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TRIPOD OMNIDIRECTIONAL LOW PROFILE ANTENNA: A VERTICALLY POLARIZED ANTENNA WITH 90% BANDWIDTH

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ABSTRACT: *A new vertically polarized omnidirectional antenna, inspired by an old design, has been studied, optimized, realized, and measured. With a radiation pattern similar to the classical monopole on a ground plane, the proposed antenna concept provides a much larger bandwidth and a very low profile. This antenna has numerous potential applications for mobile communications, UWB, and others.* © 2012 Wiley Periodicals, Inc. Microwave Opt Technol Lett 54:516–521, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27340

Key words: *low-profile antennas; omnidirectional antennas; vertical polarization; wideband antennas*

1. INTRODUCTION

Vertically polarized antennas with omnidirectional radiation pattern are probably the most frequently used antennas; these antennas can be found on the roof of nearly each vehicle (cars, ships, trains, and airplanes), on buildings, used as an element in radiogoniometer arrays, and so on. There is a wide variety of such antennas, starting from the simplest ones like the monopole on a ground plane or the vertical dipole; in order to increase the bandwidth, more complicated geometries are used, like cones, tapered shapes, or even fractals. If all these antennas have more or less the required characteristics in terms of polarization, bandwidth, and radiation pattern, they share a common inconvenient: their height, which is comprised between one and about 1/5 wavelengths. In many situations, a much smaller vertical dimension is desirable so that the antenna can be better integrated in its environment.

2. THE ANTENNA CONCEPT

The antenna concept proposed here is based on a very interesting antenna covering the 1.2–2 GHz band (50% bandwidth) with a very particular geometry that was first described at in 1976 [1]. This antenna was called quadripod kettle antenna (QKA) by its inventor. This name probably finds its origin in the shape of the old kettles used to heat up water on a wood fire. As shown in Figure 1, these kettles usually have three (or four) ‘‘legs’’ to position them at the proper height over the heat source, and the relation between both structures becomes evident when considering the QKA simulation model depicted in Figure 2.

The QKA is a self-standing purely metallic structure that consists of (i) a ground plane (GP), to which the external conductor of the coaxial feeding is connected, (ii) a lower power division stage, with a central square patch connected to the inner conductor of the coaxial and four grounded pods (or legs), and (iii) an upper power combining stage in the shape of a square (an octagon or a circle are possible variations) whose periphery is connected to the lower stage by means of another four pods. With both the stages properly aligned and the inner conductor of the coaxial connected to the center of the square of the lower

Figure 1 A tripod kettle from the 19th century. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

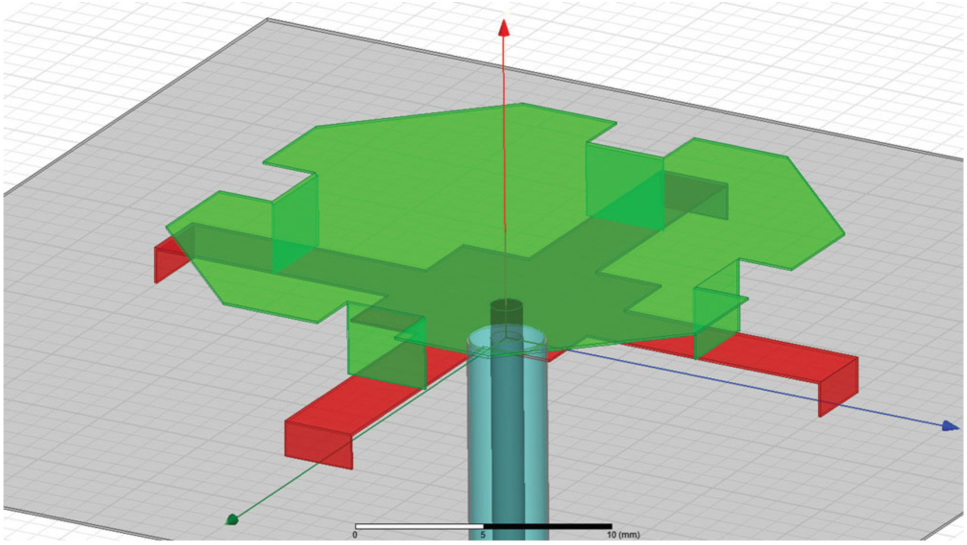

Figure 2 View of the QKA (HFSS model). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

