Theoretical and Experimental Analysis of a Planar Wideband Antenna

Slavi R. Baev[1]

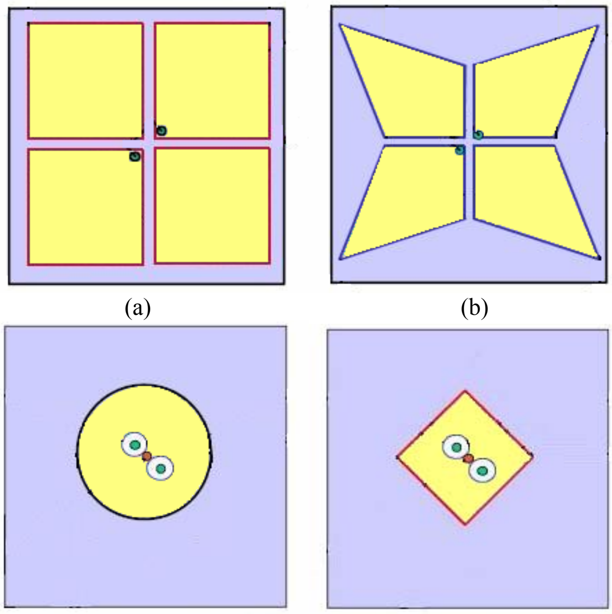
***Abstract* – A planar antenna with an impedance bandwidth of about 95 % is described in this paper. The antenna is a modification of the so-called Foursquare element. An electromagnetic simulation tool is used for the design process. A test model is then produced and measured to verify the simulation results. Main antenna parameters such as input impedance, return loss, radiation pattern and gain are evaluated and analyzed.**

***Keywords* – Planar antenna, Foursqure, wide bandwidth.**

I. INTRODUCTION

The Foursquare antenna is presented for the first time in 1999 [1]. It is a planar antenna and has several advantages over the other microstrip antennas. It has a very wide impedance bandwidth – the first antenna of this type has a bandwidth of about 1.8:1. This property makes the Foursquare very promising for wideband and UWB applications. The antenna element has a very compact size and low profile. Depending on the feed system the Foursquare can operate with one sense of linear polarization, dual orthogonal linear or circular polarization. In an antenna array the Foursquare elements can be positioned closer to each other. This property allows reduction of the grating lobes in a wider frequency range.

Fig. 1 shows different configurations of the Foursquare antenna developed throughout the years. The main difference between these antennas is the shape of the radiating elements. The vertical structure and the feed system are similar for all the variants so they will be described in the next section. The first investigated Foursquare geometry has a bandwidth (BW) of about 20 % [1],[2]. It is shown in Fig. 1a. There are four identical square patches, which radiate the energy. The same antenna with an optimized distance between the radiating patches and the ground plane exhibits a bandwidth of 35-40 % [2],[3]. An improved variant of the Foursquare antenna which shows better frequency characteristics is the so-called Fourpoint antenna [2],[4]. As can be seen in Fig. 1b the radiating elements are no longer square but rather have the shape of a diamond. The typical Foursqure (Fig. 1a) has an excessive inductive reactance near the upper band limit. The Fourpoint shape introduces an additional capacitance to the input impedance for higher frequencies and thus improves the matching for this region. The result is an improved operating bandwidth – values between 44 % and 54 % are reported. The addition of a tuning plate under the main radiating patches is another way to broaden the bandwidth. Fig. 1c shows a circle and a square tuning plates etched on the bottom side of the substrate. The shape of the tuning plate is not limited to those shown in the figure – it can be various. The resonance of the tuning plate overlaps the operating band of the antenna at the upper end and thus the higher frequency limit is shifted upwards. The values for the bandwidth of the Foursquare antenna with a tuning plate and the Fourpoint antenna with a tuning plate are respectively 60 % and 87-92 % [2],[4],[5].



(a) (b)

(c)

Fig. 1 Different variants of the Foursquare antenna: a) typical Foursquare; b) Fourpoint; c) tuning plates etched on the bottom side of the substrate

II. PROPOSED ANTENNA

A drawing of the investigated Foursquare antenna along with the main dimensions is shown in Fig. 2. The values of the geometrical parameters are listed in Table I.

As seen in Fig. 2a there are four square patches etched on the top side of a dielectric substrate. Two of the opposing patches are directly fed by coaxial lines. These two elements are the main radiators while the other two are parasitic elements. The operation of the Foursquare is similar to that of a dipole antenna. The two directly fed elements are the arms of the dipole. To obtain radiation only in the upper half space there is a reflector (ground plane) positioned below the substrate. A thick foam layer can be used to support the substrate over the ground plane.

