

**EE 198B**  
**Final Report**

**“WIRELESS BATTERY CHARGER”**  
**(RF/ Microwave to DC Conversion)**

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## **I. ABSTRACT**

This report covers the basis and design of the wireless battery charger. The wireless charger will convert the RF/ microwave signal at 900 MHz frequency into a DC signal, and then store the power into an AAA battery. The project is divided into 3 parts: transmitter, antenna, and charging circuit. A complete discussion of the specifications of the battery charger is provided after data measurements. This report also includes component list, financial, data results, and other key information.

## **II. INTRODUCTION**

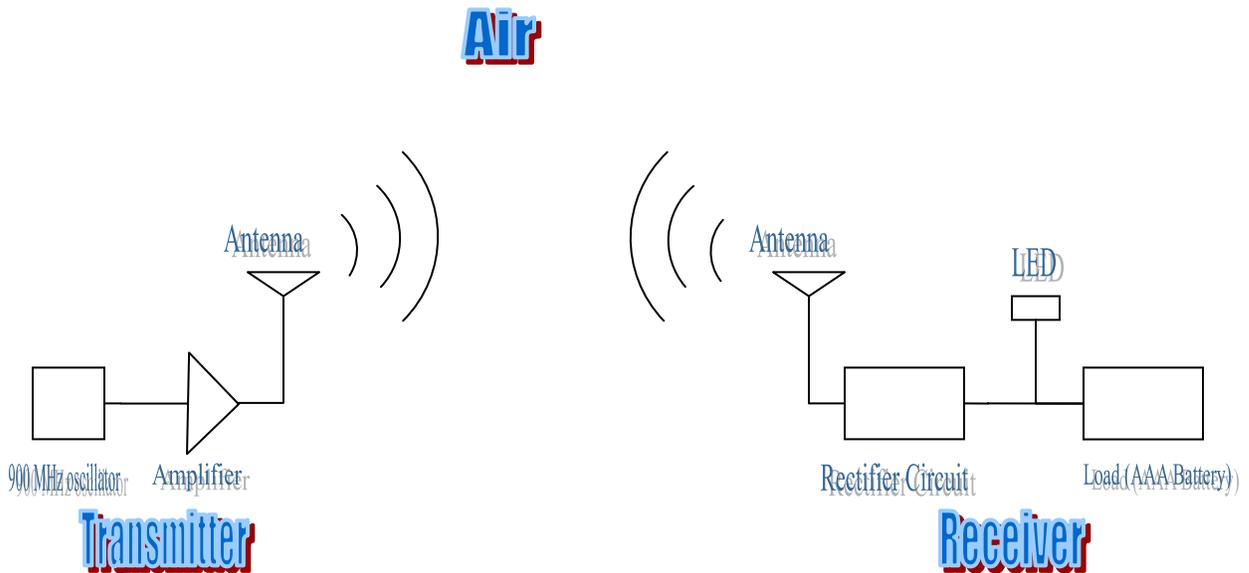
Portable electronic devices are very popular nowadays. As the usage of these portable electronic devices is increasing, the demands for longer battery life are also increasing. These batteries need to be recharged or replaced periodically. It is a hassle to charge or change the battery after a while, especially when there is no power outlet around. Therefore, our team is inspired to design a wireless battery charger. This wireless battery charger is expected to eliminate all the hassles with today's battery technology.

As for now, there are no known companies that are developing the wireless battery charger. This means that there might be a good opportunity in the market for this type of product. Moreover, people tend to spend more money for convenience that meets the price. The outlook of this device is supported by the above predictions.

It would be convenient not having to worry about charging or changing the batteries and still have a working device. The advantage of this device is that it can wirelessly charge up the batteries which can save time and money in a long run for the general public. Base on this concept, the design team has come up with a new way to charge the batteries wirelessly. The project is to make a prototype device that converts microwave signals to DC power. Once the prototype has been proved to be working, it is possible to implement this prototype into other applications such as in television remote control, fire alarm, clock, and places that are far to reach to change battery.

### **III. DESIGN OVERVIEW**

This wireless battery charger is designed to operate at 900 MHz. In this project, a power transmitter acts as the power source. It will transmit power to the receiver side. And then, the rectifier circuit in the receiver will convert the RF/ microwave signal into DC signal. After the DC signal is produced, the charging circuit will store the power into the battery. Here is the block diagram of the overall design.



