MINIATURE ANTENNA FOR CIRCULARLY POLARIZED QUASI ISOTROPIC COVERAGE

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Abstract

A novel miniature antenna with quasi-isotropic radiation pattern and optimized circular polarization is presented. This structure is well suited for small wireless devices whose orientation is arbitrary with respect to each other, especially for future applications such as wireless sensor networks. The miniature antenna (λ/5 x λ/5 x λ/38) consists of 4 Inverted-F Antennas (IFA) arranged in a rotational symmetry and mounted on a small dual layer PCB. IFA elements are fed by a micro-strip network etched on the bottom layer. We obtain a total efficiency of more than 65% on a 100MHz bandwidth, a quasi-isotropic radiation pattern with an absolute maximum 3.6dB deviation relative to the ideal isotropic pattern and circular polarization in two large circular sectors pointing upward and downward with an average -3dB axial ratio beam width of 105°. Finally, according to a previously published criterion, the isotropic coverage, radiation performances of this antenna are evaluated and compared to common antennas in the typical context of devices communicating together with arbitrary orientations with respect to each others.

1 Introduction

Wireless sensor networks for home, industrial or environmental monitoring [8], personal body area networks, motion capture systems based on body sensors as well as satellite positioning devices are typical upcoming applications demanding for reliable wireless transmissions with constant link budget between devices even if randomly oriented or quickly rotated with respect to each other. In such systems, various phenomena's can deteriorate the transmission at the physical layer level such as obstruction between devices, multi-path fading or presence of interferers. These phenomena's are particularly sensitive to moving of the devices or objects in the environment.
Concerning the impact of arbitrary device orientation, the two main phenomena appear to be the anisotropy of the radiating pattern as well as the polarization mismatch between antennas [6]. Directions of departure and arrival of a beam can change rapidly while in use and fall into antenna radiating holes. Tilt between polarization states of antennas causes an attenuation of the transmitted power. These effects can be greatly mitigated by a proper design of the radiation pattern properties of the antenna. It can be shown that an isotropic directivity pattern with uniformly circularly polarized antenna is insensitive to orientation. Although truly isotropic antennas do not exist [3], we propose in this paper a novel antenna with optimized quasi-isotropic pattern and circular polarization in order to provide an enhanced spatial coverage. This compact, antenna is mountable with commercially available components, is well suitable for integration on a multilayer circuit board and present the advantage of being almost insensitive to PCB sharing with others component placed on its bottom side.
The antenna structure, feeding network as well as far-field pattern results are successively presented below. Finally, in order to evaluate its transmission performance in the context of arbitrary orientations, a criterion called the isotropic coverage [5,6,7] is computed and compared with two common antennas: a half wave length dipole and a combination of two crossed dipoles fed in phase quadrature.

2 Antenna configuration

The antenna structure is depicted in Figure 1. Four IFA elements [4] are located along the sides of a 25 mm square dual layer PCB in a C4 rotational symmetry. IFA are fed through a ground plane by a microstrip network etched on the bottom side of the PCB.

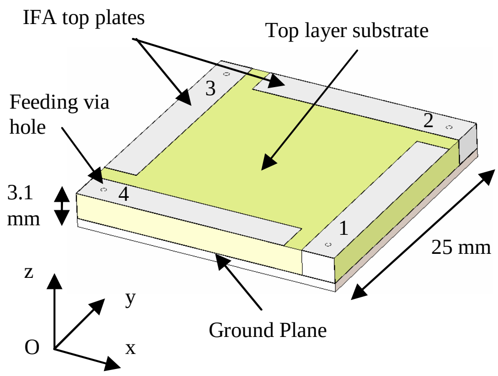

Figure 1: Structure of the four Inverted-F Antennas.

