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# Battery Charger using RF Signal

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**Abstract—**In this paper, I am propose an efficient circuit based on use of RF signals for charging the cellular phone. Through the basic circuit which uses to convert the AC signal in to DC voltage and a isotropic antenna. The design example provided in this work demonstrates an easy, portable wireless battery charging system than wall outlet.

## I. INTRODUCTION

Cellular telephone technology became commercially available in the 1980's. Since then, it has been like a snowball rolling downhill, ever increasing in the number of users and the speed at which the technology advances. When the cellular phone was first implemented, it was enormous in size by today's standards. This reason is two-fold; the battery had to be large, and the circuits themselves were large. The circuits of that time used in electronic devices were made from off the shelf integrated circuits (IC), meaning that usually every part of the circuit had its own package. These packages were also very large. These large circuit boards required large amounts of power, which meant bigger batteries. This reliance on power was a major contributor to the reason these phones were so big.

Through the years, technology has allowed the cellular phone to shrink not only the size of the ICs, but also the batteries. New combinations of materials have made possible the ability to produce batteries that not only are smaller and last longer, but also can be recharged easily. However, as technology has advanced and made our phones smaller and easier to use, we still have one of the original problems: we must plug the phone into the wall in order to recharge the battery. Most people accept this as something that will never change, so they might as well accept it and carry around either extra batteries with them or a charger. Either way, it's just something extra to weigh a person down. There has been research done in the area of shrinking the charger in order to make it easier to carry with the phone. One study in particular went on to find the lower limit of charger size [1]. But as small as the charger becomes, it still needs to be plugged in to a wall outlet. How can something be called "wireless" when the object in question is required to be plugged in, even though periodically? Now, think about this; what if it didn't have to be that way? Most people don't realize that there is an abundance of energy all around us at all times. We are being bombarded with energy waves every second of the day. Radio and television towers, satellites orbiting earth, and even the cellular phone antennas are constantly transmitting energy

What if there was a way we could harvest the energy that is being transmitted and use it as a source of power? If it could be possible to gather the energy and store it, we could potentially use it to power other circuits. In the case of the cellular phone, this power could be used to recharge a battery that is constantly being depleted. The potential exists for cellular phones, and even more complicated devices - i.e. pocket organizers, person digital assistants (PDAs), and even notebook computers - to become completely wireless.

Of course, right now this is all theoretical. There are many complications to be dealt with. The first major obstacle is that it is not a trivial problem to capture energy from the air. We will use a concept called energy harvesting. Energy harvesting is the idea of gathering transmitted energy and either using it to power a circuit or storing it for later use. The concept needs an efficient antenna along with a circuit capable of converting alternating-current (AC) voltage to direct-current (DC) voltage. The efficiency of an antenna, as being discussed here, is related to the shape and impedance of the antenna and the impedance of the circuit. If the two impedances aren't matched then there is reflection of the power back into the antenna meaning that the circuit was unable to receive all the available power. Matching of the impedances means that the impedance of the antenna is the complex conjugate of the impedance of the circuit.

Another thing to think about is what would happen when you get away from major metropolitan areas. Since the energy we are trying to harness is being added to the atmosphere from devices that are present mostly in cities and are not as abundant in rural areas, there might not be enough energy for this technology to work. However, for the time being, we will focus on the problem of actually getting a circuit to work. This thesis is considered to be one of the first steps towards what could become a standard circuit included in every cellular phone, and quite possibly every electronic device made. A way to charge the battery of an electric circuit without plugging it into the wall would change the way people use wireless systems.

The remainder of the paper is organized as follows. Section II presents the general idea of the proposed pre-computation scheme. The example of a high-rate code and the details of the design are discussed in Section III. Section IV presents the simulation and synthesis results, followed by conclusion in Section V.

## II. THE TRANSMITTER

The most basic transmitter setup consists of a piece of equipment that generates a signal whose output is then fed into an amplifier that is finally output through a radiating antenna – the air interface. A condition must be met where the antenna operates optimally at the desired frequency output from the signal generator. In the current case, an antenna was connected through an amplifier to a radio-frequency (RF) source. The RF source is a circuit that outputs a signal at a user-specified frequency and voltage. The range of frequencies of the signal generator resides in the radio frequency band, 3 mega-hertz (MHz) to 3 giga-hertz (GHz). The output power of this device is limited. For this reason, an amplifier is required on the output. The transmitting antenna is called a patch antenna and is fabricated from copper plating that is soldered to a feed wire and has a ground plane. The frequency of 915MHz was chosen for this project because it is one at which our team has experience, and it falls in one of the Industrial-Scientific-Medical (ISM) RF bands made available by the Federal Communications Commission for low power, short distance experimentation. This frequency was chosen mostly for simplicity in using the available equipment. It is not used for mass communication or anything else on a major scale, and therefore is not going to be interfered with, or interfere with other devices at low power levels. This also means that transmitters for short distances are readily available. In fact, 915MHz is a very common frequency used in RF research. This makes a transmitter system easy to construct and manage. The source is nothing more than a signal generator, capable of outputting a low-noise AC signal at 915MHz. This setup results in the antenna beaming approximately 6mW of power per square meter. This was the limit of the gain of the amplifier.