**Figure 1: The overall wireless battery charger design**

## IV. ENGINEERING PROCEDURE

### A. Transmitter

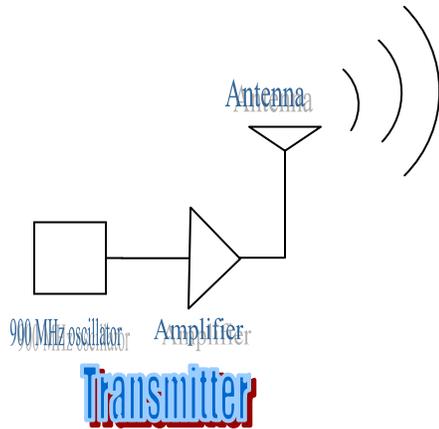


Figure 2: Block Diagram of the Transmitter



Figure 3: 900 MHz Video/Audio Transmitter

Since the group does not design the transmitter, therefore the design is mainly focus on the receiver side. A power transmitter is bought from a commercial website. It is a 900 MHz video/audio transmitter. Here's the specification of the transmitter\*.

Power:	12V DC, 900 mA
Output Power:	3 Watts
Operating Frequency:	900 MHz
Connector Type:	SMA – Female
Output Impedance:	50 $\Omega$

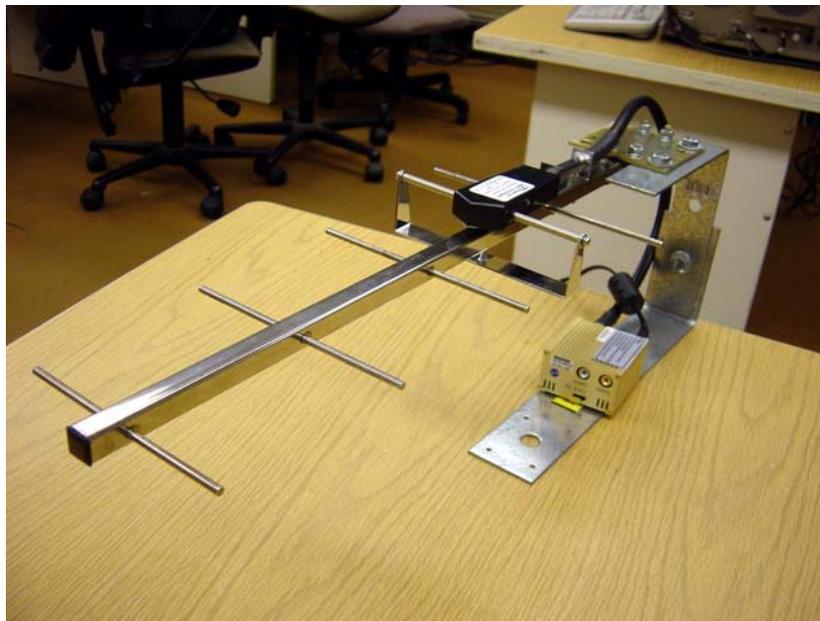
(\*Note: Further information is available in the Appendix)

## B. Antenna

The antenna plays a very important role. To charge a battery, a high DC power signal is needed. The wireless battery charger circuit must keep the power loss to the minimal. Therefore, there are many considerations to choose the correct parts for the design. The considerations of choosing the appropriate antenna are:

1. Impedance of the antenna
2. Gain of the antenna

Taking the above design spec in consideration, the team found Yagi antennas that fit our spec. Below is a picture of the Yagi antenna.



**Figure 4: A picture of the 9 dBi gain Yagi antenna**

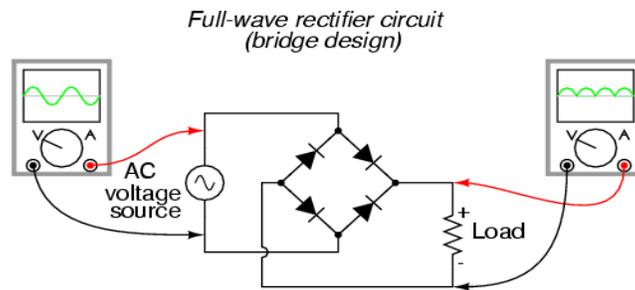
The impedance of the antenna should match with the output impedance of the power transmitter and input impedance of the rectifier circuit. Non-matching impedance between circuits can cause a tremendous power loss due to signal distortion. Since the output impedance of the transmitter is  $50 \Omega$ , the antenna should also have  $50 \Omega$  impedance.

