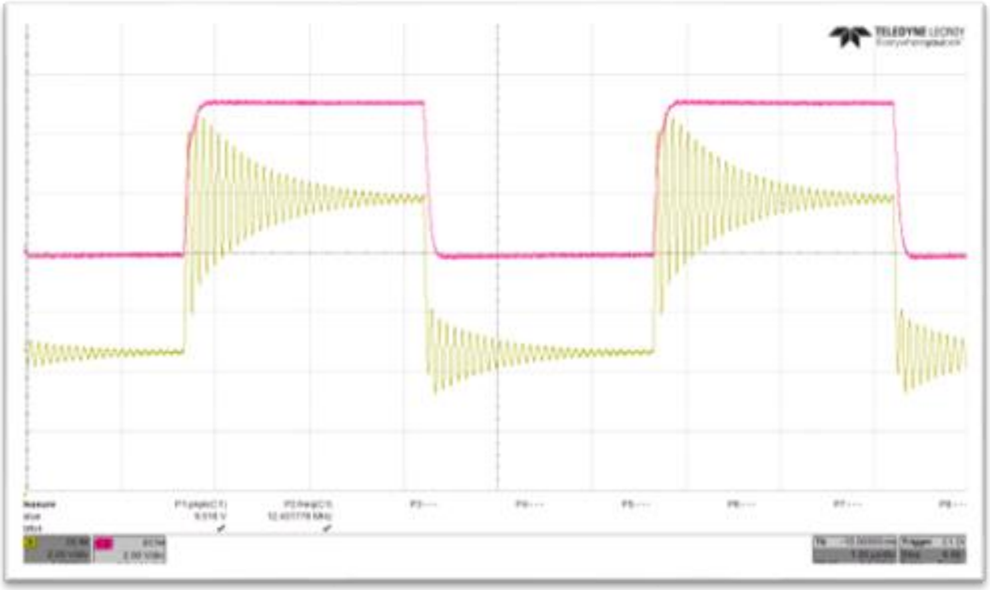


Figure 5.9: Gate Signal at R15 (magenta), Gate Signal at M03 (yellow)

Note the signals are of the same amplitude but were offset for clarity. Talking with our advisor, he stated that the resistor, R15, that leads to the gate terminal of the MOSFET needs to be larger. A larger value for R15 should help reduce the amplitude of the noise seen in the MOSFET gate terminal.

The trace could also be picking up noise from the power portion of the MISO board. So, the trace can be shortened or straightened out to prevent the creation of noise. It also needs to be stated that M07 pads do not seem to work. Some of the troubleshooting that was done for board 3 included adding M07 to try reducing that load on M03. Having the MOSFET in parallel should have helped distribute the load, but this was not the case. There was no change heat reduction, so M03 was removed to test if the pad of M03 was bad.

At this point, the board should push all the current through M07 to find out why it did not improve load distribution. When the source was turned on there was not 48V at output and the LED was not on. So, M07 was not functioning, which also points to a layout or gate signal problem. It is believed the gate signal is not being received properly and not turning on M07.

There is also a problem when boards 1 and 2 were tested together in the motherboard. When the boards were tested together above 50% load, they would periodically both turn off, and then turn back on. Because of the periodical shut offs, the boards do not let the boards react to thermal equilibrium. This could be an effect of using only one power supply, or the on/off pins of the MISO boards were set up incorrectly. Troubleshooting should be done with separate power supplies to see if it was just an error of running parallel sources.

Chapter 6. Conclusion

This senior project sought to test and validate the 200W MISO board and a 600W system. This is done to ensure proper functionality when implemented in the AC/DC House. One of the fundamental issues was the M03 MOSFET that was overheating on the previous version of the board. This MOSFET would reach temperatures as high as 109.9°C at full load, this leads to a shorter life span for the device and a decrease in efficiency. To combat this issue a ground plane was added to assist in heat dissipation.

Firstly, it was important to ensure that the 200W MISO board was working with the new ground planes. Chapter 5 goes over the lab setup and procedure for obtaining the following data and calculated values.

