A Packaged Miniature Antenna for Wireless Networking

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Abstract

A novel miniature antenna structure (approaching the smallest fundamental size limits) having numerous qualities such as low cost, efficient circuit (broad bandwidth) and radiation characteristics (suitable for wide angular coverage) has been developed. Owing to its very small size and radiation performance, it is compatible for packaging constraints and can be easily integrated in a big variety of portable devices. In addition, the dual band behavior of the antenna makes it an excellent candidate to be used in communication equipment in which different radio modules are integrated. Experimental prototypes operating at different frequencies were built and measured. Comparison between measured data and simulated results are provided for both impedance behavior and radiation characteristics.

Key Words: small antenna, communication systems, wireless networking, packaging.

I. Introduction

The new emerging standard of radio interfaces (Bluetooth, Hiperlan, etc..) allows a broad kind of home and handheld electronic devices to be rapidly interconnected into ad hoc networks. Building these new wireless networks also represents, however, a number of new challenges, one of which is related to the antenna and radio link interface. In order to get low cost, compact and reliable RF units, a big effort has been made to further reduce the actual antenna size, increasing its robustness at the same time. The current trends in communication systems to integrate different radio modules into same piece of equipment and miniaturization of every possible component require small size multi-band antennas. In addition, the need to employ antenna diversity on the communication system to improve receiver performance is another factor that drives demand for small antennas.

A novel miniature antenna (diameter<0.1λ and thickness<0.03λ) compatible with the packaging constraints and easily integrable in a large variety of portable devices, having dual band characteristic is presented in this paper. The design landmarks as well as the impedance characteristics and radiation behaviors of the novel antenna are presented. Antenna prototypes operating at different frequencies have been designed, fabricated and tested for validation and prototyping purposes. Very good agreement between numerical and experimental results has been obtained with frequency bandwidths of up to 13%. An embedded geometry adapted to the common chip dimensions (10x10x1.3mm), designed for dual-band operation covering frequency range from 5.3 GHz to 6.3GHz are presented and its circuital and radiation characteristics are discussed.

The miniaturization of communication system components such as semiconductors, filters, resistors, capacitors, etc. is mainly limited by technology issues such as tightly controlled clean room facilities. Reduction of antenna size, on the other hand, can be obtained at the cost of antenna performances: narrower bandwidth, low gain and efficiency. The reason is that the antenna’s electrical dimensions, gain and bandwidth are related through fundamental physical laws [1]. So the key issue of designing a small size antenna is to exploit the limits of fundamental laws. Various techniques have been used to reduce the size, increase the bandwidth, and shape the radiation pattern of antennas, such as using of high permittivity material [2], shorting pins or walls [3], slot etching [4] and stacking several layers [5]. Our proposed antenna, so called the dime antenna, has a structural geometry that combines the
advantages of these different techniques and exploits the range of the fundamental limits.

In section II, the dime antenna is introduced and a computational study on antenna performance is presented. The comparison between measured and computed results for both return loss and radiation pattern are also provided to validate the accuracy of the simulation tool used. We describe the reduced size dime antenna in section III. Conclusions are presented in section IV.

II. Structure and Characterization of the Proposed Antenna

A. Structure

The proposed antenna geometry is shown in Fig.1. It consists of two stacked circular patches, namely upper and lower patches, with a perimeter close to \( \lambda/2 \), over a ground plane having twice the diameter of the patches. In order to exploit the limits exposed by physics we propose to use volumetric geometry different from printed antenna structure. A sectoral slit, with \( \theta_s \), being the slit angle, was etched into the lower patch to reduce the size of the patch and control the impedance matching level. This structure forms two planar radial transmission lines between three planes (upper patch, lower patch and ground plane), ended by the upper and lower cylindrical slots with the length of \( S_u \) and \( S_l \) and limited by the upper and lower connecting sectoral walls (or shorting walls) with lengths of \( w_u \) and \( w_l \) (refer to Fig.1). Upper and lower layers are of the thicknesses \( h_u \) and \( h_l \), respectively.