The higher of the antenna gain yields a better result of the design. However, higher gain will also increase the cost and the size of the antenna. This becomes a major factor in choosing the antenna due to the group's limited financial resources. After consideration, a 9 dBi Yagi antenna is chosen for the design (see Appendix for specifications)

## C. Receiver

The receiver's main purpose is to charge an AAA battery. A simple battery charging theory is to run current through the battery, and apply a voltage difference between the terminals of the battery to reverse the chemical process. By doing so, it recharges the battery. There are other efficient and faster ways to charge the battery, but it requires a large amount of energy which the wireless battery charger can not obtain, yet. Therefore, in our design, we use a straight forward method to charge the battery.

Microwave signal is an AC signal with a frequency range of 1 GHz – 1000 GHz. 900 MHz is in between the RF/ Microwave range. No matter how high the frequency is, AC signal is still AC signal. Therefore, the signal can also be treated as a low frequency AC signal. In order to get a DC signal out of the AC signal, a rectifier circuit is needed.



**Figure 7: Full-wave Rectifier Circuit**

A full-wave rectifier is chosen for the project due to its simplicity and efficiency in converting the AC signal. The full-wave rectifier is consisted of four diodes. Since the power received by the receiver will be relatively low and the signal frequency is high, the diodes are required to have a very low turn on voltage and operating frequency at 900 MHz. For this reason, a Schottky diode by Skyworks is chosen for the design. (SMS3929-021 Bridge Quad Schottky Diode)

At the output of the rectifier, the signal is not a fully DC signal yet. Thus, by adding a capacitor and a resistor can smooth out the output to become DC signal. However, the time constant produced by the capacitor and the resistor should be calculated carefully to fit the desired time constant.

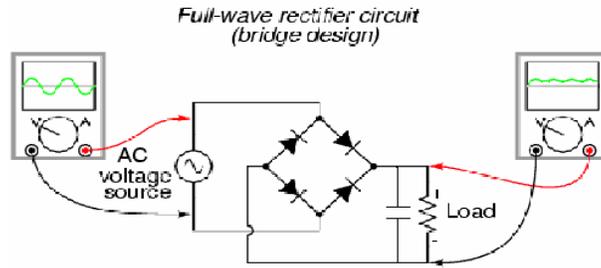


Figure 8: Full-Wave Rectifier with Capacitor and resistor.

## V. FINAL DESIGN

### A. P-SPICE SIMULATION

This is the PSPICE simulation results of the final design:

Figure 9: P-Spice Simulation of the Final Design

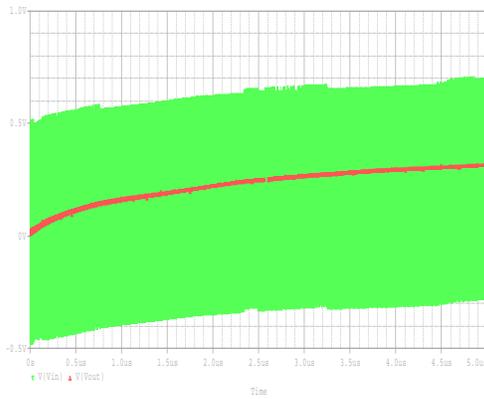


Figure 10: Simulation Result I (t: 0 – 5 us)

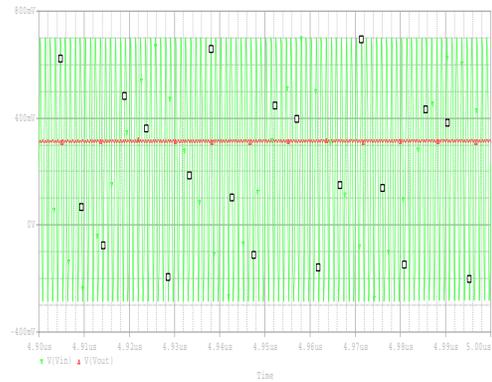


Figure 11: Simulation Result II (t:4.9 – 5.0 us)

## B. THE FINAL DESIGN CIRCUIT

The final design of the wireless battery charger consists of: these major components:

