

# Wireless Power Transmission for Charging Mobiles

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**Abstract**—Wireless power transmission holds a promise able future for generating a small amount of electrical power for charge mobile wirelessly. growing Importance in wireless field which has numerous benefits such as it would completely eliminate the need of carrying charger along with mobiles, no more need of keeping mobiles nearer to socket as cables have shorter length than area covered by wireless field. This paper presents architecture of wireless transmission for mobile systems(WPTM), design specifications with simulation of quarter wave printed monopole antenna which is best suitable for the project because of its high gain & efficiency and low loss. A Schottky diode based charge pump circuit performance is also studied with simulations result with input of 0dBm and -10dBm. Purpose of this paper is to build an architecture for wireless low power transmission system which is, simple, affordable robust and to identify promising directions for future research.

**Keywords**—Wireless power transfer for mobile(WPTM), Nikola Tesla,  $\lambda/4$  printed monopole antenna, schottky diode.

## I. INTRODUCTION

The technology and theory behind wireless charging exist around for a long time – the idea was initially suggested by Nikola Tesla, who demonstrated the principle of wireless charging at the turn of the century [3]. This paper implies wireless transmission of power using RF waves. A suitable charging circuitry is demonstrated which can capture high frequency signal and convert it into DC signal.

The application scenario considered in this paper is as follows. A low noise AC signal at 915MHz is to be generated using a signal generator. At receiver end a  $\lambda/4$  printed monopole antenna tuned at same frequency will capture signal transmitted, output of which is to be given to charge pump circuit which is multi stage voltage multiplier. Finally output is to be measured at output of voltage doubler.

This paper is organized as follows: Section II gives a brief description of background of wireless power transfer system and information about basic antenna and mobile charger mechanism. Specifications of monopole antenna are proposed in section III. Section IV deals with charge pump circuitry. Section V

shows the simulation results, Section VI represents the conclusion of the study. Finally future work will be referred to in section VII.

## II. WIRELESS POWER TRANSFER

Nikola Tesla is the one who first proposed the idea of Wireless Power Transmission and demonstrated “the transmission of electrical energy without wires” in 1891 [2]. In 1893, he invented the illumination of vacuum bulbs without using wires for power transmission at the World Columbian Exposition in Chicago. The Wardenclyffe tower was designed and constructed by Tesla mainly for wireless transmission of electrical power [3].

Energy harvesting has been in the focus of the research community in recent years. There are numerous sources of power that energy harvesting can benefit from, and solar energy harvesting is one of the key examples since it has the highest energy density among other candidates. However, it has a drawback of being able to operate only when sunlight is present. In [11], a solar energy harvesting module is used to power a sensor mote. Vibrational energy harvesting is presented in [12] while harvesting energy from thermoelectric device attached to human is discussed in [13]. Small amount of work has been done on RF energy harvesting due to its low energy density. Wireless battery charging system using RF energy harvesting is discussed in [7]. In [5], the energy of  $60\mu\text{W}$  is harvested from TV towers, 4.1 km away, and is able to operate small electronic device. Ambient RF energy harvesting with two systems has been studied in [14]. Recently prototypes for such RF harvesters have been developed in the academia [4], [8], [9], as well as commercial products have been introduced by the industry [15].

### A. Wireless power transmission system

William C. Brown has designed, developed a unit and demonstrated to show how power can be transferred through free space by microwaves [6]. In the transmission side, the microwave power source generates microwave power and the output power is controlled by electronic control circuits. In the receiving side, an antenna receives the transmitted power and converts the microwave power into DC power.

B. Architecture of wireless power transmission for mobile(WPTM) systems

Fig. 1 shows the architecture of the Wireless Power Transmissions for mobile systems. Signal generator transmits a low noise AC signal at 915MHz into space while the antenna of the receiver catches it to convert it into electricity. Theradio waves cannot be captured efficiently if the length of an antenna is not accurately right for the frequency used. It should not be too long, or too short. A good transmitting antenna is always a good receiving antenna, and for ordinary uses, one antenna can be served for both functions.

