# Circular and Elliptical CPW-Fed Slot and Microstrip-Fed Antennas for Ultrawideband Applications

Evangelos S. Angelopoulos, Argiris Z. Anastopoulos, Dimitra I. Kaklamani, *Member, IEEE*, Antonis A. Alexandridis, Fotis Lazarakis, and Kostas Dangakis

***Abstract*—This letter presents novel circular and elliptical coplanar waveguide (CPW)-fed slot and mictrostip-fed antenna designs targeting the 3.1–10.6 GHz band. The antennas are comprised of elliptical or circular stubs that excite similar-shaped slot apertures. Four prototypes have been examined, fabricated and experimentally tested, the three being fed by a CPW and the fourth by a microstrip line, exhibiting a very satisfactory behavior throughout the 7.5 GHz of the allocated bandwidth in terms of impedance matching ($\mathrm{VSWR} < 2$), radiation efficiency and radiation pattern characteristics. Measured impedance bandwidths of beyond 175% will be presented.**

***Index Terms*—Circular, coplanar waveguide (CPW), elliptical, microstrip, slot, ultrawideband (UWB).**

## I. Introduction

ULTRAWIDEBAND (UWB) communications have attracted great interest lately, being one of the most promising technologies for short range mobile systems. UWB systems use short duration pulses of some subnanoseconds to transmit coded signals. The short duration of the pulse spreads the signal energy to a very wide bandwidth as indicated by the Fourier transform relationship. This feature combined with the low transmission energy ensures minimal interference with common narrowband systems. Because of its immunity to multipath fading, since it resolves reflections, the very low power requirements and the guaranteed high bit data rates, UWB technology seems adequate to numerous potential applications. To name a few: radars, ground penetration radars, through-the-wall or medical imaging, precision location systems and other military communications setups.

In this letter, we investigate the properties of circular and elliptical configurations which meet the 802.15.3 protocol requirements, in terms of impedance bandwidth, in the 3.1–10.6 GHz band. Up to now, there has been a vivid stir of interest among antenna engineers in trying to develop novel UWB antenna designs operating throughout the entire 7.5 GHz spectrum. In [1] and [2], designs of single ended or differentially fed elliptical disc monopoles, and planar teardrop-like dipoles have successfully exhibited measured bandwidths of several gigahertz. Alternatively, by using CPW to feed circular monopoles [3], U-shaped stubs [4], or curved exotic configurations [5], UWB behavior has been equivalently demonstrated.

In the current study, novel circular and elliptical slot antennas fed by 50 Ω planar transmission lines (either CPW or microstrip) are examined. The first three configurations are CPW-fed slot antennas, where the coplanar transmission line is terminated to an elliptical or circular tuning stub which is included within a slot of same shape, etched from the ground plane. So far, a similar configuration with a rectangular stub [6] has been shown to exhibit 60% of impedance bandwidth with respect to the center frequency of 2 GHz. Here, we present measured impedance bandwidths of 175%. The fourth proposed radiator is a novel microstrip-fed elliptical stub which is excited over a similar-

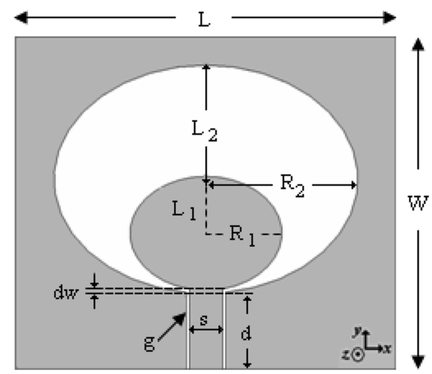


Fig. 1. Geometry of the proposed CPW-fed slot antenna configuration.

TABLE I
DIMENSIONS OF THE FOUR ANTENNA PROTOTYPES (I, II, III, AND IV) ON $e_r = 3$, $h = 1.575$ mm

| in (mm) | $L$ | $W$ | $L_1$ | $R_1$ | $L_2$ | $R_2$ | $d$ | $dw$ | Type |
|---|---|---|---|---|---|---|---|---|---|
| **Prototype** I | 40 | 35 | 6 | 8 | 12 | 16 | 8 | 0.3 | **CPW Elliptical** |
| **Prototype** II | 40 | 40 | 7.5 | 7.5 | 15 | 15 | 8 | 0.3 | **CPW Circular** |
| **Prototype** III | 90 | 90 | 20 | 20 | 35 | 35 | 12 | 0.3 | **CPW Circular** |
| **Prototype** IV | 40 | 35 | 6 | 8 | 12 | 16 | 8 | 0.3 | **Microstrip Elliptical** |

Manuscript received February 14, 2006; revised May 26, 2006. This work has been partially funded by the E.U. in the framework of project IST-2003-508009, ACE (Antenna Center of Excellence).