Figure 2 illustrates the dual layer stackup. The top layer hold the antenna structure, it is made of a low permittivity low loss substrate in order to optimize antenna efficiency and bandwidth. A Roger Duroid® laminate with εr=2.2 and tanδ=9e-4 was chosen. Three laminates of 0.787mm standard thickness were pressed together in order to obtain the required 2.4mm layer thickness. A copper layer is coated between both substrates. This layer serves as a ground plane for the antenna structure as well as for the feeding network. The bottom layer holds the microstrip feeding network. In order to reduce its size, a high permittivity substrate is preferred. Arlon AR1000® with εr=10 and tanδ=0.003 and a standard thickness of 0.787mm was used.

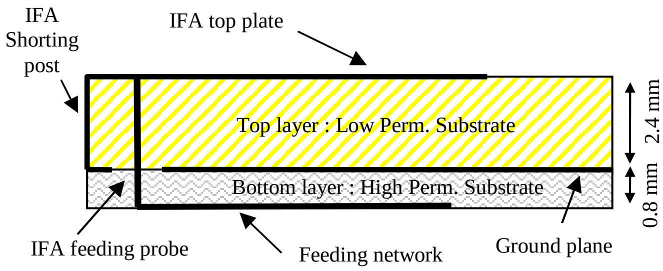

Figure 2 : Dual layer stackup and arrangement of the Inverted-F antenna

The elementary IFA top plates are 20.1 mm long, 3.1 mm wide and are copper-coated on the PCB top layer. They are fed by 0.5 mm via holes located 2 mm from the shorting posts along the IFA axis. Via holes are connected to the feeding network located under the ground plane.

IFA #	*1*	*2*	*3*	*4*
Amplitude relative to IFA # 1	1	1	1	1
Phase delay relative to IFA # 1	0°	90°	180°	270°

Table 1 : Amplitude and phase constraint of the antenna..

Each IFA is fed in equal amplitudes and with a 90° phase delay between successive elements when rotating anticlockwise. This feeding scheme leads to the targeted particular quasi-isotropic radiation pattern and the circular polarization properties of the antenna. This scheme also presents the advantage of greatly reducing the mutual coupling between IFA. For a given IFA, the coupling from its right-handed neighbour is equal to the coupling of the left-handed one due to symmetry of the arrangement. Since both neighbour IFA are feeding 180° out of phase, their respective contributions to the given IFA exactly cancels each other. Only coupling between opposite IFA limits the antenna performance, especially its total efficiency. With the current arrangement, this coupling is made to be below -9dB in the operating bandwidth (2.36-2.46GHz).

3 Feeding network and antenna efficiency

The feed network aims at feeding each IFA with the required equal amplitudes and 90° phase shifts between each successive IFA as previously stated. A microstrip network with three 90° hybrid couplers is located in the bottom side of the PCB. The network architecture is shown in Figure 3. The input signal is divided in two by a first hybrid coupler. Outputs are in phase quadrature. They are linked to two second couplers. One is directly connected; the other is connected through a quarter-wavelength line.

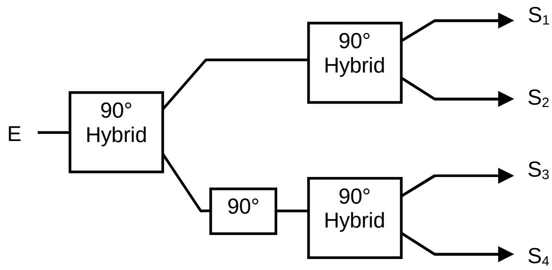

Figure 3: Schematic of the feeding network for equal amplitude and 90° phase shift between successive outputs.

The circuit layout is illustrated in Figure 4. Components are ultra small SMT. Network input is connected through an U-fl coaxial connector. Hybrid couplers are Mini-Circuit® QCN series LTCC hybrid couplers [9], they are mounted together with 50Ω isolation resistors.

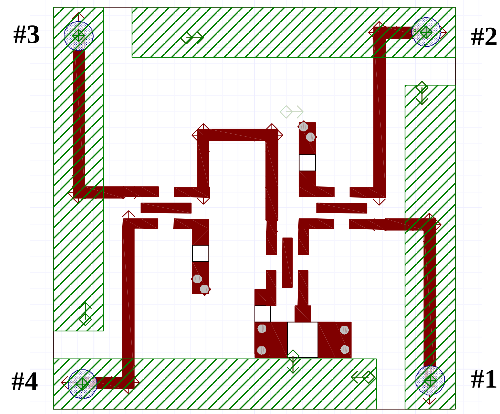

Figure 4: Layout of the microstrip network.
Plain lines: bottom layer side.
Hatched area: top layer side.

