Design and Fabrication of Aperture Coupled Microstrip Increased Bandwidth Antenna

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Abstract **─** This paper presents aperture coupled microstrip antenna with three resonants. The antenna bandwidth has been enhanced due to clip in the patch edges and varies the current distribution well in order to create the third resonant. There is a compromise between radiation characteristics and the antenna bandwidth. These two factors have been optimized in designed and fabricated samples. E-plane and H-plane patterns indicate the appropriate propagation pattern of antenna is between 1.3 to 2.3 GHz frequency band, which clarifies achieved bandwidth more than 53% by using certain method in the novel one radiating element. Of course, there is bandwidth enhancement up to this limit by utilization of multiple radiating elements.

Index Terms **─** Aperture coupled microstrip antenna, bandwidth enhancement, coupling, resonant frequency, slot.

I. INTRODUCTION

The microstrip antennas have many applications due to their planar structures and mechanical formations, but they suffer from narrow bandwidth. Many procedures have been done for bandwidth enhancing and different methods proposed; although these methods decrease the performance of antenna propagation [1]. Conventional methods for increasing bandwidth of these antennas are categorized in three general groups: bandwidth enhancement by feeding network, variation in patch's physical structure and material connected with feeding network and patch. Many types of microstrip antennas such as rectangular, circular, semi-circular and triangular patches have been investigated with mathematics concepts in [2]. The basis of current structure design has been adopted from aperture coupled microstrip antenna which introduced by Pozar [3].

The general purpose of this paper is enhancement of aperture coupled microstrip antenna bandwidth as possible as it can; consequently, the radiation characteristics of an end-fire antenna have been observed here.

Fundamental discussion of current paper is achieving three resonants in the antenna by employing one radiating element which it is contrary with other two resonants aperture coupled microstrip multiple radiating element antennas.

As a result, optimum energy coupling methods have been considered for a patch [4]-[9]. One H form slot has been created which it is responsible for controlling the coupling energy on patch. Also, slot structure size increasing cause to create a degree of freedom for bandwidth enhancement.

With variation on patch structure by cutting both sides (clipping dimensions from edges in addition to patch length and width), it is possible to add degree of freedom for controlling S_{11} antenna parameter. Nevertheless, the current distribution form in the patch changes, which this cause to multiple controlling in antenna bandwidth; consequently, the bandwidth enhancement is achieved more than 53%. Certainly, it is necessary to draw attention to this point that multiple radiating elements aperture coupled antennas have bandwidth enhancement up to this limit [10] and many procedures have been done in this field [11]. Next section presents aperture coupled microstrip antenna design and its important parameters, then simulation results are obtained in HFSS software, finally the fabrication results have been demonstrated for verification of design procedure.

II. ANTENNA STRUCTURE AND ITS DESIGN PRINCIPLES

Side view of designed physical structure of aperture coupled microstrip antenna has been illustrated in Fig. 1. The center frequency of this L-band aperture antenna is

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1.7 GHz. In this type of antenna, the radiating element is the upper metal patch. The energy is coupled from feeding network through the aperture which is located on metal plate under the upper patch. Therefore, the effective coupling parameters are antenna feeding network, slot and patch dimensions. Indeed, the degree of freedom for broadbanding of aperture coupled microstrip antenna is its feeding network which it consists of a probe or microstrip line that it causes bandwidth enhancement about 5% to more than 15% [12], [13].

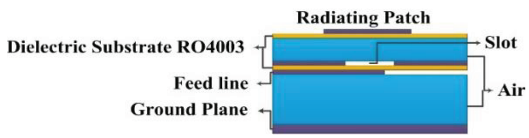


Fig. 1. Side view of aperture coupled microstrip antenna.

So, fundamental cases engaged with the bandwidth and radiation characteristics of microstrip antennas can be studied as below:

A. Dimensions and dielectric characteristics of upper section

It is obvious that antenna radiation performance and its bandwidth become so well as increase the upper dielectric layer thickness and decrease its relative permittivity coefficient [14], whereas coupling factor will be decreased. RO4003 substrate type is used with dielectric constant ε_r=3.38 and thickness of 1.52 mm and its lower air layer thickness is equal to 12 mm.

Employing simple calculations [15], the ε_{eff} of this combined structure (RO4003 with dielectric constant ε_r=3.38 and air with ε_r=1) is calculated which it is less than using microstrip dielectic absolutely. The air layer role is creating one degree of freedom for antenna bandwidth enhancement.

