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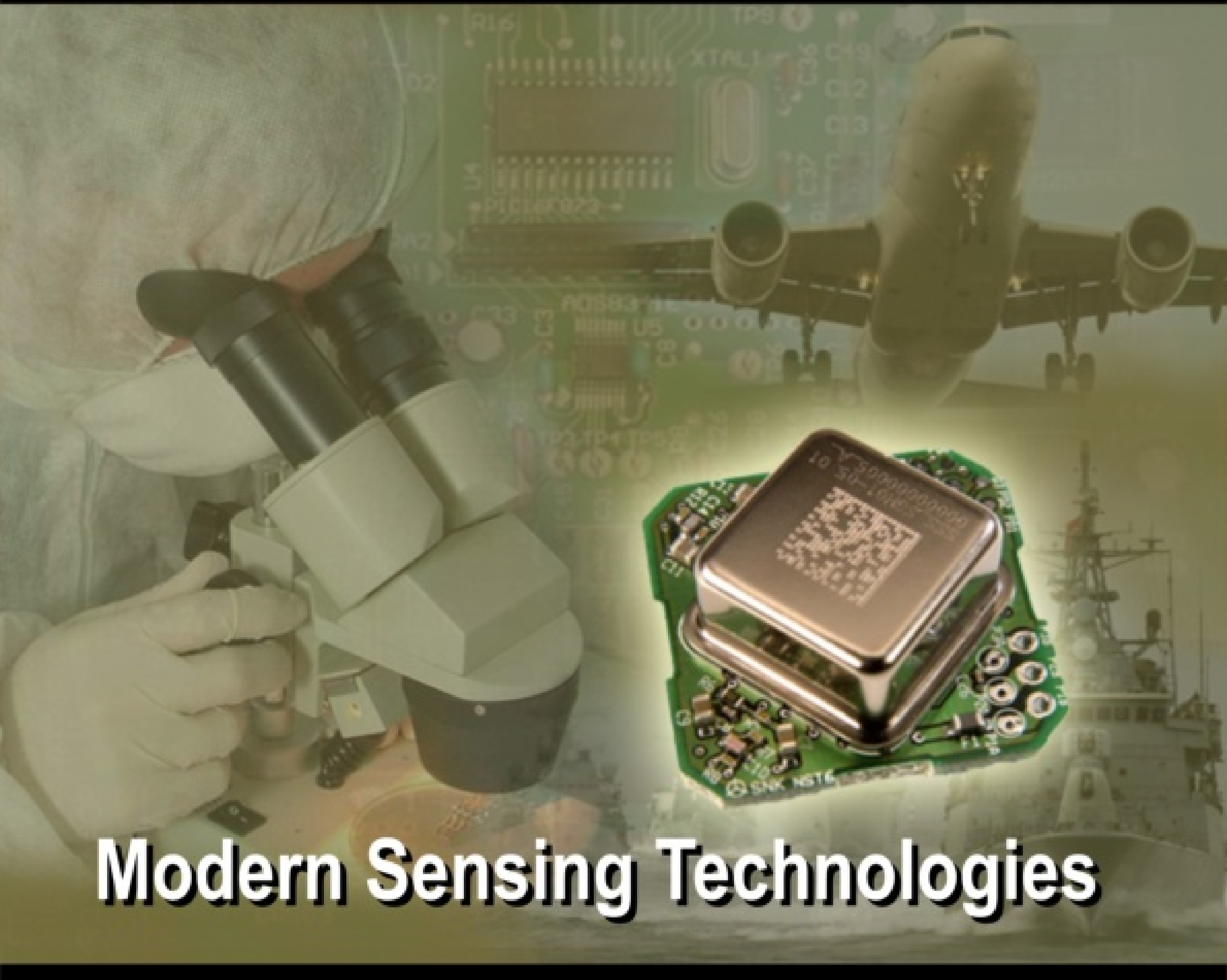

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Broadband and Improved Radiation Characteristics of Aperture-Coupled Stacked Microstrip Antenna for Mobile Communications