E. S. Angelopoulos, A. Z. Anastopoulos and D. I. Kaklamani are with the National Technical University of Athens, School of Electrical and Computer Engineering, Microwave and Fiber Optic Laboratory (MFOL), Athens GR-15780, Greece (e-mail: vagee@esd.ece.ntua.gr).

A. A. Alexandridis, F. Lazarakis, and K. Dangakis are with the Institute of Informatics and Telecommunications, NCSR Demokritos, Athens GR-15310, Greece (e-mail: aalex@iit.demokritos.gr).

Digital Object Identifier 10.1109/LAWP.2006.878882

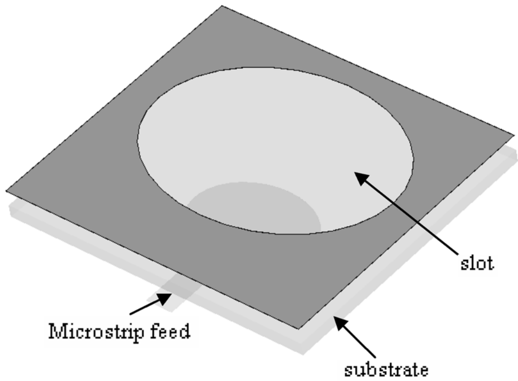


Fig. 2. Prototype IV. Microstrip-fed elliptical slot antenna geometry.

shaped aperture ground plane. It comes as a direct modification of the CPW-fed designs and can be considered as an alternative UWB radiator for multisubstrate PCB boards, exhibiting a bandwidth ratio of 142%. Details of the simulation procedure and experimental results exhibiting the UWB characteristics of the proposed radiators are analyzed and discussed.

## II. Antenna Description

### A. Elliptical and Circular CPW-Fed Slot Designs

A general design layout of the CPW-fed slot antenna is shown in Fig. 1. All developed prototypes are photochemically etched on a TLC—30 substrate of 1.575 mm (h) of thickness and relative permittivity of 3 ($\varepsilon_r$) from Taconic. The ground plane dimensions are $L$ mm by $W$ mm and the metal cladding is 0.018 mm. The $x$ and $y$ axes of the elliptical slot are denoted with $R_2$ and $L_2$, respectively, while $R_1$ and $L_1$ are the axes of the stub tuning element. The coplanar line has a length of $d$ mm, while a strip width of $s = 3.5$ mm and a feed aperture of $g = 0.3$ mm, ensure characteristic input impedance of 50 $\Omega$. The offset distance from the tuning stub (elliptical or circular) to the edge of the coplanar line is denoted as $dw$. The circular geometry arises when $L_1 = R_1$ and $L_2 = R_2$.

The design layout illustrated in Fig. 1 has been rigorously investigated using HFSS. For various values of $L_1$, $R_1$, $L_2$, $R_2$ and $dw$, UWB behavior has been achieved. As indicated in [1], the distance from the antenna stub to the surrounding ground plane with respect to the feeding point, is symmetrically and gradually increasing. As a consequence, the impedance change from one resonant mode to another is small, therefore enabling very large bandwidth from the fundamental mode to much higher resonant modes. Consequently, apart from the optimal value settings of the stub's and slot's radii, $dw$ (it controls the offset gap) has been specially arranged in order to satisfactorily arrange the depth of impedance matching, without sacrificing bandwidth. In all occasions $dw$ was fixed to 0.3 mm.

Three prototypes hereafter denoted as I, II, and III, were the product of the aforementioned simulation study. Their dimensions can be seen in Table I. Prototype I is an elliptical configuration, while Prototype II and III are circular configurations. Prototype III has been tuned to serve an even lower frequency range (starting from around 1 GHz), therefore having almost twice the size of the other CPW prototypes.

