Low Cost Pure Sine Wave Solar Inverter Circuit

Final Report

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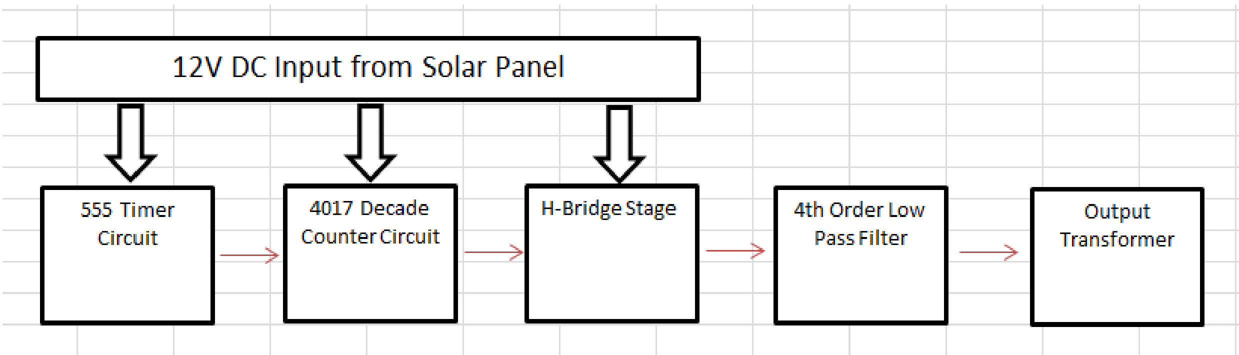
Background Information: Recent rises in electrical energy costs have created attractive alternative energy options. Solar energy is one of the most popular of these options, since energy from the sun is readily able to be harnessed. A device such as a solar panel is able to convert photons from the sun into DC electrical currents that can be used by society. These panels can be rather expensive, but have seen improvements in efficiency recently and are becoming a more viable option. However, there is a problem with this; our electric grid is AC based so the energy needs to be converted from DC to AC to be useful. A pure sine wave is highly desirable because the vast majority of electrical plug-in appliances are designed to run on a true sine wave signal. This is accomplished through an inverter circuit using electronic components. Two types of inverters currently exist on the market; a modified sine-wave inverter and a pure sine wave inverter. A modified square wave inverter outputs a wave similar to a square wave with a delay in between cycles, while a sine wave inverter outputs a true sine wave. Pure sine wave inverters tend to be much more expensive than their modified-square wave counterparts, due to the extra control and filtering stages that are necessary. They also often require a sine-wave reference signal to act as an input to the circuit, which also raises price. Efficiency of these types of circuits can create a problem in the entire DC-AC system if they are too low. If the efficiency is too low, the system may not be worth the initial investment cost. The cost of these circuits can also be rather high depending upon the application. Solar inverters on the market today can cost anywhere from $300-$500 with an efficiency of over 85%.

Goals: Our goal is to design a low cost solar inverter circuit without sacrificing the integrity of a pure sine wave output signal. We are looking to fill a current niche on the market and supply a possible low cost design that also has an appropriate sine wave output signal. Our circuit will not have a sine-wave reference signal in order to reduce cost. It will be able to transform DC to a pure sine wave without the use of this reference signal. The cost of the project will not exceed $200, however we are truly looking to have a design cost of about $50. This will ensure that our current design would be much cheaper than any circuit currently on the market. Efficiency will be measured to ensure that the circuit is a viable option, but is not one of the main deliverables of the project. Efficiency will be defined as the ratio of useful AC power out of the circuit at 60Hz divided by the DC input power to the circuit. The circuit will function as a micro inverter circuit, meaning it is intended to be connected to a single solar panel. This is a slightly more expensive option for a solar system; however, it greatly increases the reliability and efficiency of the total system. If connected in parallel to many solar panels, our design should be able to drive actual loads on the electrical grid at 120V and 60Hz.