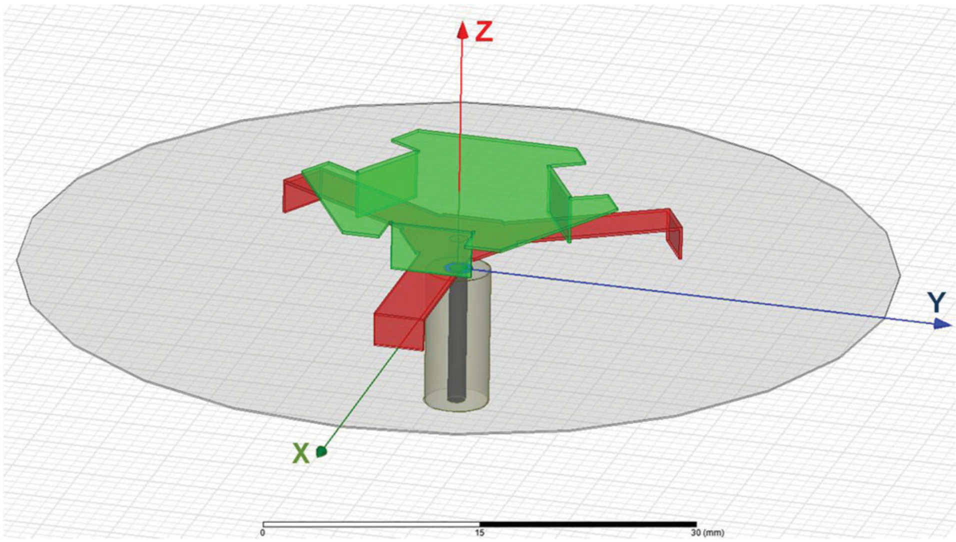

Figure 3 HFSS model of the TKA. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

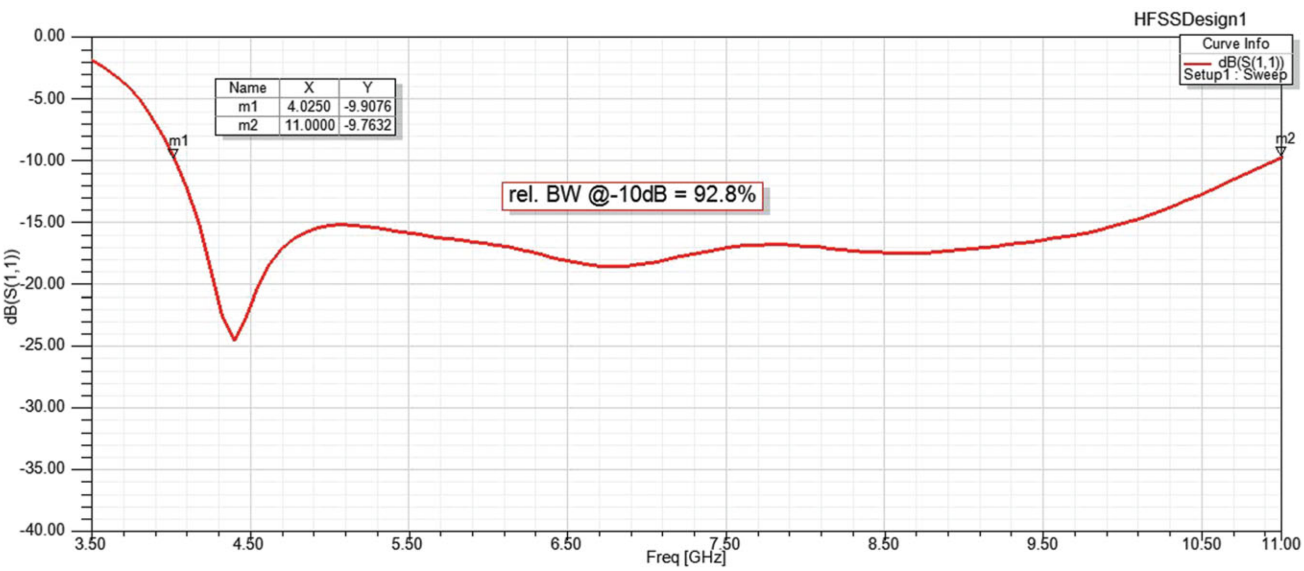

Figure 4 S_{11} of the final TKA after optimization. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