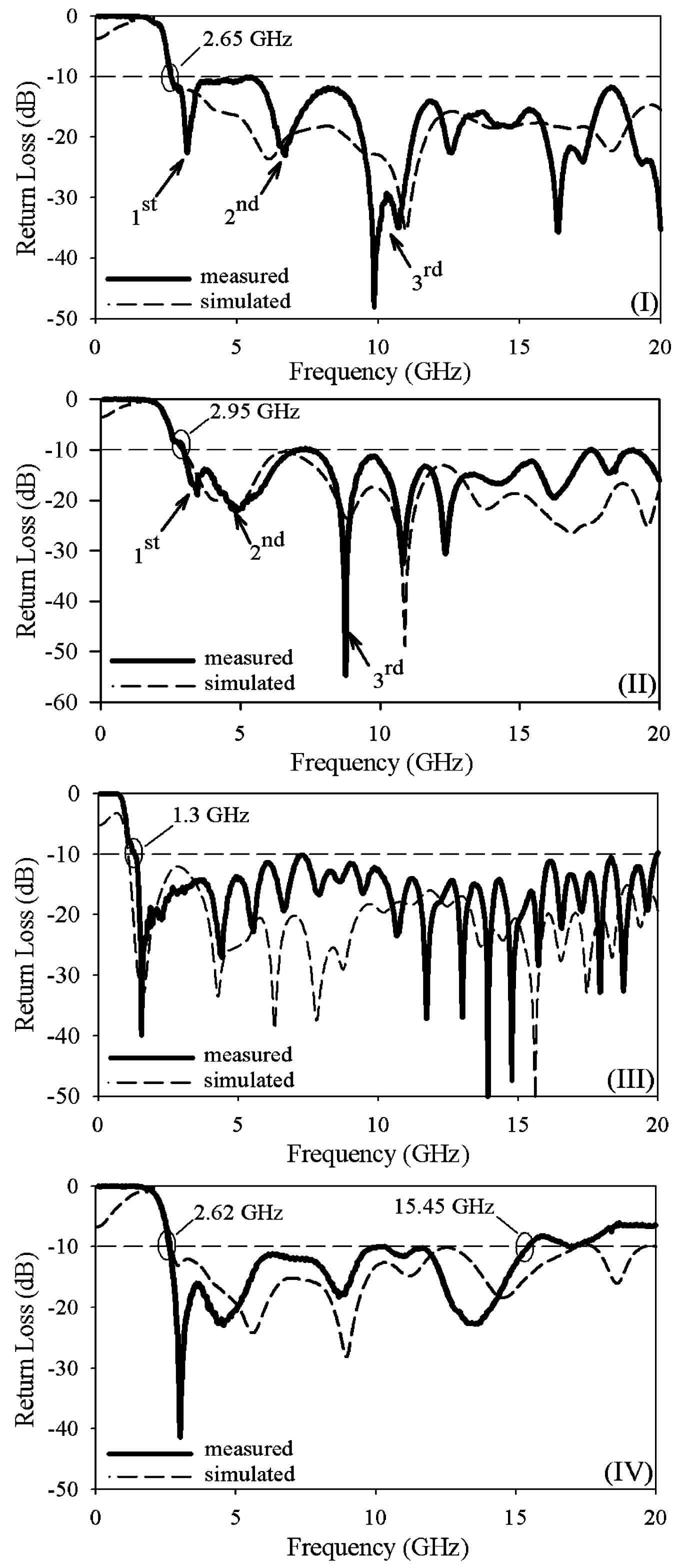


Fig. 3. Measured versus simulated return loss of Prototype I, II, III, and IV.

### B. Microstrip-Fed Elliptical Slot Design

The microstrip-fed module, henceforth denoted as Prototype IV, is derived from the elliptical configuration (I) simply by transferring the feeding network on the other side of the substrate, as can be seen in Fig. 2. We have chosen to feed the elliptical stub with a 50 Ohm impedance line ($s = 3.5$ mm),