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Abstract: A new broadband microstrip antenna has been reported in this paper. A significant breakthrough in bandwidth enhancement has been achieved by optimizing the antenna's dimensions, substrate materials, substrate thickness, aperture dimensions and by positioning a thin conductor at a particular angle as a reflector to stop the back radiation. The measured ultra-bandwidth has been found to be 73% at VSWR = 2.0 at 850 MHz. The gain of the modified microstrip antenna has also improved from 8.6 dB to 9.2 dB. It is found that the back radiation has reduced significantly due to the conducting plane inserted below the microstrip feed line. The front-to-back ratio has improved from 12 dB to 20 dB. This antenna can find useful applications in wireless communications. *Copyright © 2008 IFSA.*

Keywords: Microstrip antenna, Broadband, Stacked patch, Substrate, Aperture-coupled

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1. Introduction

Although microstrip antennas have the advantages of low-profile, conformal, small size, low weight, low production cost and high design flexibility, its narrow bandwidth characteristic seriously limits its application. Microstrip antennas also have some other limitations such as: lower gain; lower power handling capability; excitation of surface waves; poor cross-polarization, radiation from feeds, and junctions etc.

Significant research has been pursued during the last two decades to increase the bandwidth [1-12] of the microstrip antennas. Design of broadband and dualband microstrip antennas were studied by Palit et al [1-6]. It is found that a properly designed notched microstrip patch can exhibit wideband and dualband operations. The two resonant frequencies are probably the results of the coupling between the main patch and the notch resonant frequencies. The maximum impedance bandwidths of 38 % for band 1 and 27 % for band 2 were achieved for coax-fed single notched patch. Palit et al [6] described a composite patch antenna to enhance bandwidth by adding a patch on top of the primary patch and another patch as a director in the right radiating side of the top one. It is found that the bandwidth is very sensitive to the gap between the main patch and the parasitic patch. The feed location is very important for good matching, which increases the bandwidth.

This paper presents a broadband aperture fed stacked patch antenna. The notable features of this feed configuration are wider bandwidth and the shielding of the radiation patch from the feed structure. Aperture-coupled microstrip feed uses two substrates separated by a common ground plane. The slot can be of any shape and size and these parameters are used to improve the bandwidth. The radiation of the open end of the feed line does not interfere with the radiation pattern of the patch because of the shielding effect of the ground plane. This also improves the polarization purity. This paper shows a very significant bandwidth enhancement achieved (73 %) by adding a reflector at the bottom of the aperture coupled stacked microstrip antenna. It also enhanced the front-to-back ratio of the radiation level and gain of the designed antenna.

2. Aperture Coupled Stacked Patch Antenna Design

Fig. 1 shows the schematic diagram of the designed aperture coupled stacked patch antenna.

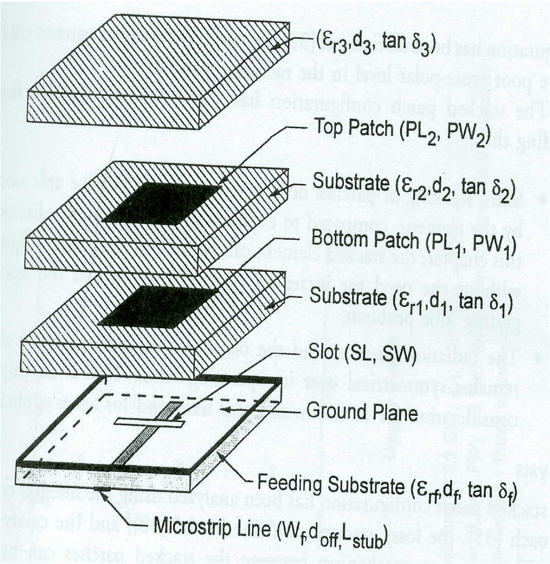


Fig. 1. Aperture coupled stacked microstrip antenna.

The size of the lower patch is different from that of the upper patch to obtain a slightly different resonant frequency. Various parameters such as substrate thicknesses d_1 and d_2, dielectric constants ε_{r1} and ε_{r2}, patch sizes and feed location were adjusted to optimize the bandwidth. The stacked patch configuration has been designed and analyzed using Ensemble - a software package based on method of moment and the lossy transmission line model. Fig. 1 shows our designed antenna having two resonant patches that are different in size, with the lower patch fed by a microstrip line through a resonant slot in the common ground plane. The basic feature of this structure is that each of the three resonators (two patches and the slot) has its own impedance loop. There are also mutual couplings among these resonances. The resonator parameters are adjusted to bring the impedance loops closer to each other. The substrate thickness and the dielectric constant between the resonators are also varied to adjust the mutual coupling between them resulting in a wider bandwidth.

