

CALIFORNIA POLYTECHNIC STATE UNIVERSITY

Bipolar Pulse Width Modulation Inverter

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Abstract

The project entails the design of an improved PWM inverter circuit for the inverter lab experiment in the introductory power electronic course. The improved PWM inverter uses bipolar switching with a half bridge control circuit. The inverter utilizes two ICL8038 chip to generate both the control and carrier signals. The improved inverter enhances the system's portability, protection and is easy to understand from the prior design. The improved PWM inverter provides AC variable single phase 65 Hz AC output voltage from DC input signal. The finished product will be used specifically in the EE 410 laboratory course.

Acknowledgements

We would like to thank Cal Poly Electrical Engineering Department for their awesome lab facilities. Without these facilities, we would not be able to complete our inverter project. Additionally, the department also helps in providing us with equipment to finish building our project. We would like to thank all the professors at Cal Poly for guiding and teaching us everything we need to know about electrical engineering to succeed in the work field. Finally, we would like to express special thanks to our advisor, Taufik, for teaching us countless concepts regarding power electronics and offering immense advice on designing the inverter. The amount of knowledge provided to us helped in developing strong techniques that will make us better designers and troubleshooters.

Chapter 1. Introduction

Power electronics is a rapidly growing field in Electrical Engineering. The field of power electronics deals with applications involving solid-state electronics and power conversion.

Electrical power can be converted into two different types of power: direct current (DC) and alternating current (AC). These two types of power can be converted through 4 different methods. These methods include AC to DC, DC to AC, DC to DC, and AC to AC.[1] A rectifier is an electronic circuit that will convert AC power to DC power. On the other hand, the conversion between DC to AC can be done through an inverter circuit. The other 2 methods require either a DC to DC converter or an AC to AC converter that only converts the input to another voltage level for output without changing the type of input. As the world become more innovative, each of the 4 different types of circuit can be further expanded depending on what outputs are desired. An inverter, for example, can use bipolar or unipolar switching to generate an AC pulse signal. There are many methods of building inverters, such as using LC filters, or split-wound coupled inductors; however, the most common way is using pulse width modulation.[2][3][4] PWM is widely used in power electronics and especially for induction motors, photovoltaic solar power and etc.[5]

Due to the growing interest of power electronics, as a senior project design, we will build a bipolar PWM inverter that is safe, portable, and easy to use for a lab experiment in one of the power electronic courses of Cal Poly. The key objective is to implement the concept of pulse width modulation and thus allows students to understand how PWM inverters work. By completing this project, the resulting inverter experiment will allow students that are taking EE 410: Power Electronics to get hands on experience on the basic functionality of an inverter.

Chapter 2. Background

There are many applications that use a DC to AC inverter. A common example of this would be a DC to AC inverter to convert a car's 12V DC battery to 120V AC. This allows people to charge their electronics that use AC power through the outlets of common household, in the car. Uninterruptible Power Supplies (UPS) also uses a DC to AC inverter in conjunction with a battery to generate AC power. This will allow the UPS to act as a backup power supply when the main power is not available.



Figure 2-1: APC Smart Uninterruptible Power Supply.[6]

Every police officer carries around with them a taser gun when they are on patrol. These electroshock weapons use a small 9V DC battery as a power source, so how can so little voltage be able to shock people? The answer is simple. The taser uses a DC to AC inverter that will convert the 9V DC to 400-2000 V AC, which is then amplified with a rectifier and a step up transformer to a large amount of electricity that is able to temporarily paralyze a suspect. The other applications for DC to AC inverter are induction heating, power grids, solar power, electric motor speed control, high-voltage direct current power transmission and many more.



Figure 2-2: Police using a taser gun that build using a DC to AC inverter.[7]

The understandings for inverters play an important role for people who are trying to get into the power electronics field. As such, for students that are taking EE 410 Power Electronics I, we want to design a power inverter that will provide students with some hands on experience on what inverters do and how it works. Therefore, we want to build a bipolar PWM inverter that takes in a DC input signal and outputs an AC signal. The inverter will be powered by a single DC power source from a power supply. In the previous year, a group of electrical engineering students designed a unipolar PWM inverter for EE 410 Power Electronics I; however, the finished product was not lab ready. Despite the product being fully operational, the fact that the bottom of the unipolar PWM inverter contains many wires makes it difficult for lab use because it could cause safety concerns for students who are working with the inverter. Additionally, the inverter is fairly large in size. As an improvement, we will be creating a new design for the PWM inverter that is a lot simpler, cheaper, compact and safer so that it can be used for lab experiments.

Chapter 3. Requirements and Specifications

This chapter contains the design requirements and specifications for the bipolar PWM inverter. There are 5 engineering specifications and 6 marketing requirements. Each design specifications have marketing goals that needs to be met. Each design specification play an important role in completely the project, however, most important specification is that the circuit has to invert the DC input and provide a sinusoidal AC output. The conversion is done by sending a PWM square signal into the half bridge control unit to generate bipolar switching and be filtered out to produce a sinusoidal AC output. The square signal is generated using pulse width modulation where a sinusoidal signal is compared with a triangular signal. The second specification is that the circuit will run on a single DC power supply source. This source will provide enough power to run all operations of the circuit. Additionally, the inverter will have variable amplitude on the sine wave that is controlled by a potentiometer. The PWM inverter should be built on a PCB and have dimensions that should not exceed 6" x 6" x 4". Last but not least, the cost of building the inverter should be low and not exceed \$100. This benchmark is set at \$100 because anything higher would make this circuit very expensive for the amount of components used in this design.

Main marketing requirements that go along with the design specifications include working under PWM operation, safety, portability, and convenience. The inverter must perform PWM operation and has to be safe for students to use. Secondly, the circuit should be portable as the size isn't very large. The PWM circuit is built with a single DC supply source to make it convenient for students to use, as it would be a hassle to use both an AC and DC source. Other marketing requirements include having a cheap cost for building the circuit and having the major component in the circuit easily replaceable.

Table 3-1: Bipolar PWM Inverter Requirements and Specifications.

Marketing Requirements	Engineering Specifications	Justification
3, 6	The circuit will act as an inverter and provide a ac output from a dc input.	The circuit is a PWM inverter; it should be able to convert a dc input into an ac output.
3	The PWM inverter will run on a single DC power supply.	Having a single power supply source will make the inverter very convenient to use.
3, 6	The AC output waveform amplitude is able to be varied by the dc input.	The AC output signal needs to have variance therefore, the amplitude needs to be adjustable, which is adjusted through a potentiometer.
1, 5, 4	The dimensions of the inverter should not exceed 6" x 6" x 2".	The build for the inverter should be relatively small to reduce noise and power loss, along with making it more portable.
2	Production cost does not exceed \$100.	The cost of building the inverter should be small as majority of the components are inexpensive.
Marketing Requirements 1. Safe. 2. Low cost. 3. Easy to use. 4. Replaceable 5. Portable. 6. PWM operation		

Table 3-1 shows the requirements and specifications for the PWM inverter. Every engineering specification is backed up by at least one marketing requirement. The justification column explains the importance of our engineering specifications. All engineering specifications and marketing requirements are designed to make the inverter simple for students to understand when taking the power electronics course.