B. Dimensions and dielectric characteristics of lower section

In spite of energy coupling which performs from this line, increasing in dielectric constant and its thickness reduction is a reason for coupling improvement [16].

Also, the microstrip material type of RO4003 with dielectric constant ε_r=3.38 and thickness of 1.52 mm for this dielectric. Thickness of each microstrip antenna layer has been shown in Fig. 2.

Fig. 2. Distances and thicknesses of antenna layers in mm.

C. Dimensions and characteristics of feeding network and slot

Obviously, the feeding network has a direct relation with its characteristic impedance. If the impedance matching meets its requirements, the S_{11} and antenna bandwidth parameters will be improved. The feeding network alignment must be vertical on slot without any deviations for improving coupled energy [16]. It is important to notice that the feeding network length effects on bandwidth, too.

In other side, the slot dimensions have direct effect on coupling and antenna radiation characteristics. Its structure is in H form and vertical on feeding network alignment as mentioned above. The effect of slot dimensions on S_{11} parameter is inevitable as presented in simulation.

Slot and feeding network have been placed in two sides of RO4003 microstrip line and physical structure and its dimensions have been shown in Fig. 3.

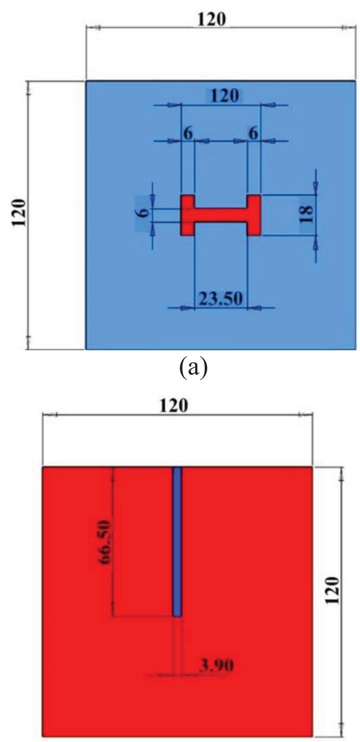


Fig. 3. (a) Feeding network and (b) slot (dimensions in mm).

D. Dimensions and characteristics of patch (radiation element)

Patch dimensions have direct relation with resonant frequency and bandwidth of antenna. The antenna bandwidth has been enhanced intensely due to clip in the patch edges and varies the current distribution well in order to create the third resonant. This operates notwithstanding transformation linear into circular polarization by adjusting of exact dimensions and sufficient energy coupling of slot. In the next section, clipped patch effect has been presented by HFSS software.

The patch is placed in structure's center for optimum coupling [4] and its characteristics and dimensions have been illustrated in Fig. 4.

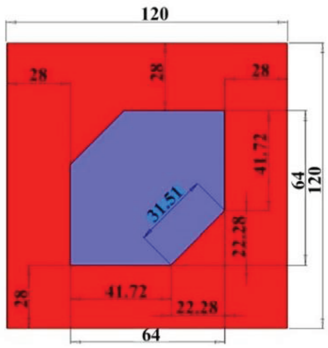


Fig. 4. Patch characteristics and dimensions (in mm).

III. SIMULATION AND FABRICATION RESULTS

There is a compromise between radiation characteristics and the antenna bandwidth. As mentioned previously, many parameters related to optimizing coupling are in contrary with increasing bandwidth. The three resonant frequencies effect on upper (due to patch), lower (due to slot) and mid (due to feeding network) band frequency of S_{11} parameter, respectively. Of course, all of these resonants influence each other. The simulation design has been done in HFSS software. Schematic (Fig. 5) and results of aperture coupled antenna presented in the following.

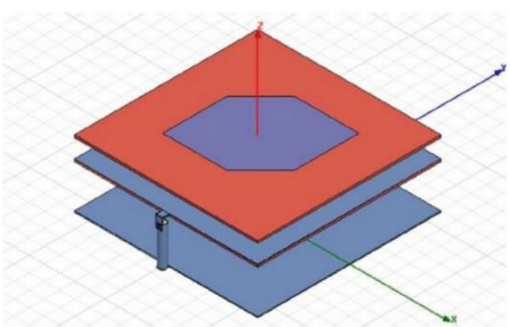


Fig. 5. Illustration of aperture coupled microstrip antenna.

A. Return loss and VSWR diagram

The S_{11} diagram has been presented with and without using clipped patch in order to investigate its effect on antenna bandwidth. The VSWR and return loss diagrams have been illustrated in Figs. 6 and 7, correspondingly.