Table 6.1: Summary of MISO Data

Test	Specifications	MISO 200W	MISO 400W
Efficiency at Full Load	$\geq 90\%$	97.82%	98.1 (95% load)
Line Regulation	3% with 12V-36V	5.65%	2.5%
Load Regulation	3%	4.09%	0.62% (90% load)
Output Voltage Ripple	3%	2.82%	1.29%

As shown in the table above, not all values could be obtained at full load. However, it was possible to obtain values at full load in some of the configurations. The values that were acquired at full load fell within or just outside of expectations. When attempting to get efficiency and load regulation in the MISO 400W configuration at full load, the output voltage would drastically drop preventing an accurate reading for both calculations. The M03 MOSFET has cooled to 76°C after the inclusion of the new ground planes, proving that the ground plane did help with the overheating issue.

In addition, a major component of this senior project was modifying the 200W MISO board to work in a current sharing configuration to allow for a 600W system. This required design for an edge connector and motherboard. A card slot method used for the motherboard design which allows for secure installment, removal, and replacement of input power devices. The slots also have a locking mechanism for the MISOs to ensure a secure connection. In doing so, the life span has been improved and reduced the size of the board altogether permitting easy access. Also, an LED was added to the board to indicate when the board is in operation.

Future revisions of the MISO can improve the heating issues with the MOSFET by switching the material type with another that is more heat resistant or has a higher ceiling for the operating temperature. Adding more ground planes may reduce the heat more rather than increasing the ceiling for operating temperature. An issue that was unknown was why we were unable to do some calculations at full load. The output voltage would drop a drastic amount when doing full load. Also, the minimum voltage used in line regulation was not 10V. Whenever we approached 18V, the output voltage would once again drop a drastic amount. Another concern to be addressed was mentioned in chapter 5. Only 2 boards were constructed without issue and worked individually to some degree. However, when connected they would shut off and turn back on periodically when tested above 50% load.

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APPENDIX A — 200W MISO BOM

Designator	Quantity	Value	Description	Part Number	Rating
C01, C06	2	1uF	0805 Cap	490-14436-1-ND	100V
C02	1	4.7uF	0603 Cap	490-7203-1-ND	25V
C03	1	0.47uF	0603 Cap	490-3291-1-ND	25V
C04	1	3.3nF	0603 Cap	720-1366-1-ND	50V
C05, C07, C08	3	0.1uF	0603 Cap	720-1366-1-ND	25V
C09, C10, C15, C16, C17, C18, C23, C24	4	56uF	Aluminum Electrolytic Capacitor	63PEV56M10X10.5CT-ND	63V
C11, C12, C13, C14, C19, C20, C31, C32	8	2.2uF	1210 Cap	490-3385-1-ND	100V
C21, C22, C25	3	10nF	0603 Cap	720-1531-1-ND	50V
R01	1	4mΩ	2512 Res	CSNL2512FT4L00CT-ND	2W
R02	1	24mΩ	2512 Res	541-10129-6-ND	1W
R03	1	226kΩ	0603 Res	311-226KHRCT-ND	0.1W
R04	1	14.3kΩ	0603 Res	P20102DKR-ND	0.2W
R05	1	499kΩ	0603 Res	541-499KSCT-ND	0.333W
R06	1	21.5kΩ	0603 Res	P20121DKR-ND	0.2W
R07, R34	2	604kΩ	0603 Res	311-2639-6-ND	0.1W

R08, R09, R11, R12, R29, R32, R35	7	100kΩ	0603 Res	541-2820-6-ND	0.25W
R13	1	511kΩ	0603 Res	311-2377-6-ND	0.1W
R14, R15, R16, R17	4	4.7Ω	0603 Res	541-4.7SADKR-ND	0.333W
R18, R19, R36	3	1kΩ	0603 Res	511-1732-6-ND	0.3W
R27, R28, R31	3	10kΩ	0603 Res	541-2817-6-ND	0.25W
R33	1	383kΩ	0603 Res	1276-4891-1-ND	0.1W
U01	1		28-pin SOP	LT8390EFE#PBF	
U02	1		16-pin SOIC	LT1467LCS	
D03	1		2-Pin SMB	MBR0520LT1	PIV = 20V Iavg = 500mA
DS1	1		LED, Blue	630-HSMR-C191-S0000	Vf = 3.4V I = 20mA
JP01	1	3x2	Header, 3-Pin, Dual row	67997-410HLF	
JP02, JP03	2	2x2	Header, 2-Pin, Dual row	67997-410HLF	
L01	1	22uH	Inductor	SER2918H-223KL	Imax = 20A Isat = 12A
M01, M02, M03, M04	4		5 Pin DFN	FDMS86520L	PIV = 60V Iavg = 13.5A

