Bandwidth Improvement of an Aperture-Coupled Stacked Microstrip Antenna

Slavi R. Baev[1], Nikola I. Dodov[2]

Abstract – **The impedance bandwidth of a microstrip antenna is enhanced by a combination of planar and stacked parasitic elements. The proposed antenna configuration is compared with a typical aperture-coupled stacked microstrip antenna. A simulation analysis is performed and a comparison between some characteristics of the two antennas is presented.**

Keywords – **microstrip antenna, parasitic elements, bandwidth.**

I. Introduction

Microstrip antennas are widely used in the communication systems due to their advantages, which make them preferable to other types of antennas. These advantages are low profile, light weight, small size, and easy production process. The application of these antennas is limited because of their drawbacks – most important are the inherently low gain and narrow bandwidth.

There are many publications and books, which describe the variety of approaches for bandwidth improvement of the microstrip antennas [1], [2]. These approaches can be classified into three main categories. First is the impedance matching where a matching circuit is used between the feed line and the radiator. Next, the introduction of multiple resonances in the impedance characteristic of the antenna can be applied by cutting slots, excitation of several resonant modes or addition of parasitic elements with slightly different dimensions. The third approach includes insertion of loss to the system, which lowers the quality factor and therefore improves the bandwidth.

By excitation of multiple closely spaced resonances in the impedance characteristic the antenna bandwidth can be enlarged to a great extent. As already mentioned, several resonances can be excited by the use of parasitic elements. In this case the antenna construction includes two or more radiating elements with slight difference in their dimensions. Usually one element is directly fed and the others are coupled to the electromagnetic field radiated from it. The parasitic elements can be placed in horizontal direction (planar configuration) [3], [4], [5] or in vertical direction (stacked configuration) [6], [7], [8] compared to the main radiator.

The aim of the present publication is to propose a new antenna construction, which combines the advantages of the planar and stacked configurations in order to improve the impedance bandwidth of a typical aperture-coupled stacked microstrip antenna. For the purpose two pairs of microstrip dipoles with different size are placed above the main radiator, instead of one wide rectangular patch. In this way two additional resonances are introduced into the impedance characteristic, instead of one.

In Section 2 the construction and the principles of operation of the two antennas are described. In Section 3 a simulation investigation of the two configurations is performed and a set of graphs for some of the antenna characteristics are presented.

II. Antenna Description

The authors of this publication use as a reference antenna a typical aperture-coupled stacked microstrip antenna. The main advantages of this antenna are: small geometrical area; symmetrical construction, which keeps the phase center constant and the radiation pattern symmetrical in the working frequency band; very broad impedance bandwidth. The main disadvantages are the thick construction and the high level of back radiation. The second effect appears when the feeding aperture resonates and acts as a radiator in the antenna bandwidth. This drawback can be alleviated by making the slot width short enough to move its resonant frequency away from the working band. This implies that the bandwidth is narrowed because the number of resonances is reduced by one.

The structure of a typical aperture-coupled stacked microstrip antenna with its main parameters is shown in Fig. 1.

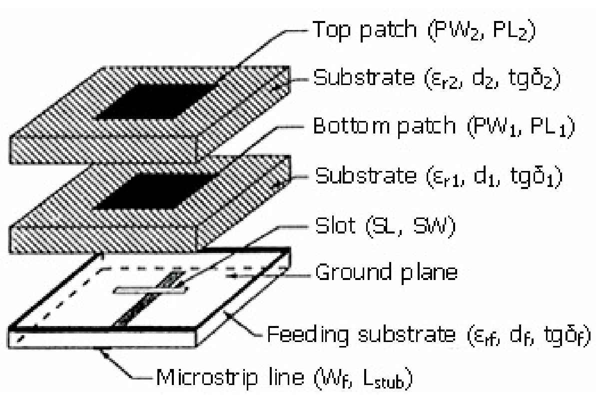

Fig. 1. Aperture-coupled stacked microstrip antenna

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The designations are as follows:

PL_i, PW_i	Length and width of the patches,
ε_{ri}, d_i, $tg\delta_i$	Relative dielectric permittivity, thickness and loss tangent of the substrate materials,
SL, SW	Length and width of the coupling slot,
W_f, L_{stub}	Width of the feedline and stub length of the line beyond the center of the slot.

