Semi-Elliptical Dipole Antenna for RF Energy Scavenging

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***Abstract*— A method to miniaturize a planar semi-elliptical dipole antenna in the FM band (88-108 MHz), is presented. The proposed method modifies the antenna's structure, having dimensions of a roof tile (L = 432 mm x W = 345 mm), so that an array can be created. The first step was to use slots to meander the surface current path of the antenna lowering the resonating frequency and size. The second step involved using a passive matching network to further reduce the overall dimensions of the antenna with minimal loss. It was shown by using both slots and a matching circuit a size reduction of 0.31λ x 0.25λ was achieved with a bandwidth of 6% and a gain of 0 dBi at 100 MHz. This antenna can be used for RF energy scavenging applications.**

I. Introduction

In recent years, the use of radio frequency (RF) has increased with advancements in communication systems such as radios, television's, mobile devices, Wi-Fi, GPS and Bluetooth. As a result, there is a large amount of excess electromagnetic energy available in the environment. RF energy scavenging systems convert this excess ambient energy into electrical energy to provide a sustainable source for low powered devices. Basic RF energy scavenging systems commonly include components such as source, antenna, rectifier and load. Of these components, the antenna is essential as it collects the excess electromagnetic energy so that it can be converted to electrical energy.

Shariati et al. have demonstrated through RF field investigations that the best RF scavenging sources in Melbourne, Australia are in the broadcasting systems at 540 MHz (20 MHz bandwidth) and 100 MHz (88-108 MHz) [1].

To make these scavenging systems versatile and manageable, these systems often contain broadband omnidirectional miniaturized antennas.

However, fundamental limitations arise when the physical size of the antenna is reduced. By decreasing the dimensions of an antenna, undesired influences to its performance characteristics such as bandwidth, gain, efficiency and polarization usually emerge [2]. The challenge is then to improve these parameters while still maintaining the reduced physical size.

Recently, numerous antenna designs have been proposed to improve on both bandwidth and efficiency. Some designs include a small handset antenna for FM reception, using a spiral antenna mounted on a PCB board [3], a meander line dipole antenna, that was analyzed and included calculation of radiation efficiency [4], and a rectangular slot antenna with patch stub [5]. While these papers present miniaturized antennas, these designs have also demonstrated low gain.

Many popular techniques exist to miniaturize antennas: using substrates with high dielectric constant to reduce the antenna's size. Another approach is to use high permeability materials to reduce the resonant frequency due to the inverse relation that exists between them. In addition, the bandwidth is also maintained due to the direct proportionality of the bandwidth with the substrate's permeability [6]. Metamaterials, which are artificial materials synthesized by specific inclusions, can also be applied to miniaturize the antenna's size as these materials exhibit a negative permittivity and permeability [7]. However, the use of metamaterials makes the antenna highly directional, which is an undesired effect for omnidirectional antennas. Another approach is to use non-foster impedance matching [8]. However, complex active matching networks are often required.

In this paper, an omnidirectional planar antenna will be miniaturized using a combination of slots cut into the radiator as well as a passive matching network to further reduce the size, making it small enough to be fabricated on a house roof tile for use in RF scavenging systems. The results presented in this paper show that the proposed methods reduce the antenna's size to 0.31λ x 0.25λ, having a similar gain compared to a 0.5λ antenna.

II. Concept

An antenna array, where each individual antenna is connected to a rectifier, increases the incident power delivered to the load and thus a large area would be preferred.

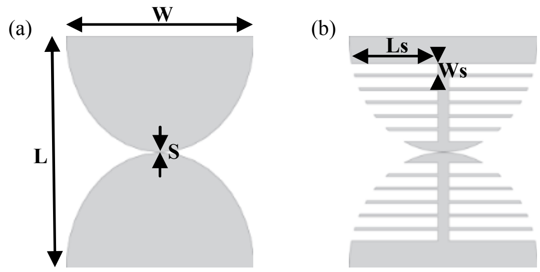

Fig. 1 Configuration of (a) original semi-elliptical dipole antenna (b) miniaturized antenna

To meet this requirement a roof top was chosen, where each antenna could be placed on a roof tile with dimensions of L = 432 mm and W = 345 mm. The first step, before any miniaturization, was to simulate a semi-elliptical dipole antenna as proposed by Abbosh et al. [9] in the frequency range of 200 MHz – 1 GHz. The dimensions were that of a roof tile (with length L and width W), matched to a 50Ω load. The geometry of the proposed antenna is shown in Fig 1a. There is a spacing, *S,* between the antenna feed points. In Fig 1a, the antenna substrate is a low-cost FR4 laminate with a thickness of 1.7 mm and a relative permittivity of 4.7. Overall, the area occupied by the antenna was smaller than 0.31λ x 0.25λ, where λ is the wavelength calculated at the lowest frequency of operation (100 MHz). The reason for the chosen antenna was because of its simplicity and broadband characteristics.

