A Linearly-Polarized Compact UHF PIFA with Foam Support

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Abstract: Preliminary work on the design of a low-cost linearly-polarized broadband PIFA operating in the UHF band (440 MHz) is presented. Extensive simulations using Ansoft HFSS are performed in order to model and optimize the antenna performance. High-density polystyrene foam is employed as a dielectric substrate/support for all antenna prototypes. The metal sheets are made of copper foil. To minimize the antenna dimensions, a tapered patch with slots and capacitive loading is used. The fabricated antennas have the measured bandwidth of about 60MHz (14%) and are centered at 440 MHz. Change in antenna performance close to the human body is briefly discussed.

Keywords: PIFA, UHF, foam substrate, broadband antennas

1. Introduction

The subject of this work is a design of a linearly-polarized UHF antenna with the center frequency 440 MHz and with the bandwidth of at least 10%. 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 substrate 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 $0.5\lambda_0$ 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 antenna system.

2. 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 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 the 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 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. Through the optimization process, we tried to avoid using nested parametric loops in Ansoft. Such loops typically take a long time and are difficult to analyze visually.

3. 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 a 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. The foam loss tangent was not measured (expected to be about 0.002 for the present foam type). The foam is cut using the HCM-2S hotwire foam cutter of Manix.

In order to investigate the effect of manufacturing uncertainty two identical antenna prototypes were built and tested. Fig. 2 shows a foam-based prototype optimized at 440 MHz. A phantom for the anticipated metal enclosure is seen on the left. The size of the phantom can be varied from 85 to 110 mm. One division on the grid corresponds to 5 mm. The antenna was fed through a 50 Ω SMA connector attached to the ground plane (not seen in Fig. 2) by a nut/washer. A thin long screw was soldered to the SMA connector prior to assembly. The antenna feed was then attached in a solderless way, using screw fastening with the second nut/washer seen in Fig. 2 and two small aluminum fastening plates attached directly to the foam from both top and bottom. This method demonstrated a good electrical contact and mechanical stability.

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.

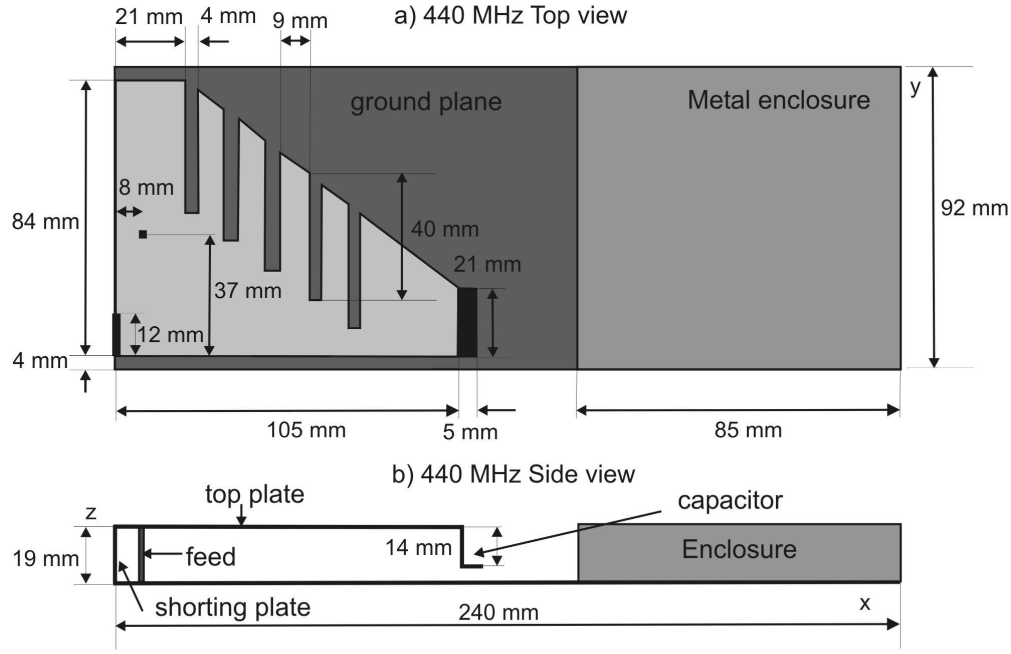

Fig.1. Reduced-size PIFA antenna optimized for 440 MHz.

440 MHz PIFA prototype

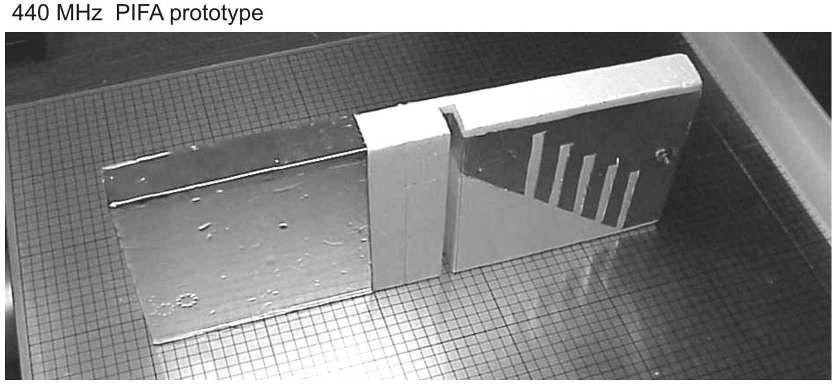

Fig.2. Foam-based antenna prototype at 440 MHz.