Table 3-2: Function Table for the Bipolar PWM Inverter

<i>Module</i>	Bipolar PWM Inverter Circuit
<i>Inputs</i>	20 V _{DC} input $\pm 12\text{V}_{\text{DC}}$
<i>Outputs</i>	65 Hz sinusoidal AC signal
<i>Functionality</i>	The PWM inverter converts a DC input to an AC output using pulse width modulation. The circuit will generate a triangular and sinusoidal signal that sent to a comparator to generate a PWM square wave, which is then sent to the half bridge control unit to output bipolar switching and a 65 Hz sinusoidal AC signal.

Table 3-2 describes the inputs, outputs and functionality of the full PWM inverter. The inverter will generate a sinusoidal AC signal that has the same frequency of the control sine signal. Figure 3-2 indicates the topology for our design. It is a half bridge inverter that outputs an AC output by closing and opening the switches in sequence. The half bridge topology utilizes two switches instead of four that people see often in the full bridge.

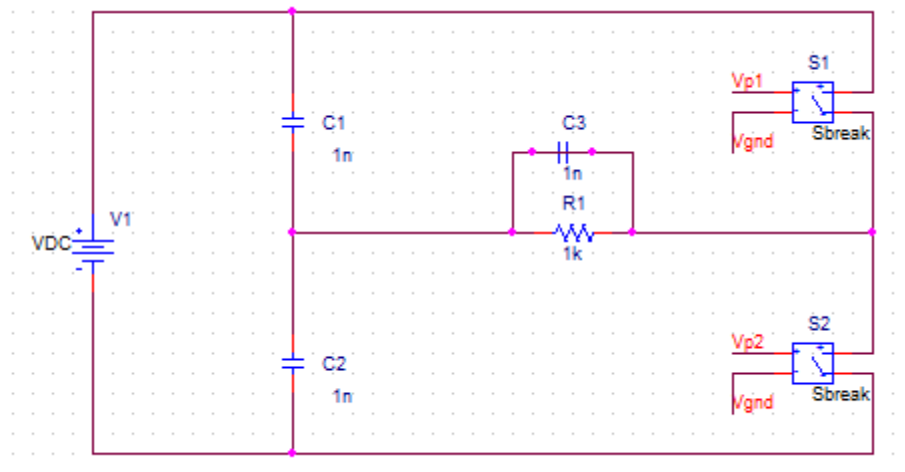


Figure 3-1: Half Bridge Topology for Bipolar PWM Inverter

Table 3-3: Bipolar Switching Logarithm

Switches [On]	Bipolar Switching Logarithm
S1	$V_{\text{sine}} \geq V_{\text{tri}} \Rightarrow V_o = -\frac{1}{2} V_{\text{dc}}$
S2	$V_{\text{sine}} < V_{\text{tri}} \Rightarrow V_o = +\frac{1}{2} V_{\text{dc}}$

Table 3-1 shows the bipolar switching logarithm for the half bridge inverter. When the top switch is on, the bottom switch will be off resulting in the output voltage through the filter to be $-V_{\text{dc}}/2$. On the contrary, when the top switch is off and the bottom switch is on, the output voltage is $+V_{\text{dc}}/2$.

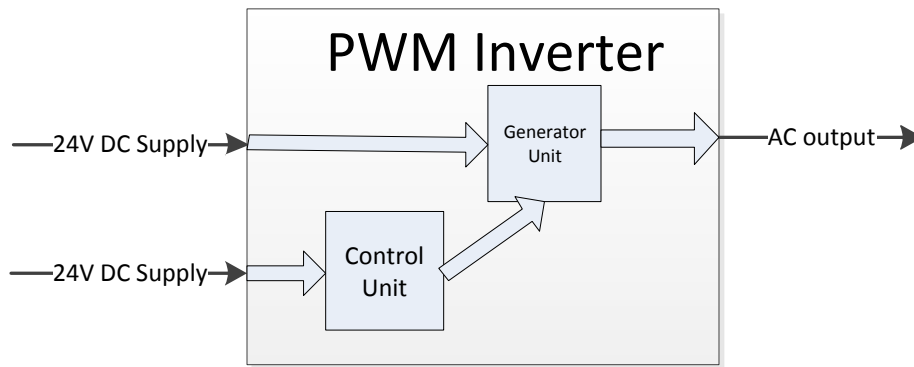


Figure 3-2: Level 0 Block Diagram of PWM Inverter

The Figure 3-1 indicates our design for the PWM inverter. The design will consist of two units, the generator unit and control unit. Tables 3-4, 3-5, and 3-6 describes the inputs, outputs and functionalities of each individual chip in the units. The control unit consists of the half bridge n-channel power MOSFET driver, while the generator unit consists of the waveform generators and the comparator. The comparator of the generator unit and control unit is supplied by 24 V DC Supply, while the waveform generator chips are powered by ± 12 V DC. The waveform generators will produce a triangular and sinusoidal waveform, while the comparator will produce the PWM square waveform. The control unit will take the PWM square signal and

utilize a half bridge switching logarithm to produce bipolar switching. That signal is then filtered to obtain the sinusoidal AC output signal.

Table 3-4: Function table for the Waveform Generator of the generator unit.

<i>Module</i>	ICL8038 Waveform Generators
<i>Inputs</i>	$\pm 12V_{DC}$
<i>Outputs</i>	65 Hz sinusoidal signal 16.5 kHz triangular signal
<i>Functionality</i>	The waveform generators will produce signals that are used to generate the PWM square signal. Using the $\pm 12V_{DC}$, the waveform chips are able to generate sinusoidal and triangular waveforms. The frequency and peak to peak voltage of the waveforms are dependent on the sizing for the resistors and capacitors connected to the chip.

Table 3-5: Function table for the Comparator of the generator unit.

<i>Module</i>	LM393N Comparator
<i>Inputs</i>	24 V _{DC} Triangular signal Sinusoidal signal
<i>Outputs</i>	PWM square signal
<i>Functionality</i>	The comparator compares the sine and triangle signals to generate a PWM square signal. The frequency for the signal should be that of the triangular waveform.

Table 3-6: Function table for the MOSFET driver of the control unit.

<i>Module</i>	LT1158 Half Bridge MOSFET Driver
<i>Inputs</i>	PWM square signal from comparator 24 V _{DC}
<i>Outputs</i>	65 Hz sinusoidal AC signal
<i>Functionality</i>	The MOSFET driver uses the PWM signal from the comparator along with the half bridge switching sequence to produce bipolar switching. The bipolar switching signal is filtered out to generate the sinusoidal AC output signal. The frequency of the sinusoidal output will be the same frequency as that of the control sine signal.

Chapter 4. Design

This chapter is the design aspect of the PWM inverter, where we sized components to allow for a 16.5 kHz triangular input signal, 65 Hz sinusoidal input signal, bipolar switching and also 65 Hz sinusoidal AC output signal.

