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A Low-Profile Wideband Microstrip Patch Antenna with Simple Configuration

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Abstract – **An antenna with compact size and enhanced impedance bandwidth (BW) is proposed using a novel approach to operate in the industrial, scientific, and medical band (ISM) applications. The approach relies on exciting two resonant modes and coupling them to improve the BW.**

Keywords – **Wireless Communication, ISM, Antenna.**

I. Introduction

The microstrip patch antennas with high performance are extensively demanded for many applications such as aircraft, missile, navigation and satellite communication because their compactness, and easiness of fabrication and installation [1-2]. Major practical drawbacks of microstrip antennas are their poor efficiency, narrow fractional bandwidth (FBW) (typically 1.6%) [3], low power handling capabilities and poor scan performance. Thus, the conventional microstrip patch antenna is bulky in the microwave frequency range of modern communications. Different approaches have been utilized to increase the FBW of the microstrip Patch antennas such as the slot-loaded antenna with loading asymmetrically multi couple staggered slots can have an FBW of 3.9% [4]. A rectangular-shaped patch with a U-shaped slot was proposed in [5] to obtain an FBW of 47%. In [6], an E-shaped microstrip antenna was proposed to achieve an FBW of 37%. The BW for a microstrip antenna was also improved by using a multi-mode; the FBW is about 57% with over dimensions of 1.29λo ×1.01λo × 0.044λo [7]. However, this manuscript proposes a simple and low-profile structure of a microstrip patch antenna that performed a fractional bandwidth of 27% with overall dimensions of 0.33λo×0.33λo×0.004λo. The enhanced bandwidth is achieved by the coupling between two resonant modes that are excited using a radiator with specific dimensions. Where the proposed antenna consists of a simple U-shape radiator with two stubs and a ground plane with truncated corners and meandering slits is used to improve the matching impedance of the antenna. The antenna is designed using vinyl polymer-based flexible substrate. The important feature of the antenna is that it is constructed on a thin substrate with a wideband frequency response, while it is well-known that the bandwidth and thickness are directly proportional where a decrease in thickness leads to a decrease in bandwidth. This antenna working principle and its measurement results in comparison with the simulated results are demonstrated in Section II.

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II. Structure Design and Analysis

This manuscript investigates the design and implementation of compact and wideband antenna. The proposed methodology in this manuscript aims to increase the BW of the microstrip patch antenna. The idea is based on improving the coupling between two resonant modes which are excited by using a U-shape radiator with specific dimensions. It is worth mentioning that for all microstrip patch antennas, if L > w > h, where L is microstrip patch length, w represents the width and h is the height of substrate, the smallest frequency dominant mode is the TM010 whose resonant frequency is calculated from [8]:

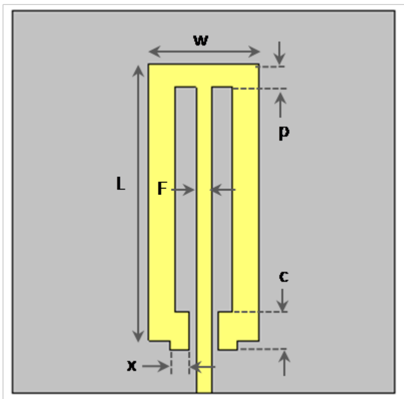
$$f_{010} = \frac{v_o}{2L\sqrt{\varepsilon_r}} \tag{1}$$

where υ_0 is the light-speed in free space. However, in case that, $L > L/2 > w > h$, the second order mode is the TM_{020} and its resonant frequency is calculated from

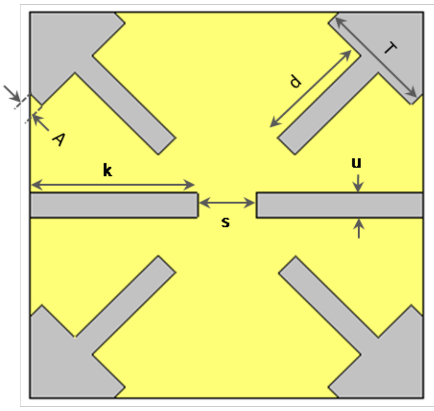
$$f_{020} = \frac{v_o}{L\sqrt{\varepsilon_r}} \tag{2}$$

Two modes require that are excited concurrently rather than sequentially to improve antenna bandwidth performance. In this proposed rectangular patch antenna, both TM010 and TM020 are excited simultaneously based on the shape and dimensions of the radiator. In other words, the TM010 is dominant in the designed structure because the dimension (length) of the radiator (top-layer) is greater than its width, at the same time the second-order mode TM020 is excited because of the half of patch length is longer than its width. Fig. 1 below shows the designed antenna with the dimensions of the structure, where Fig. 1(a) is a top layer (radiator).