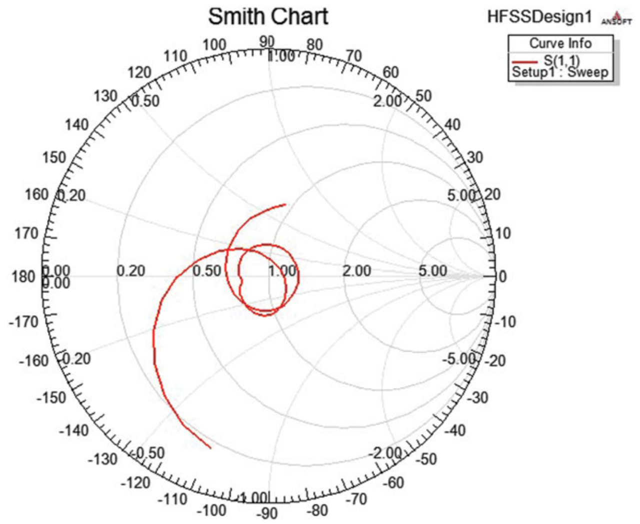

Figure 5 The double resonance (two loops) is clearly visible. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

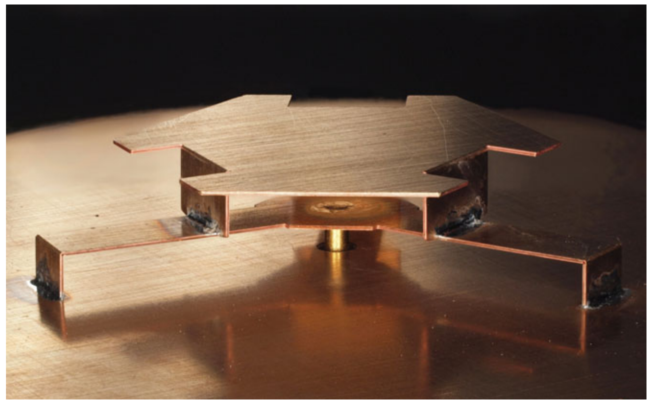

Figure 6 Prototype of the TKA, with the pin of the SMA connector visible at the center. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

stage, the QKA is an axially symmetrical antenna, which is an attractive feature for omnidirectional antennas.

The author of the present article fabricated and measured by curiosity a prototype of this antenna (in the 1.2–2 GHz band) in the 1980s and found very promising results. Later on, a systematic parametric study was conducted experimentally with the fabrication and measurement of about 30 prototypes [2]; this was necessary because at the time no simulation program powerful enough was available! This study confirmed the results presented in [1] and permitted to slightly increase the bandwidth of the antenna up to 55%.

The QKA is again cited in 1997: the measured results obtained in [2] were used to validate theoretical developments obtained during a PhD thesis dealing with MPIE technique to modelize structures with vertical conductors [3]. The comparison between simulations and measurements have been presented in [4] and shows excellent agreement. Then this odd-shaped antenna was practically forgotten.

Recently, the need for a vertically polarized and low-profile omnidirectional antenna with a very wide bandwidth recalled the author the promising features of the QKA, and a new study on this subject was started, this time with the help of modern simulation tools.

3. ANTENNA CONCEPT EVOLUTION

All simulations results presented here have been obtained with ANSYS HFSS v. 13.0.1 [5]. Bandwidth (BW) in this article is the relative bandwidth (in %) for which $S_{11} \leq -10$ dB. Figure 2 shows the geometry of the original QKA as designed in HFSS. A systematic parametric study was done on this geometry, using either clever tuning and/or optimization in order to maximize the bandwidth. A clear improvement over the ''hardware optimization'' made in [2] was attained, increasing the bandwidth from 55% to 67%. However, it was not possible to make further improvements with this geometry.