1. Transmitter
2. Yagi antennas
3. Full-wave rectifier circuit
4. RC circuit
5. Battery holder

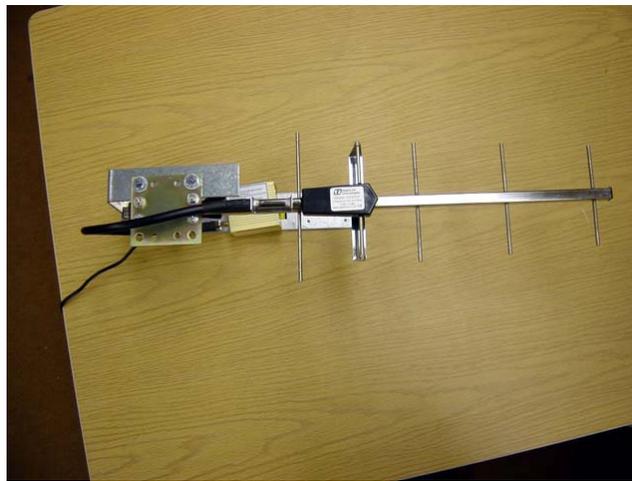


Figure 12: A picture of the transmitter with the Yagi antenna

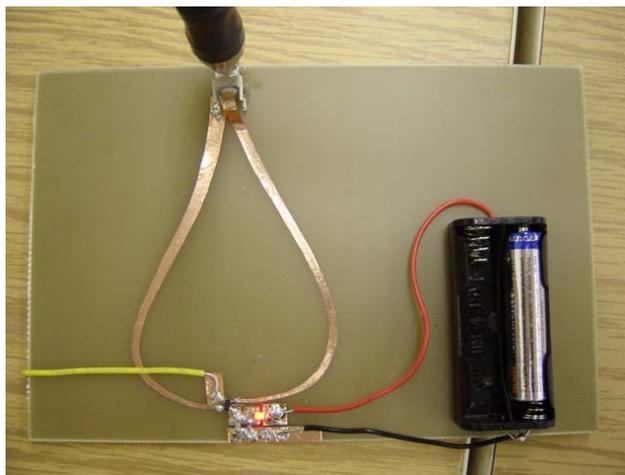


Figure 13: A picture of the final design circuit of the charging circuit

The input impedance of the quad bridge rectifier diode is non-linear. Based on the I-V curve of a diode, the impedance of a turned-on diode is relatively high. The data sheet does not provide the I-V curve data, thus the group assume that the impedance of the rectifier is very high. Therefore, the width of input transmission line is getting thinner as it gets closer to the input rectifier.

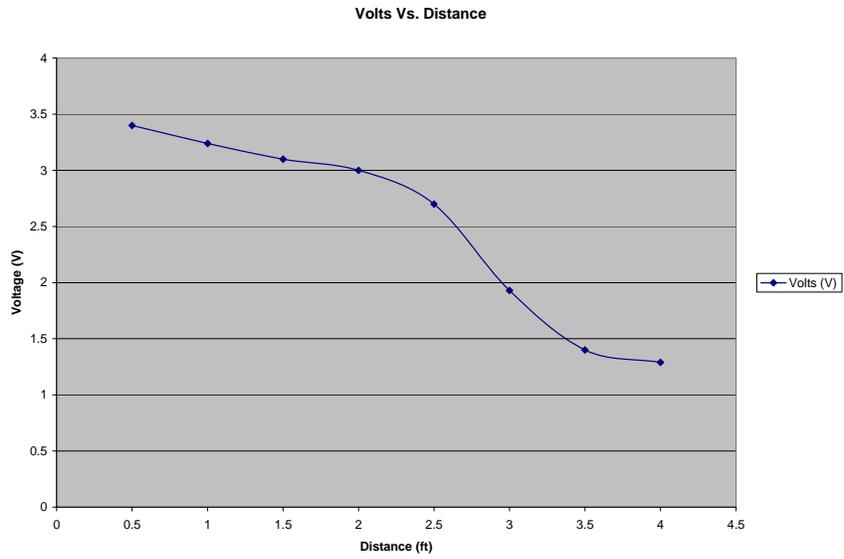
The length and the shape of the transmission line need to be considered. The length of the transmission line has to be approximately a quarter wave of the wavelength. The shape of the transmission line needs to be as smooth as possible to avoid power loss. Our design uses a circular shape and gives us the best results.