## III. THE PHONES

The design aspect of this project is focused on the receiving side. For this stage of research, of which the goal is to prove that the wireless battery charger idea is feasible, it was decided to incorporate the energy harvesting circuitry and antenna in some sort of base station or charging stand. It is necessary to hide the components for demonstration purposes. This being the case, two phones were chosen that have accessories currently available to use as our charging stands. The Nokia 3570 was the first phone that was received for the research. This phone comes standard with a battery and an AC/DC travel charger. The battery included with the phone has a voltage range from 3.2V - when the phone shuts off - to 3.9V when fully charged. This battery only takes about 2 hours to charge when plugged into the wall through the travel charger supplied with the phone. This charger has an unloaded, unregulated direct current (DC) output voltage of 9.2V. When connected to the phone, the charging voltage goes to the battery voltage, approximately 3.6V, and then slowly increases until it saturates at 3.9V. This charger regulates the current to around 350 mA.

## IV. THE CHARGE PUMP

At this point, it is necessary to explain what exactly a charge pump is, and how it works. A charge pump is a circuit that when given an input in AC is able to output a DC voltage typically larger than a simple rectifier would generate. It can be thought of as a AC to DC converter that both rectifies the AC signal and elevates the DC level. It is the foundation of power converters such as the ones that are used for many electronic devices today. These circuits typically are much more complex than the charge pumps used in this thesis. Power converter circuits have a lot of protective circuitry along with circuitry to reduce noise. In fact, it is a safety regulation that any power-conversion circuits use a transformer to isolate the input from the output. This prevents overload of the circuit and user injury by isolating the components from any spikes on the input line. For this thesis, however, such a low power level is being used that a circuit this complex would require more power than is available, and it would therefore be very inefficient and possibly not function. In that case, it is necessary to use a simple design.

The simplest design that can be used is a peak detector or half wave peak rectifier. This circuit requires only a capacitor and a diode to function. The schematic is shown in Figure 3.1. The explanation of how this circuit works is quite simple. The AC wave has two halves, one positive and one negative. On the positive half, the diode turns on and current flows, charging the capacitor. On the negative half of the wave, the diode is off such that no current is flowing in either direction. Now, the capacitor has voltage built up which is equal to the peak of the AC signal, hence the name. Without the load on the circuit, the voltage would hold indefinitely on the capacitor and look like a DC signal, assuming ideal components. With the load, however, the output voltage decreases during the negative cycle of the AC input, shown in Figure 3.2.

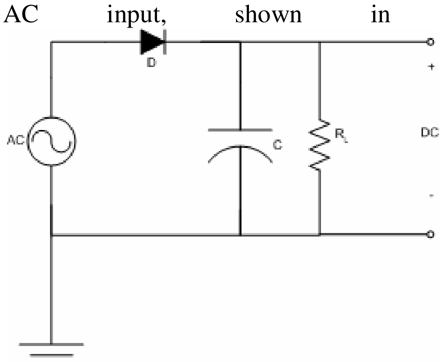



Figure 3.1: Peak Detector

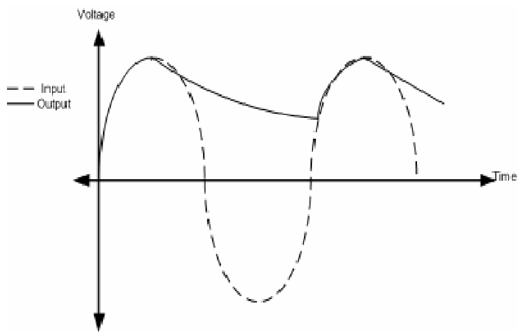



Figure 3.2: Half-wave Peak Rectifier Output Waveform

This figure shows the voltage decreases exponentially. This is due to the RC time constant. The voltage decreases in relation to the inverse of the resistance of the load, R, multiplied by the capacitance C. This circuit produces a lot of ripple, or noise, on the output DC of the signal. With more circuitry, that ripple can be reduced.