At this point, questions raised are: how to further increase the bandwidth? Is the bandwidth dependent on the number of pods? Would a tripod, hexapod, or octopod be better? Simplicity being often better than complexity, the tripod version was chosen.

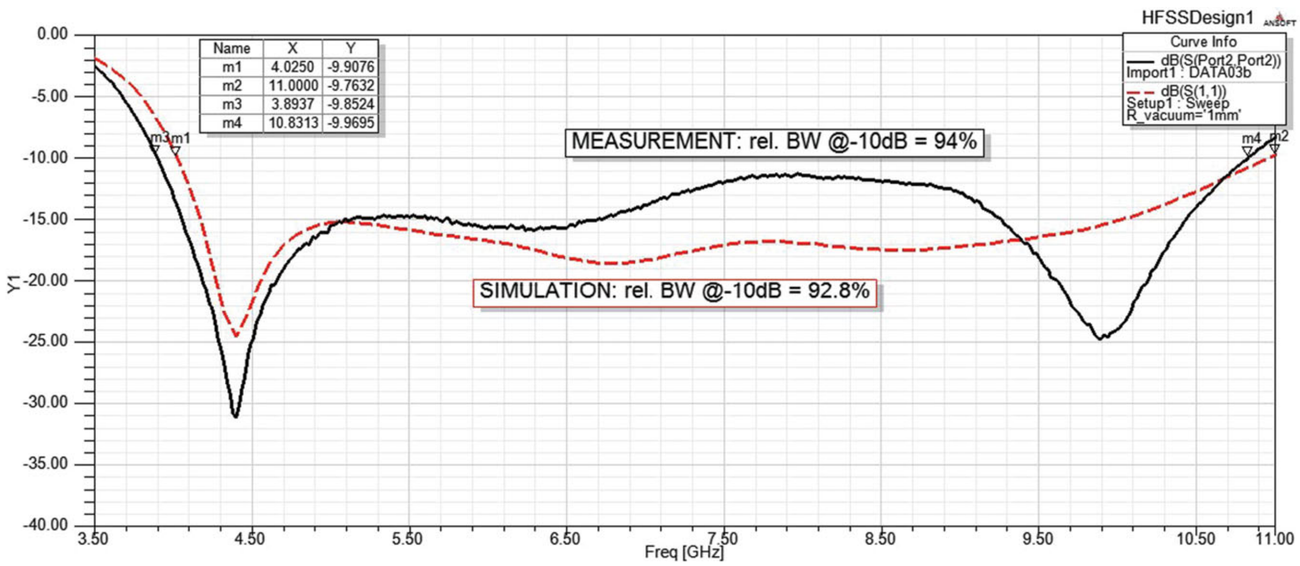

Figure 7 Comparison of measured (—) and simulated (---) S_{11} for the TKA Nr 1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

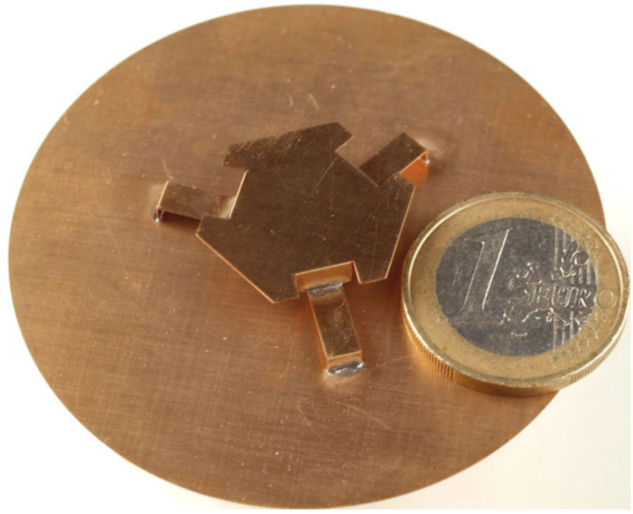

Figure 8 The TKA with a 1 coin. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

If the inventor of the QKA decided to make his antenna ''Quadripod,'' it was probably for reasons related to the antenna realization, which is much easier with a geometry having lines only at 0°, 90°, and 45°. However, with modern CAD fabrication techniques, any geometry can be realized quite easily, so that it is worth testing variations on the original antenna shape.