The feeding system of the antenna consists of two identical coaxial lines. They feed the main patches with equal

[1]Slavi R. Baev is with the Department of Radio Communications and Video Technologies, Faculty of Telecommunications, Technical University – Sofia, 8 "Sv. Kliment Ohridski " Blvd., 1000 Sofia, Bulgaria, E-mail: sbaev@tu-sofia.bg

amplitude and opposite phase. The outer conductors of the cables pass through the ground plane and the foam layer and are soldered together on the bottom surface of the dielectric substrate. This ensures balanced feeding of the radiating elements. The inner conductors of the coaxial lines pass through the substrate and are soldered to the metallic squares on its top side. The parasitic elements are excited through a capacitive coupling to the main patches.

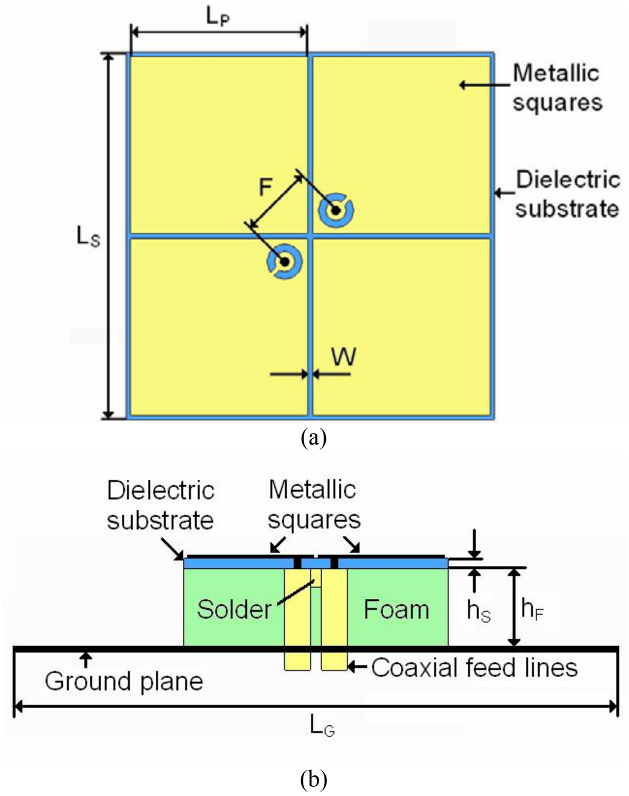


Fig. 2 Proposed Foursquare antenna: a) top view; b) side view

The antenna structure described above and shown in Fig. 2 radiates linear polarized field. The E vector is oriented along the main diagonal of the Foursquare antenna containing the two feed probes.

The wideband behavior of the antenna is due to the shape of the two arms – they ensure large surface. A technique similar to that of the bow-tie antenna is used to increase the surface of the dipole arms. Also the presence of two parasitic patches contributes to the wideband nature of the Foursqure element.

TABLE I
DIMENSIONS OF THE INVESTIGATED ANTENNA

Parameter	Symbol	Value, mm
patch length	L_P	10.5
substrate length	L_S	21.8
distance between patches	W	0.3
distance between probes	F	4.3
substrate thickness	h_S	0.81
foam thickness	h_F	6.4
ground plane length	L_G	50

A modification of the typical probe feeding technique is applied to the antenna construction in order to achieve a good impedance matching in a wide frequency range. Fig. 2a shows two incomplete circular ring slots cut in the two directly fed patches around the feed probes. These slots introduce an additional inductance to the input reactance since the current paths become longer. In this way structures with unwanted capacitive input reactance can be balanced and well matched to the desired impedance point.

III. Analysis Results

Ansoft HFSS was used for the simulation analysis of the investigated antenna. Then a real test model was produced and measured. The S-parameters of the antenna were measured with an Agilent N5230A PNA-L Network Analyzer and the radiation properties were measured in an anechoic chamber.

A picture of the test antenna is shown in Fig. 3. RO4003 is used as a material for the dielectric substrate. In the real antenna the foam layer is replaced by four dielectric spacers, which support the substrate over the ground plane.