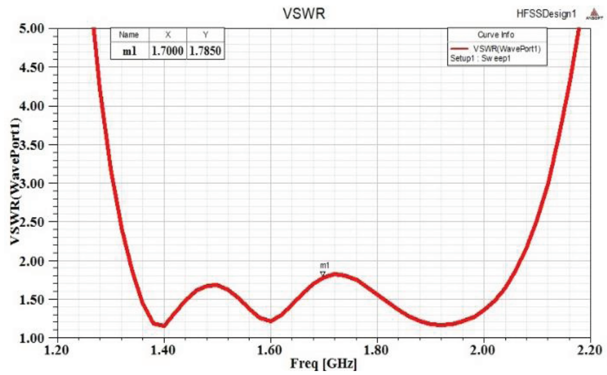


Fig. 6. VSWR diagram of the antenna.

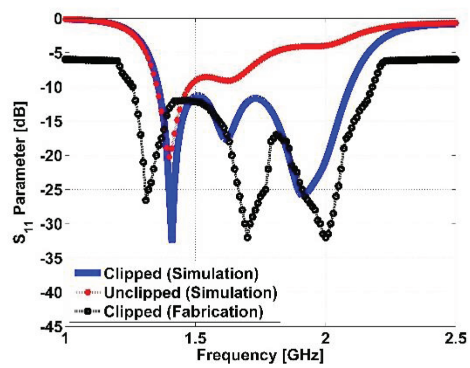


Fig. 7. Power reflection coefficient diagram of the antenna.

B. Gain diagram

The gain of a conventional rectangular patch is in order of 6 or 7 dB. As shown in Fig. 8, aperture coupled antenna gain has been reached to 9 dB by employing mentioned methods.

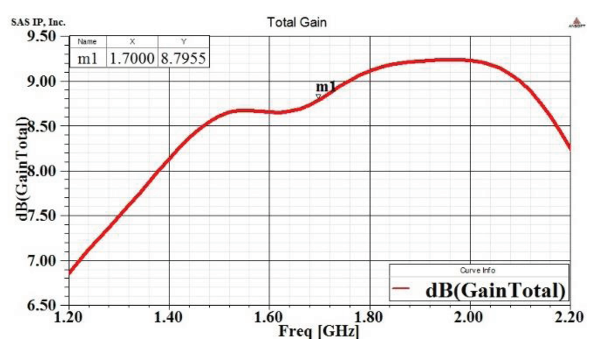


Fig. 8. Gain diagram versus frequency of the antenna.

C. Axial ratio diagram

The axial ratio parameter is defined for elliptical or circular polarization. The axial ratio is the ratio of the magnitudes of the major and minor axis defined by the electric field vector. The axial ratio in the proximity of center frequency (1.7 GHz) shows that there is (quasi) circular polarization in this band (Fig. 9).

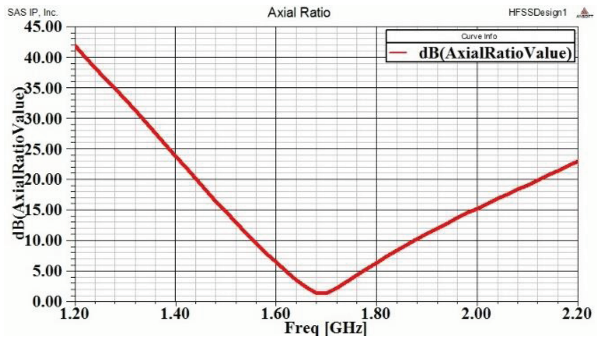


Fig. 9. Axial ratio (AR) diagram versus frequency of the antenna.

The aperture coupled microstrip prototype has been shown in Fig. 10. The fabrication results are categorized in two groups as mentioned in the following. The fabricated S_{11} parameter of this antenna illustrated in Fig. 7 with its simulated one. It is important to notice which the return loss result of aperture coupled microstrip antenna fabrication complies with its simulation result, appropriately.

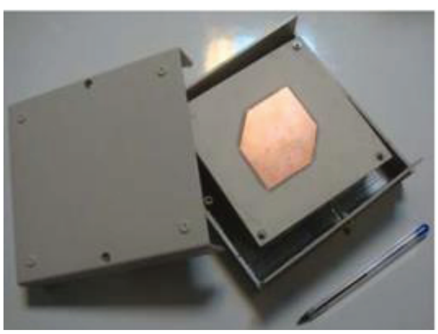


Fig. 10. Prototype of the antenna.