Generator Unit

The generator unit, as shown in Figure 4-1, of this PWM inverter is designed to send a pulse signal into the controller. The controller requires triangular and sinusoidal waveforms which are generated from the wave generator chip. A DC power supply will control both of the wave generators. For the sine wave input, it needs to be around $24V_{DC}$, while the square wave, needs around a $16V_{DC}$ input. This will provide an output of both waves to be around 4V. The waveform generator will provide the triangle output from pin 3 and a sine wave from pin 2, respectively. The frequency is controlled by the resistors, R_a and R_b , connected to pins 4 and 5 as well as the capacitor, C , connected to pin 10. With the two resistors set to pins 4 and 5, the duty cycle will be set at 50%. There will be no R_L since the square wave output, Pin 9, is not being used. The $82k\Omega$ resistor is used to minimize sine wave distortion. The comparator is being used to determine whether the Sine wave is greater than or less than the triangle wave. If the Sine is greater than the triangle, then the output of the comparator is high, and if the sine is less than the triangle, the output would be low. There is a $72k\Omega$ resistor connected from pin 1 to the high rail. The output of the comparator is sent to the input of the control unit.

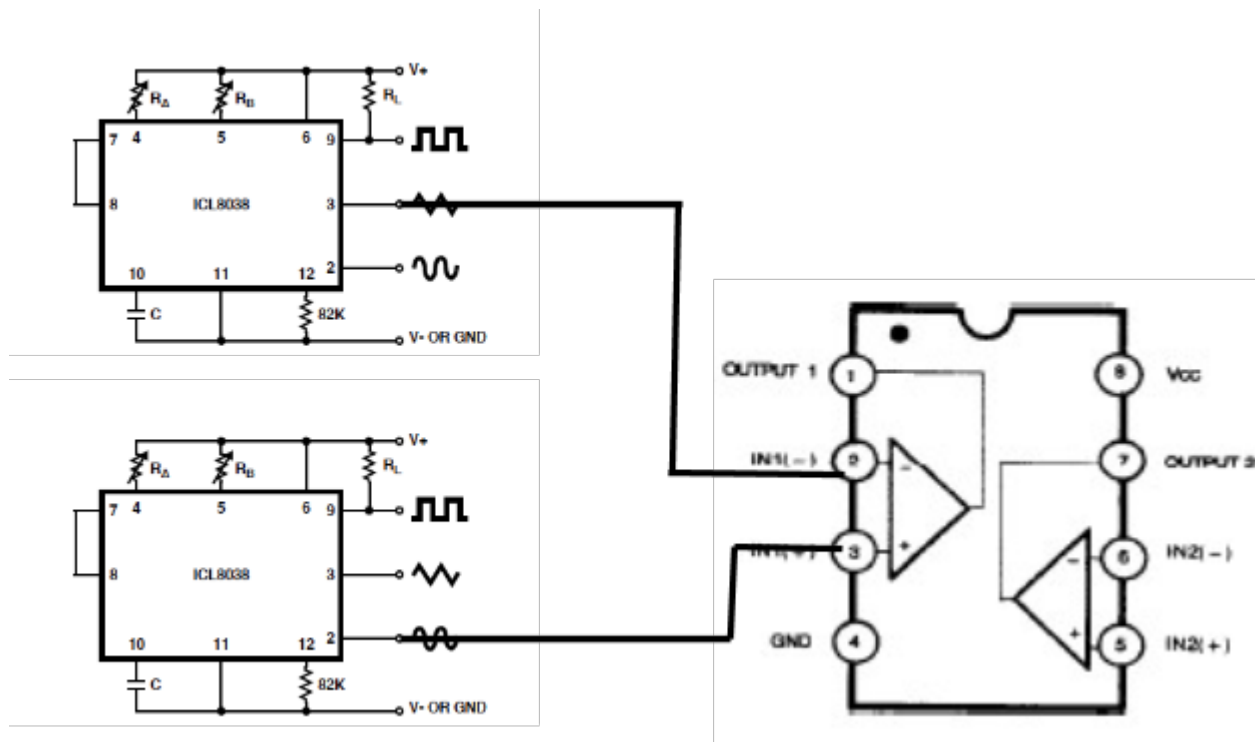


Figure 4-1: Generator Unit Block Diagram

Specifications: Waveform Generator - Model ICL 8038:

Ratings:

- Max Input Current (Pins 4 and 5): 25mA max
- Max Supply Voltage (Pin 6) : 36V

Inputs:

Sine Wave Input: +12 V_{DC}, Ground Reference: -12V_{DC}

Triangle Wave Input: +8V, Ground Reference: -8V

Component sizing:

Waveform Generator (Sine wave) – ICL 8038

Timing Capacitor Pin 10:

To set the duty cycle to 50%:

$$R_a = R_b = 56k\Omega$$

$$V_+ (\text{Pin } 6) = 12V$$

$$\text{Desired Frequency} = 65 \text{ Hz}$$

$$I_d = \frac{12V}{56 k\Omega}$$

$$I_d = 0.214 \text{ mA}$$

Using the equation given on data sheet for solving the frequency, we sized our capacitor:

$$f = \frac{0.33}{RC}$$

To obtain timing capacitance value:

$$C = \frac{0.33}{f \cdot R}$$

$$C = \frac{0.33}{65 \cdot 56 k\Omega}$$

$$C = 0.9 \mu F, \text{ choose } 0.1 \mu F$$

Waveform Generator (Triangle wave) – ICL 8038

Timing Capacitor Pin 10:

To maintain a 50% Duty Cycle:

$$R_a = R_b = 33 k\Omega$$

$$V_+ (\text{Pin } 6) = 8V$$

$$\text{Desired Frequency} = 16.5 \text{ kHz}$$

$$I_d = \frac{8V}{33 k\Omega}$$

$$I_d = 0.24 \text{ mA}$$

$$C = 0.33 \div (f \cdot R)$$

Using the equation given on data sheet for solving the frequency, we sized our capacitor:

$$f = \frac{0.33}{RC}$$

To obtain timing capacitance value:

$$C = \frac{0.33}{f \cdot R}$$

$$C = \frac{0.33}{16.5 \text{ kHz} \cdot 33 \text{ k}\Omega}$$

$$C = 606 \text{ pF}$$

Comparator - Model LM 393

Ratings:

Supply voltage: 2V - 36V

Current Max: 2.5 mA

$V_{CC} = 12 \text{ V}$, Ground Reference = -12 V

Control Unit

The control unit of the PWM inverter consists of the half bridge MOSFET driver. The MOSFET driver seen in Figure 4-2, operates on a 24 V power supply. The input to the driver is a PWM square wave signal. This signal in conjunction with the driver instructs the opening and closing of the high side and low side switches. When the input signal is high, it will turn the top MOSFET on and the bottom MOSFET off. Similarly, if the input is low, the top MOSFET will turn off and the bottom MOSFET will turn on. The output is taken as a difference between the source of the top side MOSFET and middle of the two output capacitors. The resultant will be a bipolar PWM square wave signal which will be filtered to form a sine wave. The bipolar

switching logarithm is generated between the two switches. When the top switch is on, the voltage output will be $-V_{DC}/2$ and when the low switch is on, the output will be $+V_{DC}/2$. We sized 10 different components that are key roles in getting the control unit to function properly.