Fig. 2 shows the experimental set up for measuring the impedance bandwidth of the designed microstrip antenna. Voltage Standing Wave Ratio (VSWR) and return loss (dB) as a function of frequency and impedance loops as functions of substrate thickness were measured using network analyzer. Some of the measured results are compared with the simulated ones to validate the design.

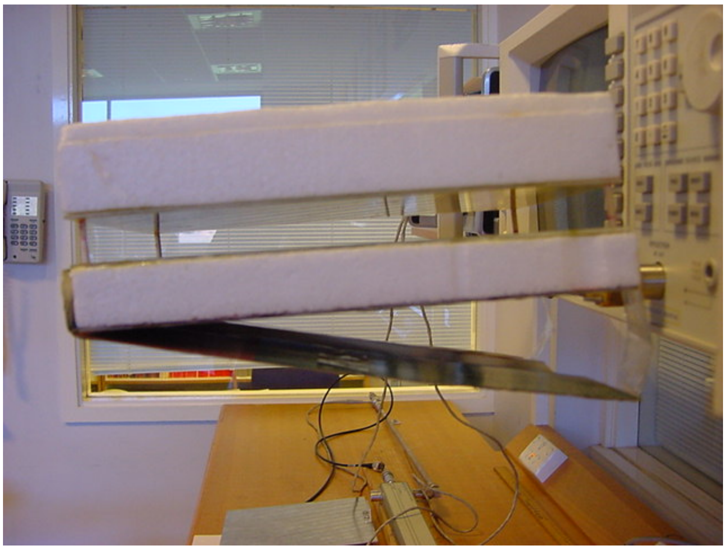


Fig. 2. Experimental set-up for measuring VSWR as a function of frequency.

In this design, two dielectric substrate layers and one foam layer were stacked together. The first layer supports the microstrip feed line on one side, and the ground plane with a coupling aperture on the other [Fig. 1]. On the second layer, the rectangular patch was etched on one side and the conducting layer (copper) was removed from the other side. The foam layer is used to reduce the dielectric constant and increase the thickness of the substrate for wider bandwidth. It is difficult to etch the patch directly on the foam because of its porosity. A thin perspex layer is used to support the second patch whose dimension is different than the first patch so as to obtain different resonant frequency. The antenna input impedance is matched to 50 Ω using a microstrip quarter wave matching which was etched on the same side as the microstrip feed line.

The dimensions of the patches and the slots were optimized using the Ensemble software package. The software is based on the full-wave method to solve a mixed-potential integral equation which takes into consideration the effects of discontinuities, surface waves and spurious radiations. Figs. 3-6 show the changes in input impedance as functions of antenna parameters. It is found that change of the lower patch size is very critical which contributes to both mutual resonances with the aperture below and the upper patch and therefore affects the size of both the loops as found in the Figs. 3-6.

There is only one inductive loop since the air gap (d2 = 30 mm) is too large for mutual coupling between the patches.

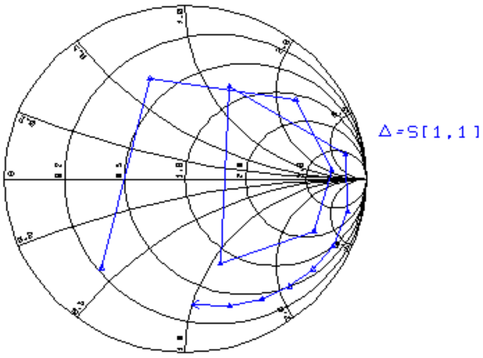


Fig. 3. SL = 118.5 mm, SW = 5.0 mm, L_{stub} = 20.0 mm, ε_{rf} = 4.4, d_f = 1.6 mm, ε_{r1} = 2.54, d_1 = 40.0 mm, ε_{r2} = 1.0, d_2 = 30.0 mm, ε_{r3} = 2.54, d_3 = 30.0 mm PL_1 = 88.6 mm, PW_1 = 88.6 mm, PL_2 = 167.6 mm, and PW_2 = 167.6 mm.