The next topology presented in Figure 3.3 is a full-wave rectifier. Whereas the previous circuit only captures the positive cycle of the signal, here both halves of the input are captured in the capacitor. From this figure, we see that in the positive half of the cycle, D1 is on, D2 is off and charge is stored on the capacitor. But, during the negative half, the diodes are reversed, D2 is on and D1 is off. The capacitor doesn't discharge nearly as much as in the previous circuit, so the output has much less noise, as shown in Figure 3.4. It produces a cleaner DC signal than the half-wave rectifier, but the circuit itself is much more complicated with the introduction of a transformer. This essentially rules this topology out for this research because of the space needed to implement it.

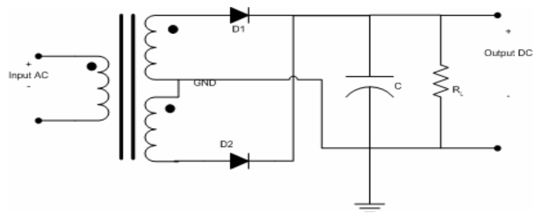



Figure 3.3: Full-wave Rectifier

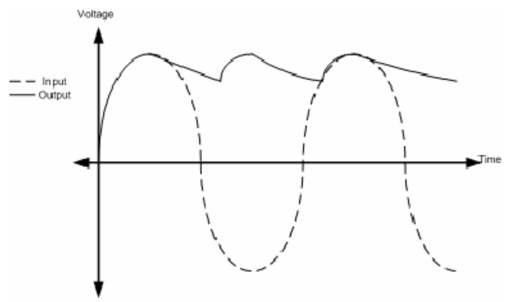



Figure 3.4: Full-wave Rectifier Output Waveform

There are other topologies for charge pumps but they will not be covered here. The others are more complex and all involve transformers, like the full-wave rectifier, and therefore take up more room than there is real estate for in this project. Instead, the circuit that was chosen to be used will now be presented. The charge pump circuit is made of stages of voltage doublers. This circuit is called a voltage doubler because in theory, the voltage that is received on the output is twice that at the input. The schematic in Figure 3.5 represents one stage of the circuit. The RF wave is rectified by D2 and C2 in the positive half of the cycle, and then by D1 and C1 in the negative cycle. But, during the positive half-cycle, the voltage stored on C1 from the negative half-cycle is transferred to C2. Thus, the voltage on C2 is roughly two times the peak voltage of the RF source minus the turn-on voltage of the diode, hence the name voltage doubler.

The most interesting feature of this circuit is that by connecting these stages in series, we can essentially stack them, like stacking batteries to get more voltage at the output. One might ask, after the first stage, how can this circuit get more voltage with more stages because the output of the stage is DC? Well, the answer is that the output is not exactly DC. It is essentially an AC signal with a DC offset.

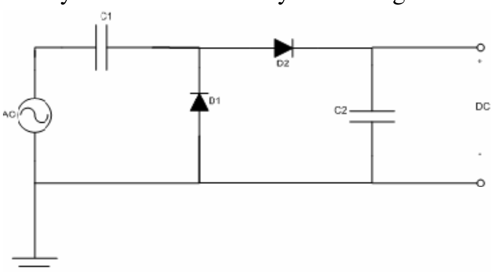



Figure 3.5: Voltage Double Schematic

This is equivalent to saying the DC signal contains noise. This can be seen in Figure 3.6. This is where the other stages come in. If a second stage is added on top of the first, the only wave that the second stage sees is the noise of the first stage. This noise is then doubled and added to the DC of the first stage. Therefore, the more stages that are added, theoretically, more voltage will come from the system irregardless of the input. Each independent stage, with its dedicated voltage doubler circuit, can be seen as a battery with open circuit output voltage VO and internal resistance RO.

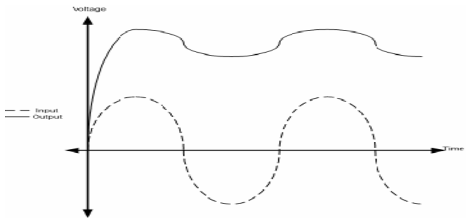
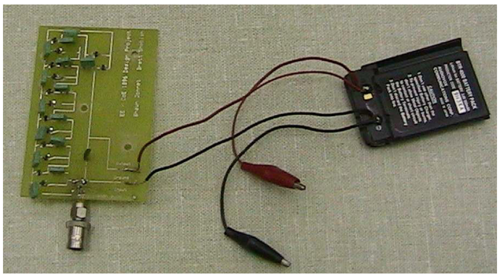



Figure 3.6: Voltage Doubler Waveform

When n of these circuits are put in series and connected to a load of RL, the output voltage will be given by Equation (1).

