# Energy Harvesting Through the Radio Frequency Wireless Power Transfer

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***Abstract*—Mobile communication, radio and television towers, satellites orbiting earth and even the cellular phones are continuously transmitting Radio Frequency waves. This immense amount of energy source around us is un-utilized and with the use of appropriate technology it could be utilized to power up small standalone applications. This research investigation studies the field intensity radiation pattern in a few areas for harvesting the radio frequency waves to power micro-watt level applications. The antenna pattern design choice, the energy harvester design, the implementation and test results are presented. Dipole, isotropic and spiral antennas are used to scavenge the power and comparison of harvested power is displayed in different locations at the coastal belt from Galle to Colombo in Sri Lanka. Among the three tested antennas, isotropic antenna is identified as the best antenna for energy harvesting in the Sri Lankan perspective. The practical application based on the designed harvester system is presented.**

Keywords— ***RF energy harvesting, wireless power, antenna design, doubler circuit***

## I. Introduction

Energy harvesting is the process of collecting energy from the surrounding environment and converting it to electricity. It is gaining more and more interest as a potential next generation green energy source to power up low power devices. In the surrounding environment – particularly the urban – is filled with radio frequency (RF) waves continuously transmitted by mobile, radio and television communication towers, satellites orbiting earth and even from cellular phones. One of the fundamental challenges in achieving RF energy harvesting is that even though the energy transmitted from RF sources is high, only a small amount can be scavenged in a real environment; the rest is dissipated as heat or absorbed by other materials. The next challenge is using the harvested energy to power up existing circuits, especially in devices over long periods of time [1-3]. RF energy harvesting is therefore based on absorbing the said RF energy and converting it into electricity for energy requirements. This research work proposes a practical solution to harvest enough RF energy to low power consumption devices. The overall objective is to develop a fully functional micro-scale RF energy harvesting unit that is able to power up devices that operate in the µW or mW range.

The main challenge is to reduce the size of the harvester and to use passive and low power components [1-3]. The power that is required to power up low power circuitries is mostly within the range of µW to mW [1-3]. The µW or mW level of power can be generated using energy harvesters that can generate electricity using RF waves [2-4]. The unit mainly consists of receiving antenna and voltage doubler circuit. The antenna is designed to receive GSM signals , because it has been identified that the most available RF energy source within Srilanka is the RF energy transmitted by the GSM towers [5, 6]. Hence it is required to design a relevant antenna that would not be limited to a single band due to the fact that GSM signals are transmitted in 900MHz, 1800MHz and 2100 MHz band spectrums. Also test measurement is made to ensure the GSM spectrum available in Sri Lanka as shown in Figure 1. Moreover, the voltage doubler circuit is utilized to raise the output DC voltage level.

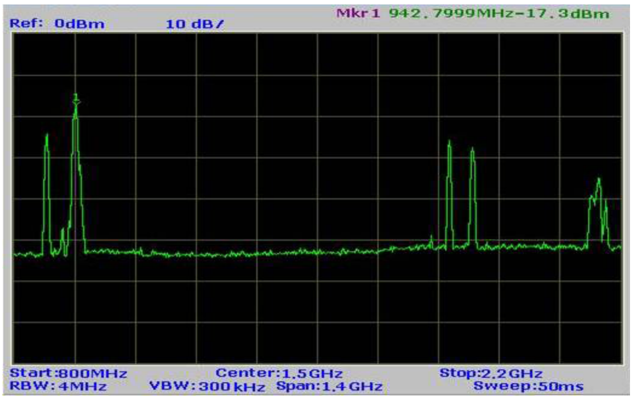



Fig.1. GSM power spectrum available at Galle, Sri Lanka

## II. Antenna Design and Analysis

One of the most important components in the RF energy harvesting device is the receiving antenna. It captures the RF energy from the environment and converts it to electric energy. It is essential to have a receiving antenna with a greater efficiency. Hence several antennas are considered while paying attention to the size and the mass of the antennas.