The tripod version was tested, with a center frequency of 7.5 GHz as required by our primary needs, and was initially called tripod kettle antenna (TKA). Apart from the evident geometry modifications that lead to the substitution of square shapes by hexagonal ones, the architecture of the TKA is composed by the same elements of the QKA: different stacked metal stages and the pods connecting and supporting them. This gives the antenna the simple and elegant shape shown in Figure 3.

To preserve the antenna symmetry, it has been mounted on a circular ground plane. All antenna dimensions have been parameterized for an easy optimization of the performance. A thorough simulation campaign of this structure resulted in an impressive 92.8% BW, with the return losses better than −15 dB over most of the band (see Fig. 4).

The wideband characteristics of the TKA are related to the double resonance behavior that can be observed in the Smith Chart of Figure 5. A prototype of this antenna was built on 200-μm-thick Beryllium Copper sheets. This material has excellent mechanical properties together with a good conductivity. Given the thickness of the sheets, chemical etching or laser cutting would be more appropriate for the machining of the complex shapes of the two stages of this antenna than milling. The prototypes shown next were all obtained using chemical etching. This technique uses the same steps and equipment as for the realization of printed circuits, with the difference that two nearly identical masks are used to make a symmetrical etching of the Beryllium Copper; etching from both sides improves the accuracy by minimizing the underetching. In the TKA structure, both the lower and upper stages have bent sections (the vertical part of the pods), and an exact positioning of the bending location is critical to obtain good performance. Introducing narrow gaps (150 μm wide) in ONE of the masks allows etching a grove with a depth of half the metal thickness; this grove allows a very accurate and easy bending of the material. The masks (Gerber format) were generated using ANSYS Designer v. 6.1.1 [6].

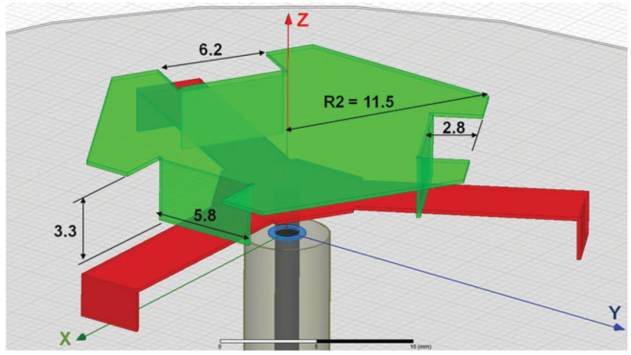

Figure 10 Dimensions of the upper part of TKA (R_2 is the radius of the upper hexagon). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

The accuracy of the parts realized with this technique is estimated to be within ±50 μm. The relative positioning accuracy of the parts should be similar. To test the repeatability of the manufacturing procedure, two identical prototypes were built and measured. The first prototype is shown in Figure 6. All parts have been soldered together by hand, and the antenna performance was measured with an HP8720D Network Analyzer. The results have been compared with the simulations and both are displayed in Figure 7.