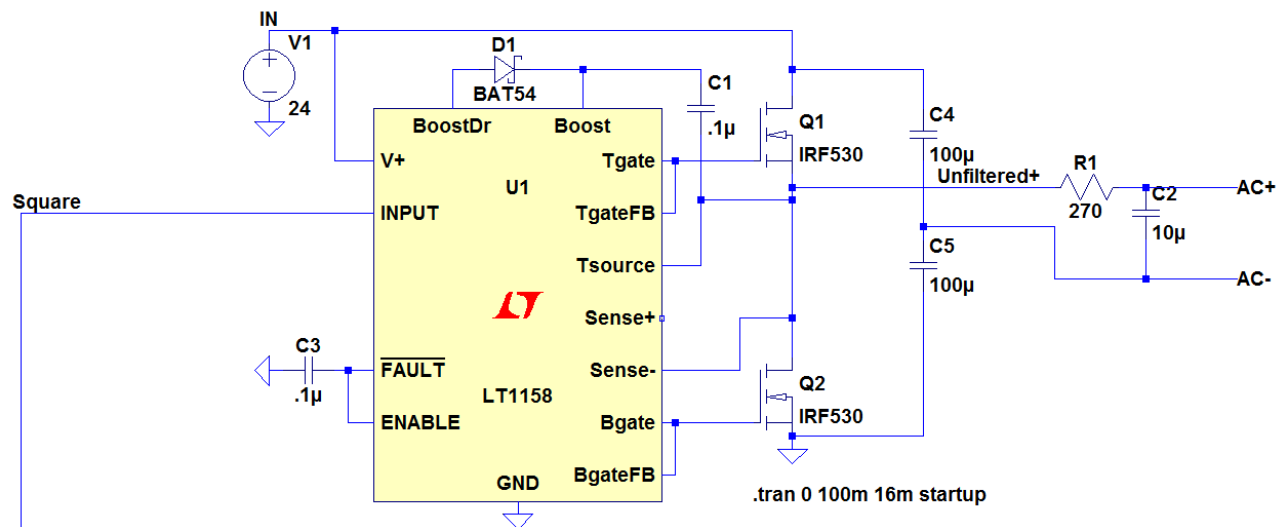


Figure 4-2: Control Unit Block Diagram

Specifications: Half Bridge N-Channel Power MOSFET Driver - Model LT1158

Ratings:

- Supply Voltage (Pins 2, 10) - 36 V
- Continuous Output Currents (Pins 1, 9, 15) - 100 mA
- Boost Voltage (Pin 16) - 56 V

Inputs:

- Input Signal (Pin 6): PWM square wave
- Power Supply Input: 24 V

Component sizing:

The capacitor C_1 connecting pin 16, the boost, and pin 13, T_{source} together is sized to be .1uF. This bootstrap capacitor is chosen to be .1uF because the datasheet provides a typical value for which this capacitor should be. Similarly, the way we sized for C_3 is also through using typical values provided by the datasheet.

$$C_1 = .1\mu F$$

The capacitors C_4 and C_5 are sized to be equal in order to provide dual DC supply. We chose 100uF so that the capacitors are able to store energy for a longer period of time. Having the capacitor equal to each other in size will result in the top capacitor having $+V_{dc}/2$ and the bottom capacitor having $-V_{dc}/2$.

$$C_4 = C_5 = 100\mu F$$

We also added a .033uF capacitor to the bias in pin 3. The typical value for the bias capacitor is .01uF, however, we choose .033uF because it was relatively similar to .01uF and it still offered decoupling. This is not shown in Figure 4-2 because the simulation circuit excludes the bias pin.

To size the AC filtered, we wanted the frequency of the sinusoidal AC output to be 65 Hz. Using the cutoff frequency equation for low pass filters, we are able to size the capacitor and resistor. We arbitrary chose 10uF capacitance value in order to solve for the resistor value.

$$f_c = \frac{1}{2\pi RC}$$
$$60 = \frac{1}{2\pi R * 10 * 10^{-6}}$$
$$R = 224.854 \, \Omega$$

We chose 270 Ω because it was standard resistor value. And finally, we sized the schottky diode to handle up to 1 A and 50 V based off of simulations. N-Channel MOSFET were also chosen through simulation current and voltage ratings.

Chapter 5. Hardware and Test Results

This chapter will give an overview of the inverter hardware testing and the results. The tests results will be represented by waveforms shown in the figures. Additionally, we have provided a step by step testing procedure on how we obtained the inputs and outputs of each unit. The output for the generator unit is represented by a PWM square waveform, whereas the control unit output is represented by the 65 Hz sinusoidal AC signal.

Generator Unit:

Step 1:

The objective of generator unit is to produce a clean triangular and sinusoidal waveform to be inputted into the comparator. For our first test, we probed pin 3 of the ICL8038 chip that was specially designed to generate a triangular wave. As shown in Figure 5-1, resulting waveform is triangular wave shape and has a frequency of 16 kHz with a $5 V_{pp}$. We then tested the sine generator chip, and obtained a sinusoidal waveform with 65 Hz and $5 V_{pp}$, as seen in Figure 5-2.

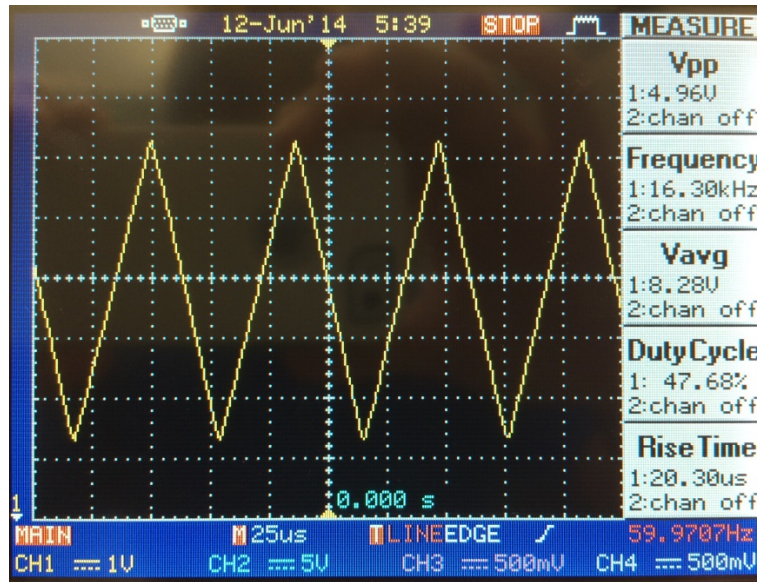


Figure 5-1: Triangular Carrier Signal

Figure 5-1 displays the triangular waveform coming from pin 3 of the ICL8038 chip. The chip is sized to generate a 50% duty cycle, a frequency 16 kHz and 5 V_{pp}. The equation for peak to peak voltage of the triangular wave is $.33 \cdot V_{dc}$, in which we used ± 12 V. This equation gives a 7.92 V_{pp}, however, we inputted a potential at pin 3 to lower the voltage to 5 V_{pp}.

