Miniaturized PIFA Design with Bandwidth Enhancement

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Abstract

Miniaturized Planar Inverted-F Antenna designs with enhanced bandwidth are presented in this work. The miniaturization effect is achieved by modifying the shape of the radiating element or patch. The proposed designs resonate at a lower frequency, when compared to a Square Planar Inverted-F Antenna with the same size. The expected performances of the proposed configurations are validated through simulations and measurements.

1 Introduction

The Planar Inverted-F Antenna (PIFA) is probably the most popular antenna configuration for personal communication devices [1]. Despite its small size, PIFA offers reasonable gain and very little back radiation into the user body, which leads it to conform with Specific Absorption Rate (SAR) regulations, as well as making it somewhat immune to the negative effects of body proximity [2, 3, 4].

The prevalent trend in consumer electronics and communication devices is towards greater integration and pervasiveness. Portable devices are gradually being replaced or augmented with wearable devices that are always on the user body [5]. On the other hand, reliable wearable antennas are required to facilitate seamless communication between wearables devices and the wider network. In order to make these devices as unobtrusive as possible, wearable antennas need to be miniaturized [6]. Standard miniaturization methods using higher permittivity substrates [7] and reactive loading [8], have lost favor as they compromise efficiency. High-tech methods such as meta-material ground-planes [9, 10] or superstrates [11], promise better performance, but they are costly to implement on industrial scale.

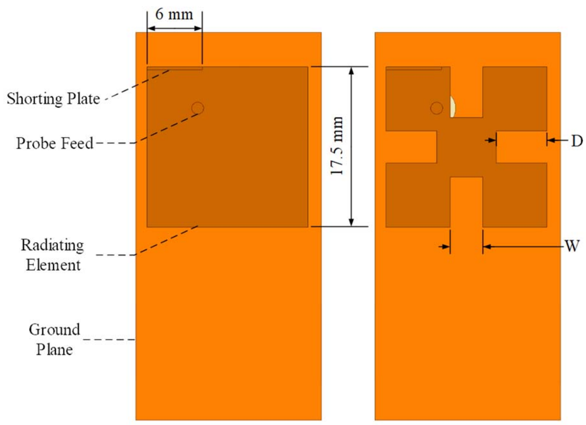
In this paper, two designs for PIFA miniaturization are presented. In particular, the size reduction is realized by decreasing the antenna resonant frequency, while maintaining overall physical dimensions. The first design adopts a Minkowski pre-fractal shaped [12] radiating element, in place of the conventional square patch. The second design is a refinement of the Minkowski pre-fractal-based design, that is simpler in construction, but it is able to offer the same performance level. The proposed configurations are fabricated and experimentally tested in the Microwave Laboratory at the University of Calabria. The antennas are designed to operate in the unlicensed Industrial, Scientific and Medical (ISM) band (2.4 - 2.5 GHz), often used for personal communication (e.g. by the Wi-Fi and Bluetooth standards).

2 Minkowski Pre-Fractal Based PIFA

A conventional PIFA with a square patch is adopted as starting point for the miniaturized design. The resonant wavelength of the square PIFA depends on the length of the path traced by the current along the edges of the patch. For a square PIFA, with a radiating element of side 'S', the resonant wavelength can be approximated as [13]:

$$\lambda = 4\sqrt{\varepsilon_r} \times (2S - L) \qquad (1)$$

where 'L' is the length of the shorting plate. Although the expression in (1) is just a rule of thumb, at best, it provides an important insight. That is, if the perimeter of the radiating element can be increased, without a corresponding increase in size, the resonant frequency can be lowered.



(a) (b)

Figure 1. Square PIFA (a) and Minkowski PIFA (b).

Employing a pre-fractal geometry, instead of the conventional polygon, increases the perimeter, while preserving antenna size. Four rectangular indentations are introduced, one on each side of the original square patch, to create a Minkowski pre-fractal shape (see Figure 1). Figure 2 shows a comparison of the simulated return loss (Ansys® Designer), for the square and the Minkowski pre-fractal shaped PIFA. The square PIFA is resonant at 2.82 GHz,while the miniaturized PIFA resonates at 2.41 GHz, corresponding to a 15% reduction in size [14]. The usable impedance bandwidth of the pre-fractal Minkowski PIFA is just under 10% at 2.41 GHz, down from 20% for the square PIFA. Nevertheless, the entire ISM band from 2.4 to 2.5 GHz is still usable with a margin of roughly 50 MHz on either side.