## **VI. TESTING AND DATA**

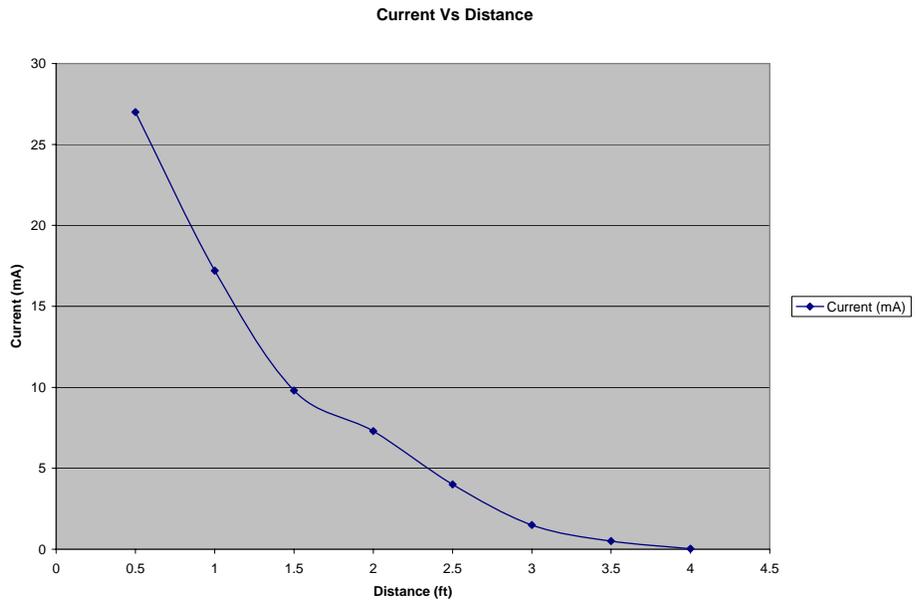
After building the complete final designed circuit, we needed to know the output effectiveness in respect to distance. The following data was taken by using a multi-meter measuring voltage and current values versus the distance between the two antennas.

Distance (ft)	Volts (V)	Current (mA)	Power (mW)
0.5	3.4	27	91.8
1	3.24	17.2	55.728
1.5	3.1	9.8	30.38
2	3	7.3	21.9
2.5	2.7	4	10.8
3	1.93	1.5	2.895
3.5	1.4	0.51	0.714
4	1.29	0.03	0.0387

**Table 4: Table of voltage and current versus distance charged**



**Figure 14a: Voltage versus distance chart**



**Figure 14b: Current Vs. Distance Chart**

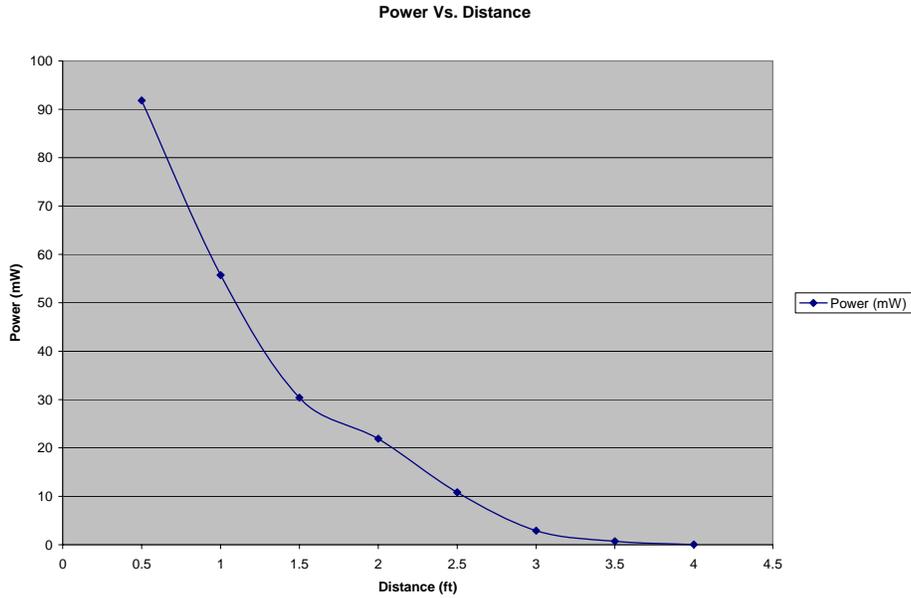


Figure 14c: Power Vs. Distance Chart

The above figures clearly show that the voltage, current and power output decreases relative to increase in distance between the Yagi antennas. One interesting observation worth noting is that the output curve is an exponential decay. The slope starts to smooth out at about 4 feet range for both voltage and current output.

## VII. SPECIFICATIONS

The design is separated into three subsystems: the transmitter, the antenna, and the charging circuit. This charger will charge the battery by utilizing the microwave signal at 900 MHz frequency. It will convert the microwave signal to DC signal, and then it will use the DC signal to charge the battery. Below are the design specifications of the charger circuit.

Design Specifications	
Source frequencies:	900 MHz
Charging distance:	1 feet
Voltage output:	2.0V
Power output:	60 mW
Battery type:	One AAA

This is achieved by using a 3 Watt 900 MHz transmitter. The charging distance can be improved by using a high power transmitter and the high gain antenna.