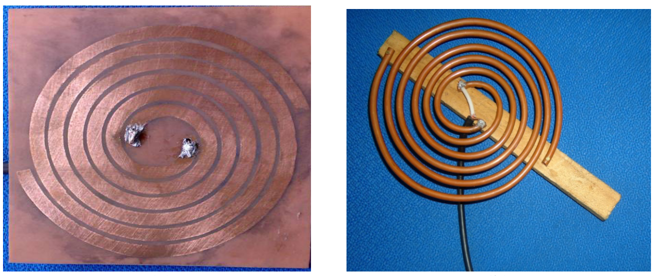
## A. *Spiral Antenna*

The wideband characteristic of the spiral antenna makes it an attractive choice where a single antenna can be used to receive over wide ranging spectrum. Archimedean spiral is the best configuration for harvesting GSM signals in the range of 900 MHz, 1800 MHz and 2100 MHz [7]. The design frequency range selected for the spiral antenna is 850 MHz to 2150 MHz. The inner radius $r_{in}$ and the outer radius $r_{out}$ of the spiral antenna are determined based on the frequency range that the antenna is supposed to cover [8].

$$r_{in} = \frac{c}{2\pi \, f_{lower}} \tag{1}$$

$$r_{out} = \frac{c}{2\pi \, f_{upper}} \tag{2}$$

where $c$ is the speed of light in the free space and $f_{lower}$ $f_{upper}$ are respectively the lower and the upper cut of frequencies of the antenna. Then the optimum combination of spiral arm width and the number of turns in the spiral antenna are determined. According to the test results the maximum power level of -40.1dBm is received from the spiral antenna with the arm width of 8 mm and 6 turns as shown in Figure 2(a). The spiral antennas which are designed using copper board basically have a two dimensional shape. It is necessary to design a three dimensional model of the spiral antenna to increase the aperture area. Thus a copper tube used to design the new spiral antenna with same dimensions as shown in Figure 2(b). The antenna design with the copper tubes gives a maximum power level of -39.1 dBm.



(a) (b)

Fig. 2. Spiral Antenna

(a) Using Copper Bead (2D) (b) Using Copper Tube (3D)

## B. *Isotropic and Dipole Antenna*

To evaluate the performance of the spiral antenna with dipole and isotropic antennas, dipole and isotropic antennas are designed for the frequency bands of 900, 1800, 2100 MHz. Isotropic antenna designed for the 900 MHz is shown in Figure 3. In the isotropic antenna, three electrical dipoles are arranged spatially along mutually perpendicular axes. The electrical leads of the antenna degrade the naturally high symmetry of this arrangement. The antenna is designed for a frequency of 900 MHz. The lengths of the three half wave dipoles used are calculated using Equation (3)

