# Wireless charging using Far-field Technology

Sohail Ahmad[1], Muhammad Haroon[2]

[1]Linköping University Sweden
[2]Ericsson AB Sweden

**ABSTRACT**

**Power harvesting using RF waves is a hot topic for more than 50 years but only few have achieved enough power that could be utilize instantly. In this paper we have discussed different type of available frequency bands and their potential to harvest wireless power. The basics of wireless power transmission systems are discussed and blueprints are created for conversion of electromagnetic signals into DC within microwave frequency range.**

## I. INTRODUCTION

The idea to harvest wireless power and use it to run small electronic devices is relatively new but wireless power transmission started with the work of Heinrich Hertz. Later Nikola Tesla built enormous coil to transmit power wirelessly. In our daily environment we are surrounded by electromagnetic waves. Ambient electromagnetic radiation emitted from Wi-Fi transmitters, GPS satellite, WLAN antennas, Bluetooth, TV/radio transmitter antennas and other sources could be converted into enough electrical current to keep a battery charging. Due to manufacturing of less power hungry mobile electrical devices, it is easy to keep their batteries charging 24/7 using this technology. The most common forms of wireless power transmission is carried out using Direct Induction, Electro-dynamic Induction Method, Electrostatic Induction Method and Resonant Magnetic Induction. Other methods under consideration are Electromagnetic Radiation in the form of microwaves and lasers [1] and Electric Conduction through natural media [2]. We can use far field of the radiations to generate power. Some rectenna has been designed in past with good efficiency. For example a modified directional antenna with efficiency of 18% was designed with single-tone RF power of -20dBm [3].

### Electromagnetic Induction and Qi standards

In August 2009 some interested companies joined together and produce industry standards for low-power inductive charging called Qi [4]. Qi was a standard for transferring wireless power over a distance up to 4cm. The system consists of a power transmission pad and receiver in a portable device. To use the system the mobile device should be placed on top of the power transmitter which charges it via resonant inductive coupling. The system was designed to transfer power up to 5W and consists of two parts i.e. a base station responsible of transmitting power using a coil which generates an oscillating magnetic field. This field is transmitted to a receiving coil which induces alternating current using Faraday's Law of Induction.

### QI standard vs. Far-field

The most popular application for Qi standard is wireless charging for mobile phones. Qi standard is widely accepted because of its efficient power transfer capabilities. But it is not suitable for mobile devices because the receiving coil should be in contact or only be 4cm apart from the transmitting coil. The solution to the problem is using far field region of the electromagnetic field to generate energy. The field follows the inverse square law for radiating power intensity of the electromagnetic radiations. So further the source lesser the power received.

A survey was conducted by Imperial College London [5] to explore the potential of ambient RF energy harvesting using frequencies within ultrahigh frequency (0.3 – 3 GHz) with an efficiency of 40%. Input RF power density measurement outside the Northfields London Underground station is shown in figure 1. The figure shows different power density levels from different source antennas.

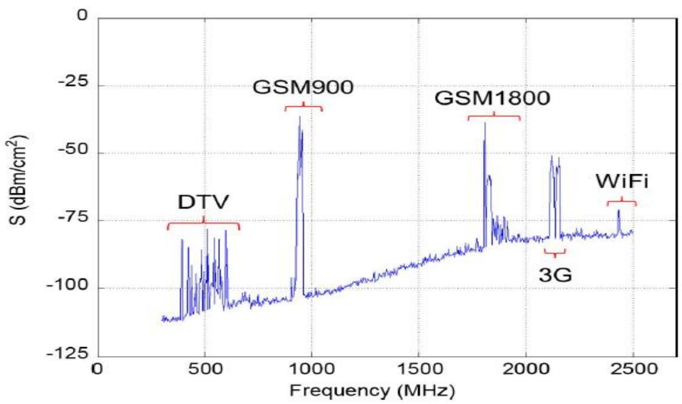


**Fig. 1 Input RF power density at different frequencies**

Some personal observations have been made from different sources at RF Laboratory, University of Linköping, campus Norrköping Sweden. RF spectrum analyzer was used to measure power levels and an average of received signals is shown in table1.