A coaxial probe simultaneously feeds the two cylindrical antennas slots. The inner conductor of the coaxial feed line is attached to the lower patch passing through the hole on the ground plane. The outer conductor is connected to the ground plane. The sectoral slit etched into the lower patch forces current to travel from the feed point along the circular slit then down to the ground level through the lower shorting wall. The placement of the inner conductor of coaxial, which is determined by the distance \( d_m \), and the length of the sectoral slit determined by \( \theta_s \) are the key parameters to achieve good input matching. The slot lengths, \( S_u \) and \( S_l \), and the length of the feed point ground path determine the resonant frequencies. Detailed discussion on how these parameters play a role on antenna performance are given in the next section.

The antenna structure utilizes stacking (two layers), shorting walls (two sectoral walls), and etching (circular slit on the lower patch) techniques to achieve good size-bandwidth compromise dictated by fundamental physical laws. The antenna radiates as two stacked circular magnetic slots, electrically equivalent to a vertical electric dipole, producing an almost omnidirectional pattern, with a slight upper tilt due to the stacked structure and shorting walls.

B. Characterization of the Antenna

An important issue associated with the evaluation and comparison of how the different design parameters play a role on the antenna performance involves the appropriate application of computational tools capable of accurately predicting antenna performance. Tools based upon different numerical techniques such as FDTD.

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**Fig.1. Structure of the proposed novel miniature antenna a) Side view; b) Top views of the upper and lower patches**
(Finite Difference Time Domain), MoM (Method of Moment) and FEM (Finite Element Method) are used extensively by today’s antenna designers thanks to the rapid development of such kinds of tools and workstations. Accurate simulation results provide insight into the impedance behavior and radiation characteristics of the antenna. In addition, these results may be used to develop design methodologies, and optimize antenna designs.

In this section of the paper the influence of the different antenna components (design variables) on performance are characterized. To perform this study, Finite Element Method (FEM) based full wave analysis tool AnsoftHFSS was used. Design variables for this novel antenna structure are the heights of the two layers \((h_u, h_l)\), radii of the circular patches and ground plane \((r_u, r_l, r_{gnd \_pln})\), lengths of sectoral walls \((w_u, w_l)\), slit angle \(\theta_s\) that determines the length of the etched slot into the lower circular patch and the distance away from the edge of the sectoral slit, \(d_m\), which determines the location of the feed wire. The effect of each design parameter on antenna performance is investigated by successively varying one, while keeping the remaining fixed. The results of this study are used to develop design methodology to design antennas for operation at a defined frequency range. The return loss as a function of frequency for different locations of coaxial feed \((d_m's)\) is graphed in Fig 2. The curves show that \(d_m\) plays a key role, as expected, on input matching level while the resonant frequency remains unaffected by varying this parameter. Impedance matching is achieved by controlling \(d_m\) such that the input impedance of the slot is transferred to the required 50\(\Omega\) at the feed point.

![Fig.2 Ret. loss of the antenna as a function of \(d_m\)](image)

\(r_u=r_l=5\text{mm}, r_{gnd \_pln}=10\text{mm}, h_u=h_l=1.85\text{mm}, d_m=0.05\text{mm} w_u=7.37\text{mm} w_l=2.2\text{mm}, \theta_s\) is variable.

\(\theta_s=90^\circ\); \(\theta_s=120^\circ\); \(\theta_s=110^\circ\)

\(w_u=5.67\text{mm}; w_u=6.5\text{mm}

The effect of various slit angles on the input impedance is shown in Fig.3. This figure indicates that the slit angle has a similar influence on the matching level, as does the \(d_m\). In Fig.4 and Fig.5 the return loss characteristic of the antenna is presented for several lengths of lower and top sectoral walls, respectively. The curves show that the length of the sectoral walls control the location of the resonant frequency. They also play a role on input matching level as a secondary effect. This is because different slot lengths result in different characteristic impedances of the planar radial transmission lines. As the lengths of sectoral walls \((w_u, w_l)\) are increased \((\text{Slot lengths, } S_u \text{ and } S_l \text{ are decreased})\) the resonance frequency shifts to higher values, as expected. Consequently, changing the length of sectoral walls allows the resonant frequency to be tuned.

