Investigation of a Wideband Foursquare Microstrip Antenna

Slavi R. Baev[1]

Abstract **– In this paper a very wideband planar antenna – the Foursquare antenna is investigated. The influence of the feeding system configuration on the antenna characteristics is analyzed. The results obtained for some parameters of the radiating structure reveal in more detail its operation.**

Keywords **– planar antenna, bandwidth, foursquare element.**

I. INTRODUCTION

The narrow bandwidth of the microstrip antennas is a major constraint. As a result of the research efforts in this direction many radiating structures with improved parameters are created. Some of the antennas with widest impedance bandwidth (BW) are: archimedean spiral (BW≈10:1), equiangular spiral (BW≈8:1), sinuous antenna (BW≈9:1). A relatively new structure in this area is the so-called Foursquare antenna [1], [2]. Its impedance bandwidth is narrower than the above-mentioned antenna types – it is approximately BW≈1,8:1. These values are valid for a single element structure.

The main factors determining the planar antenna application are bandwidth, polarization, physical size. The archimedean and the equiangular spirals work with one sense of circular polarization. This makes them unsuitable for systems with polarization diversity. The sinuous and the Foursquare antenna allow operation with circular or dual linear polarization. The dimension of the radiator for the lowest operating frequency determines the element-to-element spacing in an array structure. To avoid scan angle limitations on higher frequencies this spacing must be as little as possible. Compared to the other wideband elements the Foursquare has a minimum size, which is the reason for the better bandwidth properties in an array environment.

The Foursquare element is suitable for application in systems, which require low profile, multiple frequency or wideband operation, circular, linear or dual linear polarization, array structure.

Only a few publications concerning the Foursquare element are available [1-4]. The information contained is limited and doesn't reveal completely the element behavior. In the present paper the effect of the feeding system on some antenna parameters is analyzed with the purpose to clarify the structure's operation.

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II. ANTENNA STRUCTURE

The top and the side view of a Foursquare antenna are shown in Fig. 1.

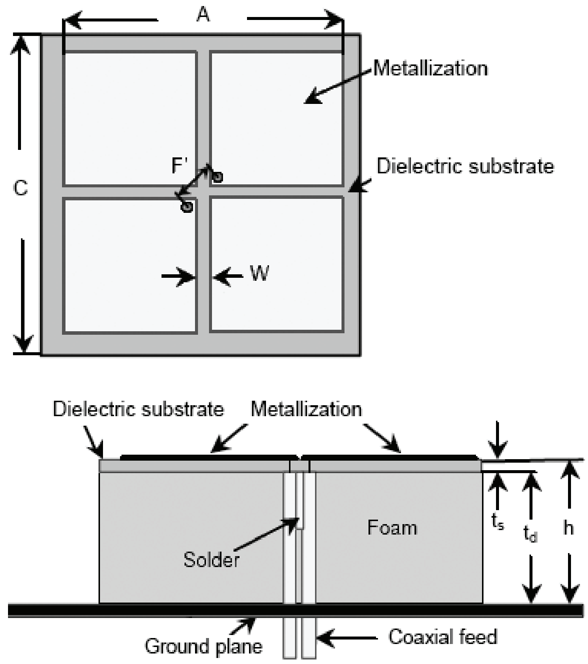


Fig. 1. Construction of a Foursquare antenna element

The antenna consists of four identical metallic patches etched on a dielectric substrate Duroid 5870 (ε_r=2,33). The substrate is positioned over a ground plane and is separated from it by a thick foam layer (ε_r=1,07).

Two of the opposing squares are fed with equal amplitude and opposite phase. The feeding system consists of two coaxial lines placed near the inner corners of the elements. The coaxial lines are embedded into the foam layer and the outer conductors are soldered together near the radiators to ensure balanced feeding. The inner conductors of the coaxial cables pass through the substrate and connect to the metallic squares above it.

The structure described above radiates linear polarization in such a way that the E-field vector is oriented along the main diagonal of the antenna containing the two probe feeds.

Table 1 contains the geometrical parameters of a Foursquare antenna working in a band with a center frequency of about 6 GHz.

The wideband behavior of the Foursquare is due to the change in the current excitation on the four elements with the change of the frequency. As radiators appear not only the two directly fed elements but also the other two parasitic patches which are fed through a capacitive coupling to the main elements. At the lowest operating frequency f_L the diagonal of the Foursquare $D=\sqrt{2}A$ is about $\lambda_L/2$. Then the resonant length of the antenna is approximately equal to D. When the frequency is increased the condition for resonance is changed and the highest frequency of the working band f_U is determined from the condition $D \approx \lambda_U$ [1], [3], [4].