## **VIII. PROBLEMS AND SOLUTIONS**

There are 5 people in the design project team, and it's a relatively large group compare to others. Each member of the team is responsible to communicate to each other and update the status of the project. In the very early stage of the project, the group had defined some specific roles for each group member, so that each group member had a defined responsibility in the design process. As time went by, the sense of this pre-defined responsibility of individual seemed to get dissolved soon after the EE 198A was over.

The progress of the project had been sluggish since the beginning of the semester and caused some uprising frustration from group members. The communication between group members and the project adviser was decaying as well. The directions of the project that were pre-defined from the previous semester had been changed several times in the beginning of EE 198B. Due to those back-and-forth changes, valuable time had been wasted.

Before the final decision was set on working with the circuitry with 900 MHz frequency, the design team had other choices of frequency range in mind. The first choice was 2.4 GHz from commercial wireless routers. The accessibility is one of the main advantages of using 2.4 GHz wireless routers. However, it fails to provide sufficient power to fit our design requirement and lack of test equipment to measure the circuitry. The second choice was to switch the design specifications using 20MHz frequency. The advantage is that at such low frequency it is possible to use function generator as the transmitter. One big disadvantage is insufficient time to build the power amplifier for the transmitter. The antenna design was another problem that we encountered when we picked this frequency. At 20 MHz, a directional antenna becomes very large compare to 2.4 GHz antennas. Finally, the team decided on 900 MHz frequency for its accessibility, power, and size of the antenna.

Even though the frequency was set on 900 MHz, the results did not meet our expectations. One of the difficulties we experienced when doing our project was the power insufficiency from the transmitter. The output power of the transmitter we bought was theoretically 3 Watts, but when we measured it using the spectrum analyzer, it only gave us 1 Watt output. With that insufficient output from the transmitter and the loss from the medium, we got only 90 mW from the antenna on the receiver side. With that small input power, our circuit did not have enough

power to drive the diodes; consequently, it did not give enough current output to charge the battery in a short time. However, the output current and voltage in our circuit could turn on the LED, but it took awhile to charge up the battery. If we have more time, we might increase the input power by increasing the number of antennas to get more output power. Then with that increased input and output, we might charge up the battery more efficiently.

Another difficulty we faced with was the team spent excess amount of time to search the parts for our project. We spent too much time searching for the diodes, and then we found out later that we could not use them due to the unmatched frequencies. At first, we planned to use the 2.4 GHz frequency, but we changed to 20 MHz and then 900 MHz later due to the restriction from the equipment in the laboratory. So those parts we searched and bought in the earlier time could not be used. Then time each member had to look around and spend time searching and ordering new parts for our project again, and those took a lot of time from our project schedule. Consequently, we fell behind the schedule. However, we could overcome this difficulty successfully and accomplish our project on time.

Although there were many negative points from the time management aspect, the bottom line is that the design project objective was successfully being implemented. The team has learned and experienced the importance of time management for this type of design project. This design project has been a valuable lesson to all members of the group, because at the end the group realized there are many ways that could have increase the efficiency of our design.

## **IX. POSSIBLE IMPROVEMENTS**

There are several possible ways to improve our design in order to increase the power output. Here are several suggestions:

### **A. Multiple Rectifiers**

One way is to use multiple rectifiers. By doing so, more power is getting rectified by these the multiple rectifiers in the circuit.

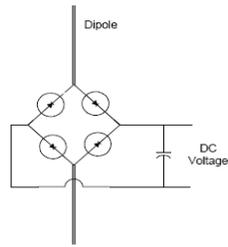


Figure 13: Single Rectifier.

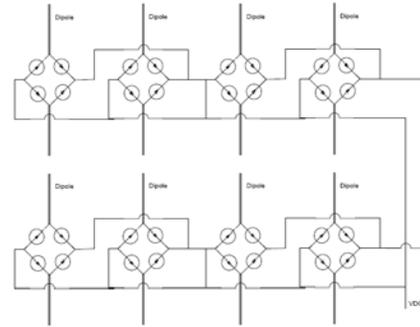


Figure 14: Multiple Rectifiers.

However, this design will need to use multiple antennas separated by a certain distance. This problem can be solved by using a spiral antenna array, which is difficult to design.