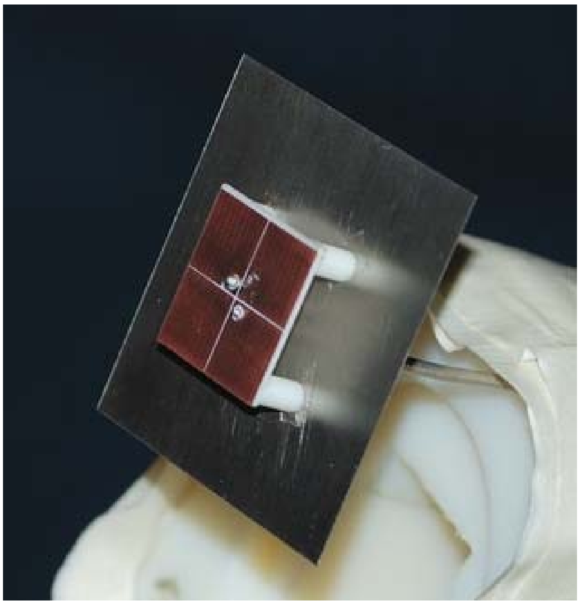


Fig. 3 Realized test model of the Foursquare antenna

Fig. 4 shows the simulated and measured return loss S_{11} of the designed antenna. As can be seen there is a very good agreement between the two curves although there is a slight shift of the measured bandwidth towards lower frequencies. The simulated return loss is below – 10 dB in the range 3.5 – 9.9 GHz while the measured bandwidth spans between 3.2 and 9 GHz. The impedance bandwidth is 95 %. This value is better than the reported values for the typical Foursquare, the Fourpoint antenna and their variants with tuning plates. Only the Fourpoint antenna with a tuning plate has a comparable impedance bandwidth (BW=92 %).

The matching effect of the slots etched around the feed probes can be seen in Fig. 5. There are two impedance curves shown in the Smith chart. The curve positioned lower in the Smith chart corresponds to the case without slots in the main patches. It is seen that the loop is off-centered and there is a strong capacitive reactance. When the slots are cut around the probes they add an inductive reactance in the system and the curve shifts upwards. Then the loop is centered very well and good matching is achieved.

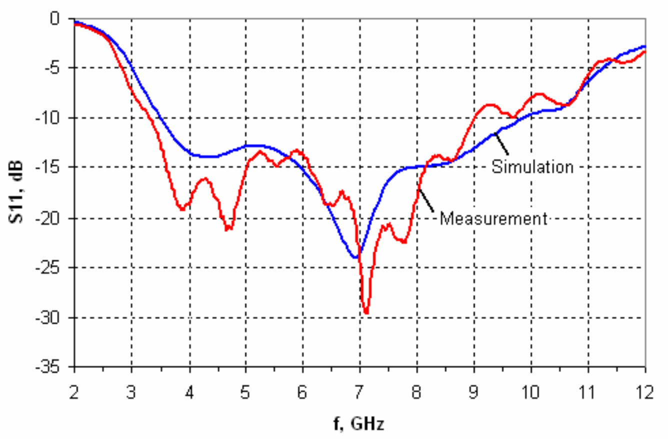


Fig. 4 Measured and simulated return loss of the Foursquare antenna

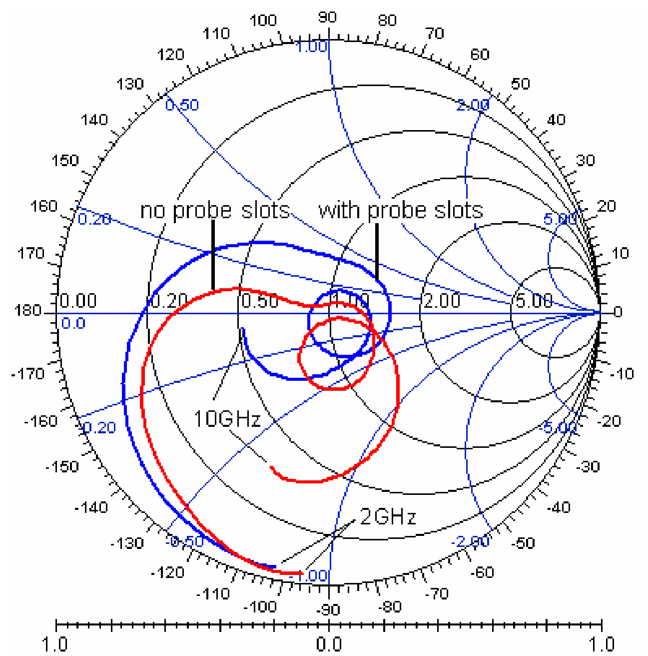


Fig. 5 Smith chart of the Foursquare antenna – with and without probe slots

The measured and simulated radiation patterns of the investigated antenna are plotted in Fig. 6a (E-plane) and Fig. 6b (H-plane). The E-plane contains the two feed probes and is orthogonal to the surfaces of the patches. The H-plane is orthogonal both to the patches and the E-plane. The simulated cross-pol level is very low and is not shown in the figures. As can be seen there is a perfect matching between the measured and simulated patterns. The HPBW in the two principal planes is about 60°. The patterns are well formed, symmetrical and the main beam is pointed at boresight. Although the measured cross-pol level is higher than the simulated it is still very low – better than – 25 dB at the main beam direction.