![Fig.3. Ret. Loss of the antenna as a function of \(\theta_s\)](image)

\(r_u=r_l=5\text{mm}, r_{gnd \_pln}=10\text{mm}, h_u=h_l=1.85\text{mm}, d_m=0.05\text{mm} w_u=7.37\text{mm} w_l=2.2\text{mm}, \theta_s\) is variable.

\(\cdot \cdot \cdot \theta_s=90^\circ\); \(\cdot \cdot \cdot \theta_s=100^\circ\)

\(\cdot \cdot \cdot \theta_s=120^\circ\)

![Fig.4. Ret. Loss of the antenna as a function of \(w_u\)](image)

\(r_u=r_l=5\text{mm}, r_{gnd \_pln}=10\text{mm}, h_u=h_l=1.85\text{mm}, \theta_s=120^\circ\), \(w_l=2.2\text{mm}, d_m=0.05, w_u\) is variable.

\(w_u=5.67\text{mm}; w_u=6.5\text{mm}

\(w_u=7.37\text{mm}; w_u=8.94\text{mm} \)
To evaluate the effect of the design parameters of $h_u$ and $h_l$, height of the layers on antenna performance, the input return loss was computed for different layer thicknesses. The results are given in Fig. 6. The resonant frequency shifts into higher values as the height ($h_u = h_l$) is decreased. It is worth noting that without degrading matching level, by varying only one of the design parameters, the layer thickness, it is possible to cover the frequency range from 4.5 to 6.2 GHz. The percentage bandwidth of an antenna is usually defined as the ratio of the difference between upper and lower frequencies for which the return loss is less than –10 dB to the average of these frequencies. Based upon this definition a 31.7% overall frequency sweeping band is achievable.

Evident in these next results is that the size of the ground plane and the length of the sectoral slit are dominant factors in the bandwidth of this antenna structure. Here, for packaging purposes, the size of the ground plane is chosen very close to the size of the circular patches ($r_{gnd,pln}=5$ mm, $r_u=r_l=4.25$ mm). Fig. 7 shows that slit angle is the dominant factor in controlling bandwidth. The case of $\theta_s=60^\circ$ results in a maximum bandwidth of 34%. To the best of authors’ knowledge this is the widest bandwidth that has been obtained so far from such a small size antenna. It should be noted, however, this antenna is not suitable for the applications where the ground plane is much larger than the size of the patches. We show in the next section that a small antenna having a ground plane much larger than its patches is able to give 13% bandwidth. The choice of antenna is determined by specific system consideration.

**Fig.5. Ret. Loss of the antenna as a function of $w_i$**

$r_u=r_l=5$ mm, $r_{gnd,pln}=10$ mm, $h_u= h_l=1.85$ mm, $\theta_s=120^\circ$, $w_u=7.37$ mm, $d_m=0.05$, $w_i$ is variable

- $w_i=1.8$ mm
- $w_i=2.2$ mm
- $w_i=2.6$ mm
- $w_i=3.1$ mm

**Fig.6. Ret. Loss of the antenna as a function of $h_i$ and $h_u$ ($h_u=h_l=h$)**

$r_u=r_l=5$ mm, $r_{gnd,pln}=10$ mm, $\theta_s=120^\circ$, $w_u=7.37$ mm, $d_m=0.05$, $w_i=2.2$ mm $h_u= h_l= h$ is variable

- $h=2.4$ mm
- $h=2.1$ mm
- $h=1.85$ mm
- $h=1.55$ mm
- $h=1.35$ mm

**Fig.7. Ret. Loss of the antenna as a function of $\theta_s$ for small size ground plane**

$r_u=r_l=4.25$ mm, $r_{gnd,pln}=5$ mm, $h_u= h_l=1.55$ mm, $d_m=0.05$ mm $w_u=6.3$ mm $w_i=1.4$ mm, $\theta_s$ is variable.