The simulated reflection coefficient of the antenna is shown in Fig 2. A broadband reflection coefficient was achieved from 217 MHz to 1 GHz with a radiation pattern of that of a dipole and a gain of 2.5 dBi, at the resonating frequency f_r = 252 MHz.

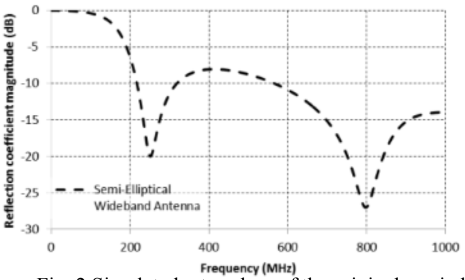

Fig. 2 Simulated return loss of the original semi elliptical dipole antenna

III. Meadering Slots

To reduce the size of the antenna, pairs of slots were cut into the upper and lower half of the semi-circular dipole antenna shown in Fig. 1(b). It was proposed by Skrivervik et al. that slots force the surface current of the antenna to meander, effectively increasing the electrical length of the antenna and thus reducing the resonant frequency [2]. The maximum dimensions of the slots after optimization for Ls and Ws were 158 mm and 20mm, respectively.

The overall length of the antenna, including the meandered slots, increased to L = 1919 mm, and thus the resonating frequency can be calculated using:

$$w = l = \frac{c}{2f_l\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

where c = the speed of light; ε_r = relative permittivity of substrate.

Using equation (1), the calculated frequency of operation for the miniaturized antenna with slots was f_r = 46 MHz. However, both the simulation and experimental results (Fig. 3) showed that the slots were only able to reduce the frequency of operation to f_r = 150 MHz, approximately three times the calculated value. While it was clear that the slot approach was effective in reducing the resonating frequency of the antenna it did not agree to the calculated value using equation (1). This descrepency can be attributed to the surface current not following the same path as the meandered slots as a result of the slot length being too short at the lower frequencies.

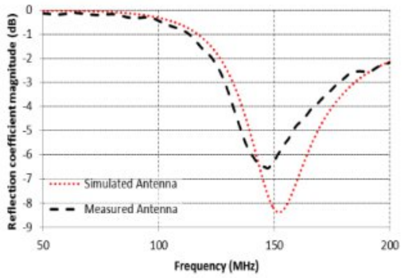

Fig. 3 Return loss of the meandered semi elliptical dipole antenna

IV. Passive Matching Circuit

To reduce the size of the antenna further a balanced passive impedance matching circuit was implemented. It had been proposed by Thompson et al. that a π-matching network, for complex impedances, was practical as it provided a greater matching flexibility and functions with three passive components rather than a traditional L-network which depends on two components [10]. Fig 4 shows the input impedance and reactance of the antenna with meandering slots.

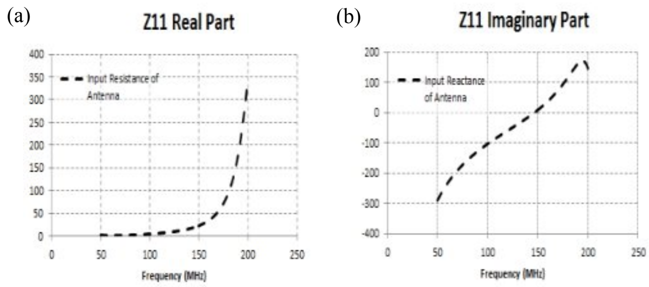

Fig. 4 Input Impedance of miniaturized semi elliptical dipole antenna before matching. (a) Real part (b) Imaginary part

At 100 MHz, the input impedance of the antenna is relatively low (Z_{in} = 4.87 – j103 Ω), with a high capacitance; this is often the case with any small antenna. As a result of such a low resistance and high capacitance value, the antenna's bandwidth after the matching circuit was implemented, reduced. More components could be added to the matching circuit to increase the bandwidth; however, this would have led to a greater loss. The antenna's S-parameter file was generated using CST Microwave Studio and then Keysight Agilent ADS was used to design the matching circuit (Fig. 5). The final circuit had dimensions L = 25 mm and W = 25 mm.

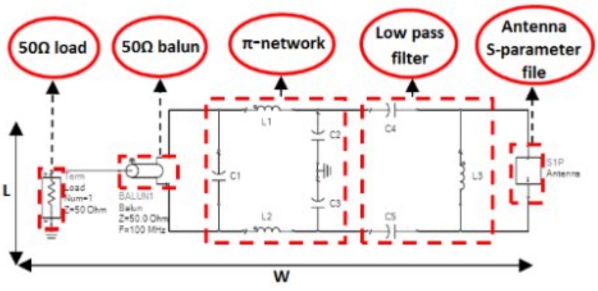

Fig. 5 Final design of both antenna and matching circuit in Keysight Agilent ADS

The matching circuit was connected to the input terminals of the antenna. A 50Ω current mode balun was also implemented in the design to have an accurate simulation.