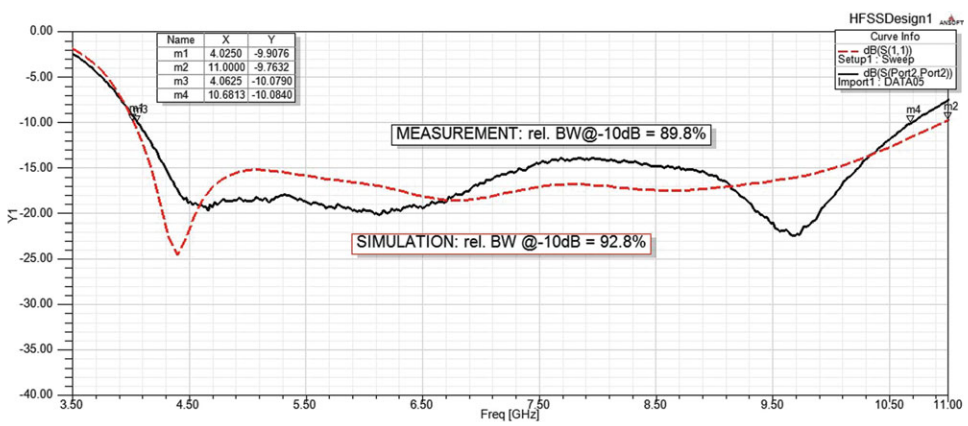

Figure 9 Comparison of measured (—) and simulated (---) S_{11} for the TKA Nr 2. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

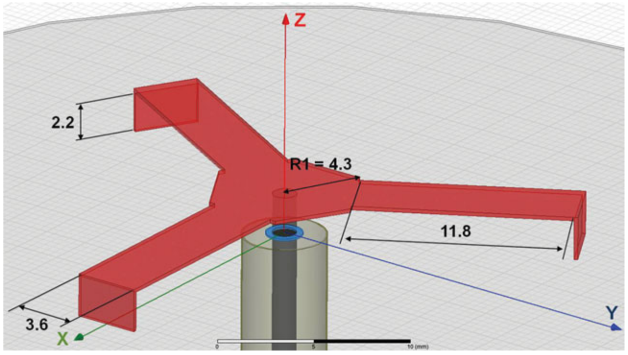

Figure 11 Dimensions of the lower part of TKA (R_1 is the radius of the lower hexagon). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

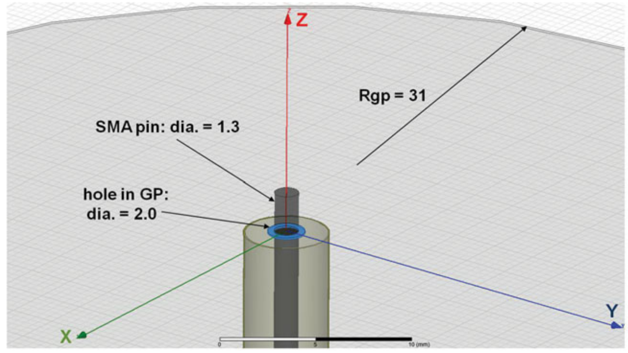

Figure 12 Dimensions of the GP and coaxial feed of TKA (Rgp is the radius of the GP). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

For the first prototype, the agreement between predictions and measurement keeps within reasonable limits. The main differences between both curves are related with a slightly more accentuated ripple of the measured response (especially between 6.5 and 9 GHz) and a small frequency shift of the curves. The measured bandwidth is 94% (92.8% for the simulation). These results are very satisfactory taking into account all the tolerances involved in the fabrication and assembly of the very small parts that compose the antenna (see Figure 8).

A second prototype of exactly the same antenna was fabricated with more care, especially concerning the reduction of etching tolerances (a more accurate etching process with another photoresist was used), and the use of improved of the assembly and soldering techniques. The results for this prototype are illustrated in Figure 9 together with simulations.

This time, the agreement between simulation and measurement is better in general, with a maximum measured S_{11} in the middle of the band below −14 dB (around 7.7 GHz); the lower

