# Smart Tennis Net Using RF Wireless Power Transfer

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**Abstract**

Tennis is a game between two or four players that repeatedly hit a ball over a net with a racket until one team makes an error or hits a winner. A rally in tennis is a series of back and forth shots between two players in a point. Because it is a game that depends on one person being able to stay in a rally longer, consistency is key when advancing a player's ability. This paper aims to underline the design of a device that can successfully record the number of shots in a tennis rally. With the implementation of sensors, the device can display the number of shots in a rally, which can ultimately give players' feedback on how consistent their game is. Giving a player the ability to know how long their average rally length can hopefully allow them to improve their consistency. Tennis is a sport that is usually played outdoors away from power sources, so it is crucial for the system to be self-powered. Radio waves are electromagnetic waves that are constantly surrounding us. With the capability to capture these radio waves, they can be used as radio frequency (RF) energy to power electronics. The proposed device uses RF power to operate in any condition. This paper describes the problem, goals, specification, and timeline for this project.

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**Problem Definition**

Tennis is a game of persistence and focus. That is why the player that hits the most balls over a net in a rally almost always ends up winning the point and eventually the match. Because of this, coaches and players like to record the length of a rally to improve the length, which leads to better consistency. If a player knows how long their average rally length is then they can work on building on their consistency. While counting rally length is very helpful in advancing a player's game, it is sometimes hard to actually record it. To count the length of a rally, someone must watch the point and count every time the ball crosses the net. During a long rally, you can imagine this leads to sore necks and wasted time by the individuals counting the rally. It also becomes an issue to keep track of the number of balls hit by each player when the rally seems to go on forever. Often times one loses track of the rally and has to wait till the next point to start counting again. This a recurring problem for tennis players when they are trying to improve the consistency in their game.

**Project Goal**

The goal of this project is to create a device that will improve tennis consistency in players by recording the length of their rallies. The device should be able to wirelessly sense the number of balls hit across the net and easily display the number. While a tennis court is a place where people are running around usually not looking at their feet, you do not want a bunch of wires on the court that could cause tripping. Some rallies might be short and some might be extremely long, so it is important for the system to sense when a point is over and be able to start taking in new data for the next point. Lastly, the device should harvest energy from its surroundings instead of having to be plugged into an outlet. Most tennis courts are in parks or away from many buildings, so it is usually hard to find an electrical outlet nearby. If the system can run on renewable energy, then it will be able to operate in a diversity of locations.

**Literature Review**

Currently, there are no devices that achieve the goals listed in the previous section, but there are a couple of systems that are similar. In November of 2011, a company called Zepp created a piece of wearable technology for tennis player's to analyze their game [1]. Zepp came out with a mount that goes on the end of a tennis racket to track different aspects of a player's game. The mount then connects to an app that displays the user's percentage of strokes, activity time, swing speed and a lot of other characteristics in someone's game. The technology doesn't directly record a player's consistency though; only the amount of shots that they hit. This means that is doesn't take in new data every time a new point is played but keeps on building on the data until the user resets the device. So if a player just plays a thousand really short points, it would look the same as playing a hundred really consistent points. There have also been complaints with Zepp's tennis tracking system that it makes the racket heavier than what a player is used to. This change in weight can completely throw off a player's game, thus altering the results of their play.

Another company, called PlaySight has created a video camera that connects to an app to analyze a player's game [2]. The video camera sits above a tennis court and records different aspects of someone's game as well. Then the video displays the statistics of the player's game to a handheld app. But again, the device doesn't record consistency because it doesn't take data every time a point is over but does so until it is reset.

**Design Specifications**

Performance: In an article written by Issam Chaour on powering low powered sensors using RF harvesting, it proposes the system operates at a frequency around 930 MHz with a bandwidth of 10 dB at 20 MHz [3]. This would be close to the wifi frequency band, but still in legal, experimental limits. The system should also be able to transfer power to a low power sensor at a maximum of 30 meters. Even though the range will be maximized at 30 meters, it should still be able to produce enough power to communicate with the sensors.

Energy: The goal is for the system to be able to run solely by harvesting RF energy in the environment surrounding the antenna. This would allow the system to run at all times of the day, every time of the year. But if this is not able to happen because of power restraints, the system should be able to run on other renewable energy. It should also be able to power two 1.05 uW motion sensors.