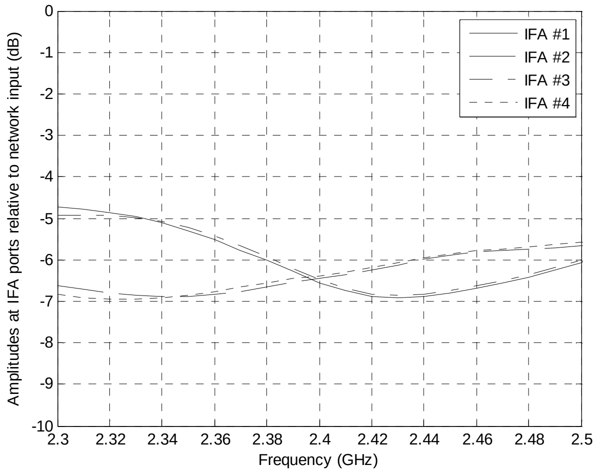

Figure 5: Amplitudes at IFA ports relative to network input.

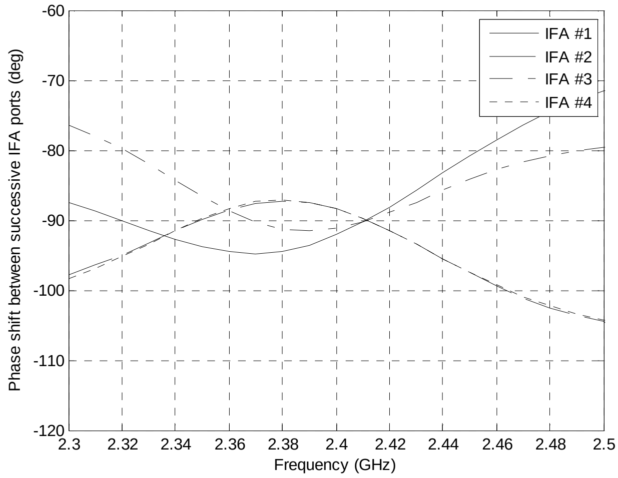

Figure 6: Phase shift between successive IFA ports.

Figure 7 shows S_{11} parameter at input connector, as well as total antenna efficiency. Impedance matching at input is well below -10dB over more than 1GHz bandwidth between 2 and 3 GHz. This is however not representative of the performance of the radiator since a feeding network with three 50Ω resistors are include in the antenna setup. In order to evaluate antenna performance, total efficiency is preferably studied. Total efficiency is defined as the ratio of total radiated power over the total input power at the feeding network port. Thus insertion losses, feed network losses and radiating structure losses are all taken into account in this definition. Two efficiency curves are plotted in Figure 7. The total efficiency with an ideal feeding network demonstrates the maximum achievable efficiency assuming an ideal lossless impairment-free feeding network. A 95% total efficiency is achieved at 2.4GHz. This limitation is due to losses in the top layer substrate and to impedance matching of each IFA with the network. The second curve gives the total efficiency of the presented structure. A maximum efficiency of 83% is obtained at 2.4GHz. The difference between both curves is due to feeding network losses.

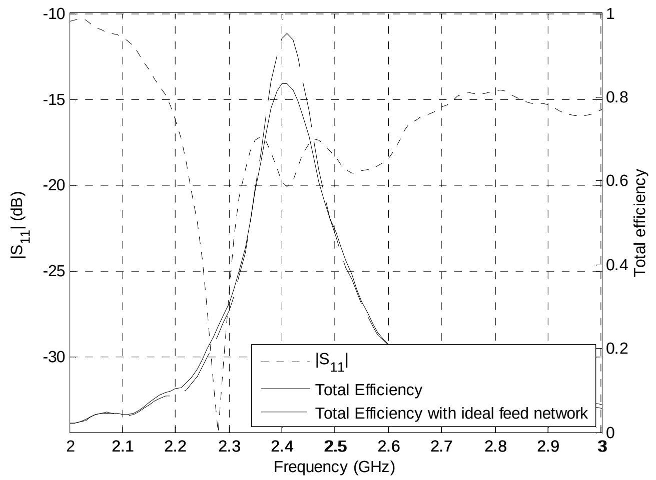

Figure 7: Impedance matching at network input and antenna total efficiency.