The final design included a semi-circular dipole antenna, a matching circuit and a balun.

While the experimental results, with all elements, showed a reduction in both antenna size and frequency (f_{range} = 98-100 MHz), this result did not match entirely with the simulated result (f_{range} = 90-96 MHz). Fig. 6a and 6b shows both the simulated and experimental return loss and Smith chart, respectively. From this it was clear that there was a shift in the frequency range and a higher reflection. This was due to the tolerance of the discrete components used in the matching network.

(a)

(b)

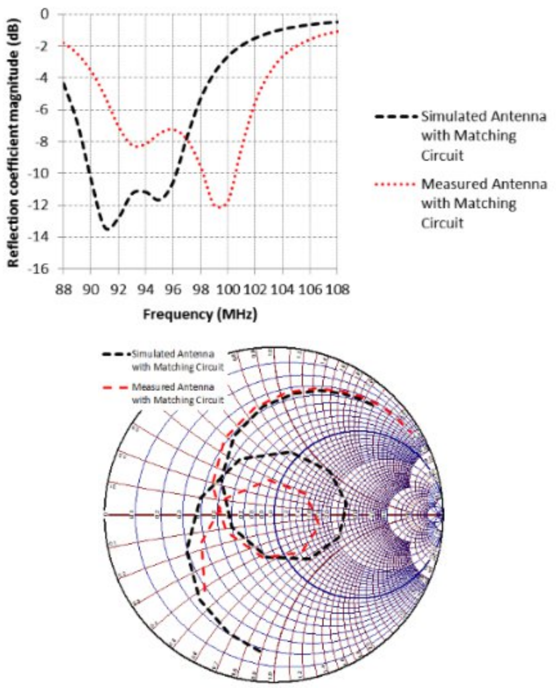

Fig. 6 Measured and simulated (a) Return loss of the miniaturized semi elliptical dipole antenna with matching circuit (b) Smith chart

The radiation pattern of the antenna measured at 100 MHz is shown in Fig. 7. This result shows that despite the size reduction that was adopted, the method maintained a dipole like performance, with a gain of 0dBi at 100 MHz (Fig. 8).

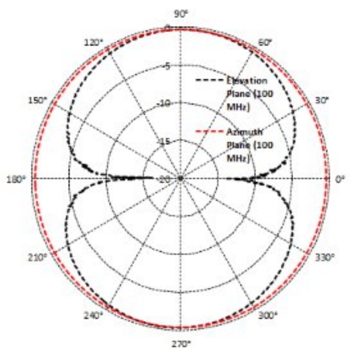

Fig. 7 Measured radiation pattern of miniaturized semi elliptical dipole antenna with matching circuit

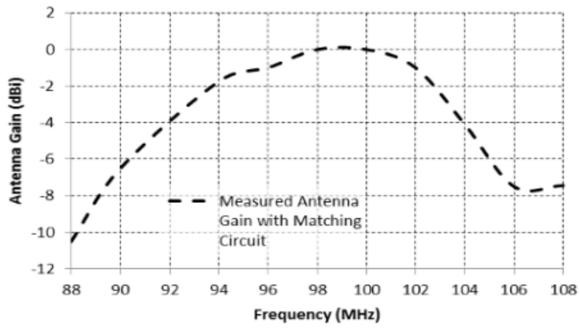

Fig. 8 Measured antenna gain with matching circuit

V. Conclusion

In this paper we have presented a miniaturized planar omnidirectional semi-elliptical dipole antenna which is operational in the FM band (88-100 MHz) having dimensions of a roof tile (L = 432 mm and W = 345 mm). Two methods were used to reduce the antennas size and frequency. First, by using slots we were able to meander the current path along the antenna to reduce the resonant frequency of the antenna from 217 MHz to 150 MHz. However, the proposed method did not reduce the antenna size as per calculated. This discrepancy can be attributed to the surface current not following the same path as the meandered slots at the lower frequencies. Hence, to reduce the size and frequency further an addition of a balanced matching circuit, consisting of both a π-network and a low pass filter, was designed and implemented. The matching circuit was then connected to the input terminals of the antenna. While both the simulated and experimental results showed a reduction in antenna size and frequency, the frequency range of both results varied. This variation can be attributed to the tolerance of the discrete components used in the matching network. However, the antenna was still operational at 100 MHz, had a total area of 0.31λ x 0.25λ and a gain similar to a 0.5λ antenna (0 dBi) and is thus suitable for use in applications such as RF energy scavenging.

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