The antenna is fed by a microstrip line located at the bottom of the lowest substrate. The aperture in the ground plane is excited by the currents flowing on the feedline. The electromagnetic field radiated by the feedline couples to the bottom patch through the coupling slot. The electromagnetic connection between the two patches is capacitive in nature. A detailed analysis of the aperture-coupling feeding technique is described in [9].

There are two resonances in the impedance characteristic of the aperture-coupled stacked microstrip antenna when the feeding aperture does not act as a radiator. The resonances result from the mutual operation of the resonant elements in the structure – the two patches and the slot. This factor determines the complex nature of each resonance. Reference [6] contains detailed parameter study on the effect that the geometrical dimensions of an aperture-coupled stacked microstrip patch has on the antenna characteristics.

In the present publication a new configuration that introduces a third resonance in the antenna impedance characteristic is presented. The working band is improved by positioning several parasitic elements displaced in the horizontal direction above the main patch, instead of just one as in typical construction.

The proposed antenna structure is identical with that shown in Fig. 1. The only difference is in the upper conductor layer, the topology of which along with the main dimensions is shown in Fig. 2.

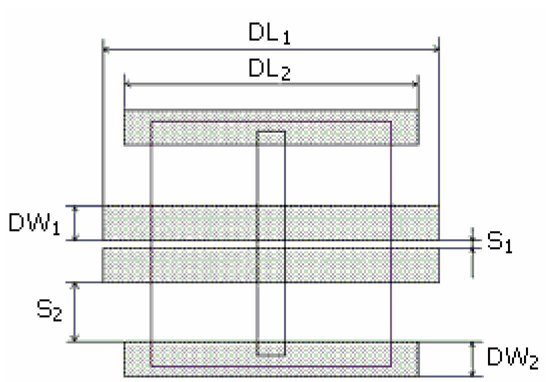


Fig. 2. Upper conductor layer layout of the proposed antenna and the contours of the bottom patch and the aperture located underneath

The designations are as follows:

DL_i,DW_i	Length and width of the two pairs of microstrip dipoles,
S_i	Dipole spacing.

The use of two pairs of microstrip dipoles as parasitic radiators is determined by the following considerations. The narrow width of the dipoles gives almost the same occupied area as the typical rectangular patch. In this way the small horizontal size of the antenna is preserved. The upper layer consists of two pairs of dipoles symmetrically positioned in relation to the center of the lower patch. Therefore the antenna geometry remains symmetrical, which predetermines a constant phase center and a symmetrical radiation pattern in the bandwidth of interest.

The geometries of the microstrip dipole and the rectangular patch being similar, their characteristics are also expected to be similar. The longitudinal surface current distributions are similar for both types of radiators, which determine the similar radiation patterns and gains. These properties of the microstrip dipole and microstrip patch are crucial for the relatively constant shape of the radiation pattern in the antenna bandwidth. However, the input impedance, bandwidth and cross-polar radiation can differ considerably. One major advantage of the dipole is the lower cross-polar radiation because of its narrow width, which decreases the transverse surface current component. A more detailed description of the printed dipoles is given in [1] and the feeding technique that uses an electromagnetically coupled microstrip line is investigated in [10] and [11]. This kind of feeding is used in the proposed structure, since the parasitic dipoles are excited by the electromagnetic field of the main patch underneath.

The addition of several parasitic elements increases the number of geometrical parameters that can be varied. This gives an additional freedom in the optimization process but at the same time makes this procedure more complex.

The dipole lengths are chosen to differ from one pair to another and also compared to the resonant length of the main patch. This leads to the presence of three resonant elements which interact and give three resonances in the system.

