O'FLYNN, B. GAETANO, D. & BUCKLEY, J. 2009. Antenna Development for Wearable Wireless Sensing Systems. Proc. IMAPS-CPMT Poland 2009, Gliwice – Pszczyna, Poland, 22-24 Sept, 2009

# Antenna Development for Wearable Wireless Sensing Systems

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**Abstract:** Embedded wireless sensor network (WSN) systems have been developed and used in a wide variety of applications such as local automatic environmental monitoring; medical applications analysing aspects of fitness and health energy metering and management in the built environment as well as traffic pattern analysis and control applications. While the purpose and functions of embedded wireless sensor networks have a myriad of applications and possibilities in the future, a particular implementation of these ambient sensors is in the area of wearable electronics incorporated into body area networks and everyday garments. Some of these systems will incorporate inertial sensing devices and other physical and physiological sensors with a particular focus on the application areas of athlete performance monitoring and e-health.

Some of the important physical requirements for wearable antennas are that they are light-weight, small and robust and should also use materials that are compatible with a standard manufacturing process such as flexible polyimide or fr4 material where low cost consumer market oriented products are being produced. The substrate material is required to be low loss and flexible and often necessitates the use of thin dielectric and metallization layers. This paper describes the development of such a wearable, flexible antenna system for ISM band wearable wireless sensor networks. The material selected for the development of the wearable system in question is DE104i characterized by a dielectric constant of 3.8 and a loss tangent of 0.02. The antenna feed line is a 50 Ohm microstrip topology suitable for use with standard, high-performance and low-cost SMA-type RF connector technologies, widely used for these types of applications. The desired centre frequency is aimed at the 2.4GHz ISM band to be compatible with IEEE 802.15.4 Zigbee communication protocols and the Bluetooth standard which operate in this band.

**Key words**: Fractal Antenna, Wireless Sensor Networks, RF Simulation, RF Design

## 1. INTRODUCTION

Embedded wireless sensor network (WSN) systems have been developed and used in a wide variety of applications such as local automatic environmental monitoring; medical applications analysing aspects of fitness and health energy metering and management in the built environment as well as traffic pattern analysis and control applications. While the purpose and functions of embedded wireless sensor networks have a myriad of applications and possibilities in the future, a particular implementation of these ambient sensors is in the area of wearable electronics incorporated into body area networks and everyday garments. Some of these systems will incorporate inertial sensing devices and other physical and physiological sensors with a particular focus on the application areas of athlete performance monitoring and e-health.

Most WSN nodes employ small integrated antennas for radio communications and it is well known that these types of antennas are especially prone to changes in the antenna's environment. Integrated antennas can suffer from large changes in antenna impedance depending on the placement of the antenna in relation to surrounding objects. This antenna detuning phenomenon can lead to a considerable amount of energy being wasted, leading to a significant reduction in radio performance and battery lifetime. It can be seen that the presence of objects in the near field of the antenna changes both the resonant frequency and return loss of the antenna, and that both are greatly affected by the proximity to the body.

The development of the envisaged wearable wireless sensing system therefore requires careful consideration of the body effect during the design stage to ensure reliable communications for the final system. In particular, it is imperative to consider the effects of the body and surrounding objects during the simulation and design cycle for the development of antennas for such wearable systems.

## 2. FRACTAL ANTENNA

The basic geometry analyzed in this paper is the Koch patch. Fractal shaped antennas have already been proved to have some unique characteristics that are linked to the geometrical properties of fractals [1]

The term fractal, which means broken or irregular fragments, was originally coined by Mandelbrot [2] to describe a family of complex shapes that possess an inherent self-similarity or self-affinity in their geometrical structure. The original inspiration for the development of fractal geometry came largely from an in-depth study of the pattern of the nature. For instance, fractals have been successfully used to model such complex natural objects as galaxies, cloud boundaries, mountain ranges, coastlines, snowflakes, trees, leaves, ferns, and much more.

One popular fractal is known as the Koch snowflake. His geometry is obtained by replacing the sides of an equilateral triangle by a Koch curve. The Koch patch at different iteration stages is shown in Figure 1.