Output of receiving antenna is to be connected to charging circuitry which converts high frequency AC signal to DC, to get more of output voltage doubler circuit is to be connected which rectifies as well as doubles the voltage present at input, number of stages used is directly proportional to number of times voltage doubles. Finally required output is to be taken at multi stage voltage doubler's end.

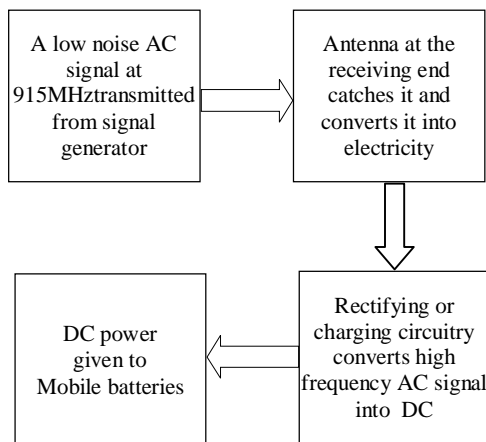


Fig. 1. Architecture of WPTM System

C. Scope and discussion

WPTM system  $\lambda/4$  printed monopole antenna is proposed which very simpler in structure, easy to construct and have low cost. In this paper specifications of monopole antenna are discussed. A multistage voltage multiplier which is used as a charging circuit is proposed. Voltage multiplier has an advantage of doubling the input voltage, though the output is not exactly DC. It is an AC signal with a DC offset.

III. QUARTER WAVE PRINTED MONOPOLE ANTENNA FOR AND DISCUSSION 868/915 MHZ

Dipole and monopole are similar in characteristics as well as structure. The difference being that a monopole has one connection point to the circuit, whereas a dipole has two connection points. For this project, the monopole antenna is the antenna of choice because it is simple in design and simple in structure. It consists of a copper wire piece with one end connected to the circuit, whereas the other left open[16]. Good quality of this antenna is that it has

quiet large operating frequency range. For research, it is helpful because exact tuning of the antenna is not required.

A. Basic properties of a quarter wave monopole antenna

Quarter wave monopole is a ground plane dependent antenna which must be fed single-ended. The antenna must have a ground plane to be quiet efficient, and ideally the ground plane should spread out to at least a quarter wavelength, or more, around the feed-point. The size of the ground plane affects the gain, resonance frequency and impedance of the antenna.

The length of the monopole PCB trace mainly determined by the resonant frequency of the antenna, but because of having very wide gain bandwidth of a quarter wave monopole, the antenna length is not that critical. But like any other antenna types, the gain of a quarter wave monopole will vary if parameters, such as case/box materials, distance to the ground plane and size of the ground plane, width and thickness of the PCB trace are varied. If any of these parameters are changed, it will affect the gain of antenna.

B. Determining the length of the printed monopole antenna

For an application operating in the 902-928MHz band, the antenna can be tuned to a frequency in between the band. Because of the fairly wide gain bandwidth of the antenna, the antenna will show good overall performance in the whole frequency range 868-928MHz when tuned to 900MHz.

The antenna is to be fabricated on a standard 1.6mm FR4 substrate material with dielectric constant  $\epsilon_r$  of 4.4 at 900MHz. The width of the monopole trace is selected to  $W = 1.5\text{mm}$ . The wavelength in free air is  $\lambda_0 = 333\text{mm}$ . So the guided wavelength  $\lambda_g$  on the FR4 substrate is approximated to about

$$\lambda_g \sim 0.75 \cdot \lambda_0 = 0.75 \cdot 333\text{mm} \sim 250\text{mm}$$

The approximate, physical length of a printed quarter wave monopole antenna will be then

$$L = 250/4 = 62.5\text{mm}$$

Provided that, the size of the available ground plane should be close to the ideal and that the antenna trace should be uniformly surrounded by the FR4 substrate. When implementing the monopole as a trace on the PCB, the length of the trace should be extended somewhat to allow for some fine-tuning of the antenna to resonance at 915MHz. If the size of ground plane is approaching the ideal size and the antenna trace is uniformly surrounded by the FR4 substrate, then the length of the trace should be extended by about 20%[15].