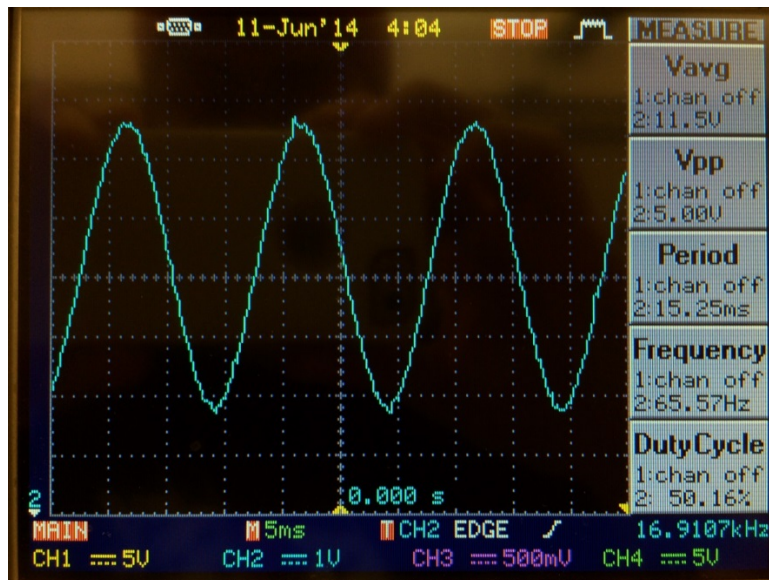


Figure 5-2: Sinusoidal Control Signal at Max Peak Value

Figure 5-2 displays the sinusoidal waveform coming from pin 3 of the other ICL8038 chip. The chip is sized to generate a 50% duty cycle, a frequency 60 Hz and 5 V_{pp}. The equation for sizing the peak to peak voltage of the sinusoidal wave is $.22 * V_{dc}$, in which we used ± 12 V. This equation gives a 5.28 V_{pp}.

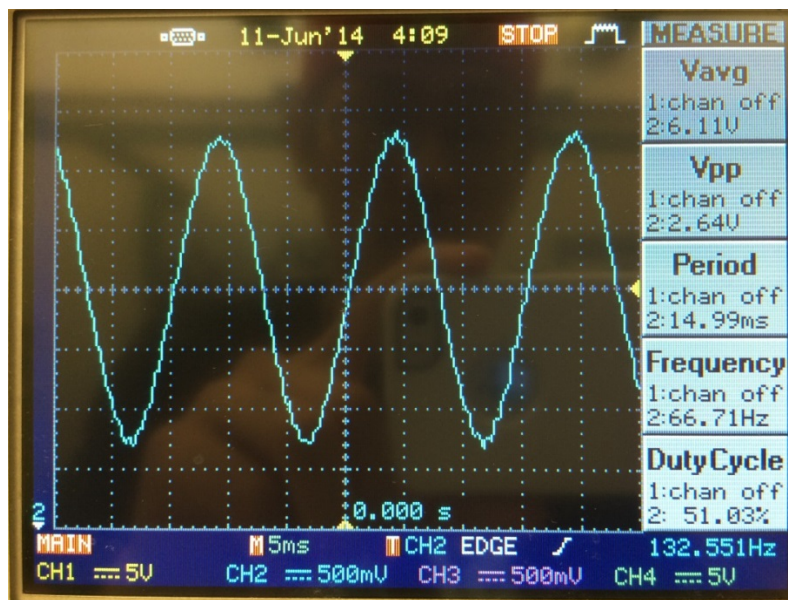


Figure 5-3: Sinusoidal Control Signal at Minimum Peak Value

Figure 5-3 demonstrates the lowest value that the peak to peak voltage of the sinusoidal waveform can reach. Linear modulation is typically desired; however, we wanted to see the effects of over modulation, so we sized the sine wave to be slightly larger than the triangular. As shown here, the sinusoidal waveform can alternate from 5 V_{pp} to 2.64 V_{pp}. When the circuit is over modulated, the PWM signal will generate a flat line.

Step 2:

The two waveform signals are then inputted into a comparator that will create a pulse width modulated square output. The comparator is to be powered by a 24V DC source. Before the comparator is powered up, we made sure both waveforms have a duty cycle of around 50%.

We then connected the potentiometer outputs of the sinusoidal signal to pin 3 and triangular signal to pin 2 of the comparator. Probing pin 1 of the comparator, we were able to obtain the resulting square waveform, which can be seen in Figure 5-4. The waveform is pulse width modulating with the correct size gap when referenced to the sinusoidal control signal.

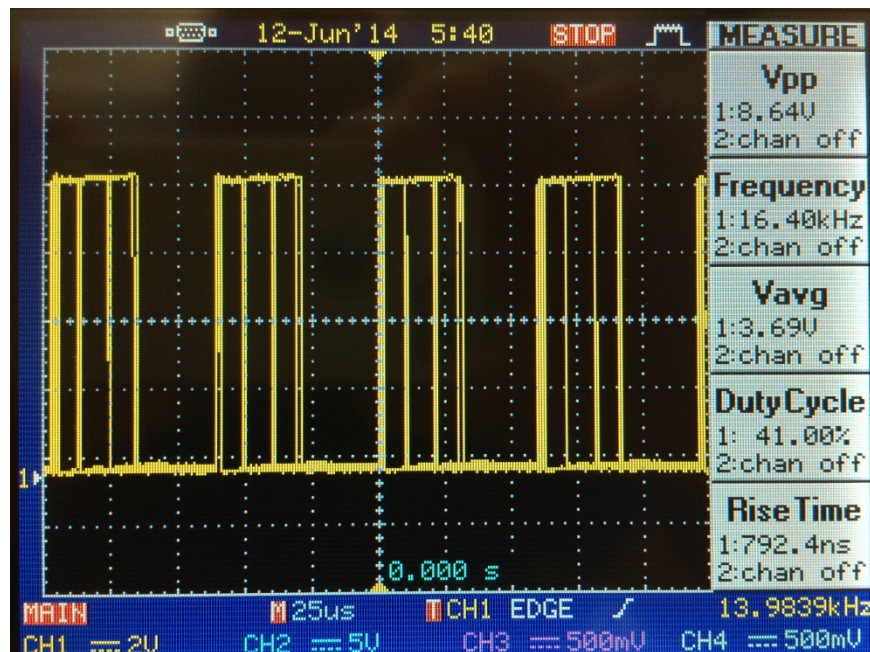


Figure 5-4: PWM Square Waveform from Comparator

Figure 5-4 indicates the PWM square output of the comparator. When comparing a triangular and sinusoidal waveform in linear modulation, this is the resultant. It is a little bit noisy, however, it still indicates that it is pulse width modulating and is a square shape.