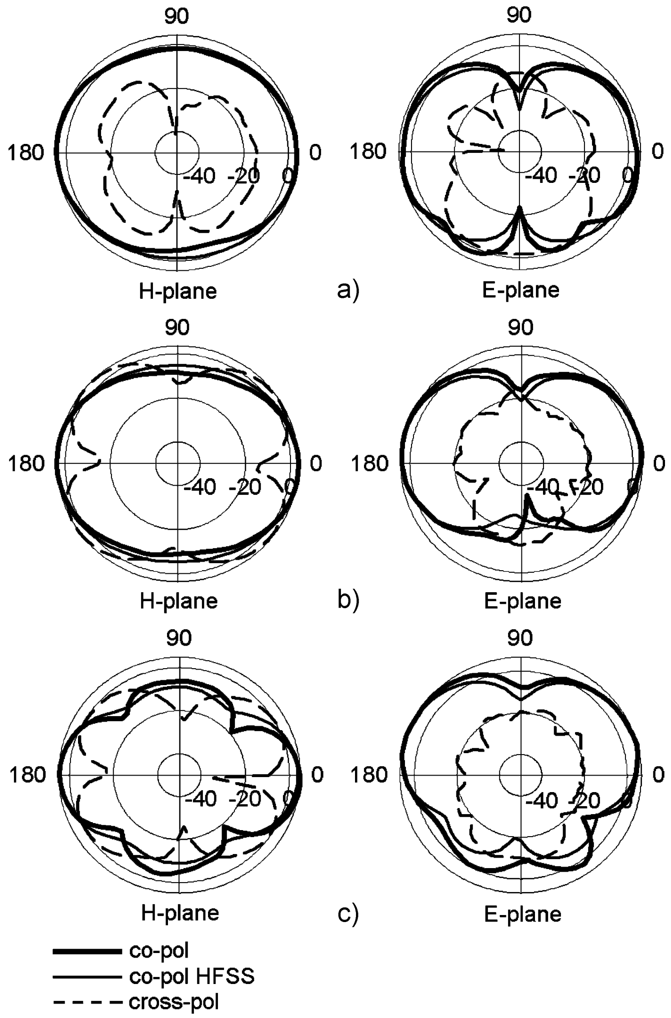


Fig. 4. H-plane (x-z plane) and E- plane (y-z plane) for Prototype I. (a) 3.4 GHz, (b) 6.8 GHz, and (c) 8.9 GHz.

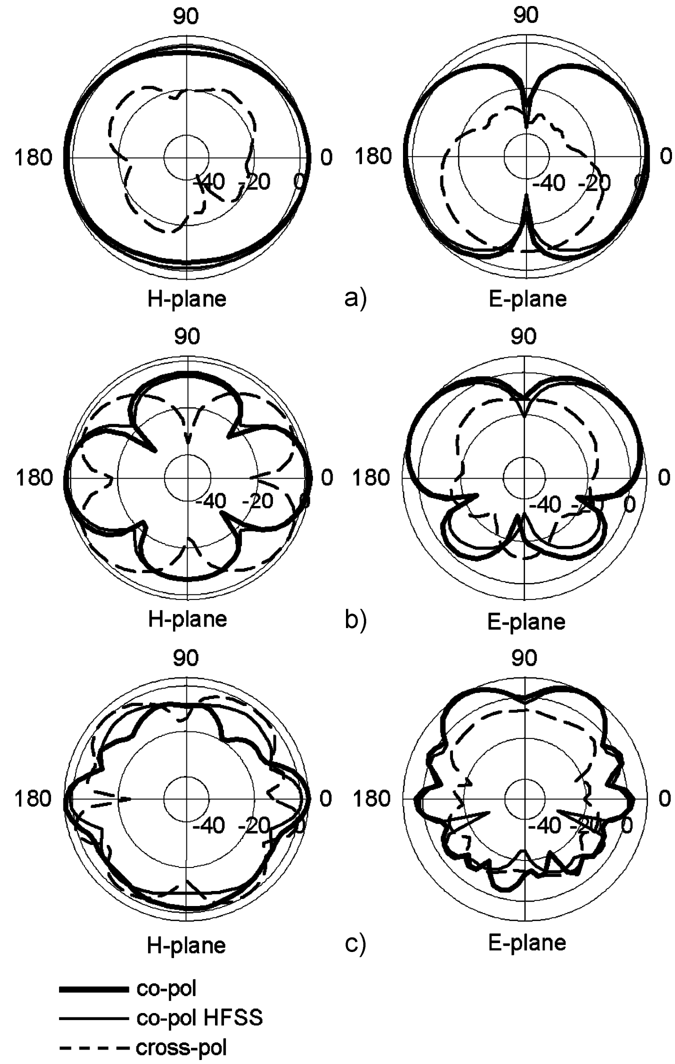


Fig. 5. H-plane (x-z plane) and E- plane (y-z plane) for Prototype III. (a) 1.4 GHz, (b) 3.9 GHz, and (c) 8 GHz.

whereas the rest of the dimensions are kept the same with the CPW-fed elliptical model (see Table I). Here, the elliptical stub element implemented as the mictrostip line termination, offers more wideband behavior than the circular one. Furthermore, the two metallization layers used are very easy to construct in single or multi-substrate PCB boards, therefore making this module appropriate for direct integration with UWB circuitry.