Fig. 7a and Fig. 7b present the simulated radiation pattern of the antenna in E-plane and H-plane respectively – for three frequencies in the operating band: 4, 6.5, 9 GHz.

It is seen that when the frequency increases the E-plane pattern becomes wider and the H-plane pattern becomes narrower. In the frequency band 3.5-9.5 GHz the half-power beam widths in the two principal planes change in the following ranges: $HPBW_E$=60°÷120°, $HPBW_H$=92°÷32°. The cross-polarization level (now shown in the figure) in the two planes is below -20 dB. There is a strong back radiation for frequencies near the low bandwidth limit. This is caused by the electrically small ground plane for these frequencies. The main beam of the radiation pattern is always at boresight – there is no unwanted splitting or tilting.

It is interesting to note that for a very wide frequency range the radiation pattern of the investigated antenna preserves symmetry and the main beam is always pointed at boresight. These properties are very important for a radiating element designed to work in a wide bandwidth.

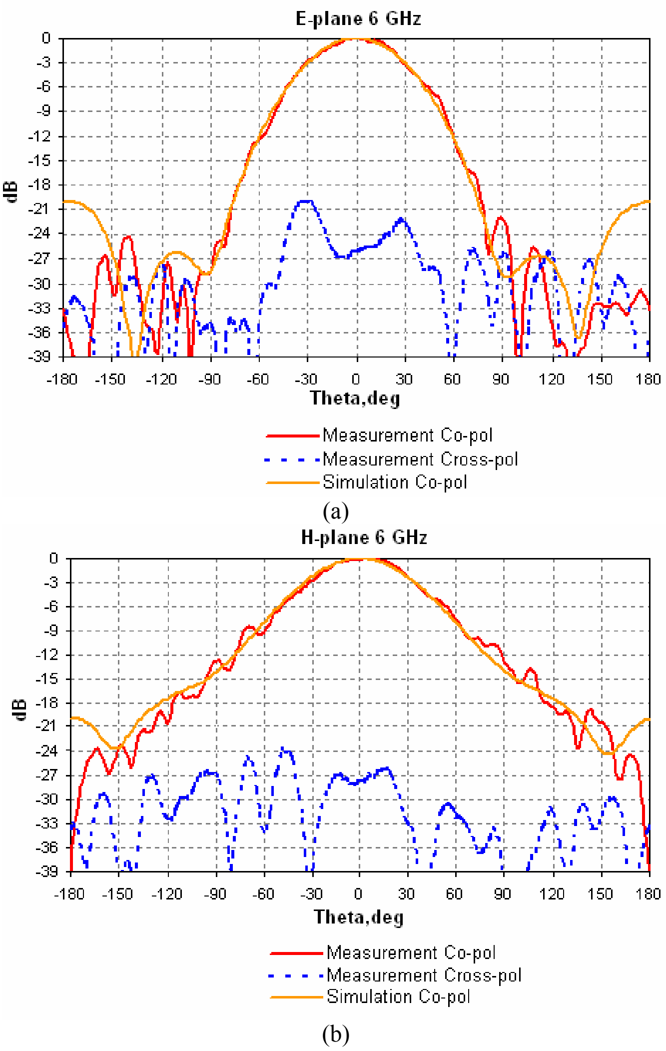
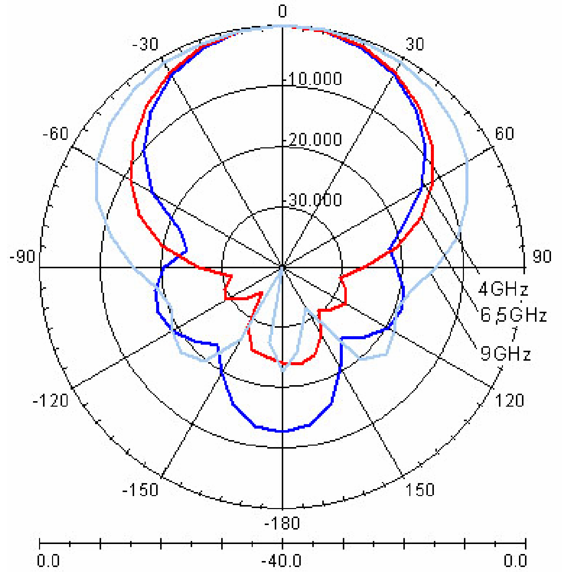
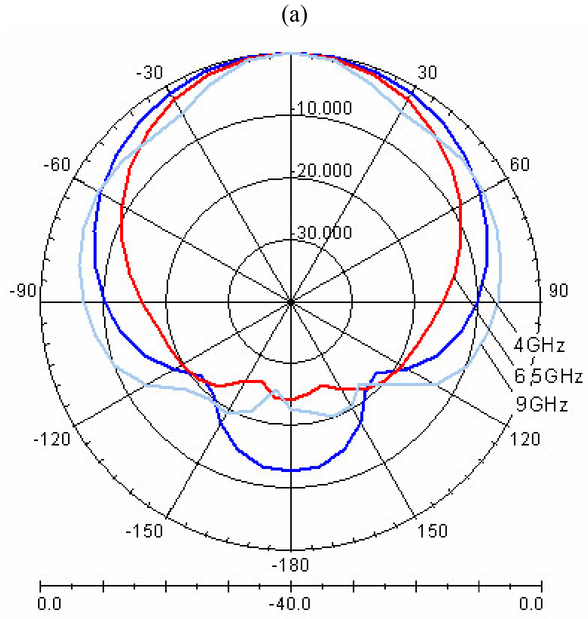