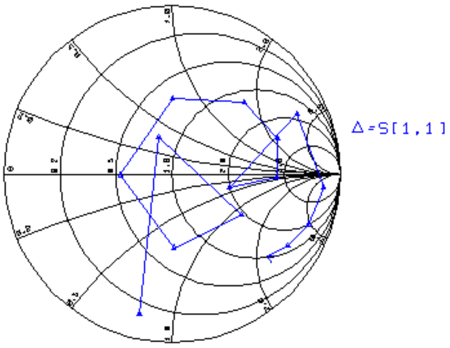


Fig. 4. SL = 98.6 mm, SW = 5.0 mm, L_{stub} = 20.0 mm, ε_{rf} = 4.4, d_f = 1.6 mm, ε_{r1} = 2.54, d_1 = 10.0 mm, ε_{r2} = 1.0, d_2 = 5.0 mm, ε_{r3} = 2.54, d_3 = 30.0 mm PL_1 = 97.6 mm, PW_1 = 118.6 mm, PL_2 = 97.6 mm, and PW_2 = 117.6 mm.

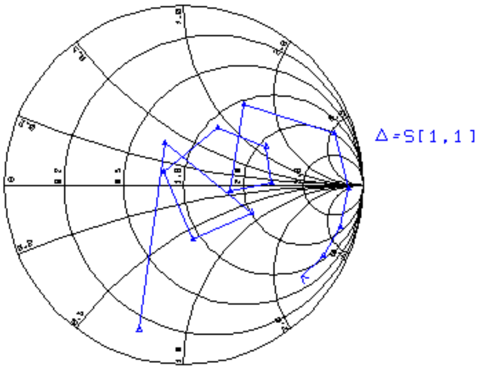


Fig. 5. SL = 98.6 mm, SW = 5.0 mm, L_{stub} = 20.0 mm, ε_{rf} = 4.4, d_f = 1.6 mm, ε_{r1} = 2.54, d_1 = 20.0 mm, ε_{r2} = 1.0, d_2 = 10.0 mm, ε_{r3} = 2.54, d_3 = 30.0 mm PL_1 = 97.6 mm, PW_1 = 108.6 mm, PL_2 = 97.6 mm, and PW_2 = 132.6 mm.

The loops are slowly coming closer and getting tightly coupled as the substrate thickness d1 and d2 have been reduced.

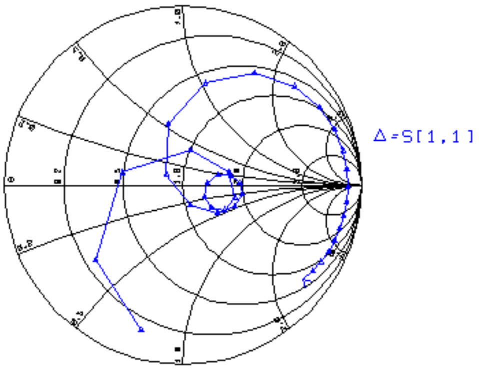


Fig 6. SL = 98.6 mm, SW = 5.0 mm, L_{stub} = 20.0 mm, ε_{rf} = 4.4, d_f = 1.6 mm, ε_{r1} = 2.54, d_1 = 20.0 mm, ε_{r2} = 1.0, d_2 = 22.5 mm, ε_{r3} = 2.54, d_3 = 30.0 mm PL_1 = 97.6 mm, PW_1 = 108.6 mm, PL_2 = 97.6 mm, and PW_2 = 132.6 mm.

Two loops are tightening further by adjusting the substrate thickness and optimum design has been achieved.

Fig. 6 represents a proper balance between the two mutual resonances and therefore yields maximum bandwidth with respect to patch size and aperture size. Fig. 7 shows theoretical (using simulation package Ensemble) and measured return losses as a function of frequency. Maximum theoretical bandwidth at VSWR= 2 is found to be 59 % at 850 MHz. Fig. 8 shows measured VSWR vs. frequency for the designed stacked microstrip antenna with an aluminum foil as the reflector at the bottom of the antenna to stop the back radiation. The optimum measured bandwidth of 73 % at VSWR = 2.0 has been achieved with the reflector positioned at an angle of 14° to the horizontal plane of the antenna which is considered to be a breakthrough in enhancing the bandwidth of a microstrip antenna.