## III. Experimental Results and Discussion

All prototypes where characterized in terms of impedance bandwidth and radiation characteristics. Fig. 3 presents the return loss measurements acquired with an HP8720C network analyzer in its full operational span (0–20 GHz). It should be noticed that the miniaturized CPW-fed modules (I and II) perform satisfactorily even beyond 20 GHz. In particular, the measured bandwidth of the elliptical configuration (Fig. 3I) covers almost 17.35 GHz (spans from 2.65 GHz to 20 GHz), or 153%, with respect to the central frequency at 11.325 GHz. Similarly, the circular module's impedance bandwidth (Fig. 1II) spans from 2.95 GHz to 20 GHz, exhibiting 17.05 GHz or 148% of bandwidth ratio. Concerning the oversized Prototype III, the lower frequency of operation is 1.3 GHz, corresponding to a bandwidth ratio of 175% (see Fig. 3III). Finally, the novel microstrip-fed Prototype IV exhibits bandwidth of 142%, with respect to the central frequency of 9.035 GHz (see Fig. 3IV). It should be noticed that the implemented modification of the feeding network, from CPW to microstrip, resulting in Prototype IV, does not affect the lower frequency of operation (see Fig. 3I & Fig. 3IV).

It can be deduced that these types of radiators demonstrate approximately the impedance characteristics of a $\lambda_g/4$ UWB monopole fed by a CPW, as has been already presented in [3]. In this case, the first resonance is controlled by the diameter of the tuning stub (or the "equivalent" diameter when referring to elliptical stubs). In the CPW-elliptical case, the first resonance at 3.4 GHz would have been generated by a circular monopole with diameter equal to 0.25 $\lambda_g$ or 12.725 mm. Here, the equivalent diameter of Prototype I lies between $2L_1$ (= 12 mm or 0.23 $\lambda_g$) and $2R_1$ (= 16 mm or 0.31 $\lambda_g$). The diameter of Prototype II corresponds approximately to the quarter wavelength at the first resonance at 3.2 GHz, since $2R_1 = 15$ mm $= 0.28\ \lambda_g$. In Prototype III, the diameter corresponds to 0.32 $\lambda_g$ at the first resonance at 1.4 GHz, whereas in IV the equivalent value ranges