Fig. 6 Measured and simulated radiation pattern of the Foursquare antenna for 6 GHz: a) E-plane; b) H-plane

The gain of the Foursquare antenna as a function of frequency is shown in Fig. 8. The gain is better than 7 dB in the whole operating bandwidth. The gain variation for frequencies between 3.5 GHz and 10 GHz is less than 3 dB. The maximum gain is 10 dB and it is achieved for 8 GHz. The gain bandwidth of the antenna defined for a decrease of the gain with no more than 1 dB from its maximum value is between 5 GHz and 8.8 GHz or this is equal to 50 %.



(a)



(b)

Fig. 7 Radiation pattern of the Foursquare antenna for three frequencies – 4, 6.5 and 9 GHz: a) E-plane; b) H-plane

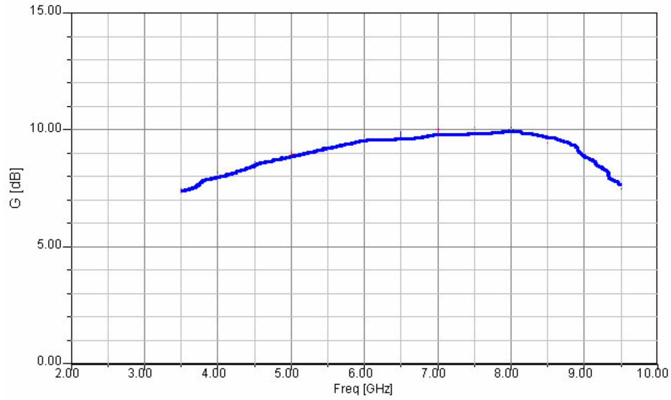


Fig. 8 Gain of the investigated Foursquare antenna

IV. Conclusion

A modification of the typical Foursquare antenna is designed and tested. The purpose is improvement of the frequency properties of the antenna. The investigated Foursquare element is capable of achieving 95 % impedance bandwidth which is better than the existing configurations of this type.

The antenna performance is evaluated both with simulation and experiment. There are graphical results for the return loss, input impedance, radiation pattern and gain. There is a very good agreement between the predicted and measured results. In the frequency range 3.5 – 10 GHz the gain variation is low and the radiation pattern is well formed and stable.

The bandwidth improvement is achieved by an addition of two slots around the feed points. This is a simple geometry modification not complicating the antenna construction or the production process.

References

[1] J. R. Nealy, "Foursquare antenna radiating element," U.S. Patent № 5 926 137, Jul. 20, 1999.

[2] S.-Y. Suh, "A comprehensive investigation of new planar wideband antennas," Ph.D. Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA, Jul. 2002.

[3] S.-Y Suh, W. L. Stutzman, and W. A. Davis, "Low-profile, dual-polarized broadband antennas," *in IEEE Int. Symp. on Antenna and Propagation Digest*, vol. 2, pp. 256-259, Jun. 2003.

[4] S.-Y. Suh, and W. L. Stutzman, "Planar wideband antennas," U.S. Patent № 7 027 002 B2, Apr. 11, 2006.

[5] S.-Y Suh, W. L. Stutzman, W. A. Davis, A. E. Waltho, K. W. Skeba, and J. L. Schiffer, "Bandwidth improvement for crossed-dipole type antennas using a tuning plate," *in IEEE Int. Symp. on Antenna and Propagation*, vol. 2A, pp. 487-490, Jul. 2005.