ANTENNA MINIATURIZATION AND INTEGRATION IN A 2.4 GHz SYSTEM IN PACKAGE.
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**Introduction:** Today, the integration of an antenna consists in most cases of positioning the antenna-component on the surface of the Printed-Circuit-Board [1], or printing the antenna directly on the PCB. Matching circuits and RF feed lines are generally still needed, increasing the time of the design phase and consuming space on the board [2].

The solution proposed in this paper is a compact three-dimensional antenna, taking advantage of the multilayer properties of the Low-Temperature-Co-Fired-Ceramics (LTCC) substrate to be directly included in a System in Package (SiP). This Antenna in Package (AiP) concept provides an all-in-one system including the antenna, the RF components and the Integrated Circuits (ICs). Therefore, no interface between the antenna and these components is required anymore.

We also demonstrate the possibility to use this technique with other multilayer substrates.

**Antenna miniaturization:** The antenna is designed to be integrated with an existing 2.4 GHz ISM band module having the following dimensions: 8 x 8 x 1.4 mm\textsuperscript{3}. The complete module uses an LTCC substrate with a permittivity of 7.8.

**Antenna structure.** The basic radiating structure of this study is an Inverted-F Antenna (IFA). To take advantage of the multilayer structure of the LTCC substrate, the antenna concept consists in meandering in three dimensions on several layers the main radiating arm of the IFA to form a kind of helical antenna. The overall size of the antenna does not exceed 2 x 8 x 0.5 mm\textsuperscript{3} (figure 1).

**Antenna performance.** After complete investigations into the shapes and simulations using Ansoft HFSS, a first batch of prototypes including more than ten different structures has been manufactured and tested. The AiP module is mounted on a FR4 mobile phone ground plane (40 x 80 mm\textsuperscript{2}) with a 2 x 8 mm\textsuperscript{2} aperture under the antenna position. Simulation and measurement curves for the best prototype are shown in figure 2.

![Fig.2: Simulated and measured |S\textsubscript{11}| of a 2 x 8 x 0.5 mm\textsuperscript{3} multilayer antenna.](image)

With a relative bandwidth at -6 dB of 3.4 % (83 MHz centered at 2.47 GHz) and a minimum radiated efficiency over the bandwidth of 25 %, this prototype achieves good performance regarding the simulations. These results are confirmed by reception of a WiFi signal measured on a spectrum analyzer with our integrated structure (figure 3).

![Fig.3: Comparison of the received WiFi signal level between our best structure and a reference monopole.](image)

During the prototypes tests, some frequency offsets were observed, due to over-simplification of the simulation, manufacturing tolerances, and especially to ground plane size variations. Even if the ISM band is
covered for applications like Bluetooth and WiFi, a relative bandwidth of 6% has to be reached in order to include all the potential frequency offset effects and ensure antenna functionality on any application ground plane size.

**Structure improvements:** Further investigations on the antenna have been carried out in order to reach a 6% or greater bandwidth. New topologies (dimensions, shapes, number of layers, ground connections) have been designed and optimized by electromagnetic simulations on a large range of antenna sizes and types of application ground planes (mobile phone, USB dongle, PC card). Each structure has a different three-dimensional shape on several layers [3].

**Simulations and performance.** New shapes offer better results in terms of bandwidth and radiation efficiency. Figure 4 shows that a 3.5 x 8 x 0.5 mm$^3$ (14 mm$^3$) antenna achieves at least a 9% relative bandwidth (220 MHz centered at 2.43 GHz) with a minimum radiated efficiency over the bandwidth of 50%, and meets ground plane size variations (the whole ISM band is covered in any case).

![Fig.4: Simulated $|S_{11}|$ of a 3.5 x 8 x 0.5 mm$^3$ multilayer antenna on two application ground plane sizes.](image)

A complete study has been performed in order to adapt these shapes to a variety of LTCC SiP configurations, varying the size of the overall module and the available volume for the antenna structure. The maximum performance obtained in terms of bandwidth and efficiency is reported in figures 5 and 6 for each antenna volume.

![Fig.5: Relative bandwidth vs. antenna volume on two application ground plane sizes.](image)

Application on FR4 substrates: Similar antenna topologies have been applied to multilayered laminate FR4 SiP. Because of a lower permittivity (between 3.5 and 5), the antenna structure is larger for the same figure of merit. A full prototype module containing the antenna and the components (figure 7) achieved the same functionality as a reference design that was four times larger. The excellent achieved performance (10% relative bandwidth centered at 2.45 GHz) validates the behavior of these three-dimensional multilayered integrated antennas.

![Fig.7: Example of a 6 x 8 mm$^2$ antenna in a 12 x 8 mm$^2$ laminate QFN SiP on its USB dongle test board.](image)

**Conclusion:** In this paper, a novel technique to integrate miniature antennas in complete Systems in Package is presented, by taking advantage of multilayer substrates to create 3D shapes. This method allows a standard industrial production of full systems in packages including AiP, reducing costs and time to market for diverse wireless applications.

**REFERENCES**