Environmental: The system should be able to be left outside year round making it resistant to temperatures of -15 degrees Fahrenheit and up to 105 degrees Fahrenheit. The system should also be water resistant. A big component to the device is making sure it does not alter the tennis court in any way that could distract or get in players' way. This being said, it should not get in the way of normal play or cause distractions.

Safety: The system should not require more RF waves to be beamed into space as some have evidence of radio frequency waveforms leading to cancer. The proposed design should not need more radio waves than there already is in the environment at a safe level. Also, the system should not require cords that could cause tripping, which can lead to injury for players.

Legal: The system should not operate at frequencies reserved for wifi of 2.4 GHz, 3.6 GHz, 4.9 GHz, 5 GHz, 5.9 GHz, and 60 GHz bands [4]. This is extremely important as there are only so many frequencies available to the public for experimental use.

Materials: There are various components that are needed for the system to operate. First, it should have a receiving antenna to capture RF energy. Then the energy must go to a rectenna, which will convert electromagnetic energy into direct current. Next, there will be a rectifying circuit that will contain a diode. The diode cannot use too much power that could take away from delivering the current to the load. Lastly, we will output the current to our load, which is the two motion sensors. There are two ways to go about this. The device can either use RF harvesting to charge a battery that powers the sensors or directly power the sensors from the RF. The choice will be made during the testing process to see which would be best implemented. A block diagram of the components is shown below in Figure 1 [5].

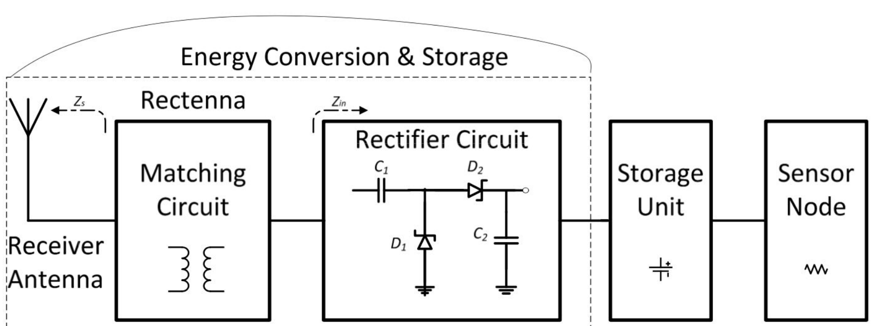


_*Figure 1. System Block Diagram*

Manufacturability: Since this project must be completed during the fall and winter term, the system must be able to be built in 15 weeks with a 5 week testing period. It should also be easily replicated for other tennis courts.

Aesthetics: The system must not have a noticeable receiver and transmitter, only the sensors should be obviously noticeable to the public. The data should be able to be presented nicely on a phone or a computer.

**Test Plan**

The design will be tested in different phases to ensure each part can work alone before working altogether:

Antenna: After constructing the antenna using a copper rod, it will be tested to see what range of frequency it can deliver. If the antenna is not in the 960 MHz range, it will be altered by cutting off pieces of the top of the copper rod to achieve the correct antenna length.

Matching and Rectifying Circuit: Using a function generator to produce 960 MHz of frequency, the matching and rectifying circuit will be tested using an oscilloscope. The oscilloscope will show how much power is being produced from that frequency. If the circuit cannot produce enough power to power the two motion sensor, then a hybrid solar/RF harvester, as shown in Figure 2 [6], will replace the antenna.

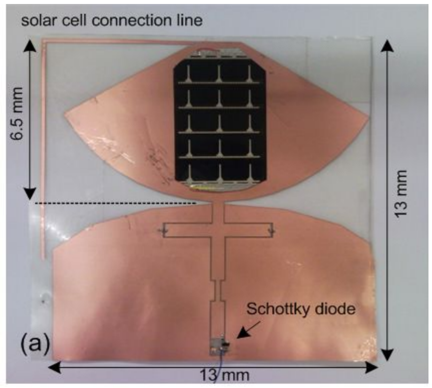


*Figure 2. Solar/RF Hybrid Harvester*

The harvester can simultaneously take in the light as well as RF energy to maximize its power output. Once the system can produce enough power, we will power the two sensors on each side of the net post.

<u>Sensors:</u> Once the antenna or harvester along with the circuit can produce enough power, we will test the system in series with two motion sensors on each side of the net post. In testing the sensors, we will test how accurately the sensors can sense when a ball crosses the net.