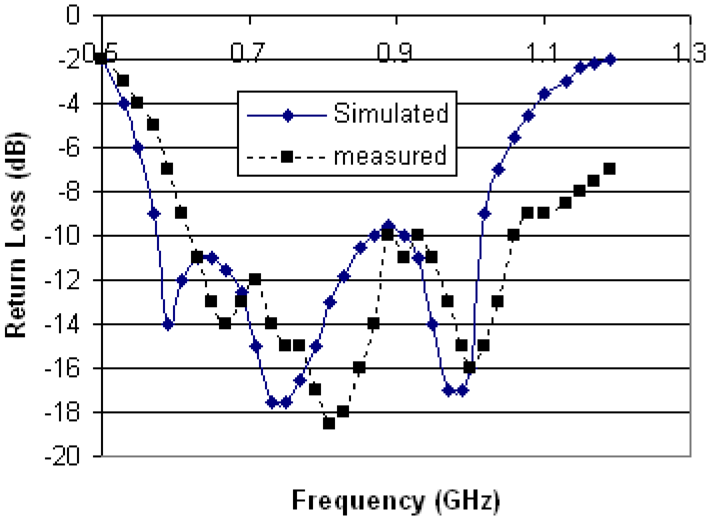
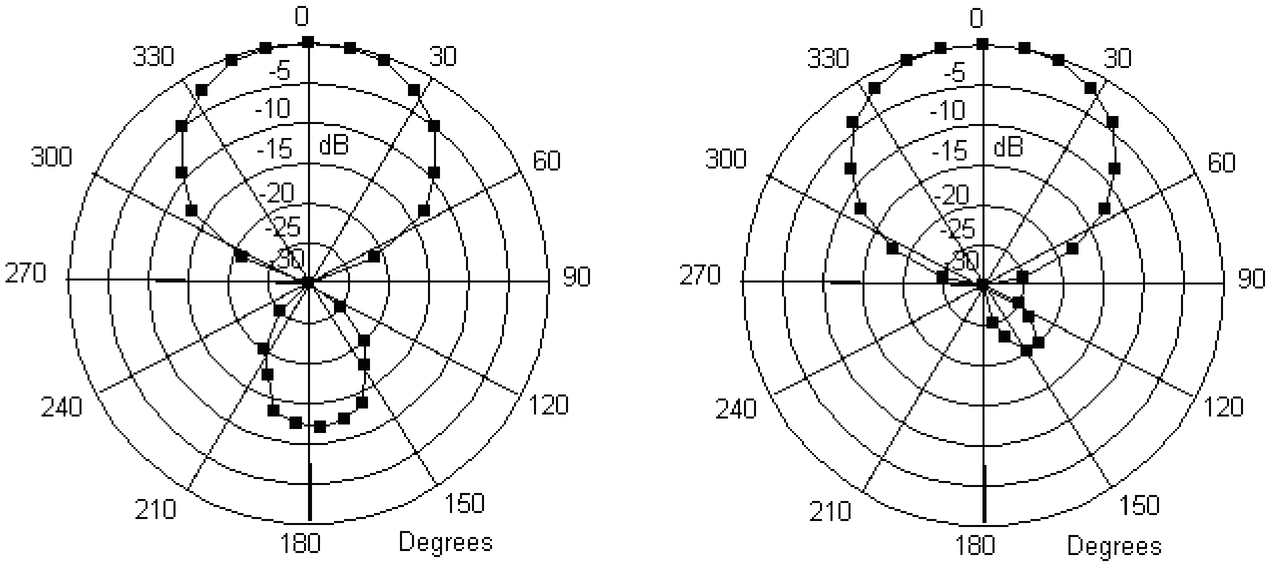


Fig. 7. Return loss as a function of frequency.

To analyze the radiation properties, the E-plane and H-plane radiation patterns were measured at 850 MHz. The half power beam width (HPBW) in E-plane and H-plane are recorded to be 60^0 and 72^0 for the designed aperture-coupled stacked patch antenna (Figs. 9 and 10). Microstrip antennas usually exhibit poor front-to-back ratio which was evidenced by our measured back lobes (E-plane = 12 dB, H-plane = 10 dB). Back radiation is undesired in mobile communications due to radiation power loss in the undesired direction and increased electromagnetic energy exposure risk for mobile users. To improve the front-to-back ratio a thin aluminum foil was used as a reflector and the result was very encouraging. The measured E and H planes radiation patterns for the modified antenna with a reflector are also shown in the Figs. 9 and 10 for comparison. It is found that the front-to-back ratios for both E and H planes have improved significantly. It is also found that the gain of the antenna with a reflector has also improved from 8.8 dB to 9.2 dB.