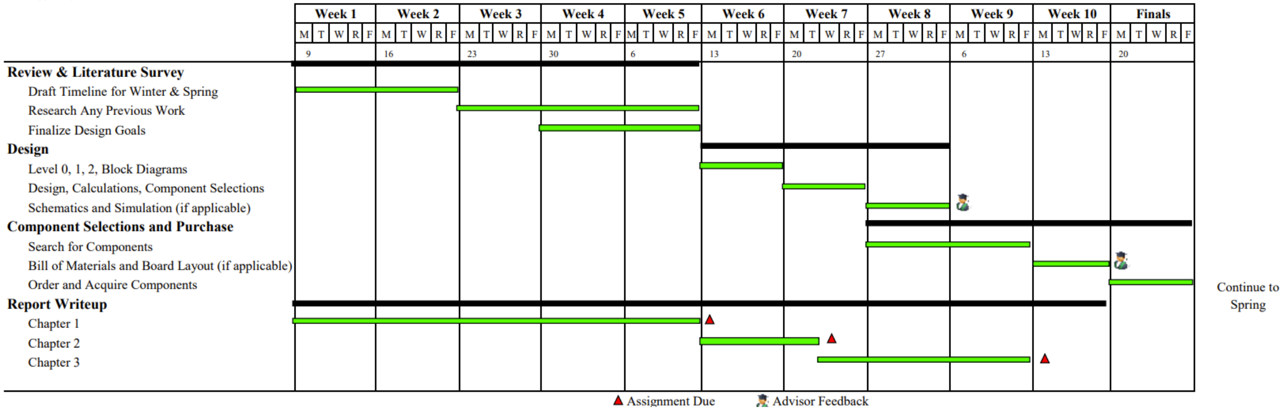
Input, Output, GND	4		Banana Jack	36-575-8-ND	
EXT SYNC	1		Test Point	36-5010-ND	
J1	1		Wire to Board Terminal	102-6145-ND	V = 300V I = 15A
Standoff	4				
Standoff nuts	4				

APPENDIX B — MOTHERBOARD BOM

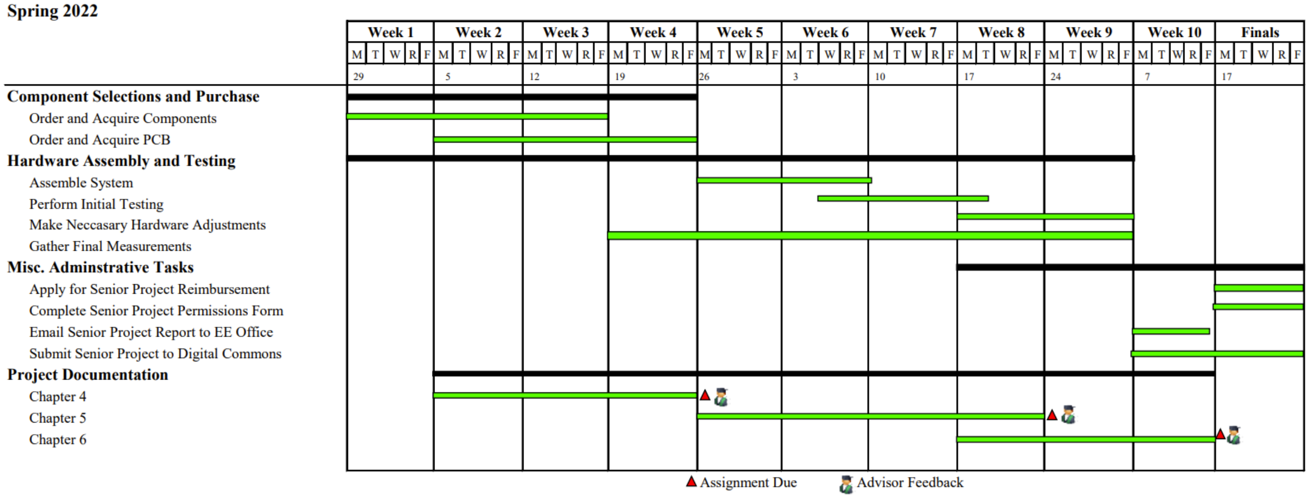
Designator	Quantity	Description	Part Number	Rating
X1, X2, X3	3	Female Connector	A113783-ND	
J1, J2	2	Wire to Board Terminal	102-6145-ND	V = 300V I = 15A