C. RF energy specifications

The main challenge faced in harvesting RF energy is the freespace path loss of the transmitted signal with distance. The Friis transmission equation relates the

received ( $P_r$ ) and transmitted ( $P_t$ ) powers with the distance  $R$  as,

$$P_r = P_t G_t G_r \left( \frac{\lambda}{4\pi R} \right)^2 \quad (1)$$

Where  $G_t$  and  $G_r$  are antenna gain, and  $\lambda$  is the wavelength of the transmitted signal. The received signal strength, diminishes with the square of the distance, requires special sensitivity considerations in the circuit design. Moreover, FCC regulations limit the maximum transmission power in specific frequency bands. For example, in the 900-MHz band, this maximum threshold is 4W[11].

#### IV. CHARGING CIRCUITRY

It is a circuit that when given an AC input, it is able to output a DC voltage typically larger than a simple rectifier generates. It is simply an AC to DC converter that rectifies the AC signal and clamps the DC level. This circuit is used in many electronic devices today. The circuit is much more complex than the charge pump used in this work. Power converters have a lot of protective circuitry in addition with circuit to reduce noise. In fact, it is for safety regulation. Any power-conversion circuits use a transformer to isolate the input from the output, which prevents overload of the circuit and user injury. For work of low power energy harvesting, a circuit of mentioned complex would require more power than available, so that it would be very inefficient and may not function. Which causes need to use a simple design. As mentioned due to an advantage of getting more voltage at output than the input voltage multiplier circuit is chosen to be used.

##### A. Voltage multipliers

Given circuit is called a voltage multiplier because according to theory, the voltage that is received on the output is almost twice that at the input if only one stage is considered. The schematic is shown in figure 2 which represents one stage of the circuit. The input is rectified by diode  $D_2$  and capacitor  $C_2$  in the positive half of the cycle, and in negative cycle by diode  $D_1$  and capacitor  $C_1$ . During the next positive half-cycle, the voltage stored across capacitor  $C_1$  during the negative half-cycle is transferred to capacitor  $C_2$ .

Thus, the voltage on capacitor  $C_2$  will be roughly two times the peak voltage. The most interesting feature of this circuit is that by adding more stages and connecting them in series, we can get more voltage at the output.

Output is not exactly DC. It is essentially an AC signal with a DC offset. This can be seen in Figure 3. If a second stage is added in series of the first, output voltage will clamp to more value.

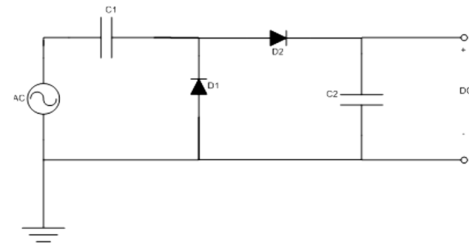


Fig. 2. Voltage Double Schematic

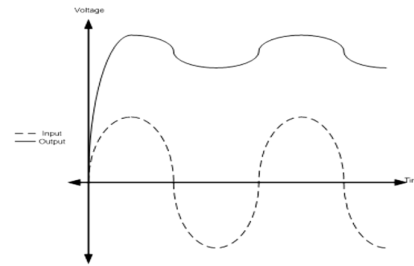


Fig. 3. Voltage multiplier Waveform

Therefore, the more the stages added, more will be the output voltage irrespective of the input. If open circuit output voltage is  $V_o$  and internal resistance is  $R_o$  and  $n$  circuits are put in series connected to a load of  $R_L$ , the output voltage is given by ,

$$V_{out} = \frac{nV_o}{nR_o + R_L} R_L = V_o \frac{1}{\frac{R_o}{R_L} + \frac{1}{n}} \quad (2)$$

##### B. System Specifications

There are many variables in the system that can cause change in the voltage developed. The stage capacitors, the number of stages needs to be optimized. Also, a value of capacitor used at the output which acts as a filter to provide a flat DC signal and store charge, needs to be determined. There are no fixed values for any of these parameters. The only specified value is the operating frequency of the system. This frequency is chosen to be 915MHz.