$$l = 0.44\frac{c}{f} \tag{3}$$

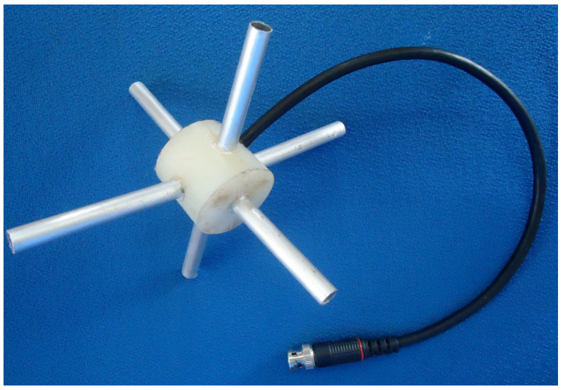


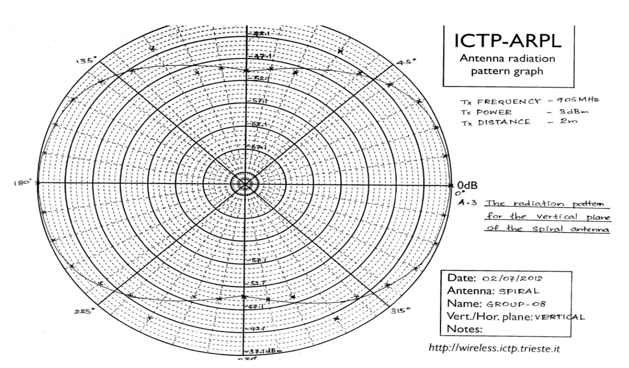
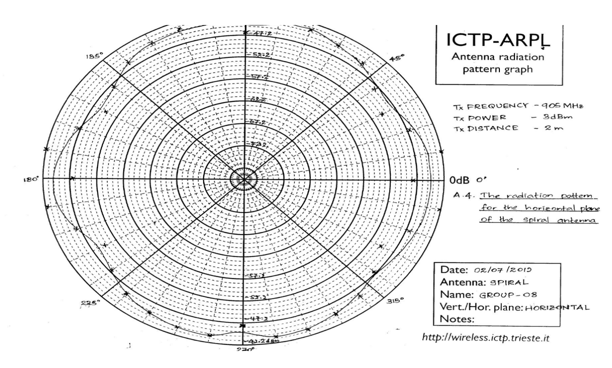
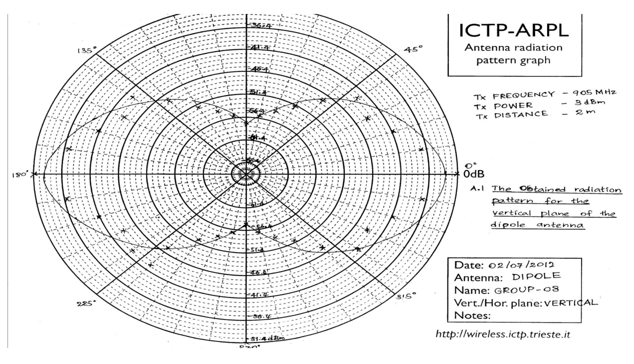
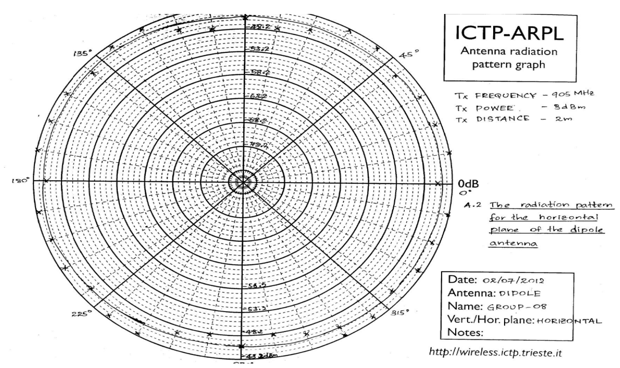
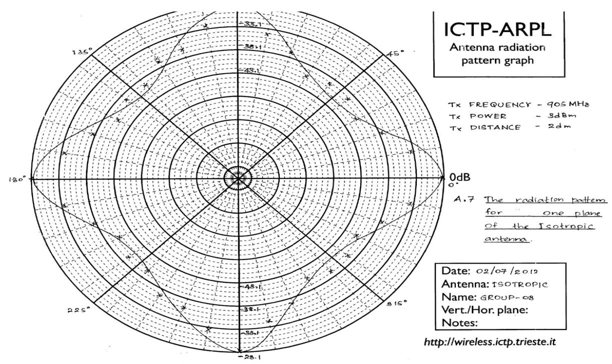
Fig. 3. Isotropic antenna for 900 MHz frequency

## C. *Radiation Pattern*

The radiation pattern is highly demanding in measurement steps and difficult to interpret. Any antenna radiates to some degree in all directions into the space. Measurements of radiation pattern should therefore be made in a plane nearly parallel to the earth surface. The Radiation patterns were measured for Dipole antenna, Spiral antenna and Isotropic antenna. The transmitter frequency is 905 MHz with transmitter power of 3 dBm while the measurement is taken from a distance of 2 m from each antenna. The radiations patterns of vertical and horizontal planes are given in TABLE 1. The peak power level was obtained as -31.4, -37.1 and -28.1 dBm for Dipole, Spiral and Isotropic antennas respectively. It shows that the gain of the isotropic antenna is the highest among all three antennas tested while the gain of the dipole antenna is higher than the spiral antenna. Since the transmitted signal is a 900 MHz level it is inappropriate to compare the gain of the spiral antenna, which is designed for the frequency range of 900 MHz to 2100 MHz, with the two other antennas that are designed for 900 MHz it. However, it shows that at the particular frequency of 900 MHz gain of the spiral antenna is the lowest. The experimental setup for radiation measurement is as shown in Figure 4.