APPENDIX C — PROJECT TIMELINE

Winter 2022



Spring 2022



APPENDIX D — ANALYSIS OF SENIOR PROJECT DESIGN

Please provide the following information regarding your Senior Project and submit it to your advisor along with your final report. Attach additional sheets, for your response to the questions below.

Project Title: Multiple Input Single Output DC-DC Converter

Student's Name: Miguel Carmona, Jose Velez, Ryan Bailey

Student's Signature: *Miguel Carmona, Jose Velez, Ryan Bailey*

Advisor's Name: Taufik

Advisor's Initials: T

Date: 6/10/2023

Summary of Functional Requirements

Our senior project encompassed the construction and verification of a 200W MISO board. This was a DC-DC Converter that could convert the power generated by a renewable energy source such as a solar polar and convert it into a regulated 48V used by the AC/DC House.

Primary Constraints

Some of the challenges that we had to deal with was the component shortage. The main influence in direction for this project was the report done by a master student working on the previous version of the MISO board. Testing the board was done similarly and collected data was compared with previous data.

Economic

This new iteration of the MISO has improved economic impacts compared to the previous iteration. The MISO as stated in the report is now made of 3 individual MISO 200W boards allowing for easy replacement if any were to malfunction or reach the end of its lifespan. The lifespan is now increased with the resolution of the heating issue allowing for more time between replacements of the MISO. As originally intended, the MISO hopes to make DC homes more attractive for the market in rural areas. This would allow for renewable energy sources to gather more attention and increase in the market. Currently, the total cost of the MISO 200W is about $30 per board. Ordering in bulk will

Environmental

The MISO hopes to re-use solar panels that have been recycled or put to the side to prevent more wasteful creation of solar panels. With the recycled solar panels in use, the MISO will be relying on solar power to power the houses located in rural areas. Another source that has been mentioned was windmills. The MISO could harness the power of wind as well. This project should not harm the natural resources or ecosystem of the area since it would power houses individually and does not take much space or technology to build.

Manufacturability

The manufacture of the DC-DC Converter should not run into problems, the design was simple, and none of the components were exceptionally difficult or sensitive to work with.

Sustainability

The MISO system is modular by design which means that it would be easy to remove any faulty units and replace them with functional units. This allows for the system to be more sustainable overall, any upgrades that could be made to the MISO boards would be easy to implement.

Ethical

The desired implementation of this design is for rural areas in third world countries, meaning misuse is possible because it could lead to undesired control over the people.

Health and Safety

As with all designs, safety is of the utmost importance, due to the device being implemented in people's homes, any possibility of unregulated voltage or overcurrent causing a fire has been considered.

Social and Political

There are not any social or political issues associated with the design, manufacture, and use since it helps those in need. This project would help those who live in rural areas as mentioned, which would allow them to be more connected and in better living situations. The direct stakeholders would be companies creating the microgrids and indirect stakeholders would be companies that provide components to the microgrid companies. This project can impact energy generation companies that utilize oil and gas companies causing said companies to lose profit. This could imply involvement from the government to help oil and gas companies who could face bankruptcy.

Development

This iteration of the MISO required Altium Designer to make some changes to the MISO. It had to be learned on the spot to make the new edge connectors for the boards to allow for ease of installment and removal.