1) *Choice of Diodes:* One of the crucial requirements for the energy harvesting circuit is to be able to operate with weak input RF power. For a typical 50 antenna, the -20 dBm received RF signal power means amplitude of 32 mW. As the peak voltage of the ac signal obtained at the antenna is generally much smaller than the diode threshold [10], diodes with lowest possible turn on voltage are preferable. Moreover, since the energy harvesting circuit is operating in high frequencies, diodes with a very fast switching time need to be used. Schottky diodes use a metal–semiconductor junction instead of a semiconductor–semiconductor junction. This allows the junction to operate much faster, and gives a forward voltage drop of as low as 0.15 V. Diode from Agilent technologies HSMS-2852 is to be employed, which has turn on voltage of 150mv.

2) Number of stages:

The number of stages used in charging circuitry, has the largest effect on the output voltage. Generally, the voltage of the output increases as the number of stages increases. However, practically force a limit on the number of permissible stages, and in turn, the output voltage. Actually, the voltage gain decreases as number of stages increases due to parasitic effect of the capacitors of each stage, and finally it becomes negligible.

3) Stage capacitance:

The stage capacitance is very sensitive parameter of the system. Sometimes, minimal changing can cause drastic effect on output voltage. The capacitance parameter is given by the following equation.

$$Q=C.V(t)$$

In above Equation, the voltage across capacitor is inversely proportional to the capacitance in relation with the charge. To hold same charge value of capacitance must be minimum to have more voltage across the capacitors.

3) Output capacitance:

Output capacitance affects least on the overall system. It only affects the speed of the transient response. Bigger the value for the output capacitance, slower will be the voltage rise time. This does not mean that no capacitor should be used. Without a capacitor there, the output will be a DC with ripple which is unfaithful.

V. SIMULATION

Design and simulation of antenna is done in sonnet software whereas, Simulation of circuit is to be done in Agilent Advanced Design System(ADS) software. The harmonic balanced analysis (a frequency domain method) is proposed in this work since objective of the project is to compute the steady state solution of a nonlinear circuit. The alternate method, the so called transient analysis that is undertaken in the time domain is not used owing to the reason that it must collect sufficient samples for the highest frequency component. This involves significant memory and processing requirements. Depending on the results of simulation, number of stages is to be selected.

A. Antenna

As said, Antenna was designed in 'sonnet' software and simulation results were studied. Design considerations were as discussed in 3.3. Figure 5 shows the design of  $\lambda/4$  printed monopole antenna which is about 100mm in length and 10mm in width. Lossless material is chosen to analyse results.

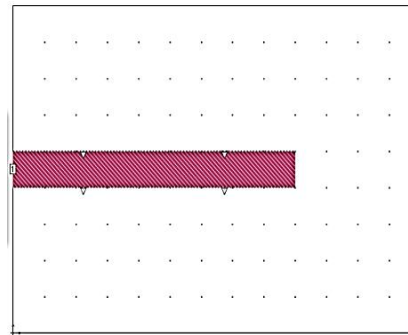


Fig. 4. Design of  $\lambda/4$  printed monopole antenna

The S11 parameter which is relative loss and Far field response of Gain with respect to frequency were as shown in figure 6 and figure 7 respectively.

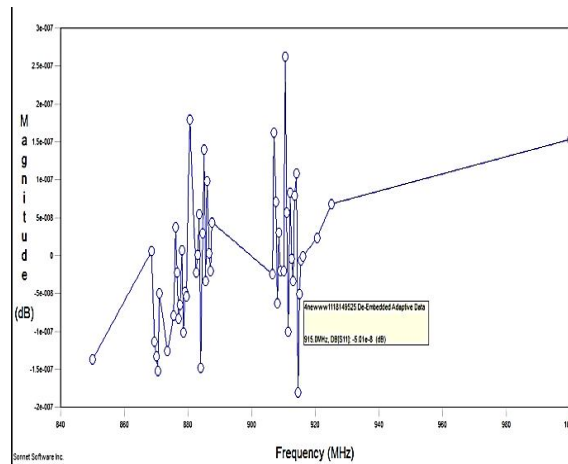


Fig. 5. S11 parameter in dB with respect to Frequency in MHz

Also the gain at 915MHz is 6.3dBi which is actually more than desirable, however use of lossy material will decrease its gain.