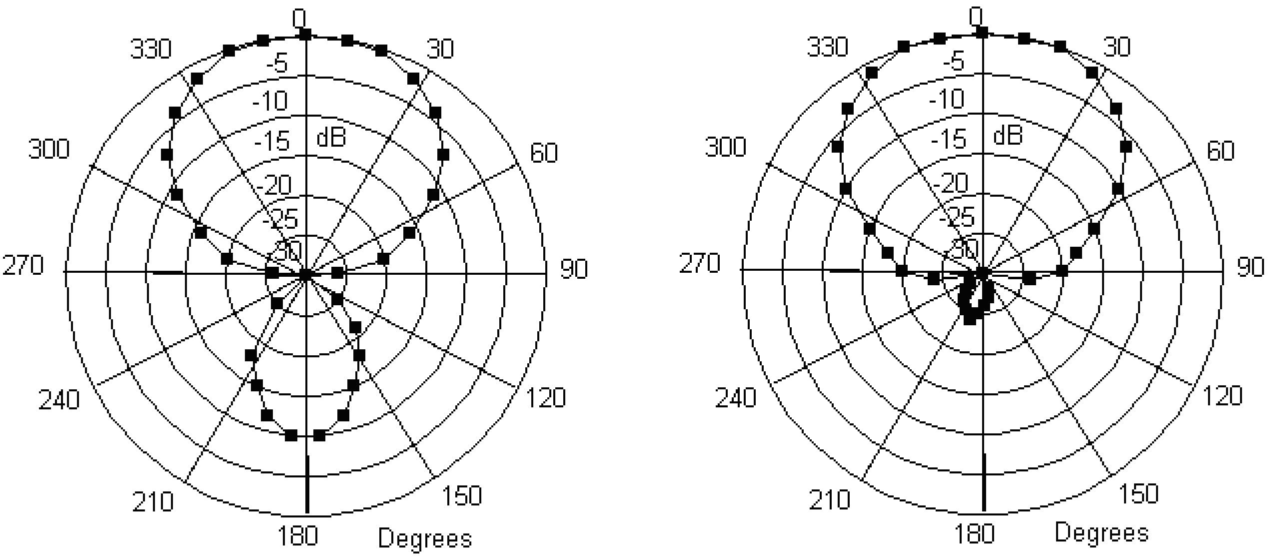
Fig. 8. Measured VSWR as a function of frequency.



(a)

(b)

Fig. 9. Measured E-plane radiation patterns of the aperture-coupled stacked patch antenna without a reflector (b) with a reflector.



(a) (b)

Fig. 10. Measured H-plane radiation patterns of the aperture-coupled stacked patch antenna (a) without a reflector (b) with a reflector.

3. Analysis of the Results

In this paper an aperture-coupled stacked microstrip antenna for mobile communications is studied. The purpose of the study is to increase the bandwidth, gain and improve the front-to-back radiation level for wireless communications. The aperture-coupled technique was initially proposed by Pozar [7, 11]. The technique consists of coupling energy from the microstrip feed line through a slot in the ground plane to the patch. The patch is isolated from the feed structure by the ground plane which reduces spurious radiation, and offers the designer the opportunity to choose different substrate materials for the feed and the radiating element. It is found that by choosing low dielectric constant substrate materials impedance bandwidth can be increased. In this design foam is used and the reflector is suspended which optimized the bandwidth. Substrate thickness also changes the bandwidth. The study found that thicker substrate offers wider bandwidth but reduces gain due to less coupling for a given aperture size. Patch length determines the resonant frequency and its width the resistance at resonance. Thinner feed substrate yields less spurious radiation from the feed line but yields higher losses due to increased resistivity. The length and the width of the coupling slot determine the coupling and back radiation. The width of the microstrip feed line and the placement control the input impedance of the antenna.

4. Conclusions

The design and analysis of an aperture coupled stacked microstrip antenna have been made and reported in this paper. A significant breakthrough in bandwidth enhancement has been achieved by optimizing the antenna’s dimensions, substrate materials and thickness, aperture dimensions and by positioning an aluminum foil at a particular angle as a reflector to reduce the back radiation. The measured ultra-bandwidth is found to be 73 % at VSWR = 2.0 at 850 MHz. The front-to-back ratio of the radiation in both E and H planes and gain are found to have improved significantly. This antenna can find useful application for base station and in-building mobile network coverage for CDMA and GSM frequencies.

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