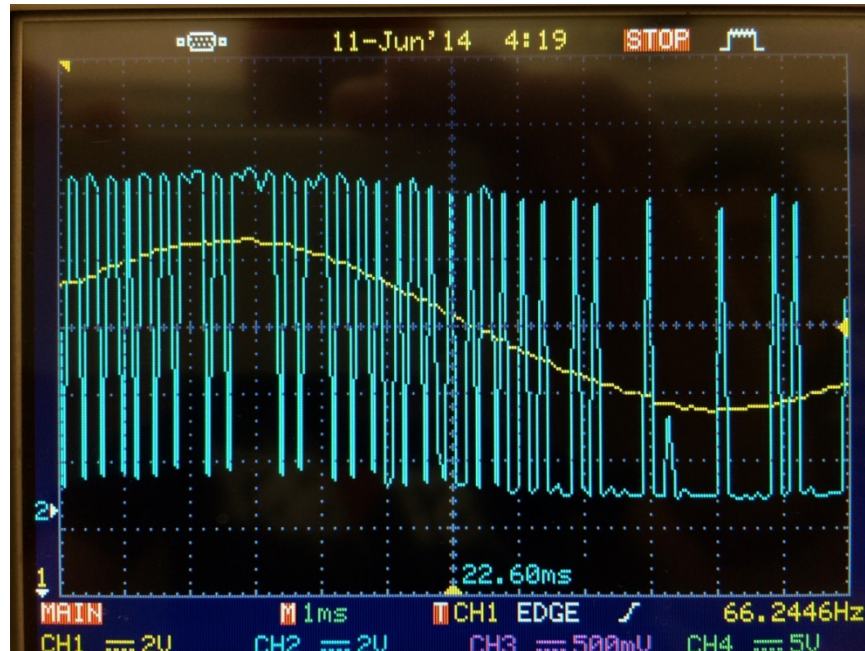


Figure 5-5: Pulse Width Modulation Output Signal with Sinusoidal Reference

Figure 5-5 demonstrates the difference in widths of the PWM square waveform with reference to the control signal. As seen in the figure, when the sinusoidal reaches its peak value, that is when the width of the PWM is largest. When the control signal is rising or falling, that is when the widths are relatively small.

Control unit:

Step 3:

To test the control unit, we powered the unit with the same 24 V DC input as the comparator. The input of the control unit, pin 6, is connected to the output of the comparator, pin 1. Be sure that the ground wires are only connected to that of the comparator and not of the waveform generator chips or else there might be a grounding problem. To validate that the switches weren't on at the same time, we probed the gate of the top switch and bottom switch and indeed, as seen in figure 5-6 and 5-7, they were switching on and off at opposite times. We

then checked the circuit for bipolar switching. We probed the drain of the top switch to ground, and probed the middle point of the two 100uF capacitors to ground. Using the math function on the oscilloscope, we were able to obtain the bipolar PWM output, shown in Figure 5-8. And after filtering the circuit, we were able to obtain a 65 Hz sinusoidal output signal, shown in Figure 5-9.

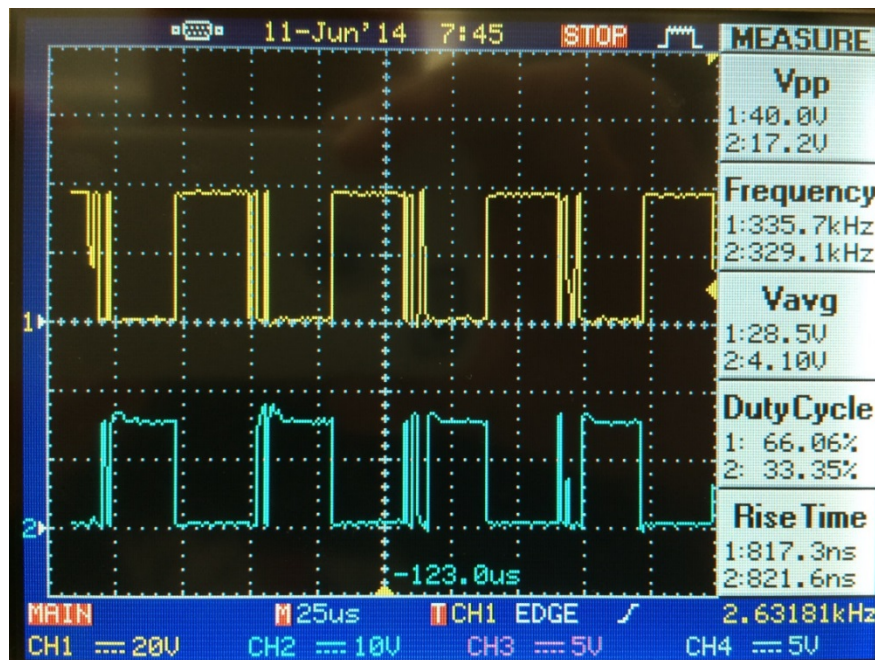


Figure 5-6: Top (yellow) and Bottom (Blue) Switches

Figure 5-6 shows the different conduction cycles at the gate of the top and bottom switches. When the top switch is on, the bottom one is off and vice versa. The switching logarithm is determined by the triangular and sinusoidal signals.

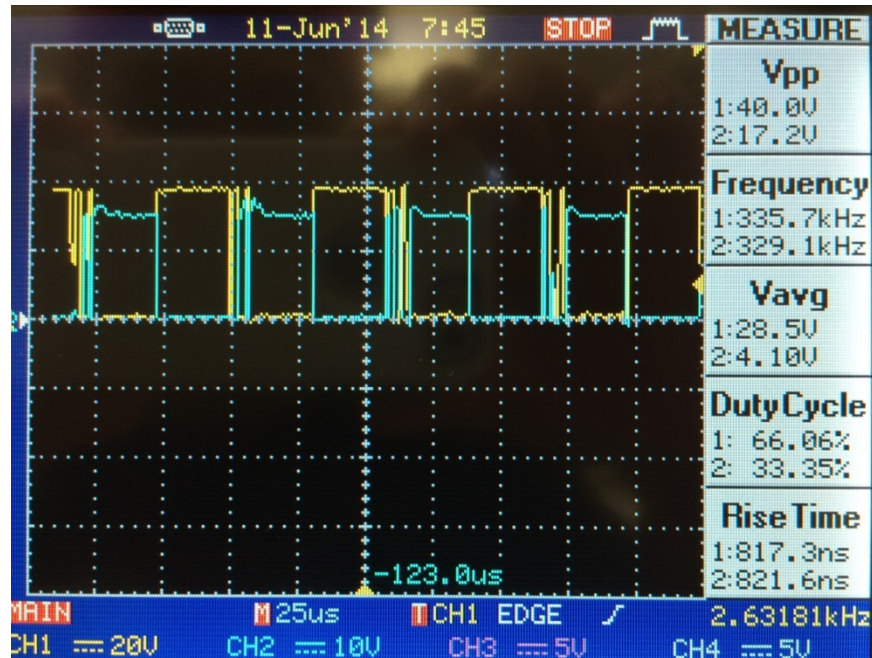


Figure 5-7: Top (yellow) and Bottom (blue) Switches Overlapped

Figure 5-7, it shows the conduction cycle of both switches when aligned together to obtain a constant conduction.