TABLE I
CONSTRUCTION PARAMETERS OF A FOURSQUARE ANTENNA

Element length	A	21,3 mm
Gap between squares	W	0,25 mm
Distance between probes	F'	4,3 mm
Substrate side length	C	21,8 mm
Substrate thickness	t_s	0,7 mm
Foam thickness	t_d	6,4 mm

As mentioned before the E-field vector is parallel to the antenna diagonal containing the two probes. The Foursquare geometry is such that its long dimension is gradually decreasing away from this diagonal. This ensures the gradual change in the resonant size, which is a prerequisite for a wideband operation.

III. PARAMETRIC ANALYSIS

The main goal of this paper is to present the effect of the feeding line configuration on the antenna excitation ant the corresponding changes in some characteristics – return loss S_{11}, input impedance, radiation pattern, gain G. The simulation results are obtained through the use of a software based on the Finite Element Method – Ansoft HFSS.

The antenna under analysis has the parameters listed in Table 1 except F' – its value is changed through the study. These dimensions are the same as those presented in [1] and [3]. This facilitates the comparison of the results.

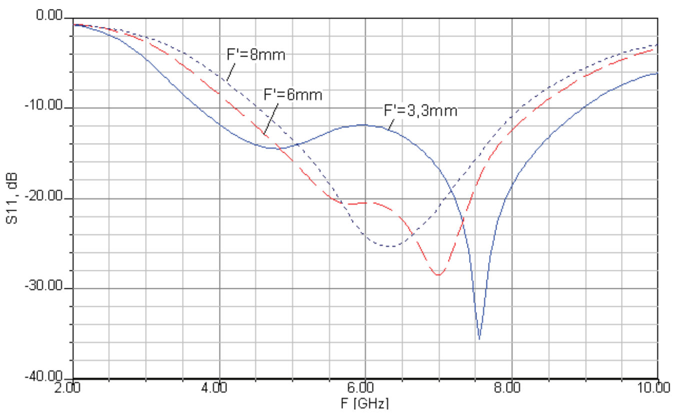


Fig. 2. Return loss S_{11} vs. frequency f for three values of F'

The first investigation shows the dependence of the antenna characteristics from the position of the two probe feeds and particularly from the distance F' between them. It is mentioned in the literature that the optimum position of the probes is as close as possible to the inner corners of the two directly fed squares. The analysis presented here includes three values for F': 3,3mm, 6mm and 8mm. The 50 Ohm coaxial cables used have inner conductor diameter d=0,9mm and outer conductor diameter D=3,1mm.

The return loss for the three values of F' is shown in Fig. 2. It is seen that the widest impedance bandwidth BW (defined for $S_{11} \leq -10$dB) appears for F'=3,3mm (BW=84%). There are two distinct resonances in the graph. A drawback is the high value of the return loss between the resonances ($S_{11} = -12$dB), which may be insufficient for some applications. For F'=6mm the bandwidth is approximately 65% and for F'=8mm it is 57%. Increasing F' causes the two resonances of S_{11} to get closer and for F'=8mm there is only one resonance in the middle of the bandwidth. As the distance between the probes increases the matching for the center region of the operating band improves but the minimum achieved values of S_{11} become worse.

The shift of the resonant frequencies in S_{11} is explained with the different surface current excitation on the radiating elements when F' is changed. Although the Foursquare antenna has a complicated resonance behavior some relations can be found. For example when F' is increased the maximum resonant length of the radiator is shorten. The surface currents on the elements flowing in opposite direction to the main currents become stronger. This decrease of the maximum resonant length increases the lower operating frequency f_L and therefore the lower resonance shifts towards the higher frequencies.