From Equation (1), we know that the output voltage Vout is determined by the addition of R0/RL and 1/n if V0 is fixed [2]. With VO, RO, and RL all constants, we can see from the equation that as n increases, the increase in output voltage will be less each time. At some point, the voltage gained will be negligible. There was a recent project using a charge pump design that involved stages of voltage doublers. This project required a minimal amount of optimization to the parameters for the charge pump in order to get a cellular phone battery to charge. This charge pump printed circuit board (PCB) is shown in Figure 3.7. On this board, you can see that the antenna is input to the system through a Subminiature version A (SMA) connector. An SMA to Bayonet Neill Concelman (BNC) connector is also included. An antenna was purchased to use instead of being specifically fabricated for this particular project. Once the signal is brought into the system, it passes through seven stages of charge pump. The capacitors for this test are through-hole making it easier to modify for optimization. The diodes are surface-mount Agilent HSMS-2820 Schottky diodes, but the diodes are fixed and are not the subject of optimization or tuning. This system uses an output capacitor for the DC leveling of the output voltage and to hold a charge.

The testing setup for this project is shown in Figure 3.8. As you can see, the output of the charge pump circuit is input directly into the battery. This is one of two ways to charge the battery. The other is to power the phone through its DC input circuitry, and let it charge the battery. But, for the early project, all that was specified was to get the circuit to charge a battery directly. The power the circuit was able to get from the system was enough to charge the battery at a rate of 2mV per second. This was an average result, calculated by letting the battery charge for a minute and checking the voltages both before and after. This result was promising enough to try charging a phone directly.



## V. THE ANTENNA

The most straightforward option for the receiving antenna is to use an existing antenna that can be obtained commercially. This idea was explored along with fabricating a new antenna. As can be seen from Figures 3.1 and 3.2, there is a coaxial connector to connect to the antenna. For the initial research, a quarter-wave whip antenna was used for all the testing purposes. This antenna is similar to that used on car radios. It is called a quarter-wave antenna because it is designed so that its length is approximately one quarter of the wavelength of the signal. This means that for a 915MHz signal, with a wavelength equal 32cm, a quarter-wave antenna would have an 8cm length. The main dilemma in using this type of an antenna is that it requires a rather large ground plane in order to work properly. This is fine for car radios that can be grounded to the frame of the car. But, for this project, the ground plane needed to receive enough of a signal to power the charging circuit is larger than the form factors of the charging stands chosen to house the circuits. A picture of the quarter-wave whip antenna is shown in Figure 3.9.

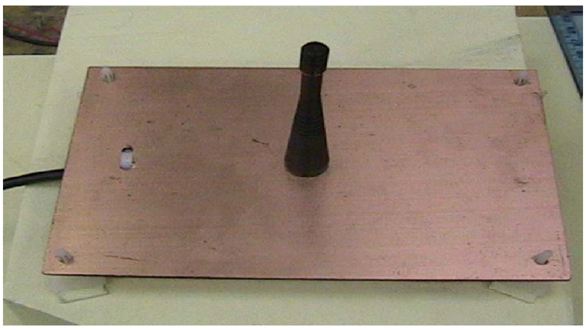


Figure 3.9: Quarter-wave Whip Antenna

The large copper plate is the ground plane. The antenna is attached to the copper, with an SMA connector on the under side of the ground plane. This type of connector uses a simple screw mechanism allowing for easy connectivity with other circuits and test equipment. The cord is connected on the other side to the BNC connector of the board. As you can see, this ground plane is rather large, too large to be used inside the stand for a cellular phone. It covers almost 50% more area than the stands that were selected for this research. With this in mind, a different type of antenna needs to be researched and tested. Other types of antennas to consider are patches, microstrips, dipoles, and monopoles. The patch antenna has two major problems when being used with a research project like this. The first is that it also needs to be relatively large, on the order of the ground plane for the quarter-wave whip antenna. The second reason is that it is highly directional, meaning that it only radiates, and accepts radiation, in one direction, i.e., it does not have a good coverage area. These reasons rule out this option. A micro strip antenna can be any type of antenna discussed previously, but what makes it unique is that it is “painted” on to a surface so that it is in the same plane as the printed circuit board. This type of antenna is used mostly on small surfaces such as silicon die to be used by the circuit on the same die. By “painted” on, what is meant is that on a silicon die it is etched onto the surface, or on a printed circuit board, it is part of a conductive layer. This means that it can be patch, a dipole, or a quarter-wave whip, as long as all the metal is in the same plane. The main problems with this antenna are its gain and its directionality. These types of antennas are appropriate to be used in RFID, but for this project they would be a hindrance. It is possibly an option to explore in future research.