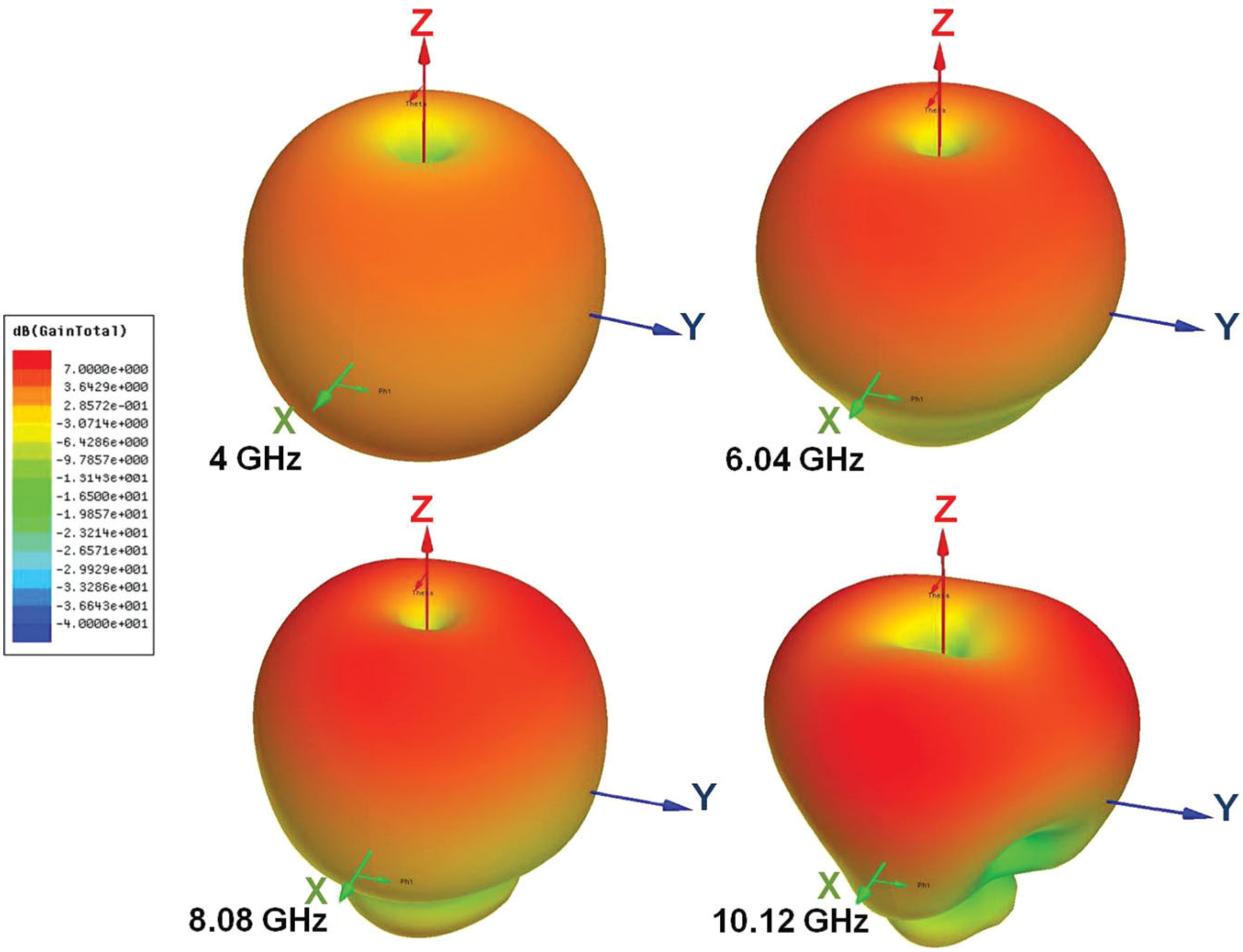

Figure 13 3D radiation patterns for 4, 6.04, 8.08, and 10.12 GHz. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

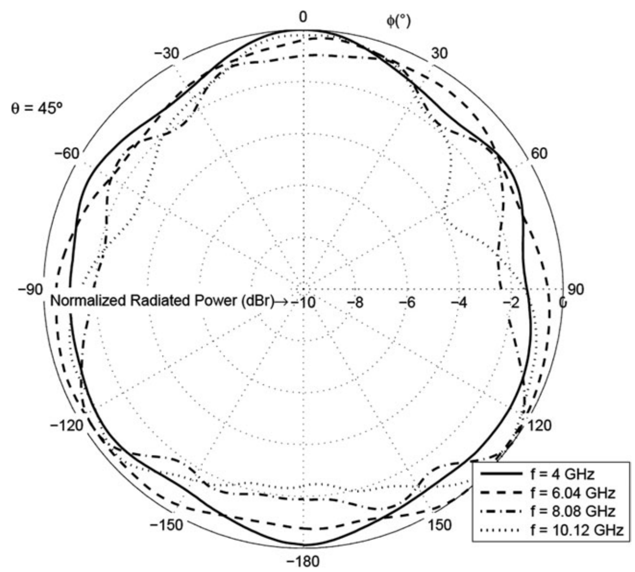

Figure 14 Measured omnidirectional behavior of the TOLPA at 4, 6.04, 8.08, and 10.12 GHz for an elevation angle of 45°

frequency limit is practically the same for both curves. However the measured upper frequency limit is lower than the simulated one, reducing the measured bandwidth to 89.8%.