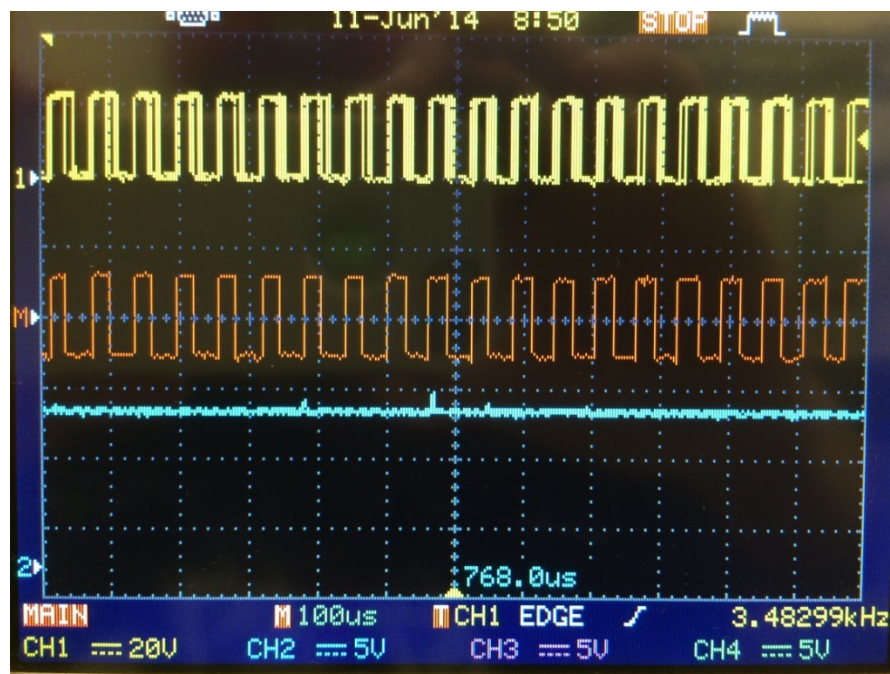


Figure 5-8: Unfiltered Bipolar PWM Output

Figure 5-8 shows the PWM signal with a peak value of 24 V coming from the source of the top switch (in yellow) and the 12 V signal coming from the middle of the capacitors (teal). The main signal (in red) shows the difference between the two signals. As shown above, the main signal is indeed bipolar and pulse width modulating.

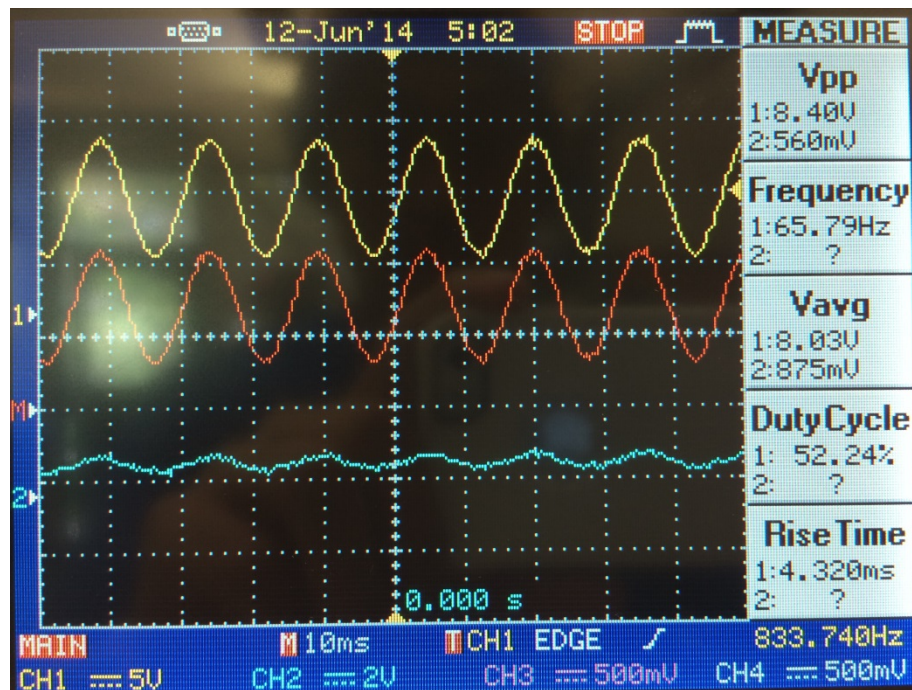


Figure 5-9: Filtered Output of Control Unit

Figure 5-9 shows the AC filtered output, which is sinusoidal with a duty cycle of 50%. The frequency of the output signal is 65 Hz which is the same as the control signal.

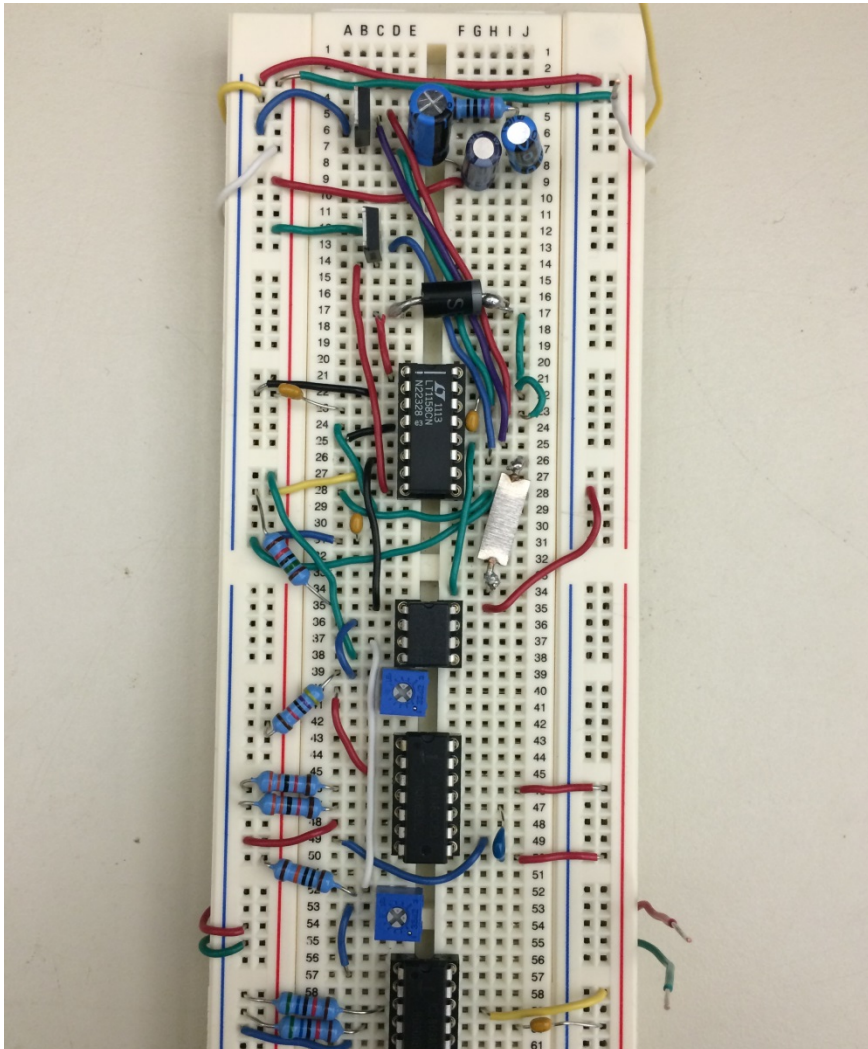


Figure 5-10: Finished bipolar PWM inverter on breadboard

Figure 5-10 shows the finished product of the bipolar PWM inverter. The breadboard consists of the two generator chips, the comparator chip and half bridge power MOSFET chip. The output of the comparator is connected to the input of the control unit. The top chip is the half bridge power MOSFET, the second chip is the comparator, and the bottom two chips are the triangular waveform generator and the sine waveform generator, respectively. The yellow wire sticking out on the top is the $24V_{DC}$ input, while the white wire is its respective ground. The red wire sticking out on the bottom is the $+12V_{DC}$ input while the green wire is the $-12V_{DC}$ input.