Technical Approach: The DC input power to our circuit will come from a 12V solar panel which will have a current output anywhere between 0-800mA depending on its conditions. This source will act as the only power supply for the circuit, so it is necessary to keep power consumption low throughout the design phase. The total circuit design will be broken up into 5 major components which will consist of a 555 timer circuit, 4017 Decade counter circuit, H-bridge stage, passive filter stage, and output transformer stage. The 555 timer stage is responsible for generating the required clock pulse necessary for the entire circuit. Again, since 12V DC is the only power source that can be applied to the circuit, it is crucial for this stage to be perfect to avoid the use of a function generator. The frequency of the clock pulse will need to be higher than the required output frequency because we will also be using a 4017 decade counter in the triggering stage. The frequency of the clock pulse is controlled through the resistor and capacitor values that will be associated with the timer. The output of the 555 timer circuit will act as an input to the 4017 decade counter circuit, which is responsible for triggering of the H-bridge stage. Also referred to as a Johnson counter, this is a powerful IC which is able to count clock pulses and introduce a delay between them. The clock signal will feed into CPO of the counter, and the clock inhibit pin will simply be grounded since the 4017 circuit will remain active at all times. Since the H-bridge will need two separate signals for triggering, two output pins will be used from the counter. An extra output pin will also be necessary in order to reset the timer. Pins 3 and 7 were chosen to act as triggering outputs, while pin 5 was chosen to act as a reset signal and connected to the reset input itself. This 3-5-7 combination introduces a delay in between the trigger signals, which will be very useful in achieving a pure sine wave output later on in the circuit. The output voltage of a 4017 decade counter IC is around 1V, which is enough power to turn on the necessary BJT's in our H-bridge stage. This is one of the reasons BJT's were chosen as the type of transistor to use in the H-bridge stage. By switching low power signals, efficiency can be kept high while maintaining low power consumption. If a transistor like a power MOSFET was to be used in the circuit, then an extra driver stage after the 4017 stage would be necessary. This would lead to more power consumption and lower efficiency making this an unviable option in our case. Since we are also dealing with 60Hz signals, there is no need for a very fast switching time which will make the cheaper BJT's a good option. Transistors 1 and 3 in the H-bridge stage are turned on at the same time, allowing current flow in one direction. In the next cycle, transistors 2 and 4 are tuned on which allows current flow in the opposite direction. This essentially creates an AC signal with an average value of zero that resembles a square wave. Since we introduced a delay to the 4017 circuit signal, a modified square wave is created at the output of the H-bridge stage. This makes the signal much easier to filter and turn into a pure sine wave signal. The filter stage was chosen to be a passive filter because an active filter would involve the use of op-amps, consuming more power and lowering efficiency. Since the H-bridge circuit has a two-ended output, the 4^{th} order low pass filter consisted of 8 resistors and 4 capacitors. The transfer function of this complicated of a circuit is very difficult to calculate, so the values of the components were found through trial and error by seeing which combination produced the best output signal. The last stage was a simple transformer to provide the circuit isolation and the correct output voltage (120V). A block diagram of the entire system is shown below.