The realization of two prototypes with the same nominal dimensions clearly shows the dispersion due to the fabrication technique. This dispersion is considered to be the main reason for the (small) discrepancies observed between simulations and measurements. In fact, a sensitivity analysis of the return loss made with HFSS and accounting for the tolerances mentioned above shows that the measured results are completely captured within the uncertainty envelope defined around the predicted nominal results.

The antenna dimensions (in [mm]) are shown in Figures
F10-F12 10–12. The coaxial feed is made of a standard SMA connector whose flange is soldered to the bottom of the GP (which is made of the same 200-μm-thick Beryllium Copper). The diameter of the hole in the GP also plays a role in the optimized performance.

The total height of the TKA structure is 5.9 mm (2.2 + 3.3 + 2 mm × 0.2 mm metal thickness), corresponding to 0.079 λ_0 at lower frequency and 0.216 λ_0 at upper frequency. At the center of the band (7.5 GHz) the antenna height is 0.147 λ_0. This antenna is clearly very low profile when compared with more conventional omnidirectional, vertically polarized antennas. For this reason, it was renamed Tripod Omnidirectional Low Profile Antenna (TOLPA).

4. TOLPA RADIATION CHARACTERISTICS

Up to now, only the S_{11} performance of the antenna has been described. An antenna has to perform as desired not only concerning its matching but also its radiation characteristics are concerned. This has been checked through all steps of the design and optimization. Simulations have shown that across the full 4 to 11 GHz band the polarization remains vertical (*E* field perpendicular to the GP), with a quasi omnidirectional radiation pattern in the *XY* plane. For all frequencies there is a deep null in the *Z* direction, making the radiation pattern similar to that of a monopole on a ground plane. In elevation, the maximum gain is practically in the horizontal (*XY*) plane at the low frequency edge; increasing the frequency, this maximum moves up. Figure 13 shows the 3D radiation patterns for four different frequencies (4, 6.04, 8.08, and 10.12 GHz). One can see that at the lower edge of the band the radiation pattern is very smooth; it changes slowly with increasing frequency, and at the upper end of the band its shape has visible maxima in the directions of the TOLPA pods. The maximum predicted gain varies between about +1.6 dBi at 4 GHz and +7.5 dBi at 10.8 GHz. The change of the elevation angle of the maxima with increasing frequency is also visible.

These simulated results have been confirmed by measurements. In particular, the omnidirectional characteristics of the TOLPA are evidenced in Figure 14, where the vertically polarized radiation patterns measured at four different frequencies along a conical cut with 45° elevation are superimposed. For all but the highest frequencies, the discrepancy from a perfect omnidirectional pattern is lower than 3 dB. At 10.12 GHz, it is below 4 dB. These results are very good for such a very broadband antenna.

5. CONCLUSIONS AND PERSPECTIVES

The TOLPA is a new antenna derived from an old design presented 36 years ago and undeservedly forgotten. Thanks to the power of actual simulation tools and to a redesign of its shape it has been possible to upgrade the antenna performance up to an impressive bandwidth of more than 90%, while preserving its omnidirectional radiation pattern and its vertical polarization. However, one of its most amazing characteristics is its low profile, making it an excellent candidate for a wide range of applications covering telecommunications, entertainment, electronic, and many other domains.

Being made only of metallic parts, it avoids the losses inherent to dielectric loaded antennas, and its manufacturing cost could be extremely low for large series realization. It might also be a good candidate for UWB applications if its dispersion characteristics are adequate; this point needs to be further studied.

Finally, the TOLPA is an antenna that can easily be scaled to cover other frequency bands. A millimeter wave version is currently under development and will be the subject of another paper. In the future, other variations on the same principle will also be studied with different numbers of pods and variations on its geometry.

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