A Compact Dual-Band Foam-Based UHF PIFA

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Introduction

The subject of this work is a preliminary design of a low-cost linearly-polarized dual-band UHF antenna (center frequencies are 440 MHz and 915 MHz, respectively) with the bandwidth of at least 10% at 440 MHz. The antenna should be relatively small in size (at most $0.25\lambda_0$), do no have a matching network (have low loss), have an almost omnidirectional radiation pattern, and be conformal (wearable). These restrictions limit the anticipated antenna type to patches (conformal TM resonators) and, maybe, to loops. Whilst the UHF loop antennas (cf. [1]) are small and have an acceptable performance close to the human body [2], they are narrowband and generally lossy due to the necessity of an impedance matching network.

A UHF array of cavity backed annular microstrip half wave patches with dual polarization has been considered in Ref. [3]. The single antenna element has a large bandwidth (46%); its center frequency is 350 MHz. The single element size is 43.2cm×43.2 cm, which scales to 34.4×34.4 cm at 440 MHz. This dimension is still too big for our purposes. Similarly, the cavity-backed CP antenna developed in Ref. [4] has the size of 15×15×6 cm at the center frequency of about 500 MHz and is not very appropriate due to the large vertical dimension. The DR-based UHF antenna developed in Ref. [5] has an exceptional performance but requires a complicated layered magnetodielectric material and a large metal ground plane. A printed fractal UHF antenna discussed in [6] has a small size; its bandwidth, however, remains unknown.

The quarter wave patch antenna or PIFA (Planar Inverted F Antenna) appears to be a natural candidate for our task since it has the approximate size of $0.25\lambda_0$ (cf. [7, 8]). The ground plane has a larger size – at least about 0.4-0.5 λ_0 in one dimension. However, this is rather a positive factor for the present work since the allocated space can be used for housing the anticipated transmitted hardware. Furthermore the size of the PIFA can be further reduced by using various techniques discussed below without reducing the operating bandwidth. This is a very inviting property for developing a compact portable UHF transmitter antenna system.

Antenna design

The miniaturization of the PIFA can be achieved using several approaches established previously for L- and S-bands: employing a dielectric material of high permittivity [9], capacitive loading of the patch antenna structure [10] and a capacitive (proximity coupled) feed [10], using slots on the patch to increase the electrical length of the antenna [8], and tapering the patch itself [11]. The high dielectric constant of the substrate is not

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very appropriate for our purpose. Therefore, the method based on capacitive loading [10] and tapering the patch [11], and the method that involves slots for longer current path [8] along the patch edges have been chosen.

The proposed tapered-type PIFA was designed and simulated at 440 MHz using the scaled antenna prototype from Ref. [11] as a starting point. Further, the capacitive loading and slots were added as suggested in [10] and [8], respectively. The capacitive load was formed by folding the open end of the PIFA toward the ground plane and adding a plate (parallel to the ground plane) to produce a parallel-plate capacitor. The length of the slots, the number of slots, the vertical length of the capacitor plate, the location of the shorting plate and of the feeding point have been carefully optimized in order to achieve the best performance.

The antenna design and optimization were done using Ansoft HFSS v10, with tetrahedral meshes that typically include 20,000-30,000 tetrahedra per structure. The parametric sweeps were organized separately over eight independent antenna geometry parameters. The results for every sweep were then analyzed and the best parameter fit has been identified. Then, the parameter value has been updated. This procedure was repeated a few times to assure the multivariable search.

Results

Fig.1a, b shows the suggested configuration of the PIFA. It consists of a linearly tapered top plate (radiating patch), ground plane, feeding wire (probe feed), and a shorting plate. The height of the top plate above the ground plane is fixed ($\approx 0.04\lambda_0$). The patch, ground plane, and the shorting plate are made of copper foil and are supported by high-density polystyrene foam (3 pcf) from Dow Chemical Company. The dielectric constant of the foam was measured using the suspended ring resonator method and is approximately equal to 1.06 in the UHF band. The foam loss tangent was not measured (expected to be on the order of 0.002). The foam was cut using the HCM-2S hotwire foam cutter of Manix. The antenna was fed through a 50 Ω SMA connector. The antenna feed was assembled in a solderless way, using screw fastening and two small aluminum fastening plates (from both top and bottom of the foam support).