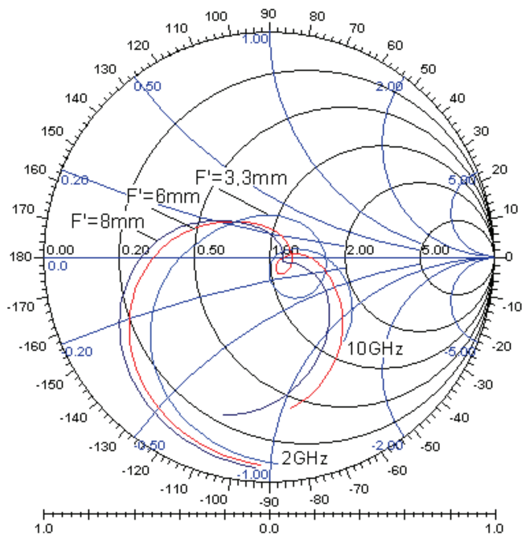


Fig. 3. Smith chart of a Foursquare for three values of F'

Fig. 3 also shows that the two resonances are getting closer. For F'=3,3mm the loop in the Smith chart is wide, which is typical for a two resonance system. When F' is increased the loop is getting smaller and for F'=8mm these is no loop, or it is very tight, which is typical for a single resonance behavior.

The following results present the influence of the distance between the probes on the radiation of the antenna. In Fig. 4 the gain G at boresight for the three configurations is shown.

The maximum achieved values of G are as follows: for F'=3,3mm G_{max}=11,2dB; for F'=6mm G_{max}=9,7dB; for F'=8mm G_{max}=9dB.

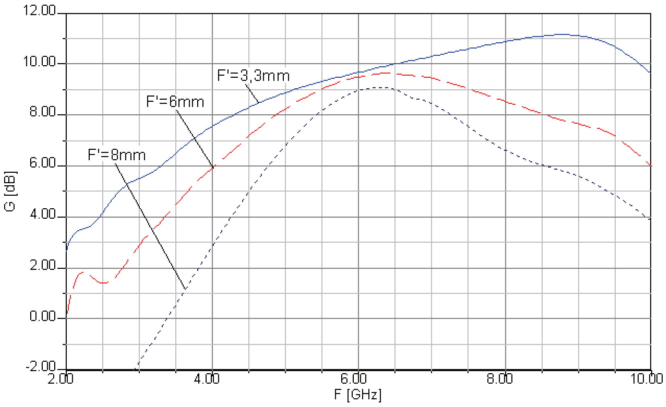


Fig. 4. Gain G vs. frequency f for three values of F'

The radiation pattern bandwidth (determined for a decrease of G with no more than 1dB from G_{max}) for the three cases are: for F'=3,3mm BW=39%; for F'=6mm BW=39%; for F'=8mm BW=29%. It is therefore apparent that the operating bandwidth of the Foursquare is limited by the radiation pattern bandwidth. Nevertheless this band remains very broad for a planar antenna.

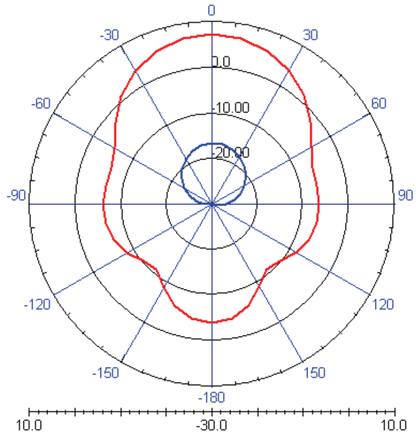
Important result is the drop of the maximum value of G when F' is increased. This is due to the stronger excitation of surface currents flowing opposite to the main currents when the probes are shifted away from the antenna center. The cross-polarization radiation is also increased in this manner. These two effects cause gain degradation.

More detailed description of the Foursquare element gives the E-plane radiation pattern shown in Fig. 5. The E-plane contains the two probes and is perpendicular to the antenna surface. It should be noted that the results are not normalized and the ground plane size is 21,8x21,8mm – the same as the substrate dimensions. In practice it is recommended to use a ground plane at least two times the antenna size [2].

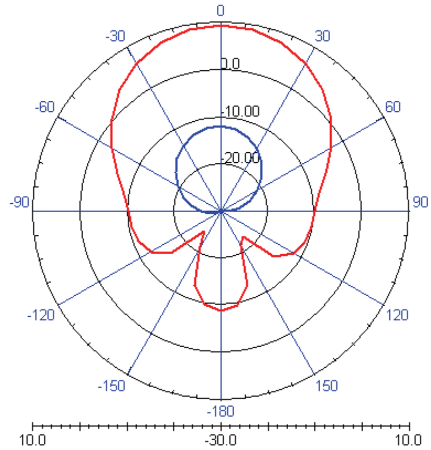
Generally the radiation patterns of the three configurations are similar to the presented in [1-4]. For brevity only the pattern for F'=6mm is shown here.

