AN OMNIDIRECTIONAL, LOW COST, LOW PROFILE, 2.45 GHz MICROSTRIP FED RECTAXIAL ANTENNA FOR WIRELESS SENSOR NETWORK APPLICATIONS

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Abstract

This paper presents the optimisation of a "rectaxial" antenna, which combines the advantages of compactness of a helical structure with the low cost and low profile of a printed antenna. By combining electromagnetic simulation with experimental verification, the key parameters governing the antenna optimisation have been determined. As a consequence, an omnidirectional 2.45 GHz microstrip fed printed antenna with size 13 mm x 5.9 mm x 0.762 mm has been realised on METCLAD duroid (permitivity = 3.48; loss tangent = 0.002) with 2.2 dBi gain, >200 MHz bandwidth, return loss ≅ -20dB. This combination of performance metrics is highly desirable for autonomous distributed sensor network applications where a small sensor node volume, omnidirectional communication and excellent power efficiency are required.

Introduction

Autonomous distributed wireless sensor networks such as those being investigated by the Speckled Computing Consortium [1] are widely predicted to have major growth opportunities in the coming years in numerous imaging, safety, biomedical and environmental applications. In most of these areas, the design challenges are somewhat different from contemporary wireless communications systems in that data rates will be low, and power consumption and size of the sensor node are the key issues [2]. Further, omnidirectional communication is vital, as the distribution of the network nodes is not known prior to deployment.

Truly "plug and forget" functionality and the opportunity to embed sensor nodes into everyday objects or the surrounding environment requires small volume solutions, the majority of which will be occupied by a battery to prolong lifetime.

These criteria place stringent requirements on the antenna for the following reasons:

i) The communication frequency should be high to minimise the size of the antenna and therefore the sensor node, yet operating at high frequencies incurs higher path loss, and higher DC power consumption for the inter-node radio transceiver.

ii) Given the low RF power levels (due to DC power constraints), the transceiver antenna should have as high gain as possible, yet given the fact that the network nodes are randomly deployed and can be moving with respect to one another, an omnidirectional radiation pattern is required.

iii) In addition to the constraint mentioned in i) above, the total volume of the antenna should be minimised to maximise the size of the battery.

iv) As large numbers of sensor nodes will be required in any network, all component costs, including the antenna should be minimised.

The "rectaxial" antenna described in this work attempts to simultaneously address these conflicting requirements by:

i) Working at 2.45 GHz to minimise antenna area (13 mm x 6 mm) whilst enabling compact RF active component realisation,

ii) Combining the concepts of planar and helical antennae to realise compact, omnidirectional solutions with good gain (2.2 dBi),

iii) Utilising a microstrip-fed duroid based printed technology to enable the antenna to be embedded within the substrate carrying the active RF circuitry which minimises the overall antenna volume and results in low cost with a simple, standard manufacturing process (no additional chip antenna required),

This work describes the optimisation of an antenna meeting the criteria for low-power wireless distributed sensor network applications by using a combination of parametric electromagnetic simulation and experimental verification.

Design of Rectaxial Antenna

The antenna design is based on the helical configuration [3] [4] [5]. As it is not a true helix, and consists of rectangular loops printed on the top and bottom of a duroid board and interconnected by a thru-board via, shown schematically in Figure 1, the antenna is described as 'rectaxial'.

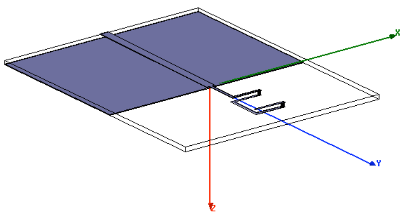

Figure 1. 3D schematic of Rectaxial Antenna.

The antenna can support many modes of propagation but the one considered is the 'normal mode' which is propagated when the perimeter is very much less than the operating wavelength. In this mode the antenna exhibits dipole-like radiation. A good starting point for the optimisation was empirically found by setting the perimeter of the helical turn to be to be one tenth of a wavelength. Using equation (1) the spacing between turns was found.

$$\text{Spacing between turns } (S_\lambda) = \text{Perimeter } (P_\lambda)^2/2 \qquad (1)$$
$$\text{Where } P=2X+2h$$

The values calculated fall within the limits described by Krauss [2] for the normal mode of operation.

Prior to optimisation in Ansoft HFSS, consideration was made of the fabrication tolerances in the practical realisation of the antenna. A duroid board of permittivity 3.48, thickness 0.762 mm and loss tangent 0.002 was used in the antenna realisation. This board is coated on both sides with 35 µm thick copper. Using the available pattern transfer techniques, track sizes with tolerance +/- 100 µm were achievable. This was incorporated into HFSS as a parametric limitation. An additional constraint was the minimum via-hole diameter of 600 µm.