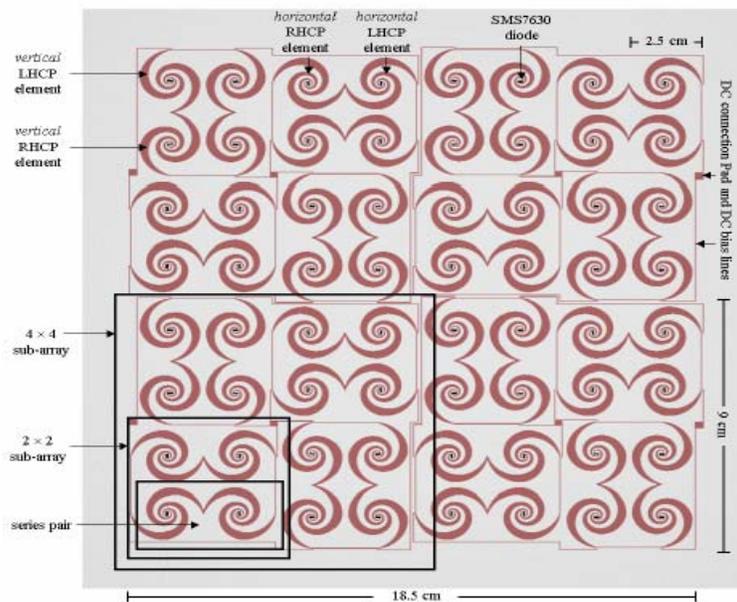


Figure 15: Multiple Rectifiers with Multiple Spiral Antennas.

## B. High Gain Parabolic Antenna

Another way is to use a high gain parabolic antenna (See Appendix). This parabolic antenna will be able to transmit power from the transmitter with a much higher gain, and receive

approximately seven times greater power than the 9 dBi Yagi antenna. The disadvantages of using this parabolic antenna are the size and the fixed direction of the antenna.

## **X. Marketing Plan**

The working prototype uses Yagi antennas for the design. The prototype may not seem like an attractive design for today's wireless devices; however it could be implemented into other applications. For instance, it could be implemented onto devices in the tower and only charge up when needed. The team strives to improve the wireless charger using the spiral patch antennas in the future. The spiral antenna is able to pick up a wider range of frequencies instead of just tuned to one particular frequency. In addition, the spiral antennas become smaller at higher frequency which is small enough to fit in a cell phone or any wireless devices. The multiple rectifier design will also increase the received power. Therefore, these improvements show that this project still holds valid market demands.

## **XI. CONCLUSION**

In conclusion, power loss and efficiency are the major problems for this design project. Our design team has noticed the potential problem whether the converted DC power will be significant enough to charge up the battery. Therefore, the characteristics of the diodes should be mounted directly onto the antenna for minimum power dissipation. In addition to harmonics, the nonlinear diode creates a DC-bias in the resonant circuit which can be extracted without affecting the RF/ microwave characteristics of the resonant circuit. The time varying voltage and current relationship at the physical point of the diode in the cavity determines the loss in the diode and, consequently, the RF/ microwave to DC efficiency.

As the wireless technology is getting popular nowadays, the demand of battery is also increasing. The battery needs to be recharged or changed eventually. Therefore our team is inspired to design the wireless battery charger. This wireless battery charger will eliminate all the hassle with the battery.

As for now, there are no known companies which develop the wireless battery charger. This means that the opportunity is very big. Also, people tend to spend more money for convenience. It gives more reason that this device will have a very good market.

## **XII. REFERENCES**

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### XIII. APPENDIX

Specification of the Yagi Antenna:

<b>Model</b>	HG909Y
<b>Frequency</b>	890-960 MHz
<b>Gain</b>	9 dBi
<b>Polarization</b>	Horizontal or Vertical
<b>Horizontal Beam Width</b>	54°
<b>Vertical Beam Width</b>	48°
<b>Front to Back Ratio</b>	14 dB
<b>Impedance</b>	50 Ohm
<b>Max. Input Power</b>	100 Watts
<b>VSWR</b>	< 1.5:1 avg.
<b>Elements</b>	5
<b>Weight</b>	1.5 lbs. (0.7 kg)
<b>Length</b>	19.6 in. (0.5 m)
<b>Mounting</b>	2 in. (50.8 mm) diameter mast max.
<b>Operating Temperature</b>	-40° C to to 85° C (-40° F to 185° F)
<b>Lightning Protection</b>	DC Short
<b>Connector</b>	N-Female