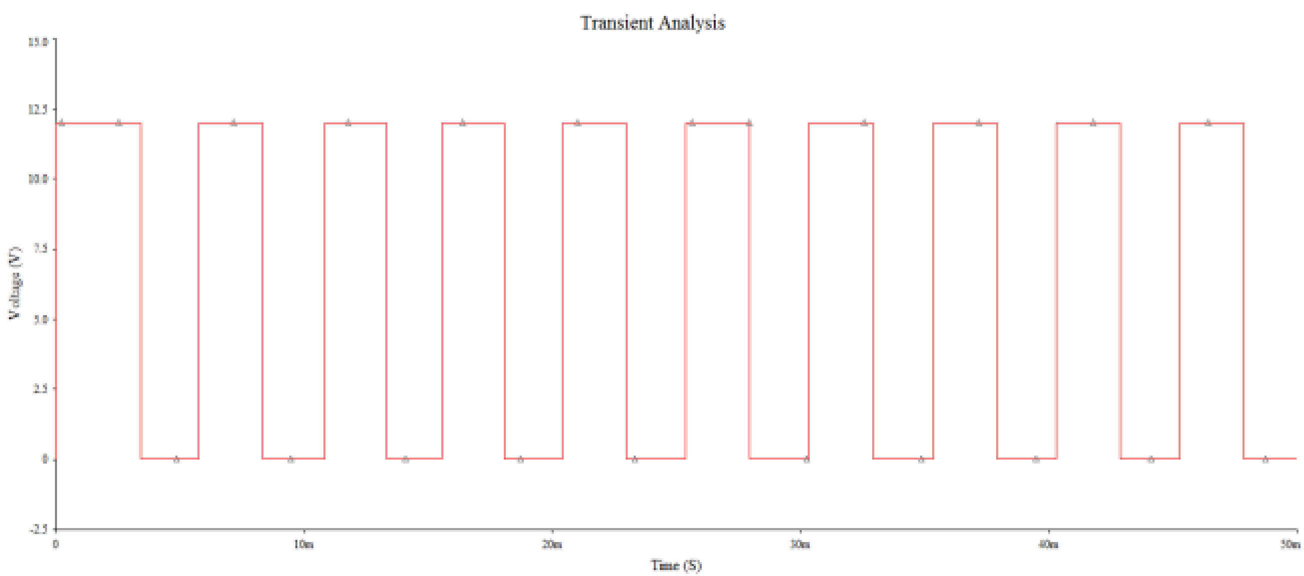


Scope of Design Work: The group is to design the circuitry involved with the 555 timer circuit, 4017 Decade counter, H-bridge stage, and the 4^{th} order low pass filter. The 12V DC solar panel and output transformer are not to be designed by the group. Being that the group consisted of 2 people, this is an adequate amount for out scope of work. A prototype of our design will also be built and tested in the lab. This is meant to act as an experimental section of our results which can be compared to Multisim simulations of our design.

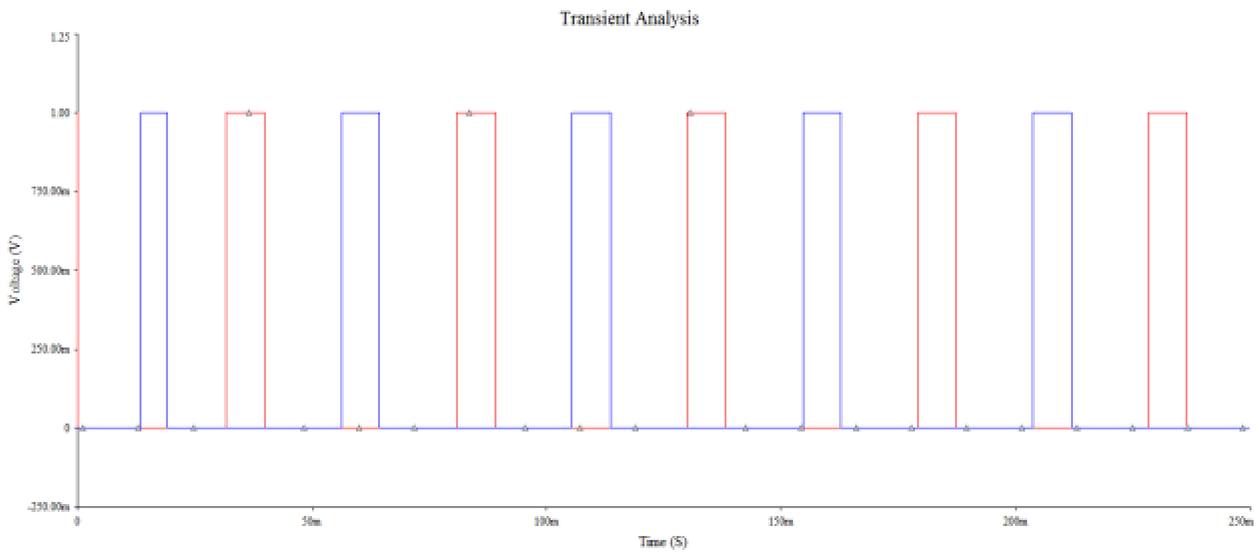
Task Distribution: Since the group consisted of 2 members, much of the design work will be done jointly. Group members did not have specific tasks; however, some group members worked on the project in some areas more than others. Cameron DeAngelis was involved more in the design stage, especially the 555 timer and 4017 decade counter. Luv Rasania was more responsible in building and testing the prototype in the lab. Work was split equally and both team members contributed to the success of the project.

Project Sponsorship: The project was accepted for funding by Public Service Electric and Gas Company (PSE&G). Funding was provided up to $500, yet all attempts were made to make the project least expensive as possible in order to make the circuit a viable option for DC-AC conversion.

Results: The **555-timer** circuit was used to generate a clock voltage input, as stated in the project technical approach. It generates a 60Hz input to the circuit, which pulses the input pin of the 4017 IC. The output of the timer circuit is shown below.