III. Simulation Analysis

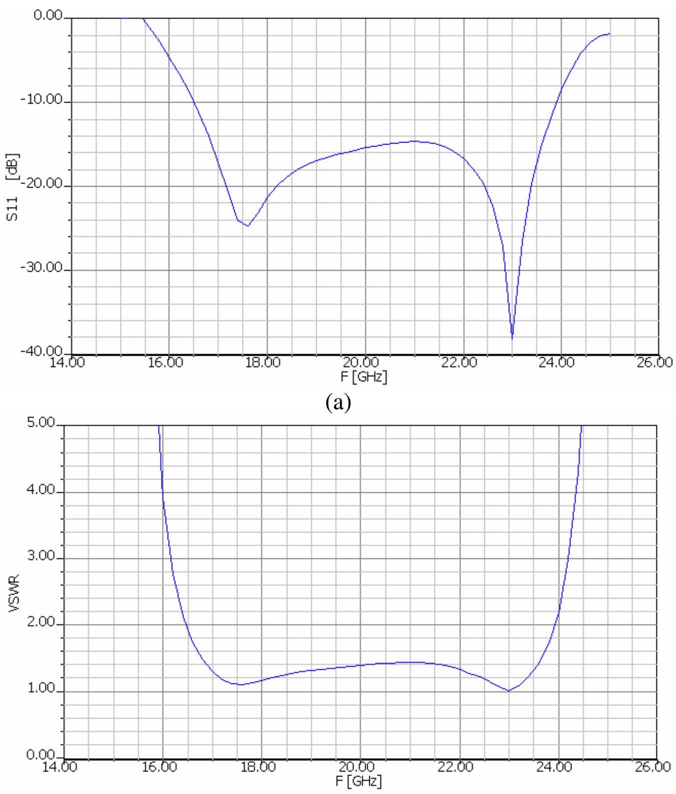
As a typical aperture-coupled stacked microstrip antenna the authors of this publication consider the Antenna #1, which is proposed and investigated in [6]. This antenna shall be called the "reference antenna" throughout the paper. The choice of this particular antenna is dictated by the good impedance characteristics and wide bandwidth. The experimental results measured in [6] show a bandwidth BW=32,5 % (17,1 – 23,75 GHz) for return loss S_{11}<-10 dB and a center frequency f_0=20,42 GHz. The aim of the present publication is to propose antenna with enhanced bandwidth (determined for S_{11}<-10 dB) compared to the reference antenna. The same materials are used in both antenna structures and slight changes in some geometrical parameters are only made for the proposed antenna in order to achieve the desired goal.

The parameters for both antennas are:

Reference antenna: PL_2=PW_2=3,8 mm; ε_{r2}=2,33; d_2=0,787 mm; $tg\delta_2$=0,0012; PL_1=PW_1=3,5 mm; ε_{r1}=2,2; d_1=0,508 mm; $tg\delta_1$=0,0009; SL=3,2 mm; SW=0,4 mm; ε_{rf}=2,2; d_f=0,508 mm; $tg\delta_f$=0,0009; W_f=1,55 mm; L_{stub}=1,8 mm;

Proposed antenna: DL_1=4,8 mm; DW_1=0,5 mm; DL_2=4,2 mm; DW_2=0,5 mm; S_1=0,1 mm; S_2=0,85 mm; ε_{r2}=2,33; d_2=1 mm; $tg\delta_2$=0,0012; PL_1=3,44 mm; PW_1=3,5 mm; ε_{r1}=2,2; d_1=0,508 mm; $tg\delta_1$=0,0009; SL=3,2 mm; SW=0,4 mm; ε_{rf}=2,2; d_f=0,308 mm; $tg\delta_f$=0,0009; W_f=1,55 mm; L_{stub}=1,6 mm;

For the purposes of a precise comparison both antennas are analyzed with the simulation software Ansoft Designer. This approach excludes the inaccuracy caused by differences in the test setups. In Ansoft Designer the surface of the patch is divided into a mesh of triangles and rectangles, the size of which depends on the working frequency. To generate a solution this software employs the mixed-potential integral equation (MPIE) method. The method of moments (MoM) is applied to the MPIE to obtain the current distribution on the surface mesh. Then the antenna characteristics like return loss (S_{11}), voltage standing-wave ratio (*VSWR*), gain, radiation pattern are calculated from this current distribution.