- $\theta_s=75^\circ$
- $\theta_s=70^\circ$
- $\theta_s=65^\circ$
- $\theta_s=60^\circ$

**C. Experimental Results**

Upon identifying the effects of all design parameters on antenna performance, we are able to design an antenna with a good impedance match for any specific resonant frequency. So, the problem at hand is to determine the values of these different design variables such that input impedance closest to 50 $\Omega$ (for good input impedance matching) at the center design frequency is obtained. At the same time by keeping in mind the influences of the design variables, presented in previous section, on antenna performance, associated dimensions have to be chosen such that wider bandwidth is achieved. We aimed at determining the dimensions of an antenna so
that it will operate at 5.2 GHz in accordance with future Bluetooth frequency band. An antenna based upon the determined dimensions was fabricated and its return loss and radiation pattern were measured. The antenna was build by etching 0.3mm-thick Copper sheet metal to obtain pieces of the antenna: ground plane, upper circular patch and lower circular patch with lower and upper sectoral walls attached to it. Soldering the individual pieces together forms the antenna structure. Fig 8, 9a and 9b show the comparative results between measurement and simulation for return loss and radiation pattern, respectively. These results validate the accuracy of the simulation technique used in terms of accurately predicting antenna’s impedance behavior and radiation characteristics. Physical dimensions of the structure are given in the figure.

III. Reduced Size Dime Antenna

Although the antenna described above is already small size antenna for many communications applications, we strive to further reduce its size, without changing its structure, in order to enable it to be employed in packaging and systems with antenna diversity.

The design methodologies presented in the previous section were utilized for the reduced size dime antenna. We incorporated typical package dimension of 10x10x1.3mm and dielectric material of \( \varepsilon_r = 4.3 \), Fig. 12. Firstly we designed a reference antenna, embedded into a packaging box, for dual band operation at frequencies of 5.4 and 6.1 GHz. Then upper and lower sectoral wall lengths \( w_u \) and \( w_l \) were varied one at a time while other dimensions were kept fixed to study the effect of different slot lengths on antenna performance. Fig 10 and 11 show the results obtained for different upper and lower sectoral wall lengths, respectively. It can be seen from Fig.10 that the first resonant frequency and matching level remain almost unaffected by changing \( w_u \) while varying this parameter allows the designer to choose the second resonant frequency. Then, we vary \( w_l \), keeping \( w_u \) fixed. As it is shown in Fig.11 the second resonant frequency and matching level are unaffected while first resonant frequency is tuned.

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**Fig.8** Comparison of calculated and measured return loss for the fabricated antenna

\( r_u = r_l = 5 \text{mm}, \quad r_{\text{gnd,pln}} = 10 \text{mm}, \quad \theta_s = 125^\circ, \quad S_{u} = 24.2 \text{mm}, \)
\( d_m = 0.05 \text{mm}, \quad S_t = 33.5 \text{mm} \quad h_u = h_l = 1.58 \text{mm} \)

**Fig.9** Comparison of calculated and measured radiation pattern. (a) E-plane (b) H-plane

- **Co-pol**(calculated)  - **Co-pol**(measured)
- **Cross-pol**(calculated)  - **Co-pol**(measured)
It is worth noting that, dual-band frequency behavior is usually obtained by using two different feeds and either same or different antennas designing for a 50Ω match at two different resonant frequencies. For the proposed antenna structure, however, dual band behavior can simply be obtained with single feed and single antenna by appropriately choosing the dimensions of the design elements.

**IV Conclusions**

A novel miniature antenna structure having attractive impedance and radiation characteristics has been proposed for communications applications where the space volume of the antenna is quite limited. An extensive and detailed numerical study has been performed to identify the effects of key antenna elements on its performance. The results of this study were used to develop a general methodology to design reduced size antennas for specific applications and for operation at defined frequency ranges. The proposed antenna was fabricated based on determined dimensions, and measured. Excellent agreement between measurement and simulation for both input impedance and radiation pattern proves the accuracy of the simulation tool used.

The dimensions of the antenna were further reduced for fitting into a typical package box. Its structural geometry allows dual band behavior that can be obtained by simply choosing appropriate dimensions of antenna elements. Its behavior was examined to provide a control mechanism for resonant frequencies.

**References:**