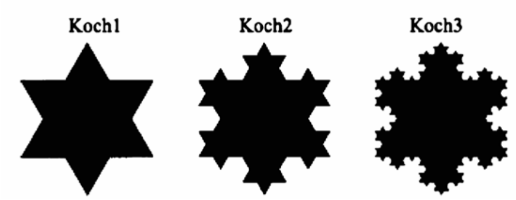


**Figure 1: Koch iterations.**

The self-similarity property of fractals makes them especially suitable to design multifrequency antennas [1, 3]. To implement the fractal, it was first developed in Matlab to various iterations and ported to HFSS RF simulation tool for system development and to ensure a resonant frequency near the 2.4 GHz region.

## 3. HFSS SIMULATION AND DESIGN

The low cost commercially available material DE104i was selected as the material for the antenna substrate as it is amongst the lowest cost FR4 materials available which lends itself to the implementation of a low cost solution. The selected thickness was 0.1 mm to enable a flexible (wearable) implementation. The copper traces were chosen to be 0.012 mm. So the antenna appears to be a normally antenna patch, with a track of its top and a ground plane on the bottom as in Figure 2.

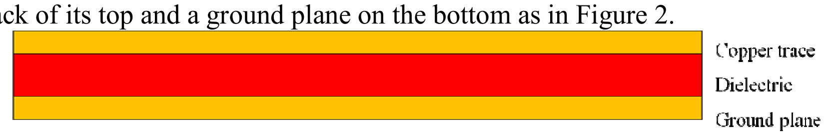


**Figure 2: Stack up of the antenna Patch**

A 50 ohm feed line is designed according to the substrate height and type using Ansoft Designer tools, the start feed line chosen was 0.2 mm. The simulation considers 2.4 GHz as centre band, according to the specification. There are several convergent passes to validate the solutions.

### 3.1. Antenna Tuning Mechanisms

A number of methods exist to tune and implement the antenna system. In a normally antenna patch the inset feed is one of the best methods to adapt and feed a RF signal to an antenna. A fractal antenna is different from a patch antenna, but the concept will be the same. The objective is to put a feed line in the inner part of the fractal, and use an inset feed to find the right point, as shown in Figure 3a. The inset feed consists of two slots that allow the feed line to reach a particular point of the antenna.

A second option is the use of a Co Planar Waveguide (CPW) feed line (Figure 3b). The main difference between microstrip line and coplanar waveguide is indeed the presence of ground lines on the same layer as signal trace, spaced at equal distances in one side and the other. CPW has some advantages over microstrip. The impedance of a microstrip line can be controlled only by changing its width (assuming a given substrate). The impedance of a CPW can be controlled by changing the signal trace width and can also be controlled by changing the width between signal trace and nearby grounds. Also, CPW radiates less RF energy into surrounding traces, due to presence of ground CPW has lower loss at high MW frequencies and it was a great advantage for hybrid Microwave Integrated Circuits (MICs), today MMICs are dominating and microstrip can be used there.`

There is also the possibility to put a slot in the ground plane (Figure 3c) to adjust the antenna properties [4] and to control the impedance and to improve the performance of the antenna.

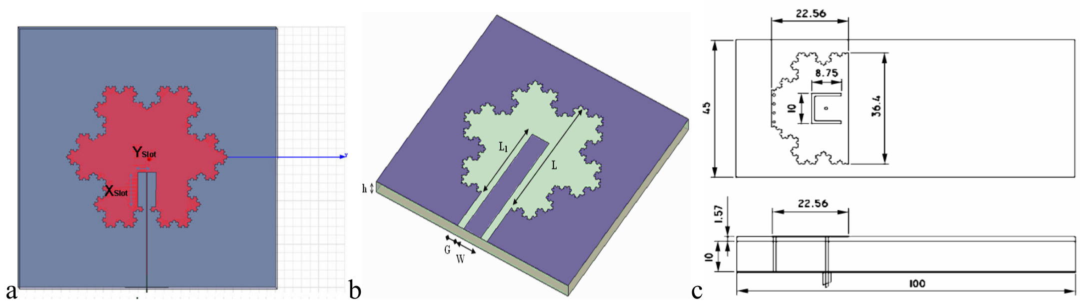


**Figure 3: a) the inset feed, b) CPW feed and c) PIFA slot in Antenna**

## 3.2. Simulation Results and considerations

An inset slot feed implementation was developed and simulated to ensure operation in the 2.4GHz ISM band various slot dimensions were simulated and evaluated to ensure optimal performance of the final implementation as shown in Figures 4 and 5.