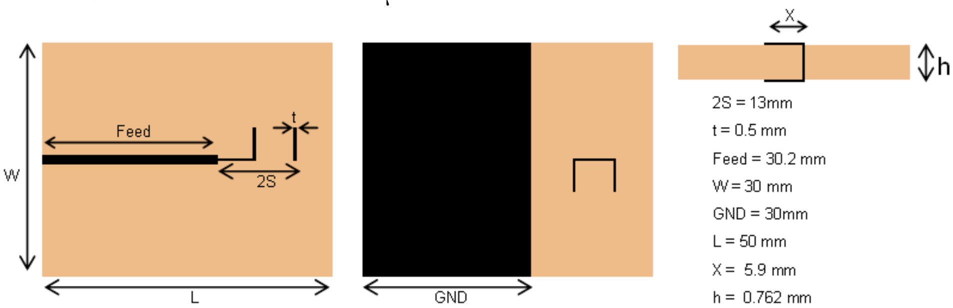

Figure 2. Diagram of rectaxial antenna with dimensions.

Investigation of the performance of the Rectaxial Antenna by simulation and experiment

Using the starting conditions and constraints mentioned above, parametric analysis and optimisation in Ansoft HFSS was used to find the dimensions to simultaneously maximise factors such as antenna gain, return loss and minimum volume. The final antenna dimensions are shown in Figure 2.

The optimisation resulted in the spacing between turns giving a slightly larger value than calculated using equation (1), because the spacing strongly influences the return loss (RL). If the spacing between turns is too small then higher reflections occur. A target value for return loss of –20 dB in simulation was set to ensure a good match and minimise power loss for the smallest possible antenna area.

The optimised antenna was fabricated and an SMA end-launcher connector added. A 9 GHz Anritsu Scorpion Vector Network Analyser was used to determine the centre frequency and return loss of the antenna. As shown in Figure 3, excellent agreement in the 2.45 GHz operating frequency between measurement and simulation is obtained. The slight degradation in return loss can be accounted for by the vias between the top and bottom traces on the duroid, which were soldered and trimmed by hand.

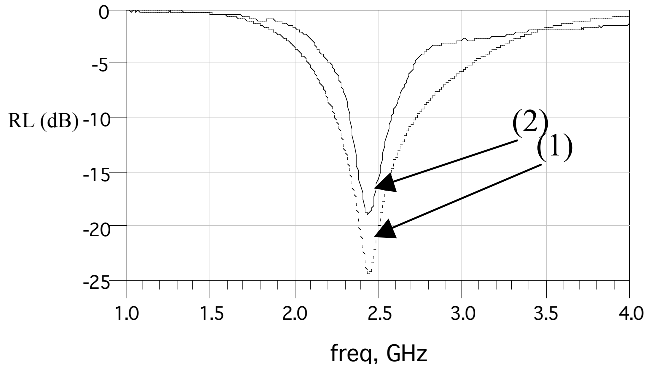

Figure 3. Return Loss (RL) results for both simulation (1) and measured (2) results.

The radiation patterns were measured using an anechoic chamber with a far field setup. The rectaxial antenna was placed upon a pedestal and connected to the receiver via a SMA Cable. The antenna was then rotated in both the vertical and horizontal to obtain cuts for the azimuth and elevation respectively. The results were then compared with the simulation plots via normalisation of the values obtained. The normalised radiation plots are shown in Figure 4. The results show good agreement between simulation and measurement. Using the received power level from a dipole as a reference, an average gain of 2.2 dBi was obtained with a peak gain of 2.69 dBi along the boresight.

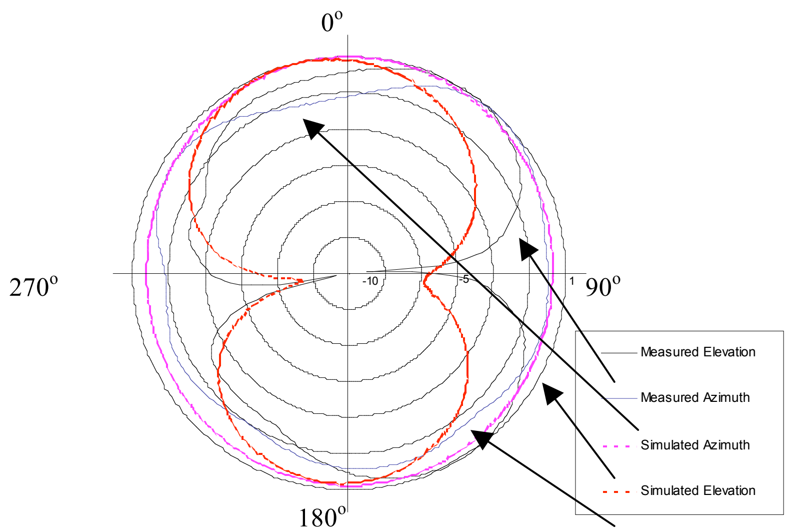

Figure 4. Normalised radiation patterns obtained by both simulation and measurement.

Conclusion

The rectaxial antenna investigated in this work has an omni-directional radiation pattern at 2.4 GHz with an average gain of 2.2 dBi and a return loss of around –20 dB. Further, it can be realised using a simple, inexpensive microstrip-based duroid technology which is integrable with the active elements of an RF transceiver. In comparison to chip antennas which are often used in these types of application, the rectaxial antenna offers superior gain (to our knowledge, the highest reported chip antenna gain is 1.2 dBi max [6]) and excellent power transfer efficiency whilst occupying only 68% of the volume of the chip referenced[6].

For the above reasons, the rectaxial antenna is ideally suited to low power distributed sensor networks as its performance simultaneously meets the often conflicting requirements for this application.

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