The other challenge is the antenna impedance matching in both excited modes. To overcome the mismatching, a ground plane has truncated corners and contains slits that have been used for this purpose. The truncated ground plane with slits alters the input impedance because this affects the reflected surface wave [9-10]. Fig. 1(b) displays the ground plane with its slots and truncated corners. The proposed antenna was etched on a 35 μm thick copper cladding with a conductivity of 5.96×10^7 S/m. The structure is designed on Rogers 5880 laminate with a relative dielectric (ε_r) of (2.23), loss-tangent of (9×10^{-4}) and size (length × width × height) of 40 × 40 × 0.508 mm^3. The size of parameters of the proposed antenna is shown in Table 1. The antenna is simulated by using CST Microwave Studio CAD tool.



(a)



(b)

Fig. 1. Designed antenna: (a) top layer, (b) bottom layer

TABLE 1 DIMENSIONS OF THE DESIGNED ANTENNA (UNIT: MILLIMETRE)

L	29	T	12
w	11.5	A	2.37
F	1.5	s	6
x	2	k	17.5
c	4	u	2.5
p	2.5	d	11.74

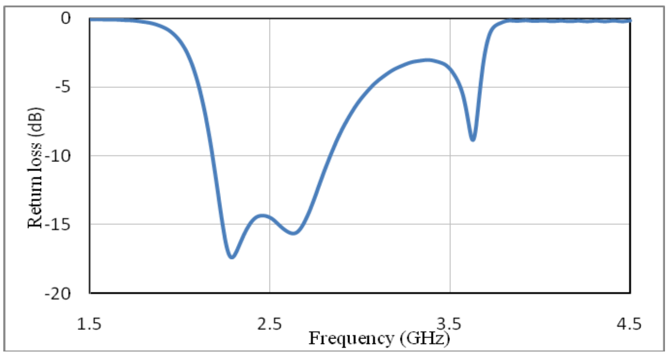
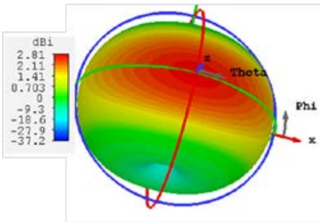
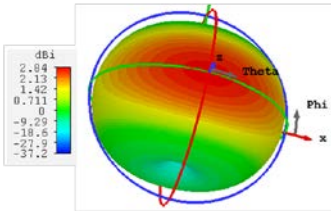


Fig. 2. Simulated reflection coefficient of designed antenna

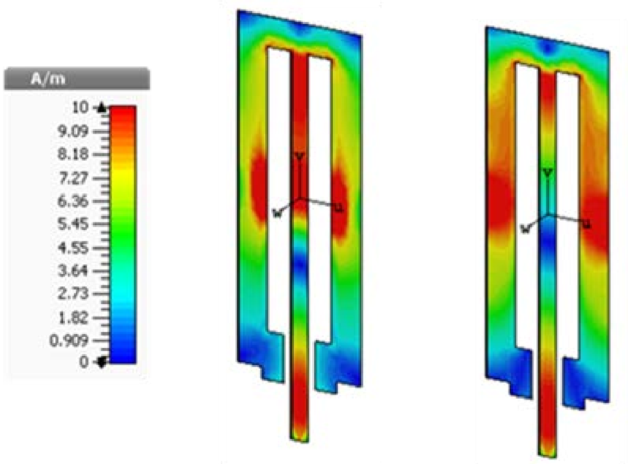


(a)



(b)

Fig. 3. Simulated 3D radiation pattern of the proposed antenna: (a) 2.28 GHz; (b) 2.68 GHz



(a) (b)

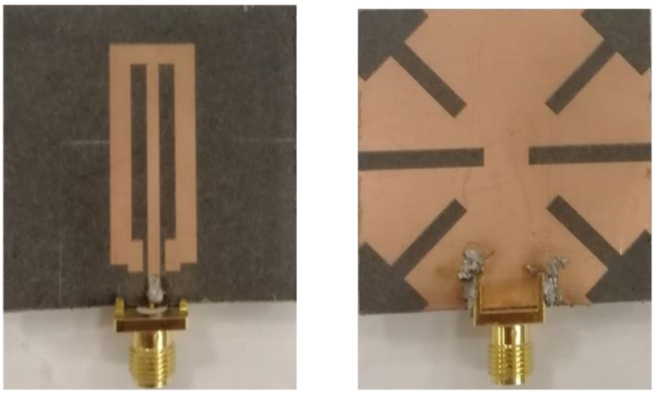
Fig. 4. Surface current distribution of designed antenna: (a) lower resonant frequency, (b) upper resonant frequency

The designed low-profile microstrip antenna has the BW enhancement and size reduction characteristics. The simulated reflection coefficient (S_{11}) is displayed in Fig. 2. There are two resonant (lower and upper) excited in this response where the lower resonant at 2.28 GHz and the second at 2.62 GHz. The gain of the proposed antenna has a stable behaviour with a uniform broadside radiation pattern through the range of interest as shown in Fig. 3.