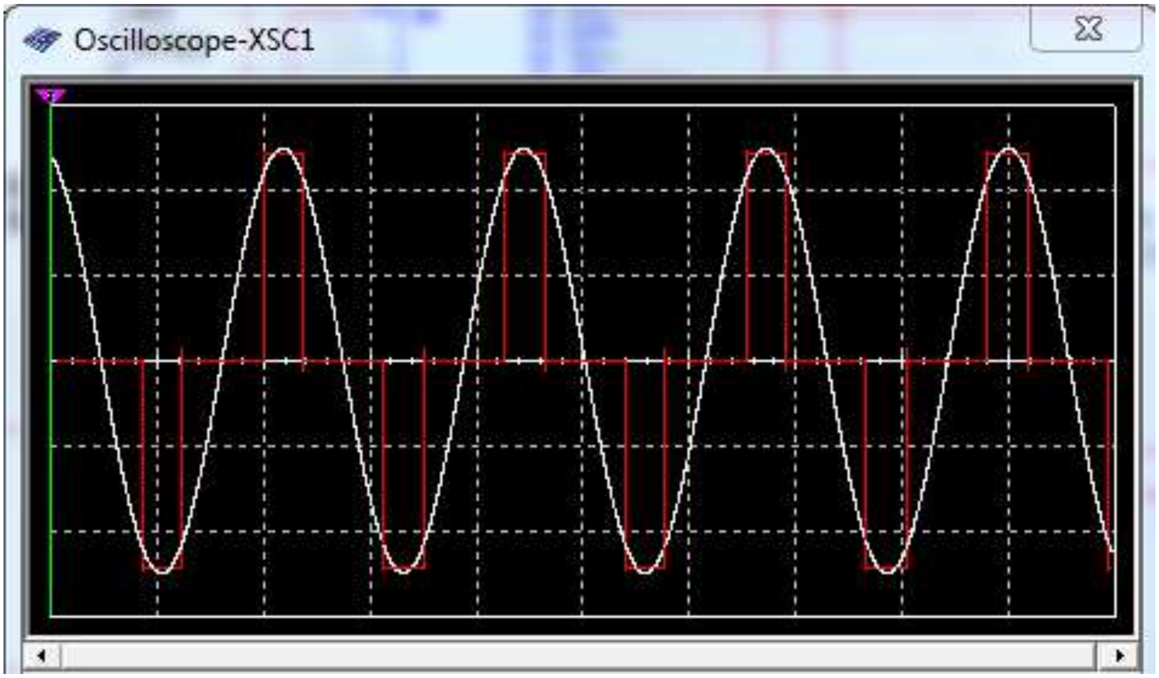


The **4017 Decade Counter IC** is the next stage of the project, which is a very important factor for the pulsing of the H-bridge. The IC receives a clock input from the 555 timer and then generates a series of 10 pulse outputs. Outputs 3 and 7 are taken from the circuit, while output 5 is responsible for resetting the device. Therefore, 2 cycles are separated between each clock pulse and being reset, which gives an even waveform. The output is shown below.



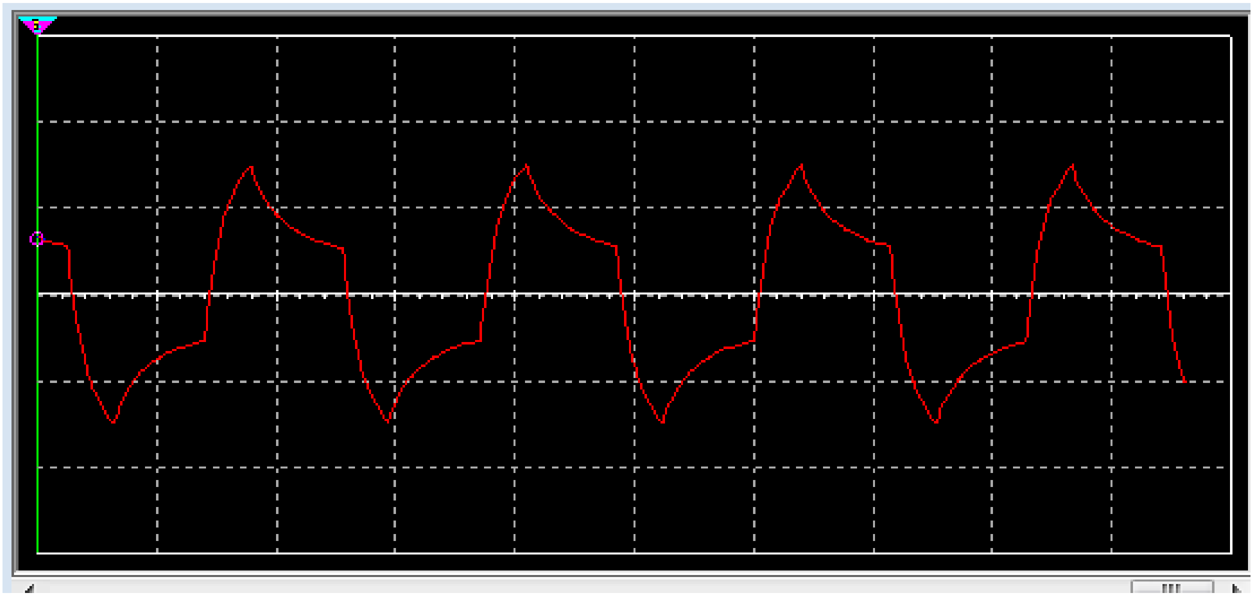
The next stage of the design is the **H-bridge circuit**, which is responsible for generating our AC signal from a DC source (solar panel). The outputs of the 4017 IC are responsible for pulsing the bases of our BJT's. Transistors across from and below one another are turned on in pairs to create current flow in one direction per cycle. In the next cycle, the other two transistors are turned on and generate current flow in the opposite direction. This is what creates our (rough) AC signal. The results were successful so far, and are shown below.