**Table 1. Transmitted and received signal powers**

| $f$ | $P_t$ | S | *Signal type* | $P_r^*$ |
|---|---|---|---|---|
| 2.4 GHz | 0dBm | 1m | Bluetooth | -40 dBm |
| 810 MHz | 33dBm | 900m | LTE | -105 dBm |
| 5 GHz | 23dBm | 10m | WiFi | -60dBm |
| 101 MHz | 80dBm | 9.5Km | Radio Station | -115dBm |

* Receiving power could be different depending on variables like distance, antenna gain, transmitting power and receiving system etc.

In table 1 $f$ represent the frequency, $P_t$ is the transmission power (regulated by FCC standards and could possibly be transmitted by source antenna) and $P_r$ represents the received power measured. This power could be rectified into DC and can be stored or used.

Early experiments of converting microwaves to DC were performed by Brown B C in 1966 in which Microwave power transmission and helicopter technologies were successfully combined and a hovering vehicle was held aloft solely by power derived from a microwave beam [6]. The experiment was performed using microwaves of 2.45 GHz and a rectenna composed of 28 half-dipoles terminated in abridge rectifier using point-contacted semiconductor diodes. A typical rectenna is composed of antenna, diode, capacitor and a load resistor, as shown in figure 2.

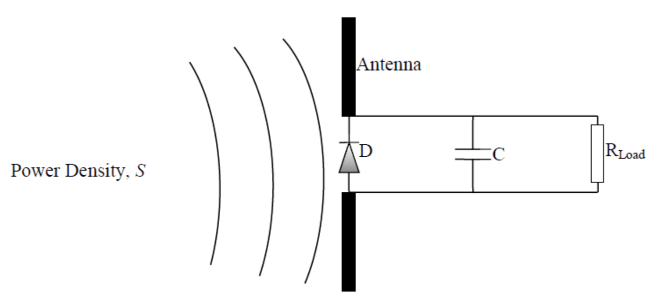


**Fig.2 Rectenna design**

**Possible frequency bands for power harvesting**

WLAN/GSM band is a candidate for harvesting energy from electromagnetic waves. The distance from the base stations could range from 25m to 100m and GSM or WLAN band produces low power densities ranging 0.1mW/m$^2$ to 1.0mW/m$^2$ on single frequency. Larger antennas are required to harvest enough energy to run small electronic devices and small antennas could result in very low electrical signals, not enough to power small sensors. Working in this band we have to trade-off between antenna size and power generation. To achieve higher power levels a relatively larger antenna could be designed which shall increase the surface area. But unfortunately it is not possible to design a source antenna due to restrictions of transmitting in licensed bands.

Open spectrums are better candidate for designing power generation circuit. The biggest advantage for working in unlicensed bands is that it allows us to transmit without any restrictions. Unlicensed ISM bands under consideration are:

(1) 433.05MHz to 434.79MHz
(2) 2.4GHz to 2.5GHz
(3) 5.725GHz to 5.875GHz
(4) 24.00GHz to 24.250GHz

Frequency range from 433.05MHz to 434.79MHz and dedicated for short range devices. RFIDs are most famous devices work in this frequency range. The corresponding limits for IEEE standards for maximum

permissible human exposure to microwave radiations at 2.45 are 81.6W/m$^2$as average over six minutes or 16.3W/m$^2$as averaged over 30 minutes. Similarly for 5.8 GHz it is 100W/m$^2$as averaged over six min and 38.7W/m$^2$ as averaged over 30 minutes, for controlled and uncontrolled environments [7]. IEEE restriction for maximum power density in public is 2W/m$^2$ over the frequency range from 100MHz to 3GHz. This is low power density but is of very great interest for scientists to generate ambient power. The power level varies between -5 and 10dBm and scientists are working to increase efficiency as close as possible to 100%.

**Wireless Power Transmission (WTP) system design**

Wireless power system can be divided into following three systems.