A 100MHz bandwidth is covers with a total efficiency higher than 65% between 2.36 and 2.46GHz. As a comparison, a total efficiency of 65% corresponds to the same ratio of radiated power over input power as the one of a lossless radiator with a return loss of -9dB.

4 Radiation properties

The main purpose of the antenna is its circularly polarized quasi-isotropic radiation pattern which allows the communication performances to be uniform between devices whatever are their orientations.

The antenna radiation pattern is circularly symmetric along the OZ axis. Figure 8 presents the antenna directivity pattern in two cutting plans at 2.4GHz. The antenna is omni directional in the plan of the substrate (XOY) with less than 1dB ripple. In the plan XOZ, the antenna presents a maximum directivity of 3.6dBi in the downward direction. This value represents the absolute maximum deviation from the ideal isotropic 0dBi pattern over the whole far-field 3d pattern.

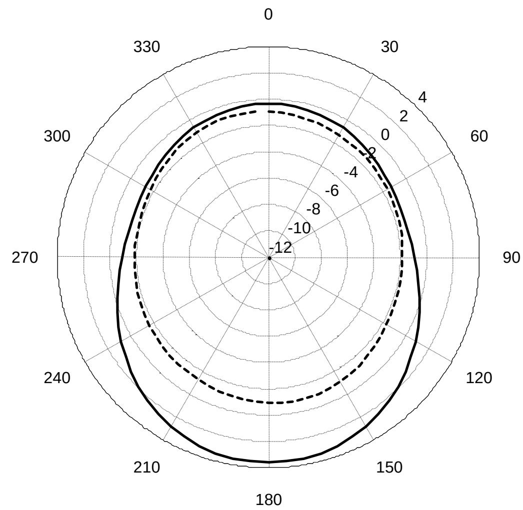

Figure 8: Directivity pattern (dBi) at 2.4GHz
XOZ plane XOY plane

Figure 9 shows axial ratio patterns at 2.4GHz corresponding to four chosen plans normal to the substrate. These patterns exhibit a figure-of-eight shape with two sectors in normal direction (OZ) where a nearly circular polarization is obtained. The antenna radiates in a left-handed polarization sense with an axial ratio superior to -3dB in a large downward-pointing circular sector of 120° beam width. It radiates in the right-handed polarization sense (>-3dB AR) in an upward pointing sector of 95° angular. These polarization characteristics are better than those of a classical arrangement of crossed half-wavelength dipoles in phase quadrature. This appears to be due to the compact size of this radiator.

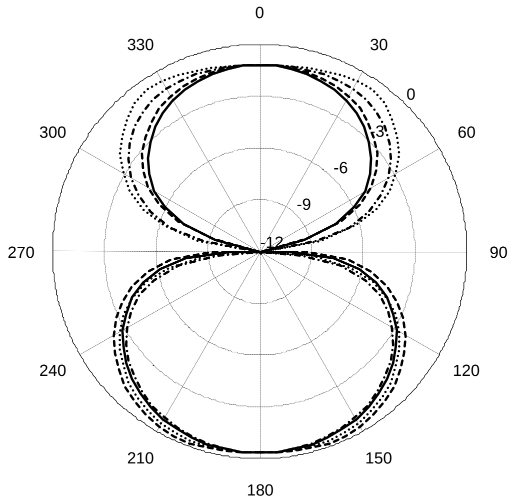

Figure 9: Axial ratio pattern (dB) for different OZ planes at 2.4GHz (0dB = circular polarization)
φ=0° φ=45° ...... φ=90° φ=135°