## VI. SYSTEM SPECIFICATIONS

This research project is primarily empirical. There are many variables in the system that can change the voltage that is developed. The stage capacitors need to be optimized. The number of stages needs to be determined that, combined with the capacitor values for each stage, will result in a sufficiently high voltage level to turn on the phone and charge the phone’s battery. Also, a capacitor can be used across the output as a filter to provide a flat DC signal and store charge. The value of that capacitance also needs to be determined. There really are no fixed parameters for any of these values. The only specified value for any element in this research is the frequency that is being transmitted to the station. This frequency is to be 915MHz.

As discussed in the previous chapter, there have been projects completed to lay the foundation for this research. One of these projects involved the charging of a cellular phone battery directly from a charge pump. The results of this experiment were sufficient to provide a starting point. The previous project used the same charge pump we have chosen, i.e., stages of voltage doublers.

## VII. SIMULATION

Using the previous project results as a starting point, the actual prototyping for the charging circuit was begun. One of the specifications of this research is to make the circuit fit inside a base station for a phone. In this case, the printed circuit boards (PCB) need to be made small to fit the available area. As presented in Chapter 3, the previous research used discrete, through-hole components in the PCB. But, in order to make the PCB small, surface mount components were used. Using surface mount components allows us to make the boards sufficiently small. However there are drawbacks to using components this small, especially when the testing is largely trial and error. Due to the small size of the surface mount components, the components are rather difficult to handle and solder in the circuit. Also, the pads to which the components are attached are small, and they do not have enough solder to allow them to be removed and replaced more than 3 or 4 times. Plus, when the components are constantly being unsoldered and resoldered, the conductive solder covering on the board loses its solder, and it becomes increasingly difficult to solder new components to the PCB. Carrying out empirical testing like this therefore calls for very good simulation software. The piece of software most people are familiar with when simulating electronic circuits is SPICE or some variation. SPICE stands for Simulation Program for Integrated Circuit Emphasis. “SPICE is a powerful general purpose analog circuit simulator that is used to verify circuit designs and to predict the circuit behavior. This is of particular importance for integrated circuits. It was for this reason that SPICE was originally developed at the Electronics Research Laboratory of the University of California, Berkeley (1975) [2].” This software, however, is too limited for this project. It is difficult to simulate complex circuits at very high frequencies, such as 915MHz, which is the desired frequency for this research. It can be done, but only for very small and less-intensive circuits, and it still takes a very long time – on the order of hours - to compute the response. However for the energy harvesting circuit, any SPICE program that was used crashed before it could complete its calculations. This means that some other program was needed for simulating the circuit. The program chosen was one that has been around a while and has an established reputation for simulating circuits and antennas at high to very high frequencies. This program is marketed by Ansoft. The first iterations were known as Serenade, but the newest versions of the software are called Ansoft Designer. A screen shot is shown in Figure 5.1.

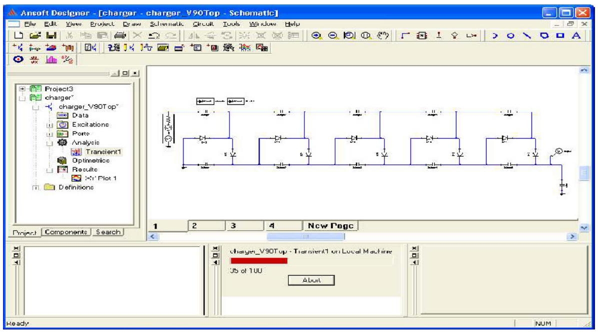


Figure 5.1: Ansoft Designer

## VIII. CONCLUSIONS

In this thesis, we submit a first step towards a goal that would have profound ramifications on the cellular phone industry and the portable electronic device industry as a whole. Experimental results show that while we were not completely successful at achieving our overall goal of having the charging circuit in a stand be able to charge the battery of a cellular phone while it was within the phone using a wireless RF source, we have completed the goal of being able to charge the battery while the phone is in its stand. Circumventing the proprietary circuitry in the charging path will allow future adaptation of the wireless RF energy harvesting concept produced by this research.

## IX. REFERANCE

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