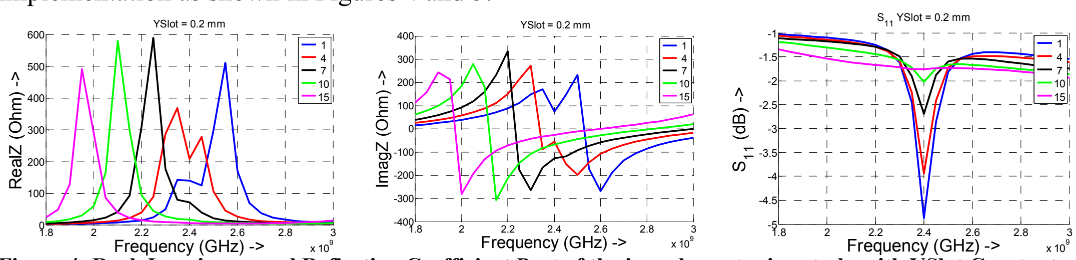


**Figure 4: Real, Imaginary, and Reflection Coefficient Part of the impedance tuning study with YSlot Constant**

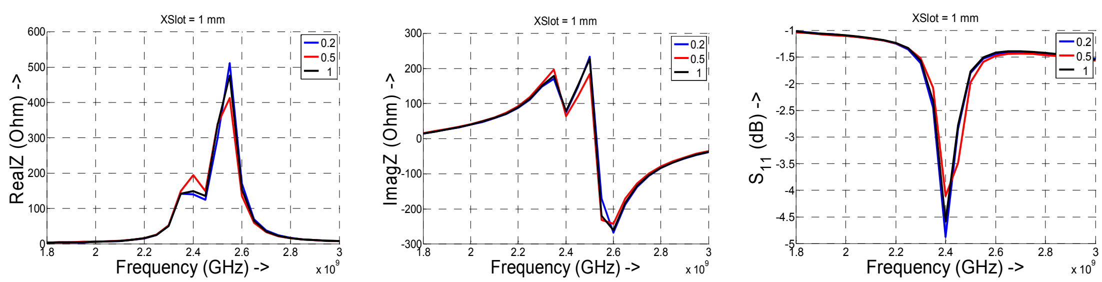


**Figure 5: Real, Imaginary, and Reflection Coefficient Part of the impedance tuning study with YSlot Constant**

The antenna simulations indicate that the inset feed cannot adapt the real and imaginary part of the input impedance, and that the efficiency value is always very low, with a correspondingly low antenna gain and an ineffective antenna. The inset feed method doesn't help us to provide a good adaptation for the antenna patch. For this reason different antenna designs are needed in order to obtain a good antenna with the selected dielectric. For this reason a new model of the antenna is investigated. In particular the presence of a slot in a ground plane allows the definition of a new generation of antennae, which provide better performance than the usual antenna patches [5, 6]

## 3.3. Antenna Design and Results.

The antenna manufactured and tested is represented in the next figure. In particular the stack of the antenna is a 3 layer implementation comprising of Top, Dielectric, and Ground Plane.

