Bandwidth Improvement of a Foursquare Microstrip Antenna

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Abstract – **A Foursquare microstrip antenna with a very wide bandwidth – about 95 % is presented. This value is better than those for the existing antennas of this type. The paper describes the antenna geometry and investigates its performance. Main antenna parameters such as input impedance, return loss, radiation pattern and gain are evaluated and analyzed.**

Keywords – **Microstrip antenna, Foursquare, bandwidth.**

I. Introduction

Wideband operation is highly desirable in modern communications systems. As part of these systems the radiating elements are also required to have a broad operating frequency range. The Foursquare antenna presented in [1] has a very wide operating bandwidth. It has also other useful properties as low profile, compact size, and dual linear or circular polarization operation.

The first investigated Foursquare geometry has a bandwidth (BW) of about 20 % [1],[2]. The bandwidth is defined for the frequency range where the return loss is less than -10 dB (VSWR<2). The same antenna with an optimized distance between the radiating patches and the ground plane exhibits a bandwidth of 35-40 % [2],[3]. Another antenna similar to that of the Foursquare also shows good frequency behavior. This is the Fourpoint antenna [2],[4]. The geometry of this antenna introduces an additional capacitance, which compensates for the high inductive reactance at the upper band 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. 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].

II. Antenna Design

A top view and a side view of the investigated antenna along with the main geometrical parameters are shown in Fig. 1a and Fig. 1b. Table I contains the values of the main antenna dimensions.

The Foursquare antenna consists of four identical metallic squares etched on the top side of a dielectric substrate. In the present design a material with a relative permittivity of 3.38 is used for this layer. The substrate is positioned over a square ground plane at a distance h_F. A foam layer is used to support the substrate. In another implementation of the antenna the foam can be replaced by air and the substrate can be supported by dielectric spacers.

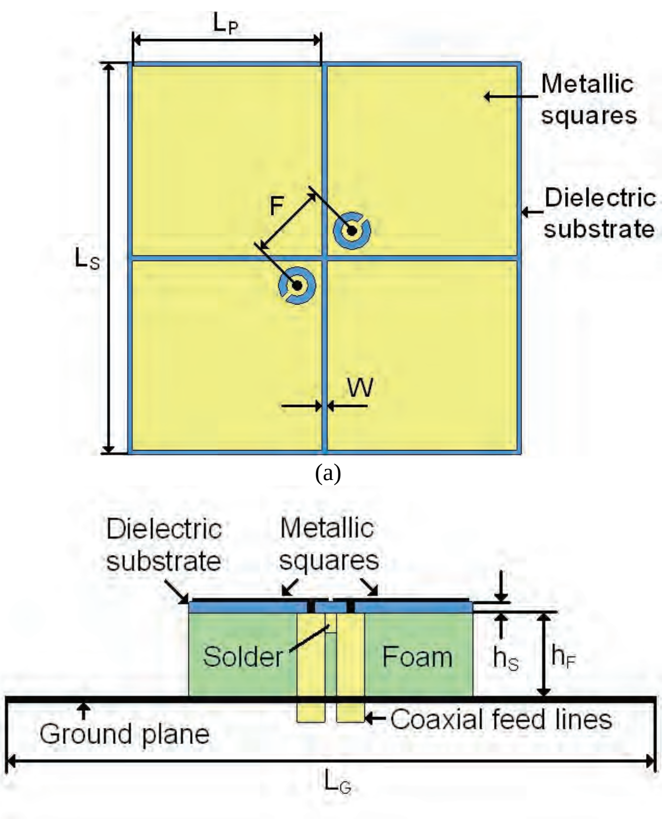

Fig. 1 Geometry of the investigated Foursquare antenna: a) top view; b) side view

Two of the opposing square patches are directly fed with equal amplitude and opposite phase. Thus the surface current vectors on the two patches have the same directions. The feeding system of the antenna consists of two identical coaxial lines. They pass through the ground plane and the foam layer and reach the bottom surface of the dielectric substrate. There the outer conductors of the cables are soldered together. 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 other

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two metallic squares are parasitic elements. They are excited through a capacitive coupling to the main patches.