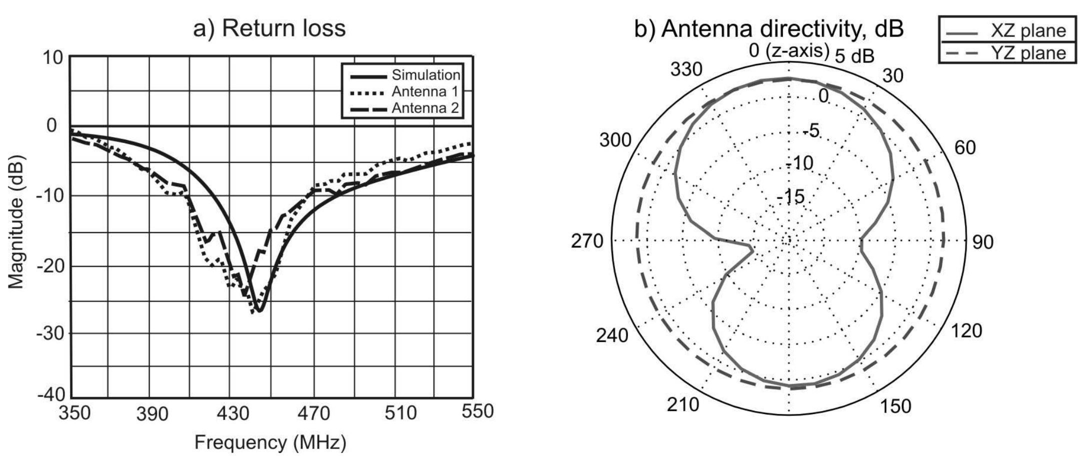

Fig.3. Return loss (measured and simulated) and two elevation radiation patterns (simulated) for PIFA optimized at 440 MHz.

Fig. 3b shows two simulated radiation patterns (total directivity in free space) 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.

Depending on the operating frequency, the proximity to the human body can lead to high losses caused by bulk power absorption, radiation pattern fragmentation, and antenna detuning [2]. Biological tissue is, for most practical purposes, non-magnetic with permeability μ (H/m) close to that of free space. The electromagnetic characteristics of tissues are described by the relative permittivity ε_r and effective conductivity σ (S/m) at the frequency of interest. Hence, the human body interacts with an electromagnetic wave as an inhomogeneous, lossy dielectric structure. Over the UHF frequency range 300-1000 MHz, biological tissues have a typical effective conductivity of $\sigma = 1.5$S/m and a relative permittivity of $\varepsilon_r = 75$ [2].

Initial simulations of PIFA performance close to the body have been carried out using Ansoft HFSS v10. The PIFA was placed at a separation distance of 5 mm from the human body. The body was approximately modeled as a large dielectric box having dimensions 50”×14” ×4”. Fig 4a shows the simulated return loss plot for the PIFA in proximity to the human body. As expected the present antenna gets detuned and now gives the maximum return loss of -10 dB at a higher frequency of about 460 MHz. The radiation pattern (Fig. 4b) would be ideal for placing the antenna on the sleeve. This circumstance has a further advantage of reducing the radiation on the head [12]. The ground plane also reduces the back radiation to other organs of the human body.

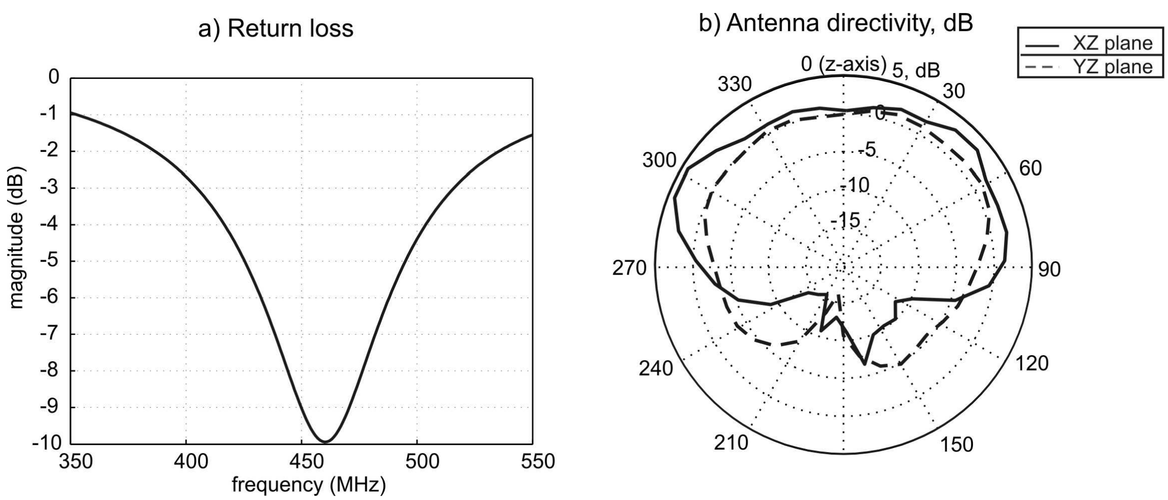

Fig. 4 Simulated performance of the proposed single-band PIFA close to the human body.

4. Conclusion

PIFA antennas manufactured on a foam substrate have shown the performance that agrees well with the simulations. The major disadvantage of the foam material – potential fragility and uncertainty of shape – is of little importance for the present broadband UHF PIFA antenna. The observed degree of repeatability of the antenna characteristics is fully sufficient for our purposes.

5. Acknowledgement

The support of the National Institute of Justice of the Department of Justice is gratefully acknowledged. The authors would also like to thank Jonathan Leslie of WPI for his help.

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