B. Voltage multipliers

The energy harvesting circuit which is voltage multiplier is simulated using Agilent Advanced Design System (ADS) software. Snapshot of the circuit is given in Figure 7. Simulation results were analysed with respect to number of stages and value of stage and output capacitance. Output from receiving antenna is assumed to be in between -10dBm to 0dBm. So the output of circuit is simulated with respect to two different inputs, i.e. at -10dBm and at 0dBm. It is found that stage capacitor of 1nF gives best optimized result, if capacitance lowered further, output voltage decreases. Output capacitance has less effect on value of output voltage. Bigger the value for the output capacitance, the slower will be the voltage rise time. Lowering capacitance to pF lowers current drastically so capacitance value is chosen to be 1nF.



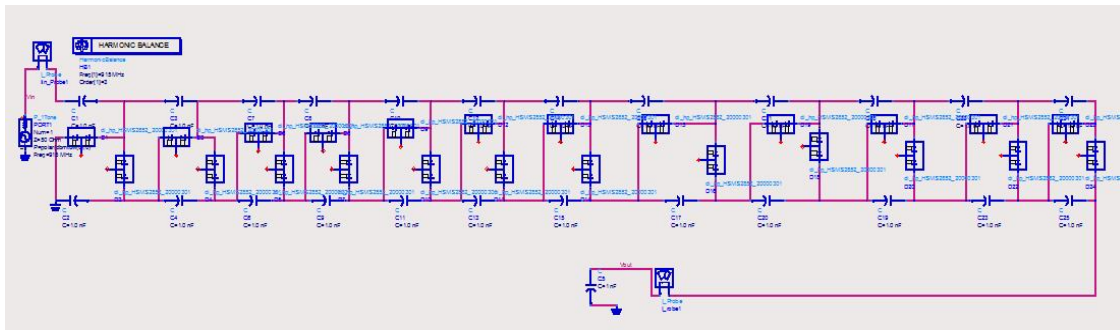


Fig. 6. 12 stage Voltage multiplier in ADS

Simulation results for stage 1 to stage 12 were studied. The voltage of the output increases with increment in number of stages, however the voltage gain decreases as number of stages increases due to parasitic effect of the constituent capacitors of each stage, and finally it becomes negligible. Table 1 and Table 2 shows the simulation results with respect to 0dBm and -10dBm input respectively.

TABLE I  
O/P VOLTAGE AND O/P CURRENT TAKEN AT INPUT OF 0 DBM

Number Of Stages	Output Voltage(Vout)	Output Current(Iout)
1	1.04V	590uA
2	2.02V	1.2mA
3	2.92V	1.7mA
4	3.74V	2.2mA
5	4.48V	2.7mA
6	5.12V	3.1mA
7	5.66V	3.5mA
8	6.10V	3.9mA
9	6.44V	4.0mA
10	6.69V	4.1mA
11	6.88V	4.3mA
12	6.91V	4.4mA

VI. CONCLUSION AND DISCUSSION

Wireless low power transmission system is studied. Among all the antennas of  $\lambda/4$  printed monopole antenna is found to be suitable for low power transmission such as mobile charger. Charging circuit model is proposed. The concept of charging a cellular phone battery using wireless RF energy harvesting can be feasible. While voltage across output is desirable but output current is quite lower showing that battery or mobile phone will require much time to charge. Wireless low power transmission system would completely eliminate carrying chargers for mobile phones or tablets.

VII. FUTURE WORK

The future studies mainly concentrate on reducing physical size of antenna and embed it in mobile itself to give high efficiency and less loss. Also designing high level power transmission system for charging laptops have good scope of work.

TABLE III  
O/P VOLTAGE AND O/P CURRENT TAKEN AT INPUT OF -10DBM

Number of Stages	Output Voltage (Vout)	Output Current (Iout)
1	233.5m V	200uA
2	432.9mV	400uA
3	649.51mV	600uA
4	817.55mV	720uA
5	954.8mV	0.9mA
6	1.06V	1.0mA
7	1.14V	1.1mA
8	1.19V	1.2mA
9	1.23V	1.3mA
10	1.25V	1.4mA
11	1.25V	1.5mA
12	1.25V	1.5mA

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