(1) A **microwave source** design with high conversion efficiency and low noise level.
(2) A microwave **receiver antenna** which could be a narrowband or wideband depending on the system design. The size and design depends upon requirement of the project.
(3) A **rectifier** design for converting received power to DC mostly using diodes.
(4) **Voltage Doubler** is optional and can be designed according to requirement.

**Microwave Source**

If a microwave source is in need then slotted wave guide antenna, parabolic dish antenna and microstrip patch antenna are the available options. Slotted wave guide antenna is the best candidate because of its high efficiency and high power handling capability. But the typical bandwidth is only a few percents [8].

**Receiver Antenna**

High bandwidth antennas are much larger than narrowband ones. For example, a log-periodic antenna has more bandwidth and less gain than a Yagi-Uda of similar size. If a dedicated microwave source is used and placed a few meter apart from rectenna, then total surface area of the receiving antenna can be minimized. The microwave source shall be transmitting monochromatic wave without any modulation and a narrow band rectenna would work efficiently.

Alternatively in the absence of a microwave source a wideband antenna can be designed to reach relatively higher power levels. A spiral antenna can be used as a receiving antenna because it could have a very large bandwidth. Its fractional bandwidth can be as high as 30:1. Within spiral antenna we have the options to choose between Long-Periodic Spiral antenna and Archimedean Spiral antenna.

**Impedance Matching & LPF**

Narrowband antennas work in a specific band and it is easy to design an impedance matching circuit and radio tuner. If a wideband antenna is designed then we can increase the bandwidth of the receiving signal by tuning into bigger bandwidth and designing impedance matching circuit for wideband. The impedance matching can be done using conventional particle swarm optimization (PSO) or Adaptive Quantum Particle Swarm Optimization (AQPSO) algorithm for maximum power transmission efficiency [9]. Higher order harmonics can be removed by using a Low Pass Filter.

**Rectification**

Rectifiers are non-linear devices are special frequency conversion circuits which convert RF signals into zero frequency signals i.e. AC to DC conversion. For rectification, high conversion efficiency is required because power harnessing is the basic objective. The characteristics under concern to select a rectifier are DC resistance, stray capacitance, turn on voltage and breakdown voltage. Schottky diodes can be used for rectification purpose and can operate up to 100GHz [10]. Rectification is mostly done by single or combination of diodes. Two techniques for rectifications include half-wave rectification or full-wave rectification.

**Voltage Doubler (optional)**

The harvested power would be in very low voltages. We can use voltage doubler circuit to produce higher voltage than produce by a single diode [11]. Fig 3 shows the possible voltage doubler circuits.

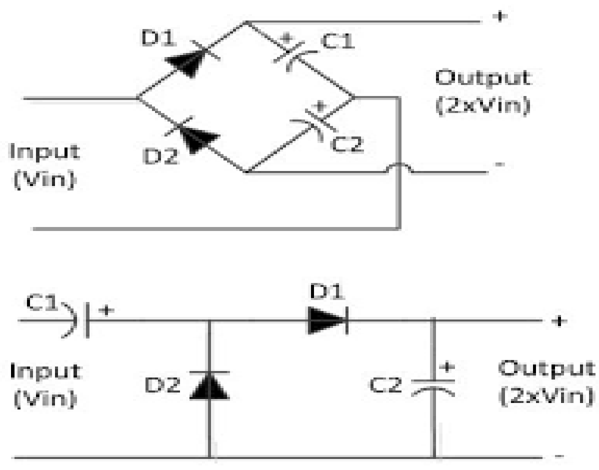


**Fig 3: Voltage doubler circuits**

## CONCLUSION

Any frequency range in ISM band is a potential candidate for designing WPT system design and 2.4GHz with 100MHz of bandwidth is ideal for this. A microwave transmitter can be designed using slotted wave guide antenna. Success of the system wholly depends upon the efficiency of the rectenna design. This can be achieved by designing efficient receiving antenna and rectifying circuit. We are confined by the emission limits by IEEE so the only possibility for success is to design an efficient Power Transmission system design.

Alternatively any frequency band within ISM could also be used.

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