Our AC signal resembled a sine wave after the filter is implemented, but a sine wave imposed on our signal is shown below. This gave the group a rough baseline of what the circuit's filtered output should look like. This signal was compared to the group's output signal at the end of the project to measure success of the project.

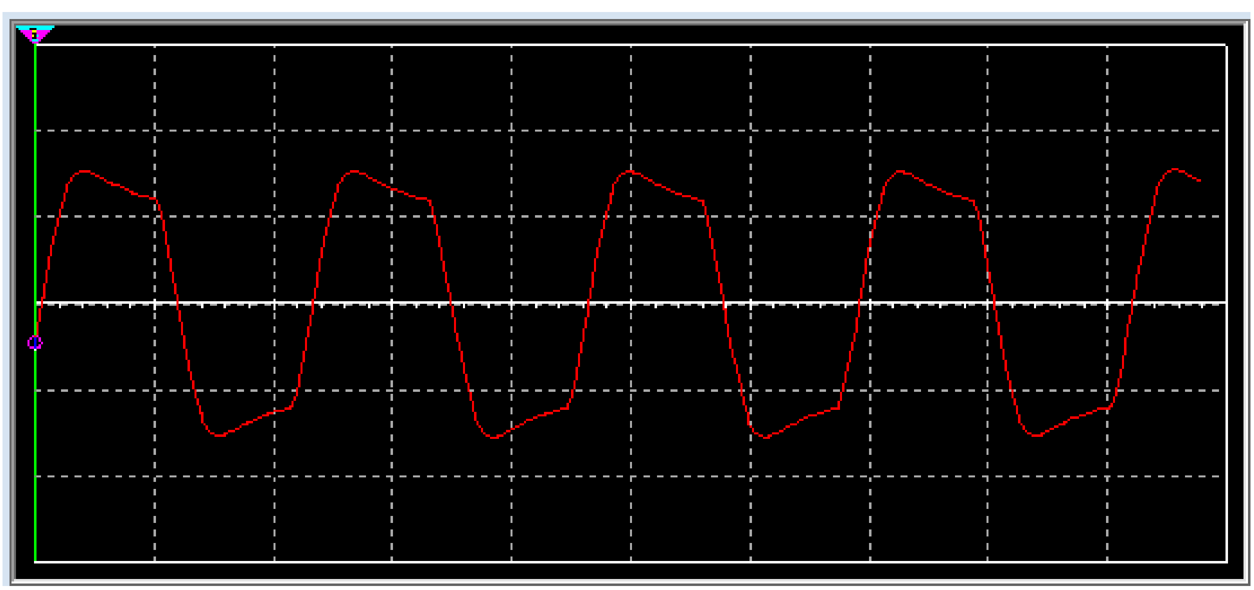


The next stage of our design consisted of the filter stage, where we used a 4th order passive filter. The output waveforms shown below will represent what the wave looks like after each stage of the filter.