The design will be built in separate steps for easy debugging but will be put together for a final product. The schedule will roughly look like below with potential variations as the project progresses.

| Week: | Agenda: |
| --- | --- |
| Two | ● Take inventory of all parts needed and finalize any changes/updates to design and schematic |

| | |
|---|---|
| Three | • Start building the RF receiver along with the RF to DC converter |
| Four | • Finish receiver and build the antenna |
| Five | • Test receiver and antenna to make any necessary changes to design<br>• Maximize power by fixing the antenna<br>• (If needed) Add 5V power to the receiver if power is not enough for sensors |
| Six | • Add sensors to design<br>• Code the communication of the sensors using C++ |
| Seven | • Test the sensors in communication with the receiver<br>• Make any necessary changes |
| Eight | • Continue testing and debugging of system |
| Nine | • Make any aesthetic additions to the project |

*Table 1. Testing Plan*

**Ethical Considerations**

There are two main ethical issues that I am worried about in my project. The first one has to do with the frequency at which my device operates. There are certain frequencies that are available to the public to use for medical devices and experimental use, like a senior project. But these frequencies available only produce so much power. If I need to use more energy to power the sensors, I might need to use a higher frequency. This becomes a problem because most higher frequencies are used for wifi, government use, airplane communication, etc.. Inferring with those frequencies is not only illegal but could do harm to other operations that need them. There is a small window of frequencies available for this project and it would be unethical to go outside of them.

Another issue that I am worried about is directing too much power from radio waves to the sensors. It has been proven that large amounts of RF energy can cause harm to humans. So to make sure that the energy I am using doesn't cause harm to people, I need to use only small amounts of energy. While using more RF would make my system work better, it would be unethical to put more RF waves into the atmosphere.

**Standards**

1. IEEE C63.27-2017 - American National Standard for Evaluation of Wireless Coexistence [7]

This standard describes the testing methods, procedures, designs and protocols that one should go through when building a device that integrates a wireless communication component. The standard focuses on making sure the wireless communication of a system does not affect the radio frequency environments around the implemented device. The purpose of the standard is to make sure engineers are going through a certain checklist when experimenting with wireless communication to make sure they do not put anyone or anything at risk.

2. NEMA WD 7-2011 (R2016) National Electrical Manufacturers Association Occupancy Motion Sensors Standard [8]

This standard gives guidelines on mounting height, angle, coverage area, etc. when using a motion sensor. The motion sensors described in the publication can be of various types including infrared, ultrasonic and microwave technology. It also describes different limitations for motion sensors in different environments.

3. IEEE C63.26-2015 - IEEE/ANSI Standard for Compliance Testing of Transmitters Used in Licensed Radio Services [9]

This standard gives different procedures one must follow when using technology that includes transmitters. The publication talks about different testing plans for transmitters operating in different legal frequencies including mobile radio, wireless, personal radio, and much more. It also gives guidelines on how much radiation can be emitted, the bandwidth use and other regulatory requirements.

**Project Schedule for Fall Term**

Week 1: Continue research and design plan. By the end of week one, I hope to have a proposed schematic with parts that I need to complete the design. If the parts are not already available, I will order them at this time.

Week 2: Start building the antenna and testing it for frequency range. I will also do final edits on the circuit schematic and wait for parts to come in.

Week 3: Build the matching and rectifying circuit using the schematic I designed. Hopefully, start testing the circuit using a function generator as the input and an oscilloscope to see how much power is being delivered.

<u>Week 4:</u> Continue working on the circuit to maximize power output. This might require a lot of testing and debugging using different components.

<u>Week 5:</u> If the power output using the antenna is not enough, implement the solar/RF hybrid harvester and test it to see how much power can be delivered. Using the harvester, we want to test it at different times of the day to see when it is the strongest and weakest.

<u>Week 6:</u> Continue trying to maximize power if not achieved yet. If it is an achieved, use this week to clean up any loose ends on the project like messy circuitry, needed parts, etc..

<u>Week 7:</u> Power the sensors using a voltage generator in the lab and make sure they work with the power anticipated. At this point, I should start coding the communication between the sensors and the computer.

<u>Week 8:</u> Continue coding sensors.

<u>Week 9:</u> Try to power sensors using wireless RF power transfer. This will require testing the distance the sensors can be away from the transmitter.

<u>Week 10:</u> Continue powering the sensors wirelessly and testing/debugging.

<u>Winter Term:</u> Things that still need to be completed during the winter term:

1. Finalizing the whole system can work together
2. Testing the sensors to see if they can record when a ball goes over the net and knows when a new point has started
3. Final aesthetic details

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