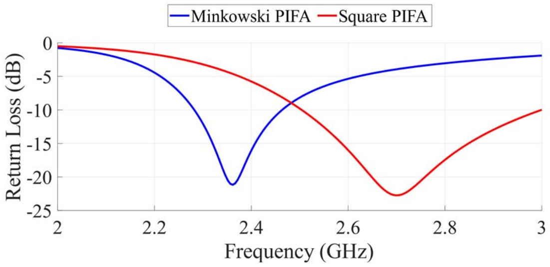


Figure 2. Return loss of the Miniaturized Minkowski PIFA and the original Square PIFA.

It is desirable for a wearable antenna to have a bandwidth much wider than its intended band of operation. The wider band serves as a pre-emptive measure against de-tuning due to body proximity or deformation [6, 15]. To increase the usable bandwidth of the miniaturized PIFA, a T-shaped ground plane modification [16] is introduced. As a result, the fractional bandwidth of the miniaturized PIFA rises to around 18% (Figure 3).

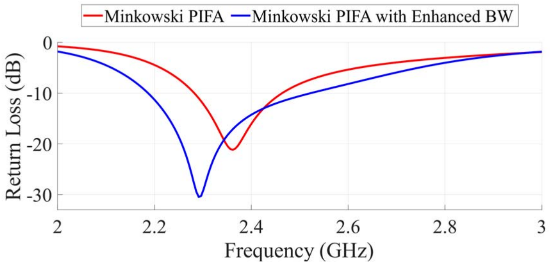


Figure 3. Return loss for the Minkowski PIFA and the enhanced bandwidth Minkowski PIFA.

Despite the miniaturization effect, the radiation performance of the Minkowski PIFA is comparable to the original square PIFA. The peak gain for the Minkowski PIFA is equal to 3.25 dBi, and it occurs around 2.4 GHz, as compared to the value of 3.48 dBi for the square PIFA at ~2.8 GHz (see Figures 6, 7).

3 Experimental Results

To validate the simulated results, the Square and the Minkowski pre-fractal shaped PIFA with T-shaped ground plane are both manufactured. The antenna ground planes and the radiating elements are fabricated from 0.3 mm thick copper sheet, while a SMA connector soldered to the ground plane is used as the feeding port.
The measured resonant frequencies of both antennas deviate by around 3% from the simulations, probably as a result of the manufacturing tolerances. The square PIFA is found to be resonant at 2.73 GHz, whereas the Minkowski based design resonates at 2.33 GHz (Figure 5). The measured impedance bandwidth is also slightly lower than the simulated bandwidth, for both antennas. Nevertheless, the measured return loss confirms the miniaturization effect of the Minkowski pre-fractal design.

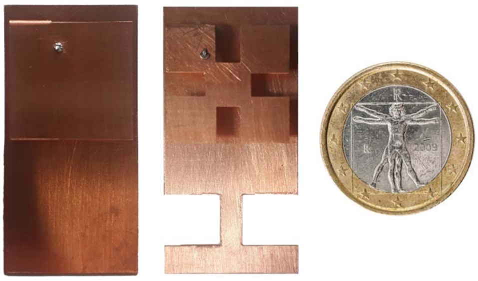


Figure 4. Picture of the fabricated antenna prototypes.

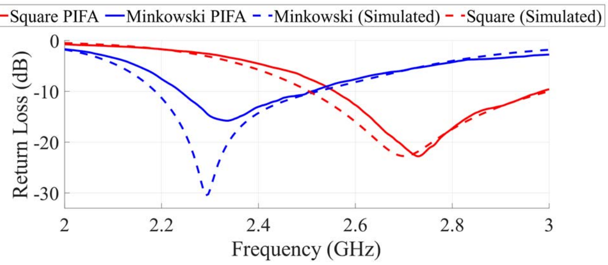


Figure 5. Return loss for the proposed Minkowski pre-fractal shaped PIFA and the conventional Square PIFA.

Figures 6 and 7 show the boresight gain for both manufactured antennas, measured into the anechoic chamber at the Microwave Laboratory of the University of Calabria.