(a)

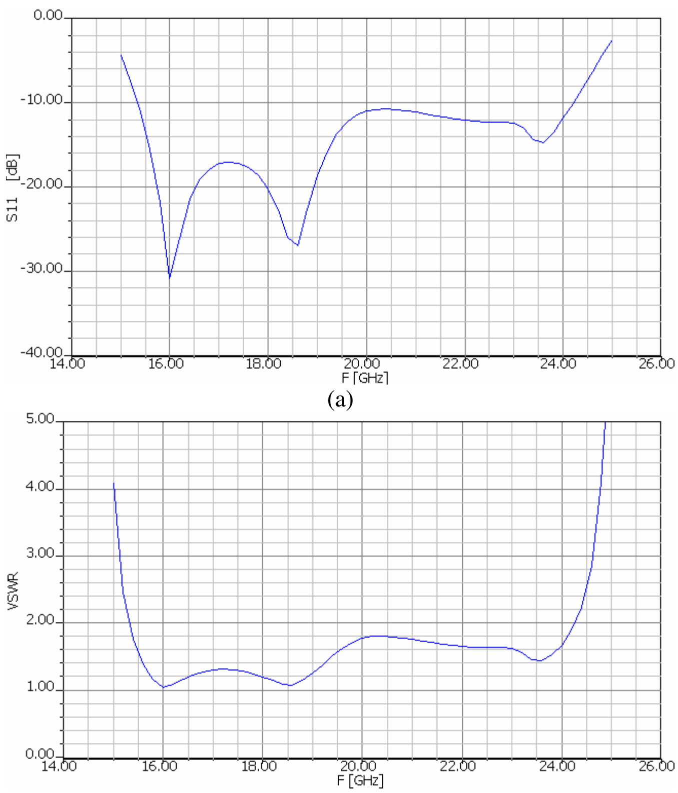
(b)

Fig. 3. Impedance characteristics of the reference antenna as a function of frequency: (a) S_{11}; (b) *VSWR*.

Figs. 3(a) and (b) present S_{11} and *VSWR* as a function of frequency for the reference antenna and Figs. 4(a) and (b) - for the proposed antenna. As expected the reference antenna has only two minima in the impedance characteristic, and for the proposed antenna there are three resonances.

From Fig. 3(a) it is seen that the reference antenna satisfies the condition S_{11}<-10 dB in the range 16,5 – 23,9 GHz or this corresponds to an impedance bandwidth of 36,6 % centered on f_0=20,2 GHz. Fig 4(a) shows the following results for the proposed antenna: S_{11}<-10 dB in the range 15,3 – 24,2 GHz or a bandwidth of 45,1 % centered on f_0=19,75 GHz. The resultant absolute value of bandwidth improvement for the proposed antenna compared to the reference antenna is 8,5 % and the relative enhancement is about 23 %. This large improvement is due to the introduction of a third resonance in the impedance characteristic of the patch antenna.

As mentioned above a given resonance can not be related only to a particular antenna element [6]. Therefore it is difficult to determine a cause for the excitation of each one resonance in the system. The study performed on this problem allows noting some specific features. When the inner pair of dipoles is removed the first resonance (for the lowest frequency – Fig. 4(a)) disappears. Only one of the low frequency resonances leaves. Hence the first resonance is determined to a great extent by the inner pair of dipoles. This behavior may be expected because these dipoles are with maximum length and therefore minimum resonant frequency. When the outer dipoles are removed the bandwidth is narrowed from its high frequency end due to the loss of the third resonance. However there remains a minimum at about 21 GHz, which is related to the coupling aperture. Therefore the third resonance is a result from the mutual operation of the outer dipoles and the slot. This is in correspondence with the high level of S_{11} for the third resonance. The outer dipoles are located above the ends of the aperture where the coupled field is weaker compared to the center. This implies weaker excitation of these dipoles and the resonance related to them.