The main effect that appears when the frequency is increased is that the E-plane pattern becomes wider. This is explained with the change of the main radiating part of the antenna aperture when the frequency is shifted. At lower frequencies the main radiators are the two directly fed patches. For the midband region all the four elements radiate and for higher frequencies the two parasitic patches are the main radiators. The analysis showed that this alteration of the radiation pattern is more significant when F' is larger. This means that for F'=3,3mm the change in the radiation pattern shape with frequency is the weakest and therefore it has the best wideband behavior.

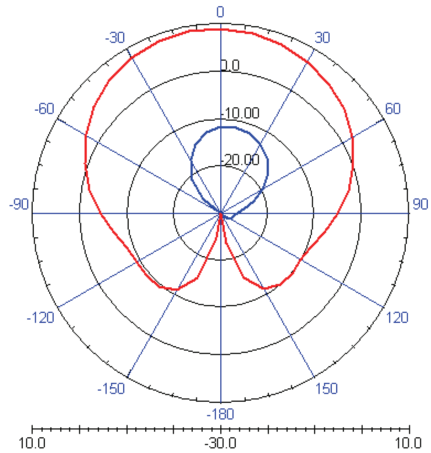
In H-plane there is just a slight alteration of the radiation pattern for the upper half space when the frequency is changed. For different values of F' the H-plane pattern remains almost the same. The backward radiation decreases with f for both E- and H- planes. It is expected that larger ground plane will improve the radiation properties of the antenna.



(a) 4,5GHz



(b) 6 GHz



(c) 7,5 GHz

Fig. 5. Co-polar and cross-polar components of the radiated field in E-plane as a function of Theta for three frequencies. F'=6mm. Values are in dB.

The second experiment resulted from the need for a better impedance matching of the foursquare. It includes an investigation of the input impedance as a function of the type of coaxial line used. Three types of 50 Ohm coaxial cables are examined: 1. d=0,5mm, D=1,7mm; 2. d=0,9mm, D=3,1mm; 3. d=1mm, D=3,5mm. The antenna under analysis has the dimensions in Table 1 except that F'=8mm. Fig. 6 shows the Smith charts for the three cases.

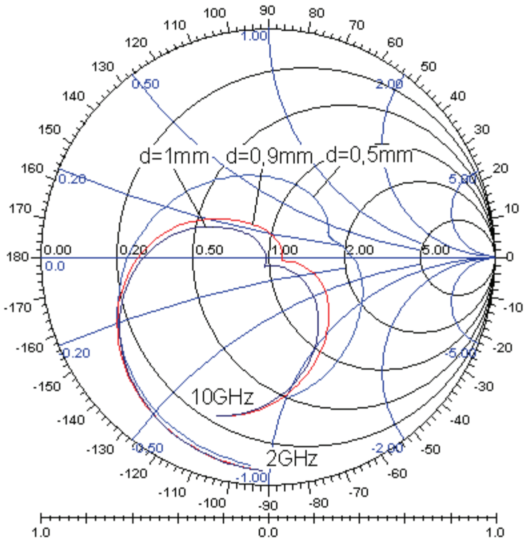


Fig. 6. Smith plot of a Foursquare for three types of coaxial lines: d=0,5mm D=1,7mm; d=0,9mm D=3,1mm; d=1mm D=3,5mm

The impedance curve is shifted to the left towards the lower resistance region as the diameter of the cable is increased. This is caused by the lower input resistance of a probe with larger conductor diameter. This result shows that the size of the coaxial line can be used as an additional instrument for impedance tuning of the Foursquare antenna.

IV. Conclusion

The publication presents the relation between the parameters of a linear polarized Foursquare antenna and the feeding line configuration. The conducted investigation shows that values between 57% and 84% for the impedance bandwidth can be achieved with the Foursquare depending on the feed line position. The operating band is limited by the radiation pattern bandwidth and still the reported values are very good – 29% to 39%.

In contrast to the expectations not all antenna characteristics are optimal when the feed probes are closest to the antenna center (F'=3,3mm). The radiation pattern is the best for this case, but the return loss is not balanced through the whole bandwidth and there is also a mismatch between the impedance and radiation pattern bandwidths.

The results of the present analysis show that the Foursquare antenna can be optimized to a great extent with the use of proper feeding system and its precise placement.

References

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