The antenna structure described above and shown in Fig. 1 radiates linear polarized field. The E vector is oriented along the main diagonal of the Foursquare antenna containing the two feed probes. In another implementation where all the four metallic patches are fed the antenna is capable of operation with dual linear or circular polarization.

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. 1a 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.

TABLE I
GEOMETRICAL DIMENSIONS OF THE FOURSQUARE 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

III. ANTENNA PERFORMANCE

The antenna geometry shown in Fig. 1 with dimensions listed in Table I is modeled with commercial software. Ansoft HFSS is used for the purpose. This is a precise electromagnetic simulator based on the Finite Element Method (FEM) and widely used for modeling of different microwave structures.

Fig. 2 presents the Smith chart of the Foursquare antenna. There are two curves in the chart, which correspond to the cases with and without the incomplete circular ring slots around the feed probes. 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. It is seen that better matching can be achieved for frequencies near the bandwidth limits - if the impedance curve is tightened closely to the loop in the center of the chart. This can be realized if an additional optimization is applied to the antenna construction.

The return loss S_{11} of the Foursquare antenna is shown in Fig. 3. It is below -10 dB in the frequency range 3.5 – 9.9 GHz. This corresponds to a percent bandwidth of 95 %. This is a very wide impedance bandwidth better than the reported values for the typical Foursquare and Fourpoint antennas. The investigated antenna shows great improvement over the Foursquare antenna with a tuning plate and the Fourpoint antenna, which have bandwidths below 60 %. It is comparable in performance with the Fourpoint antenna with a tuning plate (BW=92 %). The Foursquare radiator presented in this paper shows even better impedance bandwidth than that optimized Fourpoint antenna.