5 Isotropic coverage

In order to assess the performance of antennas in a context of communication between arbitrary orientated devices, such as with disseminated sensors networks, a criterion has been developed [5,6,7]. The isotropic coverage of an antenna is the proportion of orientations such that the transmit power between a reference source and the antenna is higher then a given threshold. Polarization mismatches between antennas are taken into account in this criterion. The isotropic coverage can be computed by orienting the antenna under test in all the possible directions and tilts in a reference incident field and measuring the corresponding received power at the antenna port. However an analytical method has been developed allowing to quickly computing the isotropic coverage from antenna 3D far-field data [5-6]. This method can be applied either in simulation or with antenna measurements setup.

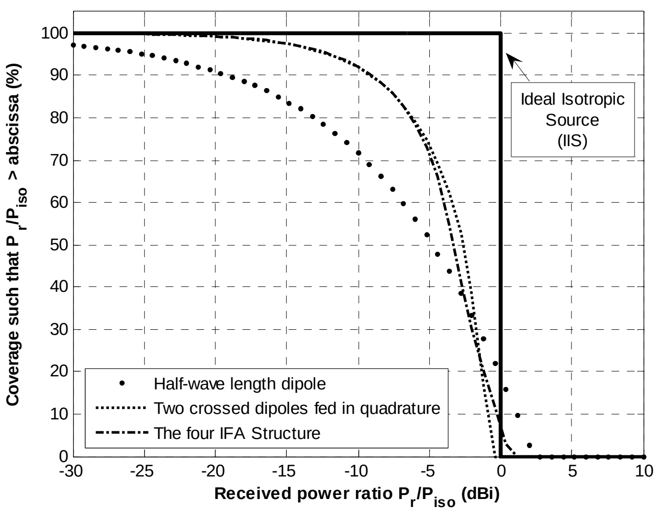

Figure 10 : Isotropic coverage of the four IFAs structure compared to 3 well-known antennas.

Isotropic Coverage curves are plotted in Figure 10 for the four-IFA structure, as well as for a half-wave length dipole [1] and a combination of two crossed dipole fed in phase quadrature [2]. For these two canonical antennas, theoretical isotropic coverages have been computed based on analytical formulae of their radiation far-fields. These coverage curves are computed assuming a linearly polarized incident field. For a 90% coverage requirement, the four-IFA antenna achieves a gain of more than 10 dB in comparison to a half-wave length dipole. Coverage is nearly similar to the one of a combination of two crossed dipoles fed phase quadrature. This is due to the fact that both antennas work on the same principle of two orthogonal modes excited in phase quadrature.
However, compared to an arrangement of two crossed dipole with its balun and feeding circuit, the four-IFA structure has several advantages for integration on a multi layer PCB-based compact sensor node device: Its size is 43% smaller and has a flat form factor; it is designed for integration on a multilayer circuit board and use commercially available components. Moreover, due to the presence of a ground plane, the radiation pattern has shown to be almost insensitive to materials place below the bottom layer such as additional layers or components.

Conclusion

It was shown that this novel miniature antenna (λ/5 x λ/5 x λ/38) consisting of an arrangement of 4 IFA presents a quasi-isotropic radiation pattern with an absolute maximum 3.6dB deviation relative to the ideal isotropic pattern and circular polarization in two large circular sectors pointing upward and downward with an average -3dB axial ratio beam width of 105°. We obtained a total efficiency of more than 65% on a 100MHz bandwidth and a return loss below -10dB on a 1GHz band around a central frequency of 2.4GHz. In a context of application where devices communicate with arbitrary and/or rapidly various orientations, the four-IFA antenna allows a gain of more than 10 dB of receiving power in comparison to a half-wave length dipole, for a 90% isotropic coverage requirement. This antenna is made on a dual layer substrate stackup and is well suitable for integration on top of a more complex multilayer circuit. Next investigations will deal both with possible miniaturization techniques and wideband properties of antenna arrangement. Results of measurements carried out on the prototype under fabrication process will be presented at the conference to validate simulation results.

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