Cross Dipole Antenna Based Glass Substrate for Ambient Energy Harvesting

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Abstract. In this paper, a crossed dipole antenna based on Pyrex Glass substrate is proposed for dual bands, GSM 900 MHz and Wi-Fi 2.4 GHz. Each dipole is placed on a side of the substrate with the antennas oriented perpendicular to each other. Both antennas participate in an omnidirectional radiation pattern in perpendicular planes to form a radiation pattern similar to the isotropic. The realised gain for each dipole and the total radiation efficiency are 1.46 dB and 88\% respectively. The glass substrate provides a reduction in the antenna size of about 36\% compared with typical individual elements in free space.

Keywords – Cross dipole antenna, Dual bands, Energy Harvesting.

1. Introduction
Ambient energy harvesting has recently attracted attention with regard to powering low power applications such as sensors and to eliminate the cost of battery replacements [1-2]. The radiation of mobile towers at GSM 900 MHz and routers at Wi-Fi 2.4 GHzs are rich sources of ambient energy [3-4], though designing an effective antenna is crucial to capturing these low power RF signals to be converted into DC power. As the polarization of the incoming signal is unknown and the direction can be changed due to multipath propagation, the receiving antenna of any energy harvesting system must be installed in a specific orientation for better reception; otherwise the received energy will be poor due to mismatch in the polarization or direction. An antenna with isotropic-type radiation pattern is a good solution to these limitations. Generally, an antenna radiates more in one specific direction than other directions. However, dipole antennas can radiate in one plane omnidirectionally while creating a directive pattern in the other plane [5].

To obtain such isotropic radiation patterns, two dipole antennas are assembled together in such way they are perpendicular to each other. Accordingly, each dipole will contribute an omnidirectional pattern in a different plane so that they work together to generate an isotropic radiation pattern [6]. In the literature, such cross-dipole antennas have been investigated by researchers in several wireless communication systems including mobile communications, satellite communications, radio frequency identifications (RFID), and worldwide interoperability for microwave access (WiMAX) [7-11]. The feeding technique of the cross-dipole antennas is based on either single or dual ports [12-13], designed to provide circular
polarization with wide bandwidth for wireless communications [14 - 15]. The cross-dipole antennas in the literature are mostly designed with reflectors to produce higher directivity and gain [14-19]. In this paper, the cross antennas are also designed as ground free to maintain the omnidirectional features of the individual elements, and they are printed on Pyrex Glass substrate to provide a reduction in the antenna size of up to 36% in free space while retaining high radiation efficiency and realised gain comparable to the half wavelength dipole in free space. In this paper, the design approach of these antennas is thus introduced in section 2, then the essential parameters of the proposed antennas are discussed in section 3. The paper is concluded in section 4.

2. Dual Band Cross-dipole Antenna
The proposed cross-dipole antenna resonates at two critical bands, GSM900 MHz and Wi-Fi 2.4 GHz. A fundamental design requirement for the dipole antenna in free space is to set the length of the antenna as a half wavelength, yet this length can be reduced slightly by controlling the width of the antenna and the gap separation between the two antenna arms. The target of this paper is to design a printed antenna on a ground free substrate to be later integrated with rectifiers to form rectennas. The results were achieved using CST Microwave Studio. The available commercial substrates, FR4 and Rogers, are a few millimetres thick, and such substrates can contribute slightly to reducing antenna length. An alternative option for such substrates is Pyrex Glass, a commercially available substrate with variable thicknesses. The dielectric properties of this substrate are $\varepsilon_r = 4.82$ and the permeability, $\mu_r$, is unity. The dimensions of the antenna and the substrate thus obtained are depicted in Figure 1. The benefit of using this substrate is a reduction in the antenna size of about 36% of the typical size in free space. The reason for this reduction in antenna size is the dielectric properties of the glass substrate. In this medium, the speed of the electromagnetic wave is changed according to these dielectric properties and hence the resonance frequency, $f_r$, and the wavelength are functions of the effective dielectric constant of the medium as seen in equation 1; thus, the size of the antenna is scaled down [20].

$$f_r = \frac{f_0}{\sqrt{\varepsilon_e}}$$

where $\varepsilon_e$ is the effective dielectric constant of the medium and $f_0$ is the resonant frequency in free space.
Figure 1: Proposed antennas on Pyrex Glass substrate.

The size of the antennas is tuned in terms of length and width to obtain resonant frequencies in the target bands GSM900 MHz and Wi-Fi 2.4 GHz. The antenna in the same dimension was then simulated on FR4 substrate with $\varepsilon_r = 4.3$ and Roger 3006 with $\varepsilon_r = 6.15$; the results are shown in Figure 2. This figure shows the advantage of using the Pyrex Glass substrate in terms of accessing lower resonance frequencies with the same antenna size.

Figure 2: Reflection coefficients of the cross-dipole antenna on Pyrex Glass, FR4, and Roger 3003 substrates.

3. Radiation Pattern of the Proposed Antenna

The proposed cross-dipole antennas offer two omnidirectional patterns in the two perpendicular horizontal and vertical planes. Each pattern is produced by one of the perpendicular dipoles, as shown in Figure 3. The horizontal dipole along the x-axis generates a vertical omni pattern while the vertical dipole along the y-axis generates a horizontal omni pattern, as shown in figure 3 (a and b, respectively).
Figure 3: Radiation pattern of the cross-dipole antenna (a) horizontal dipole and (b) vertical dipole.

The integration of both patterns can result in isotropic-like radiation patterns. The realised gain of each dipole after considering the mismatch loss and dielectric losses in the antennas is 1.46 dB; this value is close to the realised gain of the typical dipole in free space, which is 1.85 dB.

The total radiation pattern of the proposed antenna is shown in Figure 4a. A zoomed snapshot of the polar radiation pattern is shown in Figure 4b; from the front view of the cross-dipole antenna, the generated pattern covers almost all directions, with a realised gain of more than 0 dB except in a few narrow bands that still have power radiation with a minimum realised gain of -1.74 dB. The top, bottom and side views of the antenna display a 360° pattern of 1.46 dB of the realised gain. This means that the antenna can receive signal effectively from all directions.
Radiation efficiency is an important parameter determining the efficiency of the antenna in sending and receiving signals. This parameter is calculated by taking the percentage of the radiated power to the supplied power through the feed of the antenna. The total efficiency considers the loss due to the mismatch at the feeding port and the dielectric losses, and is here calculated as 88%, as compared with that of the typical dipole antenna in free space which has a total efficiency of 92%. This reduction in efficiency mainly comes from the dielectric losses of the Pyrex Glass substrate. However, this value is still comparable to the typical value if the reduction of the antenna size is considered.

4. Conclusion
In this paper a cross-dipole antenna was proposed that can resonate on dual bands GSM900 MHz and Wi-Fi 2.4 GHz. A reduction in the proposed antenna size was achieved by printing the antenna on a Pyrex Glass substrate, creating a form 36% smaller than the typical size in free space. Although the chosen substrate adds more weight to the antenna, the associated advantages are considerable. The proposed antenna offers 88% total radiation efficiency, as compared to 92% for a typical antenna. The gain of the individual element of the proposed antenna is 1.46 dB, as compared with 1.85 dB gain for a typical dipole antenna in free space. Furthermore, the radiation pattern of this antenna is similar to that of the ideal isotropic antenna, making it a good choice to be adopted as a receiving antenna for ambient RF energy harvesting systems.

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