D. Radiation patterns

Figures 11 and 12 show the simulated and fabricated results of the antenna for six frequency values of the band, respectively. The simulations and experiments show that increase of clipping number on patch edges hasn't a sensitive effect on bandwidth enhancement; therefore, it's not mandatory to increase these numbers.

The Fig. 11 (a) is in accordance with the Fig. 12 (a) and (b); Fig. 11 (b) with the Fig. 12 (c) and (d); Fig. 11 (c) with the Fig. 12 (e) and(f); Fig. 11 (d) with the Fig. 12 (g) and (h); Fig. 11 (e) with the Fig. 12 (i) and (j); Fig. 11 (f) with the Fig. 12 (k) and (l). A brief look at these pictures, it can be seen that the both simulated and fabricated results are in very good accordance each other.

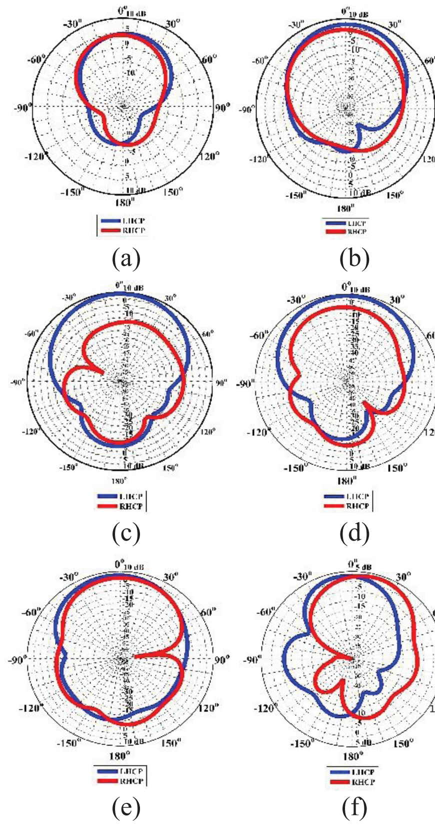
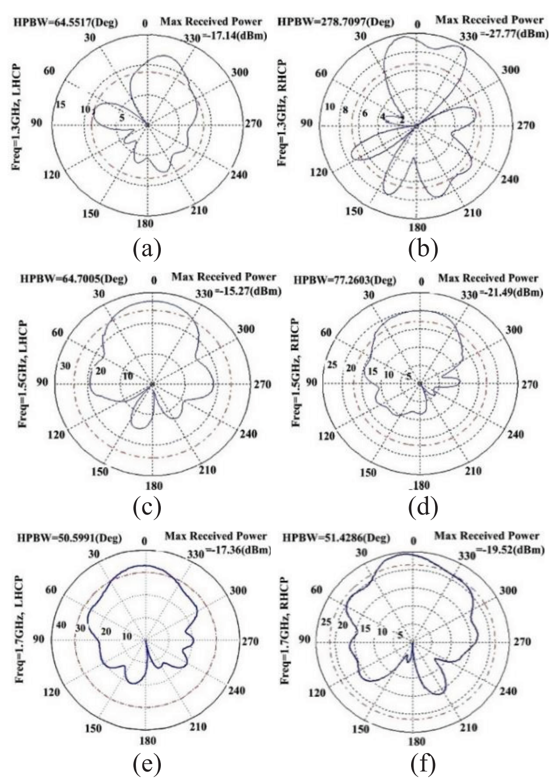


Fig. 11. Simulated radiation pattern results at: (a) 1.3 GHz, (b) 1.5 GHz, (c) 1.7 GHz, (d) 1.8 GHz, (e) 2.1 GHz, and (f) 2.3 GHz.