Fig. 4. Experimental measurement setup

TABLE 1. Radiation Pattern of Different Antenna Design at Various Planes

<table>
<tr><th></th><th>Vertical Plane</th><th>Horizontal Plane</th></tr>
<tr><td>Spiral</td><td><br></td><td><br></td></tr>
<tr><td>Dipole</td><td><br></td><td><br></td></tr>
<tr><td>Isotropic</td><td colspan="2"><br></td></tr>
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*D. Measurements at Different Locations*

According to the past researches about RF energy density, RF signal density for the GSM signals in Galle city, Sri Lanka area is considerably high among other cities in Sri Lanka [5]. The designed antennas are used to measure the RF signal measurements in different areas. The measurements were taken at all the major coastal cities from Galle to Colombo, Sri Lanka as in the map shown in Figure 5. The maximum powers obtained in the major cities are tabulated in TABLE 2 and the graphical comparison is shown in Figure 6.

The maximum powers around the urban area closed in Colombo are measured from 1800 MHz spectrum while all the other urban areas the maximum powers are recorded from 900 MHz frequency spectrum from Dipole and Isotropic antennas. However, the maximum power measurements from a spiral antenna are the broad spectrum of 900-2100 MHz. It is evident from the results that the isotropic antenna is superior among the three tested antennas. However, it cannot be concluded since the spectral pattern of available energy and the polarization of the RF wave influence the type of antenna selection.


Fig. 5. The coastal area map from Galle to Colombo

TABLE 2. Power at various locations for the designed antenna

| Location | Received Power (dBm) | | |
|---|---|---|---|
| | Dipole | Spiral | Isotropic |
| Galle | -37.7 | -39.1 | -40.7 |
| Hikkaduwa | **-18.8** | **-19.0** | -19.9 |
| Ahungalla | -30.0 | -33.2 | -32.2 |
| Ambalangoda | -33.5 | -33.9 | -32.1 |
| Aluthgama | -31.4 | -29.8 | -33.5 |
| Kaluthura | -24.1 | -25.3 | -23.9 |
| Panandura | -30.7 | -26.1 | -26.4 |
| Moratuwa | -26.8 | -29.1 | -25.2 |
| Mt. Lavinia | -22.3 | -25.9 | **-17.3** |
| Dehiwala | -19.0* | -21.7 | -17.8* |
| Bambalapitiya | **-18.8*** | -23.0 | -17.9* |
| Kollupitiya | -19.1* | -24.7 | -18.6* |
| Colombo Fort | -22.4 | -24.6 | -25.0 |
| * Measurement from 1800 MHz spectrum | | | |

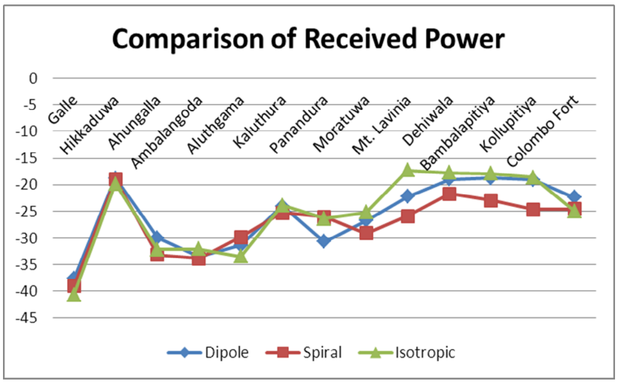


Fig. 6. Comparison of receiving power from three different antennas along the coastal belt from Galle to Colombo

## III. Harvester Circuit Design

### A. Harvester Ciruit

The Radio Frequency is an AC signal with a considerably higher frequency. In order to get a DC signal out of the AC signal, a rectifier circuit is employed. The received voltage level has to be boosted up to a higher level which is sufficiently enough to obtain the required output voltage. It is more convenient to use one suitable circuit to perform both the tasks in order minimize the power consumption of the circuit components. Therefore as the energy harvester circuit the Villard voltage multiplier is used to rectify the input voltage, by employing multiple stages the required output voltage can be obtained is as shown in Figure 7.

The output voltage that can be produced by an n stage Villard cascade circuit [4] is given in Equation (4)

$$V_{out} = 2nV_{in} \quad (4)$$

The output voltage (Vout) for n stages with a load resistance can be given in Equation (5) as

$$V_{out} = \frac{nR_L}{nR_0 + R_L} V_{in} \quad (5)$$

where $R_0$ is the internal resistance and $R_L$ is the load resistance.

A five stage Villard voltage multiplier is designed that can provide the open circuit voltage up to 2.8 V. The implemented rectifier circuit is shown in Figure 8.