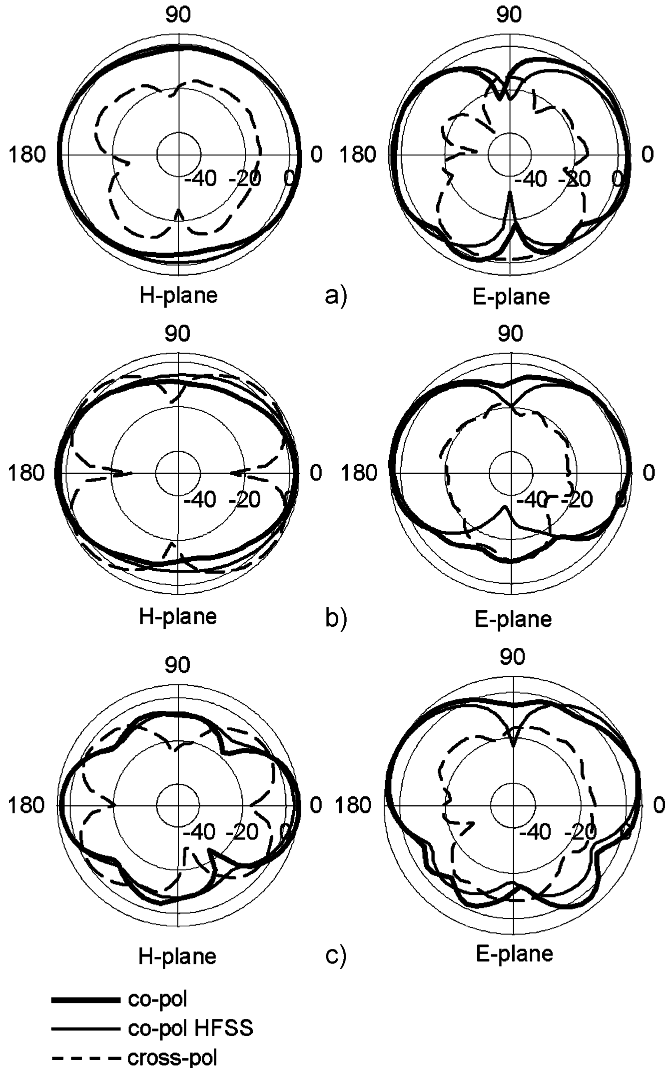


Fig. 6. H-plane (x-z plane) and E- plane (y-z plane) for Prototype IV. (a) 3.4 GHz, (b) 6.8 GHz, and (c) 8.9 GHz.

between 0.22 $\lambda_g$ and 0.26 $\lambda_g$ for the first resonant frequency at 3.2 GHz.

All Prototypes where characterized in a fully anechoic environment in both orthogonal planes. For the miniaturized modules, the frequencies of evaluation were dictated by the 2 first resonances of Prototype I, that is 3.4 GHz and 6.8 GHz and the upper frequency of operation of the network analyzer that was used (Agilent E8358A), which corresponds to 8.9 GHz. Prototype III was evaluated in the first distinct resonance at 1.4 GHz and arbitrarily at 3.9 GHz and 8 GHz.

The gain patterns of Prototypes I, III and IV can be seen in Figs. 4–6. Obtained results for Prototype II were omitted, due to their resemblance with Prototype I. A very satisfactory agreement between simulation and measurement can be seen. All designs exhibit an omni-directional profile in lower frequencies for the x-z plane and bi-directional for the y-z plane. As the frequency increases, Prototype I and IV become more directive, but still bi-directional. Prototype III radiates either with strong side lobes (3.9 GHz) or with multiple lobes (8 GHz). Polarization purity can only be considered in the low frequency regime where the cross-to-co polarization ratio is marginally kept around $-20$ dB, in contrast to higher frequencies, where cross-polarization is dominant, regarding x-z plane. Despite the different feeding mechanism, Prototypes I and IV appear to radiate with the same way as can be noted in Fig. 4 and Fig. 6. The maximum gain obtained from measurements is around 4.5 dBi.

## IV. Conclusion

Four designs of CPW-fed and microstrip-fed circular and elliptical configurations have demonstrated UWB behavior in a very broad frequency range. By transforming the CPW feeding to microstrip, the UWB characteristics are preserved along with the radiation profile. The proposed methodology provides the engineer with a unique way to choose between the two mostly used feeding networks, and therefore adapt the radiator to any emerging system requirement.

## References

[1] J. Powell and A. Chandrakasan, "Differential and single ended elliptical antennas for 3.1–10.6 Ghz ultra wideband communication," in *Proc. IEEE Antennas Propag. Symp.*, Monterey, CA, Jun. 2004.

[2] S.-Y. Suh, W. Stutzman, W. Davis, A. Waltho, and J. Schiffer, "A novel broadband antenna, the low profile dipole planar inverted cone antenna (LPdiPICA)," in *Proc. IEEE Antennas Propag. Soc. Symp.*, vol. 1, Jun. 2004, pp. 775–778.

[3] J. Liang, L. Guo, C. C. Chiau, and X. Chen, "CPW-fed circular disc monopole antenna for UWB applications," in *Proc. IEEE Int. Workshop Antenna Technol. (IWAT): Small Antennas Novel Metamater.*, Marina Mandarin, Singapore, Mar. 7–9, 2005.

[4] R. Chair, A. A. Kishk, and K. F. Lee, "Ultrawide-band coplanar waveguide-fed rectangular slot antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 3, pp. 227–227, 2004.

[5] J. W. McCorkle, "Electrically Small Planar UWB Antenna Apparatus and Related System," US 6 914 573 B1, Jun. 23, 2003.

[6] H.-D. Chen, "Broadband CPW—fed square slot antennas with a widened tuning stub," *IEEE Trans. Antennas Propag.*, vol. 51, no. 8, pp. 1982–1986, Aug. 2003.