In order to investigate the effect of manufacturing uncertainty, four identical antenna prototypes were built and tested. Fig. 2a shows a prototype optimized for the single-band operation at 440 MHz. A phantom for the anticipated metal enclosure is seen on the right. Fig. 2b shows a further optimization step –a PIFA antenna that has two operating bands centered at 440 MHz and 915 MHz, respectively. The second resonance is associated with the vertical patch length. Fig. 3a gives measured (HP 85047A Network Analyzer) and simulated return loss for two single-band PIFAs. The antenna bandwidth is almost identical in both cases - about 60 MHz. However, both antennas are slightly shifted in center frequency vs. simulations toward the left. We believe that this shift is due to dielectric constant of the foam that has been set to one for the numerical optimization.

Fig. 3b shows two simulated radiation patterns (total directivity of the unloaded PIFA) for the single-band PIFA in two elevation planes. The antenna radiation is thus almost omnidirectional with the maximum directivity of about 2.7 dB at zenith; the polarization isolation in the upper half-space is above 10 dB.

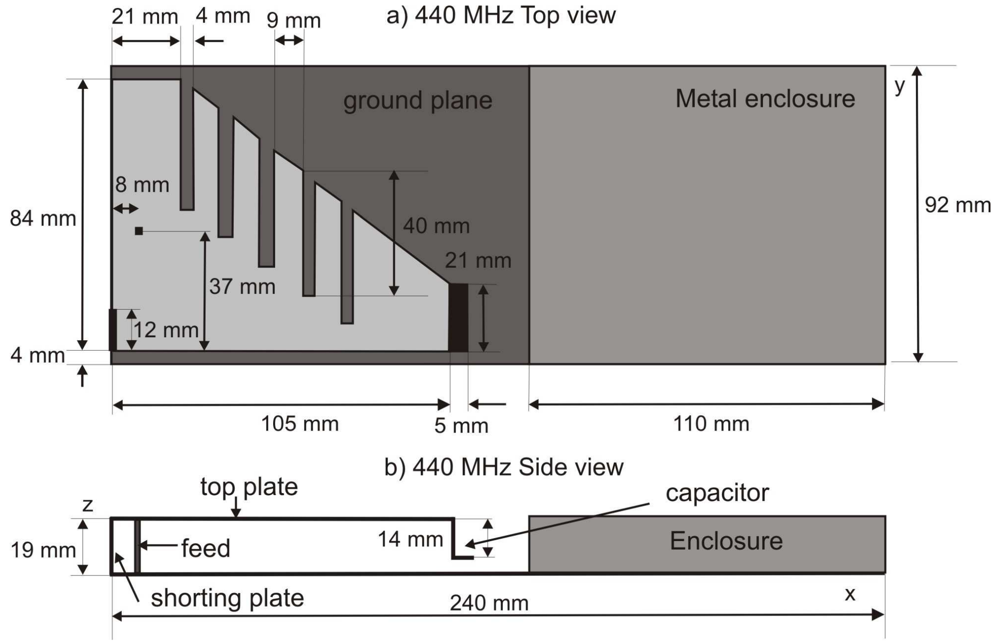

Fig.1. Reduced-size PIFA optimized for 440 MHz.

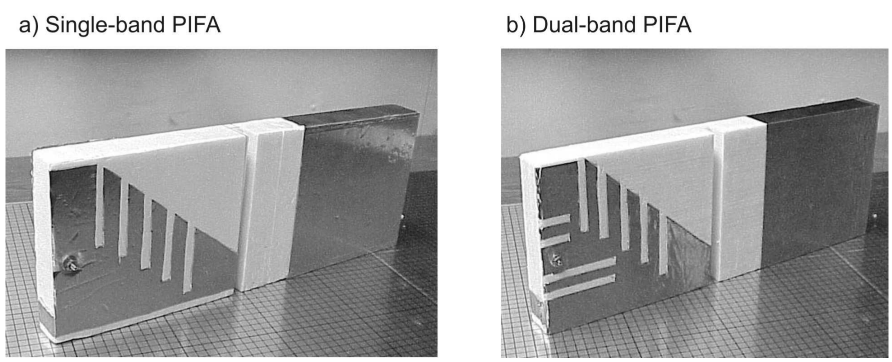

Fig.2. Antenna prototypes: a) – single-band 440 MHz PIFA; b) – extension to a dual-band design.