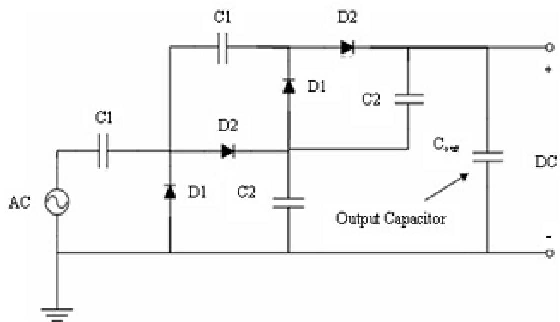


Fig. 7. Villard cascade circuit

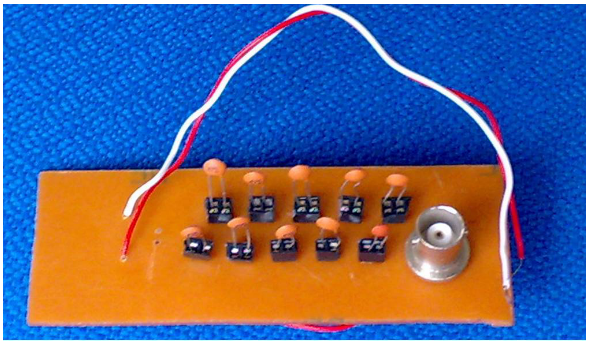

Fig. 8. Rectifier circuit with five stages

The output voltage for a number of stages with different capacitor value is shown in Figure 9.

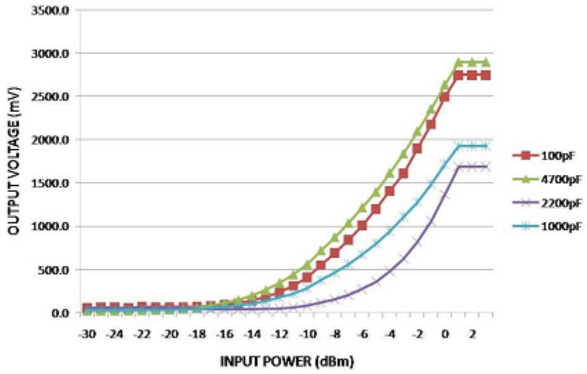


Fig. 9. Five stage output voltage for different capacitor values

## B. *Small Power Applications*

The RF energy exists in our environment appears in a relatively low power level. Hence the power that could be harvested via an RF energy harvester mechanism lies in a lower range. Therefore attempts are made to find out a low power consuming device that could be consolidated with the energy harvester circuit. Since the harvested power is in mW to µW level, we can consider powering up devices like digital sensors and wristwatches. An electronic wristwatch and a charging unit capable of charging a low power capacitor or a rechargeable battery is shown in Figure 10. According to application the number of stages of the harvester circuit can be changed.

Fig. 10: Practical energy harvesting application

# IV. Conclusions

Overall our study shows that the isotropic antenna is the best among the three antennas tested in Sri Lankan perspective. However, the selection may vary depending on the spectral distribution and the polarization of the available RF signals.

The wrist watch can be powered up for its continuous operation from the RF energy dispersed in the environment in frequency bands of 900 MHz 1800 MHz and 2100 MHz which are used for the cellular communication. Apart from that the harvesting unit as a small scale portable charging booth which facilitates to charge up low capacity storage devices like capacitors and rechargeable batteries. This can be further improved by reducing the biasing voltage of the diodes and improving the antenna performance. According to the experimental data collected from the outside experiments it is clear that the receiving RF power level in the Galle city (in Srilanka) region lies in a very low position. However, it cannot be concluded unless a large scale survey about the power level in the Galle city is done since the measurement made in this study is an arbitrary location of the Galle city. Hence with such limitations this is a successful approach to harvest the energy from the available RF spectrum within Srilanka. RF energy harvesting may be improved to a higher level by improving the aperture area of the receiving signal. Using meshes, arraying elements and directing RF beams are the other possible ways of yielding better performance. Although the application of this energy source is limited by its low power output, it can be used to power at no running cost many devices that require low power. Further, RF energy is an alternative renewable green energy source; it has its own limitations due to the size of the harvesting device. Hence future work must be focused on miniature RF harvesting devices.

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