The surface-current distributions of the rectangle patch antenna at the lower and the higher resonant frequency are simulated as displayed in Fig. 4. The surface current distribution at TM010 mode (lower resonant frequency) is shown in Fig. 4(a), while the current distribution at TM020 (higher resonant frequency) is displayed in Fig. 4(b).

A prototype of the proposed wideband antenna is manufactured with the structure parameters displayed in Table 1 to validate the design concept as displayed in Fig. 5. The S_{11} is measured using the Agilent Vector Network Analyzer and the measurement result is illustrated in Fig. 6. The measured result shows a good agreement compared with the simulated result. The lower and upper resonant of measured S_{11} are at 2.3 GHz and 2.73 GHz, respectively.

The results show that a good performance of the proposed antenna was obtained as the bandwidth is wide despite the use of a thin substrate. The antenna dimensions are $0.33\lambda_o \times 0.33\lambda_o \times 0.004\lambda_o$ where λ_o is the wavelength at the centre frequency (f_o) or it is 119.4mm at 2.5 GHz. The BW is around 0.68 GHz (from 2.17 to 2.85) or FBW is 27%. The measured radiation patterns in two orthogonal planes (*E*-plane and *H*-plane) at the frequencies of 2.28 GHz and 2.62 GHz are shown in Fig. 7 and Fig. 8, respectively, and they are in good agreement. However, the inconsistencies involved in the fabrication process and the inaccuracies in the exact values of the parameters of the insulating substrates used are the main reasons for the discrepancy between the simulation and measurement results.



(a) (b)

Fig. 5. Prototype of designed antenna: (a) Radiator, (b) Ground ‘plane

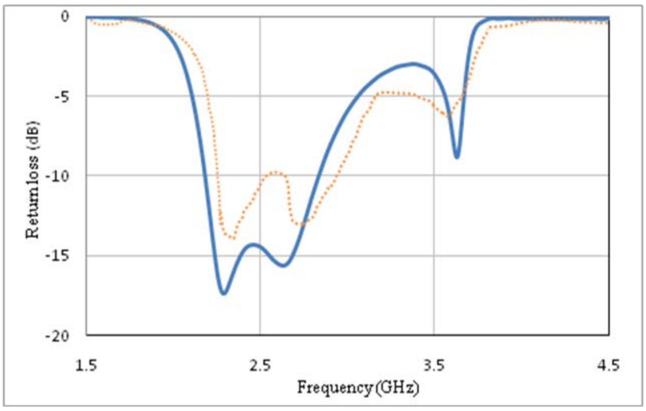
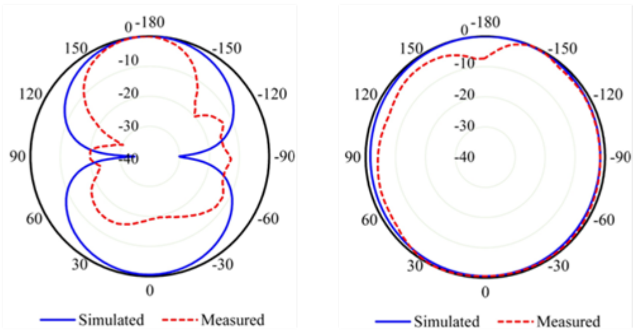


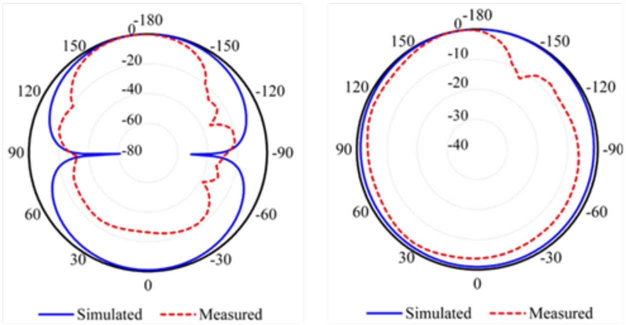
Fig. 6. Measured and simulated reflection coefficient of designed antenna



E-plane *H*-plane

(a) (b)

Fig. 7. Measured and simulated radiation patterns of designed antenna at 2.28 GHz: (a) *E*-plane, (b) *H*-plane



E-plane *H*-plane

(a) (b)

Fig. 8. Measured and simulated radiation’ patterns of designed antenna at 2.68 GHz: (a) *E*-plane, (b) *H*-plane