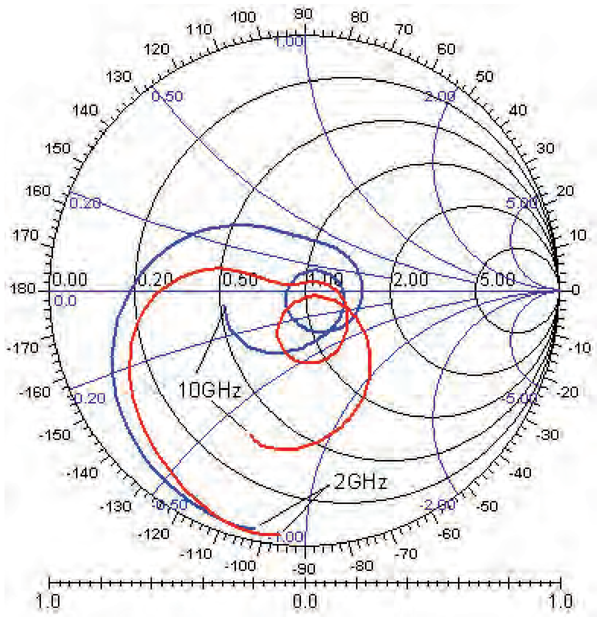


Fig. 2 Smith chart of the Foursquare antenna

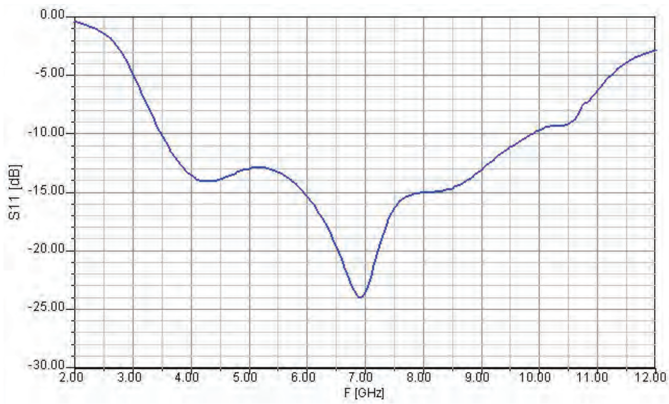
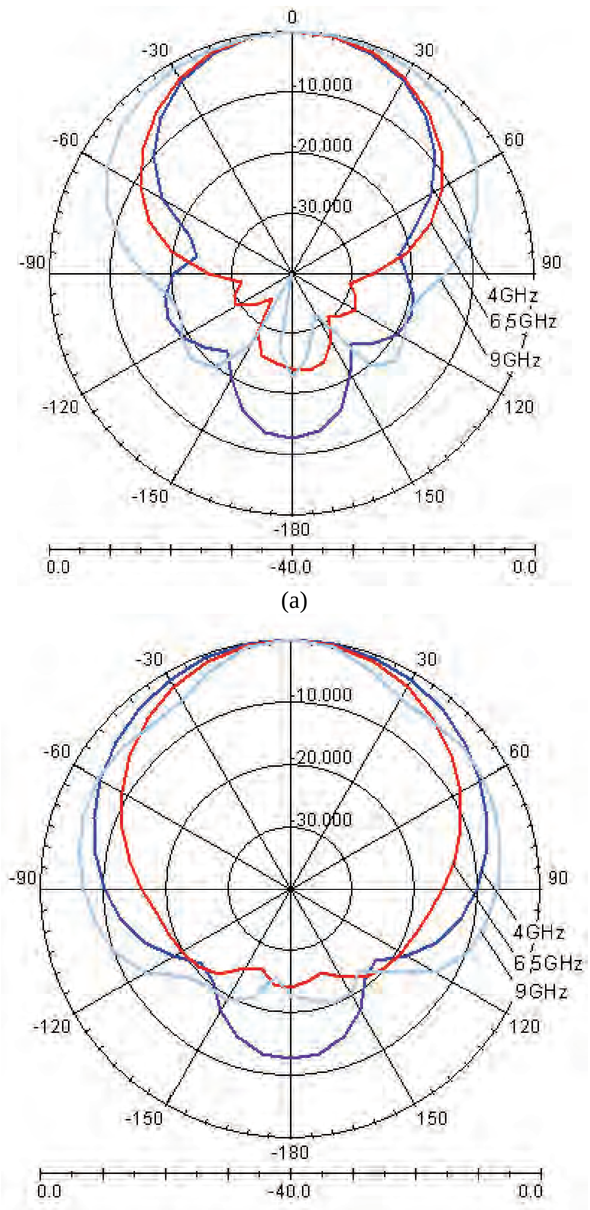


Fig. 3 Return loss of the Foursquare antenna

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

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 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.



(a)

(b)

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

The gain of the Foursquare antenna as a function of frequency is shown in Fig. 5. 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. This is a very useful property of the antenna when a wideband operation is required. 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 %.

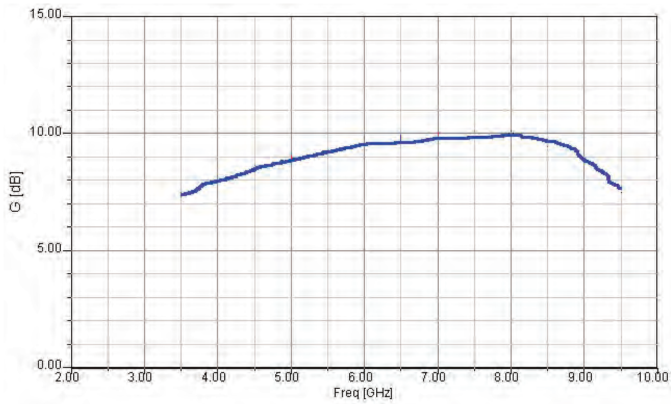


Fig. 5 Gain vs. frequency for the Foursquare antenna

IV. Conclusion

The paper presents a new design of a Foursquare antenna capable of achieving a very wide operating bandwidth. The structure is modeled and evaluated with the help of commercial software. Graphical results for the return loss, input impedance, radiation pattern and gain clarify the antenna performance.

The bandwidth of the investigated Foursquare antenna is 95 %. This is a considerable improvement over the typical Foursquare and Fourpoint antennas (BW<60 %). Only the Fourpoint antenna with a tuning plate shows comparable results (BW=92 %). It must be noted that the presented Foursquare radiator is not an optimum variant of the antenna. There are possibilities for improving the antenna operation through changing the height of the patches above the ground plane, heights of the substrate and the foam layer, the material of the substrate, the ground plane size and others.

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