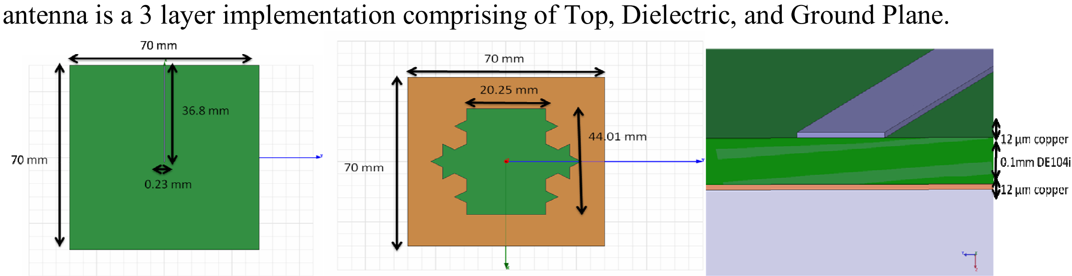


**Figure 6: Top, bottom and stack up of designed antenna**

The final design was implemented according to the following parameters: Dielectric material IS410 (thickness 0.1 mm), Height of the copper tracks equal to 17.5 µm, PCB dimension of 70 x 70 mm, Feed Length 36.8 mm, Dielectric Height 0.1 mm, Wfeed 0.19 mm, Cover Height 25 µm. The results of the antenna are represented in the following figures.

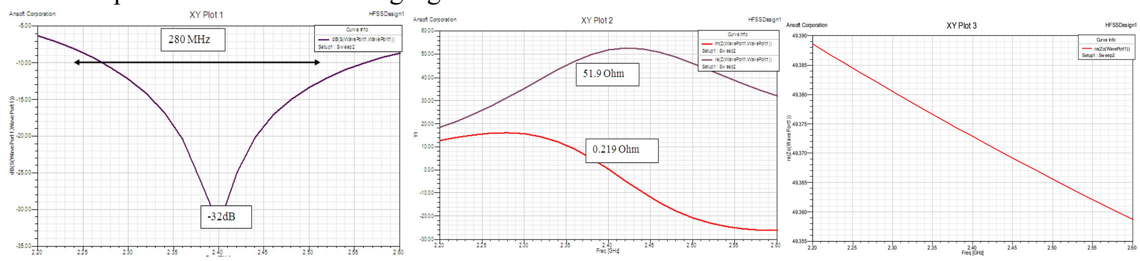


**Figure 7: Simulation results for Reflection coefficient Input Impedance Port Impedance of the final antenna design**

The antenna was manufactured and parametric measurements were made using a Rohde & Schwarz 1043.0009.50 Vector Analyzer. The comparison is showed in the following figure.

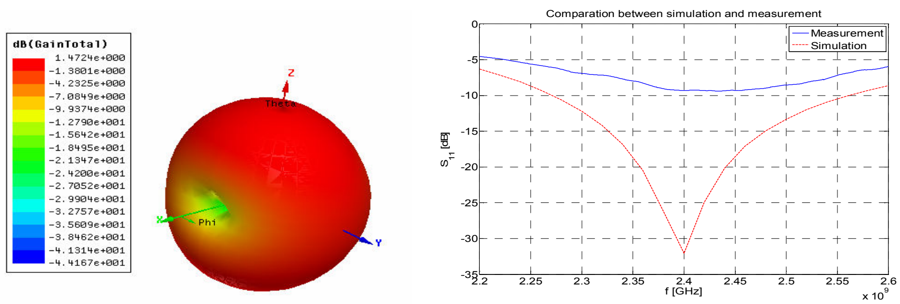


**Figure 8: Antenna Gain Pattern and comparison between simulation and measured parameters**

## 4. CONCLUSIONS & ANALYSIS OF RESULTS

In the measurement there is a minimum peak point at 2.4 GHz, but this point has a very low value. In fact actual measurements are poor compared to the simulation. This could be due to a number of factors which are under investigation, namely: The dielectric material could have different values of dielectric constant. Change of the dielectric properties lead to a shift of the frequency resonant, (but it doesn't explain different values of the reflection coefficient), The presence of the connector could introduce an inaccuracy in the input impedance which the simulation doesn't take into account, the HFSS simulations show a little change of the reflection coefficient with the presence of the solder mask. Its effects could be more heavily present. The Ansoft Designer Simulation shows more changes with the present of a bottom and top full cover solder mask with 8 um thickness. Further work is to be carried out on the analysis of results

## ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of Science Foundation Ireland (SFI) and the funding provided to the National Access Program (NAP) at the Tyndall National Institute, and Enterprise Ireland who have contributed to this work. Tyndall is part of SFIs CLARITY Centre for Sensor Web Technologies.

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