TABLE 2 COMPARISON WITH THE LITERATURE REFERENCES

REFERENCE	BW%	DIMENSIONS
[7]	57	$1.29\Lambda_o \times 1.01\Lambda_o \times 0.044\Lambda_o$
[11]	33.1	$1.67\Lambda_o \times 1.67\Lambda_o \times 0.05\Lambda_o$
[12]	26.2	$1.17\ \Lambda_o \times 0.99\ \Lambda_o \times 0.07\Lambda_o$
[13]	4	$0.23\Lambda_o \times 0.27\Lambda_o \times 0.03\Lambda_o$
THE PROPOSED ANTENNA	27	$0.33\Lambda_o \times 0.33\Lambda_o \times 0.004\Lambda_o$

However, it is noted that the proposed design has identical polarization planes and its radiation patterns are similar at the two resonant frequencies (first and second resonant frequencies). The measured gain is 2.8 dBi in operation band at the broadside direction. Thus, the dielectric loss is decreased and this mainly due to use of a thin substrate.

A comparison of the designed antenna with the references mentioned in the literature is shown in Table 2. The advantage of the proposed antenna over the antennas listed in the literature is that it is implemented on a thin substrate (Rogers 5880 laminate 0.508 mm thick) with a broadband frequency response, while the bandwidth and thickness are known to be directly proportional where if the thickness of the substrate decreases, the bandwidth will decrease.

III. CONCLUSION

A new approach for designing a compact size with only 0.508 mm substrate thickness height and FBW of 27% microstrip antenna is presented in this manuscript for 2.45GHz applications. The approach has adapted the antenna radiator dimensions to stimulate more than one mode to achieve the broadband response. The TM010 and TM020 models are stimulated simultaneously and the input impedance matching for both modes is achieved simultaneously using truncated ground plane technique. The proposed antenna was fabricated and experimentally tested, and the result matches the simulated one.

REFERENCES

[1] W. Richards, L. Yuen, and D. Harrison, "An Improved Theory of Microstrip Antennas with Applications", *IEEE Transactions on Antennas and Propagation*, vol. 29(1), pp. 38-46, 1981.

[2] D. Pozar, "Microstrip Antennas", *Proceedings of the IEEE*, vol. 80(1), pp. 79–81, 1992.

[3] K. Wong, *Compact and Broadband Microstrip Antennas*, New York, Wiley, 2002.

[4] S. Xiao, Z. Shao, B. Wang, M. Zhou, and M. Fujise, "Design of Low-Profile Microstrip Antenna with Enhanced Bandwidth and Reduced Size", *IEEE Transactions on Antennas and Propagation*, vol. 54(5), pp.1594-1599, 2006.

[5] T. Huynh, K. Lee, "Single-Layer Single-Patch Wideband Microstrip Antenna", *Electronics Letters*, vol. 31(16), pp. 1310-1312, 1995.

[6] F. Yang, X. Zhang, X. Ye, and Y Rahmat, "Wide-Band Eshaped Patch Antennas for Wireless Communications", *IEEE Transactions on Antennas and Propagation*, vol. 49(7), pp. 1094-1100, 2001.

[7] W. An, S. Li, W. Sun, and Y. Li, "Low-Profile Wideband Microstrip Antenna Based on Multiple Modes with Partial Apertures", *IEEE Antennas Wireless Propagations Letters*, vol. 18(7), pp. 1706-1713, 2019.

[8] C. Balanis, *Antenna Theory: Analysis and Design*, Hoboken, Wiley, 2005.

[9] D. Schaubert, K. Yngvessen, "Experimental Study of a Microstrip Array on High Permittivity Substrate", *IEEE Transactions on Antennas and Propagation*, vol. 34, pp. 92-97, 1986.

[10] G. Feng, L. Chen, X. Xue, and X. Shi, "Broadband Surface-Wave Antenna with a Novel Nonuniform Tapered Metasurface". *IEEE Antennas Wireless Propagation Letters*, vol. 16, pp. 2902-2905, 2017.

[11] B. Cheng, Z. Du, D. A. Huang, "Broadband Low-Profile Multimode Microstrip Antenna", *IEEE Antennas Wireless Propagation Letters*, vol. 18(7), pp. 1332-1336, 2019.

[12] A. Bhattacharyya, "Effects of Ground Plane and Dielectric Truncations on the Efficiency of a Printed Structure", *IEEE Transactions on Antennas and Propagation*, vol. 39(3), pp. 303-308, 1991.

[13] A. Farahbakhsh, D. Zarifi, "Miniaturization of Patch Antennas by Curved Edges", *AEU - International Journal of Electronics and Communications*, vol. 117(8), pp.153125, 2020.