Table 1: HG909Y 9 dBi Yagi Antenna Specification

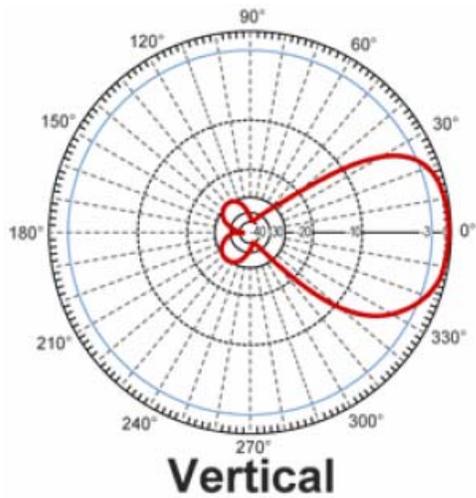


Figure 5: HG909Y Vertical Gain Pattern

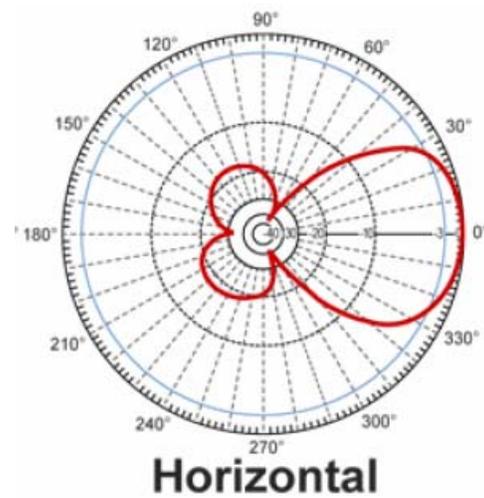


Figure 6: HG909Y Horizontal Gain Pattern

Specification of the Skyworks SMS3929-021 Bridge Quad Schottky diode:

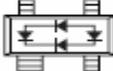
$V_B$ @ 10 $\mu$ A (V) Min.	$C_J$ @ 0 V 1 MHz (pF)	$V_F$ @ 1 mA (mV)	$\Delta V_F$ @ 1 mA (mV) Max.	$R_T^{(1)}$ @ 10 mA ( $\Omega$ ) Max.	Bridge Quad
					SMS3929-021 Marking: SQE
2	0.3–0.5	200–270	10	8	SOT-143
					

Table 2: Diode Specification I

### Absolute Maximum Ratings

Characteristic	Value
Reverse voltage ( $V_R$ )	Rated $V_B$
Forward current - steady state ( $I_F$ )	50 mA
Power dissipation ( $P_D$ )	75 mW
Storage temperature ( $T_{ST}$ )	-65 °C to +150 °C
Operating temperature ( $T_{OP}$ )	-65 °C to +150 °C
Junction temperature ( $T_J$ )	150 °C
Soldering temperature	260 °C for 5 seconds
ESD human body model	Class 1B

Table 3: Diode Specification II

Specification of the high gain parabolic antenna:

<b>Frequency</b>	890 - 960 MHz
<b>Gain</b>	18 dBi
<b>Horizontal Beam Width</b>	16.5°
<b>Vertical Beam Width</b>	16.5°
<b>Front to Back Ratio</b>	> 30 dB
<b>Impedance</b>	50 Ohm
<b>Max Power</b>	100 Watts
<b>VSWR</b>	< 1.5:1 avg.
<b>Lightning Protection</b>	DC Short
<b>Weight</b>	32 lbs. (14.5 kg)
<b>Dimensions</b>	47.2" Dia. (1.2 m)
<b>Mounting</b>	1.5" (38mm) to 3" (76mm) dia. mast
<b>Grid Material</b>	Galvanized Steel
<b>Polarization</b>	Vertical
<b>Operating Temperature</b>	-40° C to to 85° C (-40° F to 185° F)
<b>Wind Survival</b>	134 MPH

Table 6: Parabolic Antenna's Specification

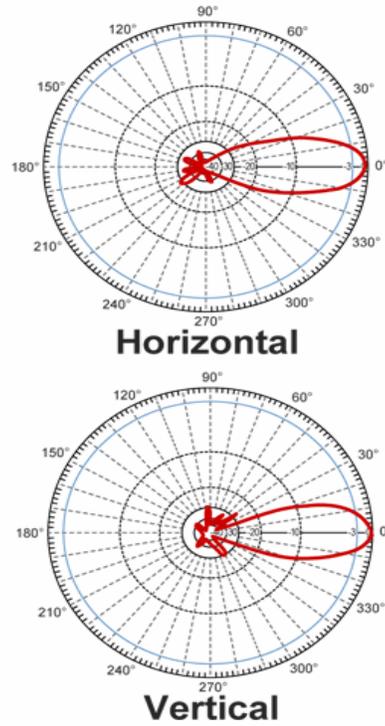


Figure 16: Parabolic Antenna Gain Pattern.