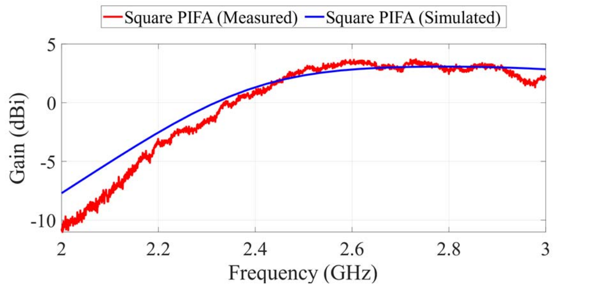


Figure 6. Boresight Gain against frequency for the conventional Square PIFA.

A satisfactory agreement can be observed between measured and simulated gain curves relative to Square PIFA design, in the frequency range corresponding to its approximate operating bandwidth (2.5-3 GHz). For the Minkowski PIFA, a slight discrepancy can be observed between measured and simulated data (see Figure 7), probably related to interferences effects due to the T-shaped indentations in the ground plane. A refined measuring campaign will be performed to solve the above problems.

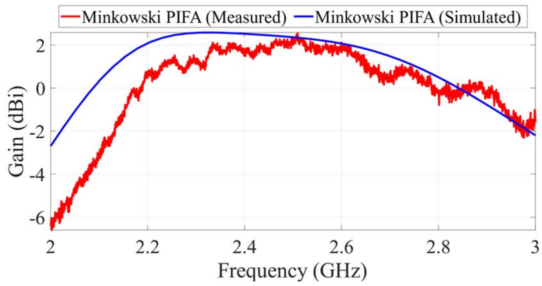


Figure 7. Boresight Gain against frequency for the Minkowski PIFA with enhanced bandwidth.

4 Simplified Design: Preliminary Numerical Results

The idea behind the Minkowski pre-fractal-based design is to augment the perimeter of the radiating element. Although the resonant frequency is reduced, simulations show that miniaturization may not be due to the increased perimeter. Under the perimeter hypothesis, each slot should contribute equally to the miniaturization, since each slot increases the perimeter by the same amount. However, varying the depth of individual slots shows that the miniaturization is mainly due to two slots, labeled ‘1’ and ‘2’ in Figure 8(a), whereas slots ‘3’ and ‘4’ do not contribute significantly to the reduction in the resonant frequency.

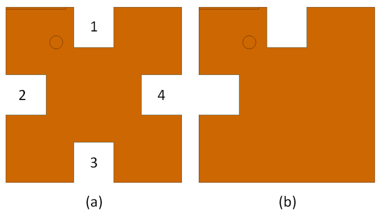


Figure 8. Comparison of the Minkowski pre-fractal based geometry (a) and the new simplified geometry (b).

As a matter of fact, simulations show that, by removing slots ‘3’ and ‘4’, an increase in bandwidth can be achieved, with negligible cost to miniaturization (Figure 9). The new simplified design provides similar resonance performance as the Minkowski pre-fractal shaped design. Future work will be focused on the fabrication and validation of the above simplified design.

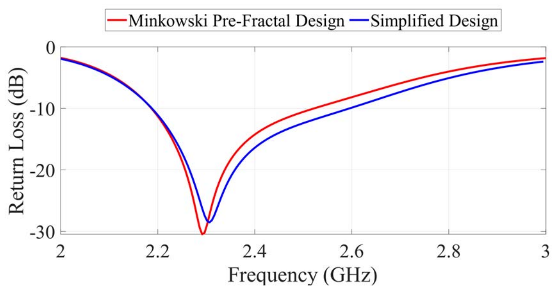


Figure 9. Return loss comparison between the Minkowski Pre-fractal based design and the new simplified design (both using T-shaped ground plane for better bandwidth).

5 Conclusion

A pre-fractal based radiating element design has been proposed for PIFAs miniaturization. The effectiveness of the presented technique has been demonstrated through simulated and measured results. The design has been proven to offer considerable reduction in size (nearly 15%), with negligible degradation in the radiation performance and the usable bandwidth. A further simplified design has also been introduced, that promises to be just as effective. Measurements for the simplified design are underway and they will be reported in future correspondence. The designs can be useful for wearable personal communication devices.

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