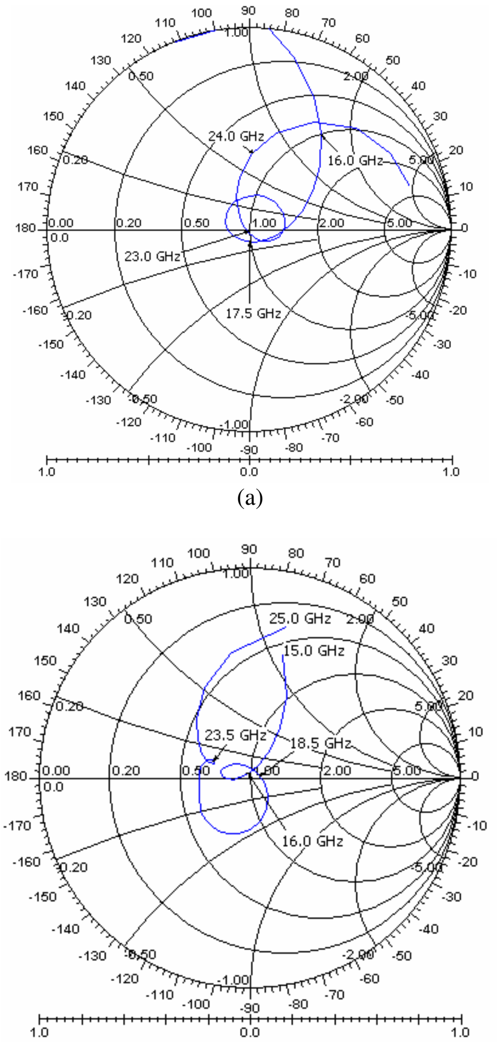


(a)

(b)

Fig. 4. Impedance characteristics of the proposed antenna as a function of frequency: (a) S_{11}; (b) *VSWR*.

Figs. 5(a) and (b) show the Smith charts for the two antennas. As expected for the reference antenna there is only one well formed closed loop in the center of the chart. This is a typical behavior for a double-resonant antenna. As seen in Fig. 5(b) there are two loops centered on the Smith chart for the proposed antenna. The bigger one corresponds to the resonances at 16 GHz and 18,5 GHz and the smaller one – to the weaker resonance at 23,5 GHz.



(a)

(b)

Fig. 5. Smith chart: (a) Reference antenna (b) Proposed antenna.

IV. Conclusion

In this paper an antenna, which combines the advantages of the planar and the stacked parasitic configurations in order to achieve bandwidth enhancement, is presented. This is realized through the substitution of the standard upper patch in an aperture-coupled stacked microstrip antenna by two pairs of microstrip dipoles with different lengths. The insertion of an additional resonant element in the antenna construction leads to the excitation of a third resonance in the impedance characteristic, while for a typical aperture-coupled stacked patch there are only two resonances. This causes improvement of the impedance bandwidth.

A simulation analysis on the proposed and a typical aperture-coupled stacked microstrip antenna is performed. A set of graphs for some of the main antenna parameters are presented. The results show relative bandwidth enhancement of 23 % and an absolute value of 8,5 %.

The addition of more geometrical parameters in the antenna construction complicates its optimization. The authors do not claim for an optimal design of the presented antenna. The main purpose of the publication is to show that the used bandwidth enhancement approach gives good results and can be realized in practice. The future efforts of the authors will be concentrated on the performance of a parameter analysis which must reveal the relation between the antenna characteristics and its geometry and to outline optimization guidelines for this type of antenna.

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