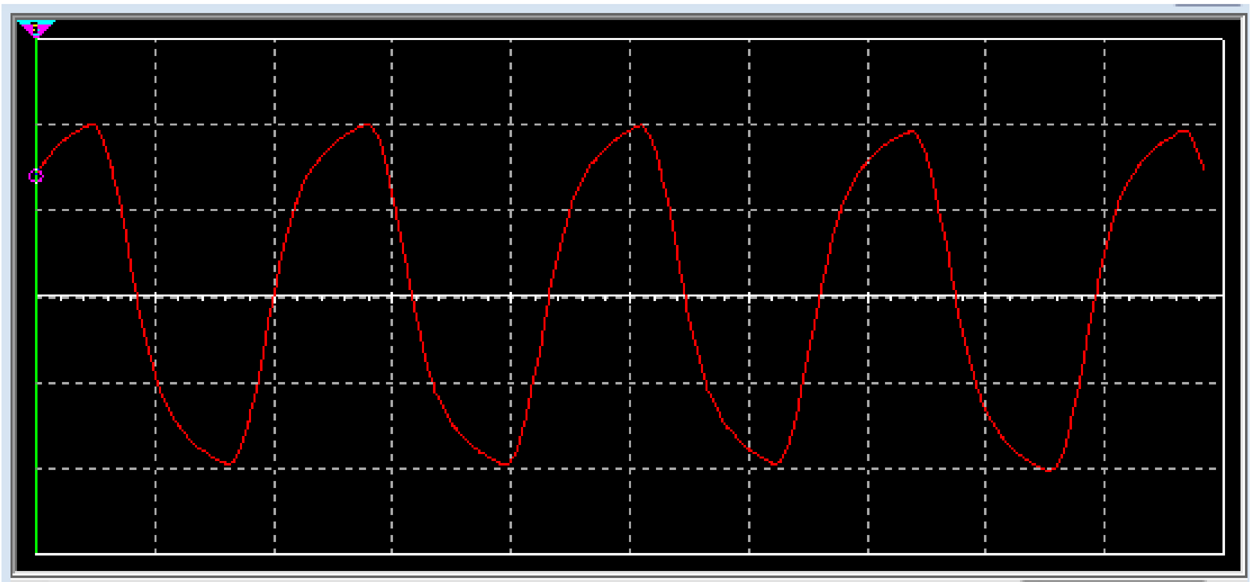
1st Stage:



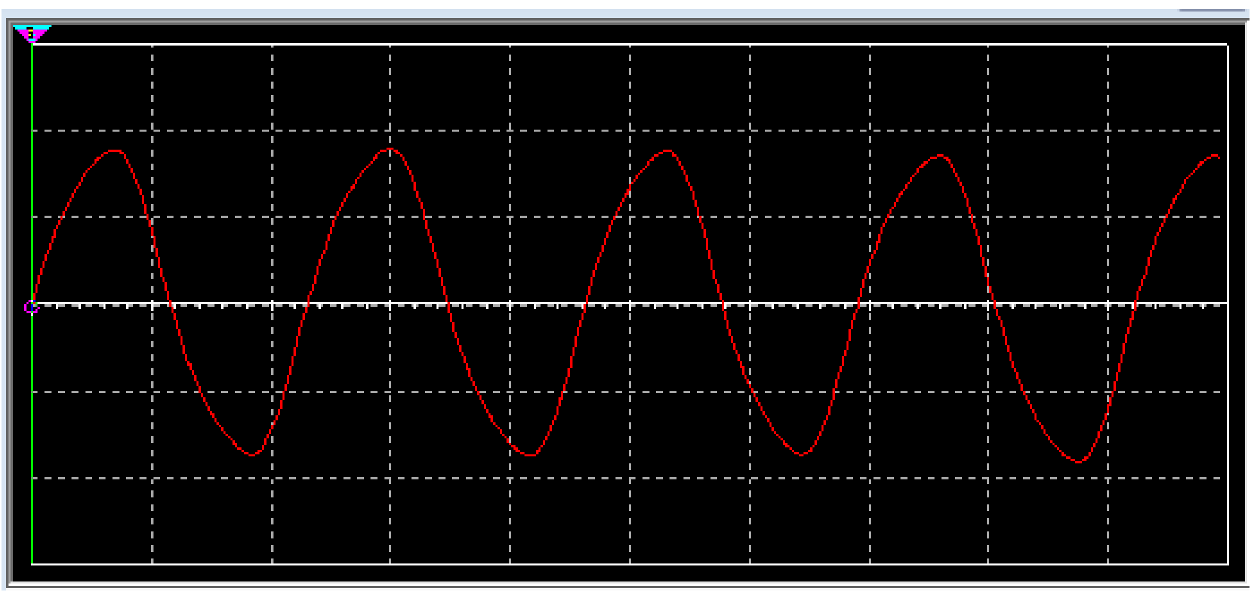
2nd Stage:



3rd Stage:

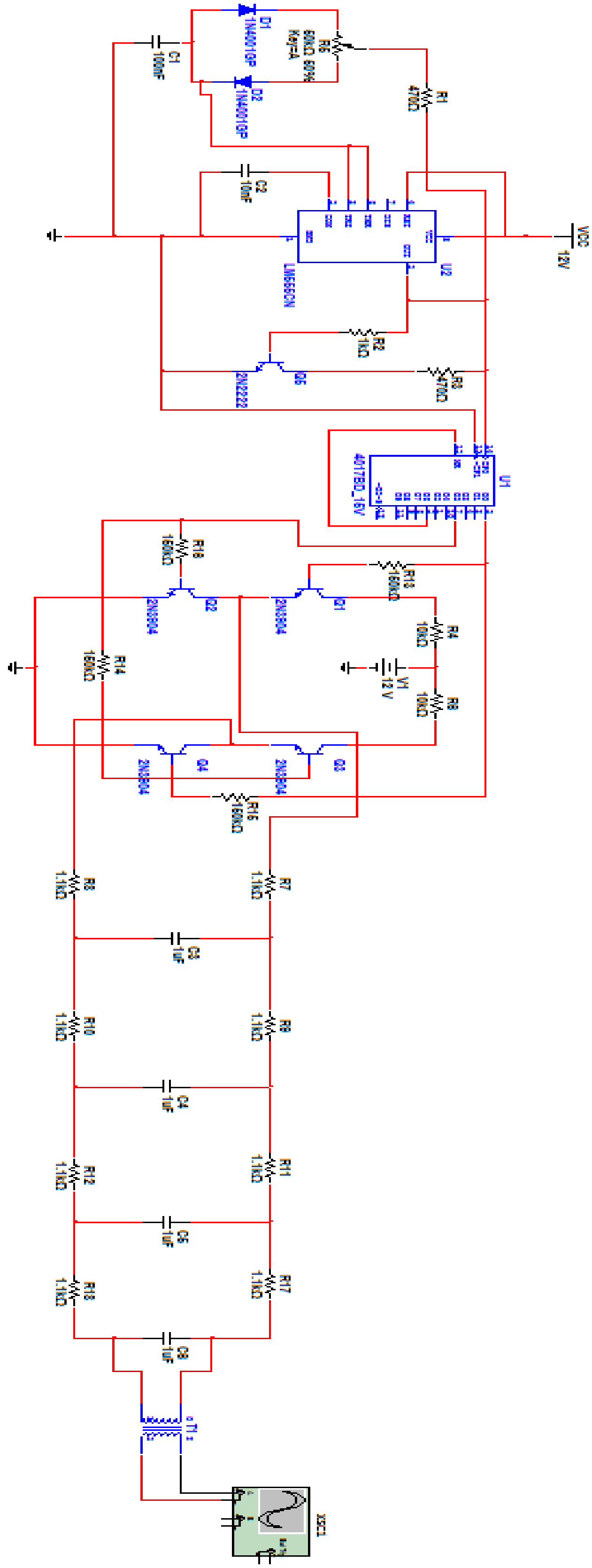


4th Stage:

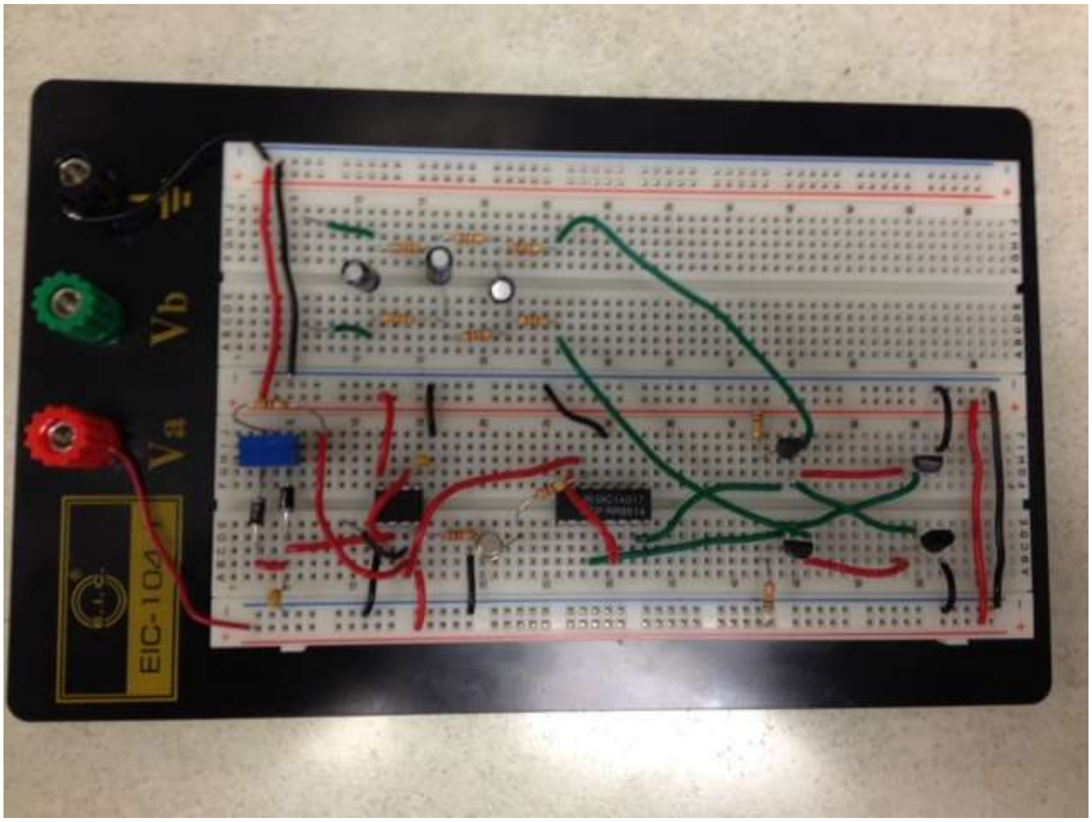


As you can see, in order for us to have a nice sine wave output a 4th order filter was necessary.

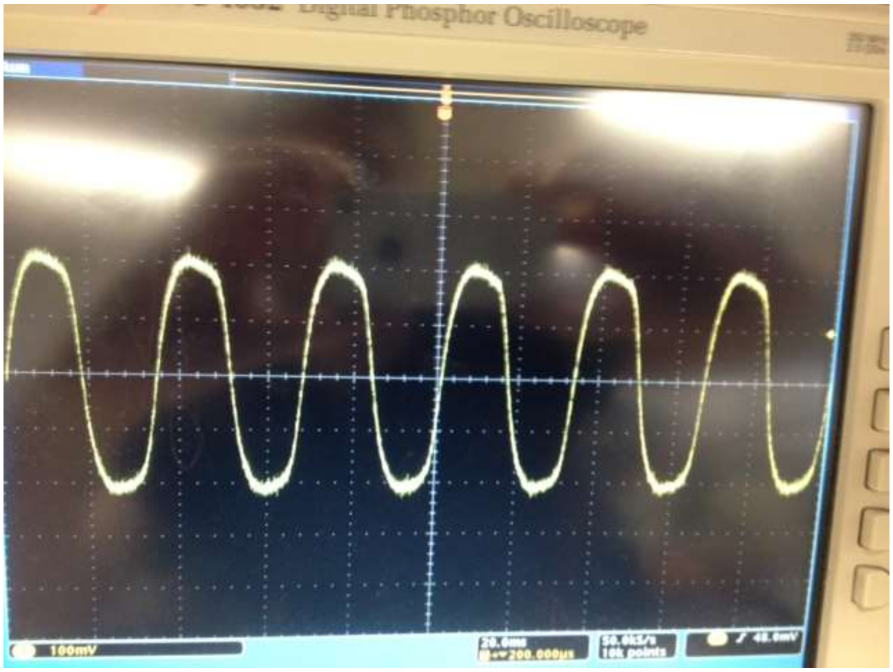
A schematic of the overall circuit diagram is shown below.



A picture of the prototype.



Output shown on the Oscilloscope taken on ECE Poster Day. Note the output is similar to the simulation obtained in Multisim.



Cost Analysis: The overall cost of the prototype came out to be about $50.

Part	Cost
Protoboard	$20.00
Output Transformer	$25.00
Miscellaneous Circuit Components	$5.00

This cost is about half of the cost of a pure sine wave inverter with the same power output on the market today. Leaving room for manufacturing cost and profit of the business, the design is a reasonable alternative to similar circuits on the market today.

Efficiency Study: The total efficiency of our circuit was calculated to be about 40% in our prototype. Since efficiency was not a deliverable of the project, this is a reasonable result due to the cost being so low.

Input Power	Output Power
12V*(1.4mA+1.06mA) = 29.52mW	120V*(98.4uA)=11.8mW

Impact of Work: Solar power is considered one of the cleanest forms of renewable energy. This inverter circuit could be used in an application to transform the DC voltage from solar panel to an AC voltage a home would consume. Since solar power is exclusively DC, there is a high demand in today's market for an inexpensive and efficient way to transform DC to AC. This circuit completes this task, and at a cost of $50, it is the cheapest option to date for transforming a DC signal voltage source to a pure sine wave signal.

Conclusion and Suggestions for Future Work: The project was an overall success and all requirements were met. However, the design could still use much improvement. If efficiency were improved, the design would be a much better alternative to the circuits currently on the market today. This added efficiency could even allow the circuit to use active filtering, which would give the circuit an even better pure sine wave output signal.

References

T. Surtell. (2002, May 5). *The 555 Monostable Circuit.* [Online]. Available: http://www.eleinmec.com/article.asp?4

V. Ryan. (2005). *The 4017B Decade Counter.* [Online].
Available: http://www.technologystudent.com/elec1/count1.htm