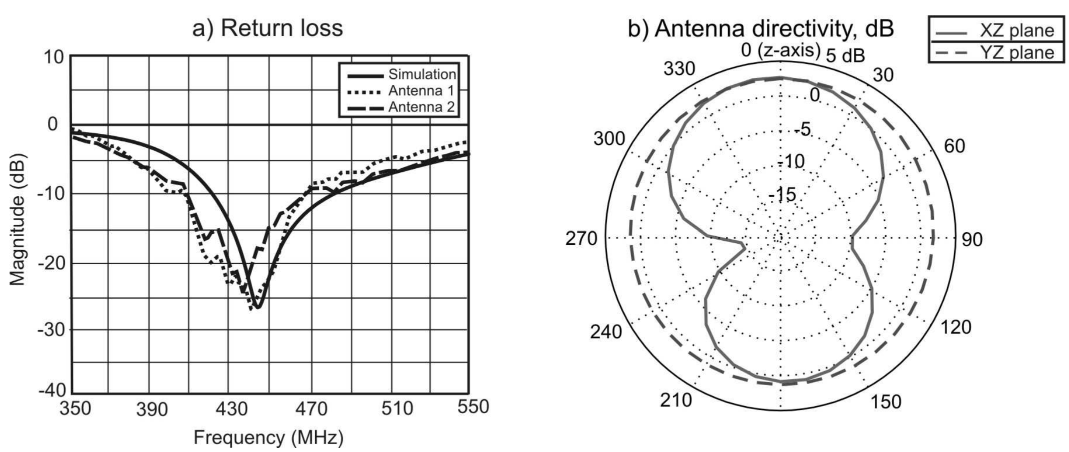

Fig.3. Return loss (measured and simulated) and two elevation radiation patterns (simulated) for the single-band PIFA optimized at 440 MHz.

Fig. 4 shows the return loss for the dual-band antenna operating at 915 MHz. The tuning at 915 MHz is achieved by introducing additional (horizontal) slots shown in Fig. 2b. Whilst the second resonance can be always tuned properly toward 920 MHz (Fig. 4b), its depth and bandwidth need to be optimized further.

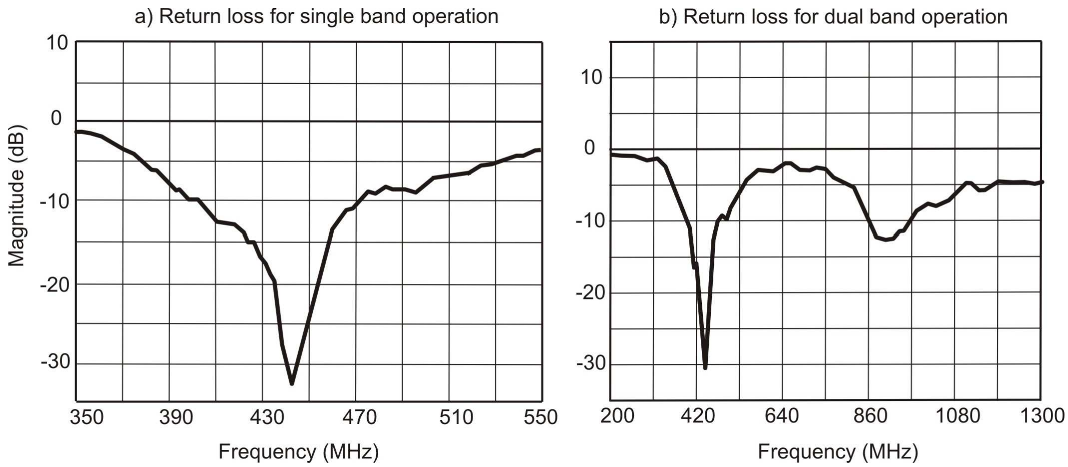

Fig.4. Return loss (measured): a) – single-band operation; b) – dual-band operation.

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