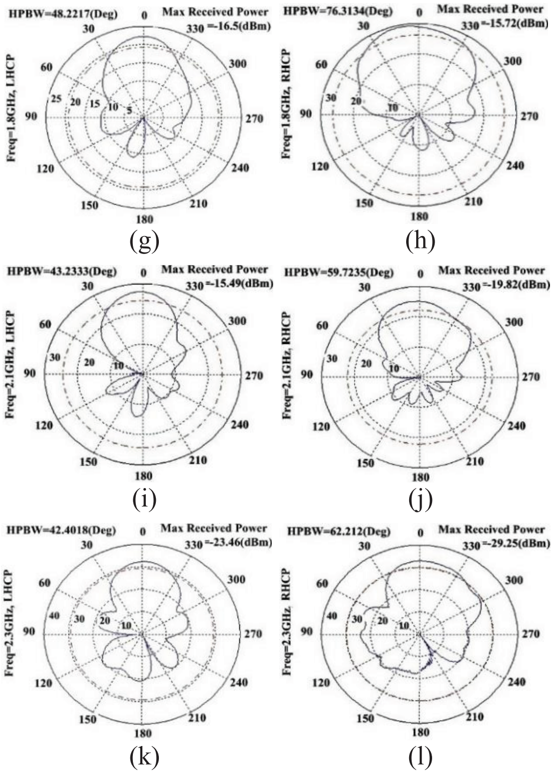


Fig. 12. Normalized measured radiation pattern results at six frequencies of Fig. 11; left column: LHCP, right column: RHCP.

IV. CONCLUSION

This paper presented aperture coupled microstrip antenna with three resonants. The antenna bandwidth enhanced due to clip in the patch edges and varied the current distribution well in order to create the third resonant. There was a compromise between radiation characteristics and the antenna bandwidth. These two factors were optimized in designed and fabricated samples. E-plane and H-plane patterns indicated the appropriate propagation pattern of antenna was between 1.3 to 2.3 GHz frequency band, which clarified bandwidth more than 53% was achieved by using certain method in the novel one radiating element. Of course, there was bandwidth enhancement up to this limit by utilization of multiple radiating elements.

REFERENCES

[1] D. M. Pozar, "A review of aperture coupled microstrip antennas: history, operation, development, and applications," *Electrical and Computer Engineering University of Massachusetts at Amherst*, MA 01003, May 1996.

[2] R. Garg and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House, 2001.

[3] D. M. Pozar, "Microstrip antenna aperture-coupled to a microstrip-line," *Electronics Lett*., vol. 21. no. 2, pp. 49-50, Jan. 1985.

[4] D. M. Pozar and S. D. Targonski, "Improved coupling for aperture coupled microstrip antennas," *Electronics Lett*., vol. 27, no. 13, pp. 1129-1131, June 1991.

[5] V. Rathi, G. Kumar, and K. P. Ray, "Improved coupling for aperture coupled microstrip antennas," *IEEE Trans. Antennas Propagat*., vol. 44, pp. 1196-1198, Aug. 1996.

[6] K. L. Wong, *Compact and Broadband Microstrip Antennas*, John Wiley & Sons, Ed. 1, ISBN: 0-471-41717-3, 2002.

[7] K. M. Luk, K. F. Lee, and H. W. Lai, "Development of wideband L-probe coupled patch antenna," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 22, no. 1, pp. 88-96, Mar. 2007.

[8] J. S. Meiguni, M. Kamyab, and A. Hosseinbeig, "Spherical aperture-coupled antennas with parasitic element," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 12, pp. 999-1006, 2012.

[9] M. M. Bilgic and K. Yegin, "High gain, wideband aperture coupled microstrip antenna design based on gain-bandwidth product analysis," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 29, no. 8, pp. 639-646, Aug. 2014.

[10] S. D. Targonski, R. B. Waterhouse, and D. M. Pozar, "Design of wide-band aperture-stacked patch microstrip antennas," *IEEE Transactions on Antennas and Propagation*, vol. 46, no. 9, Sep. 1998.

[11] N. Herscovici, B. Tomasic, J. Ginn, and T. Donisi, "A wide-band single-layer aperture-coupled microstrip antenna," *3rd European Conference on Antennas and Propagation (EuCAP)*, pp. 2357-2360, 2009.

[12] J. F. Zurcher, "The SSFIP: a global concept for high performance broadband planar antennas," *Electronics Letters*, vol. 24, pp. 1433-1435, Nov. 1988.

[13] F. Croq and A. Papiernik, "Large bandwidth aperture coupled microstrip antenna," *Electronics Letters*, vol. 26, pp. 1293-1294, Aug. 1990.

[14] C. A. Balanis, *Antenna Theory Analysis and Design*, John Wiley & Sons Inc. Publication, Chapter 14, New Jersey, 2005.

[15] E. O. Hammerstad and O. Jensen, "Accurate models for microstrip computer-aided design," *Digest IEEE MIT-S Internat. Microwave Symposium*, pp. 407-409, 1980.

[16] S. Chakraborty, T. Chakraborty, B. Gupta, and D. R. Poddar, "Transmission line model of dual patch aperture coupled microstrip antenna," *Proc. URSI General*, 2005.

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