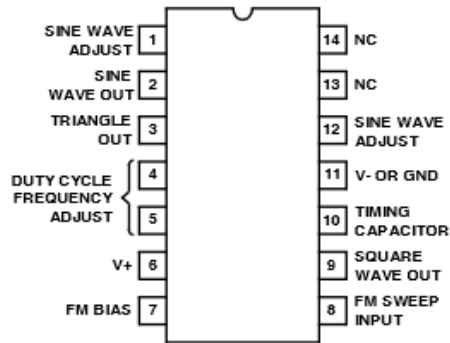
Chapter 6. Conclusion and Further Work

The bipolar PWM inverter is built for the experimental use in EE 410 Power Electronics Laboratory course. The inverter generates a 65 Hz sinusoidal AC output from a ± 12 V DC and 24 V DC input. It consists of two units: the generator unit and control unit. The generator unit produces a PWM waveform by comparing the triangular and sinusoidal to one another. The control unit creates the bipolar switching and due to the simplicity, the control unit uses a half bridge topology. To prove that the inverter works, we verified the input and output waveforms of each unit. On the generator unit, we were able to obtain a 65 Hz sinusoidal control signal, 16.5 kHz triangular carrier signal and a pulse width modulated square output signal. On the control unit, we were able to obtain a PWM square signal that is bipolar switching. And after filtering PWM signal, we were able to obtain a 65 Hz AC output signal that is sinusoidal.

There were several problems that the inverter encountered as we progressed through the quarter. Initially, the inverter was built using a single supply, however, we ran into grounding problems that resulted in clamping of our triangular waveform and deforming of the sinusoidal waveform. The triangular waveform was set to have a peak to peak voltage of 6V, however, the bottom rail of the waveform clamped at about -1V instead of reaching -3V. Another major problem that occurred was on the ICL8038 chip; as we increase the time per divisions on the oscilloscope, both the peak to peak voltages of the sine and triangle waveforms are unstable and causes the PWM signal to be deformed slightly. Some minor problems that occur was noise and the product not being on implemented on a protoboard. Because of these problems, we were only able to complete 3 of the 5 engineer specifications. We were not able to put this circuit on a protoboard, and run it on a single supply.

Future improvements for this inverter would be to use a single supply to power the whole system instead of two. This can be done by fixing the grounding problems that it will have when the inverter is connected to a single supply with common grounds. Another major improvement would be using a different waveform generator chip to generate the control and carrier signal. As mentioned above, both peak to peak voltages of the sinusoidal and triangular waveforms at high time divisions are not stable and need to be fixed. We want the PWM signal to be as precise as possible. Other improvements may be building the inverter on PCB or protoboard instead of breadboard and also adjusting some of the component sizing to obtain a 60 Hz sinusoidal as oppose to 65Hz.

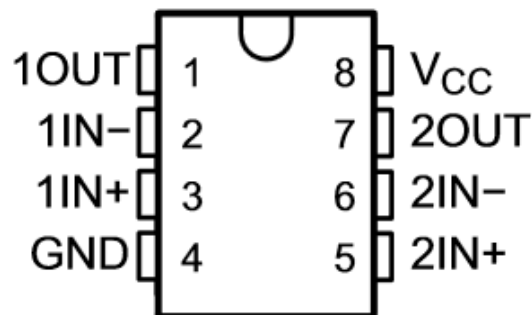
Appendix A: Data Sheets



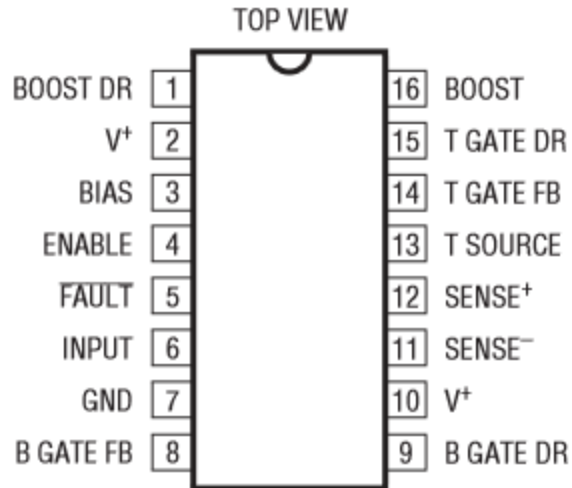
Pin	Function
1	Sine Wave Adjust
2	Sine Wave Output
3	Triangle Wave Output
4	Duty Cycle Frequency Adjust
5	Duty Cycle Frequency Adjust
6	Input Voltage
7	Frequency Modulated Bias
8	Frequency Modulated Sweep Input
9	Square Wave Output
10	Timing Capacitor for Frequency
11	Reference Voltage or Ground
12	Sine Wave Adjust
13	No Connection
14	No Connection

ICL 8038 Precision Waveform Generator/ Voltage Controlled Oscillator [14]

(TOP VIEW)

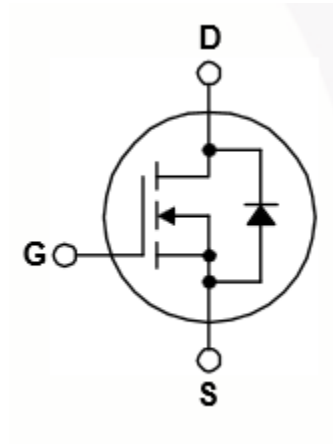
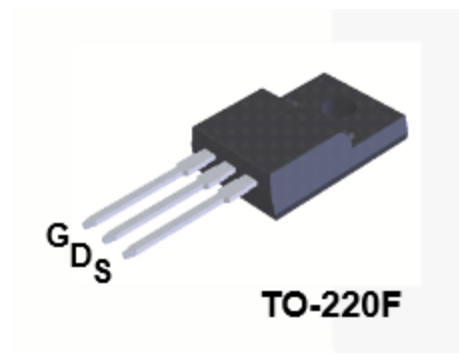


LM393 Low Offset Voltage Dual Comparator [15]



Pin	Function
1	Boost Drive
2	Input Voltage
3	Bias
4	Enable
5	Fault
6	Input
7	Ground
8	Bottom MOSFET Gate Feedback
9	Bottom MOSFET Gate Driver
10	Input Voltage
11	Negate Sense
12	Positive Sense
13	Top MOSFET Source
14	Top MOSFET Gate Feedback
15	Top MOSFET Gate Driver
16	Boost

LT1158 Half Bridge N-Channel Power MOSFET Driver [16]



FDPD3086T N-Channel PowerTrench MOSFET[17]