2023 IEEE 73rd Electronic Components and Technology Conference (ECTC)

Highly Compact and High Gain 2 x 2 Patch Array Antenna with Slotted Meanderline Loading

Hanna Jang
Electrical and Computer Engineering
University of Florida
Gainesville, FL 32611, USA
hannajang@ufl.edu

Payman Pahlavan
Electrical and Computer Engineering
University of Florida
Gainesville, FL 32611, USA
paymanpahlavan@ufl.edu

Yong-Kyu Yoon
Electrical and Computer Engineering
University of Florida
Gainesville, FL 32611, USA
ykyoon@ece.ufl.edu

2023 IEEE 73rd Electronic Components and Technology Conference (ECTC) | 979-8-3503-3498-2/23/$31.00 ©2023 IEEE | DOI: 10.1109/ECTC51909.2023.00329

***Abstract*—This paper presents a highly compact and high gain patch array antenna for Citizens Broadband Radio Service (CBRS) applications at 3.5 GHz. The meander line (ML) is etched on each patch and placed diagonally on top of the patch antenna, resulting in a large current density near the ML slot lines. The proposed antenna design offers advantages through the characteristic of these current flows: a significant size reduction of a 2 x 2 patch antenna, where the gap between neighboring patches is 2 mm (0.023 of free space wavelength), the smallest among reported, and a very high gain of 5.67 dB. The inserted meander slot structure, which increases the electrical length of the resonance circuit, contributes to a 51% reduction in the total area of the patch array antenna. The simulation exhibit that the proposed antenna has excellent antenna performance, and thus it is expected to be useful for multiple compact wireless RF systems.**

Keywords— Array antenna, miniaturized antennas, microstrip patch antenna, mutual coupling reduction, slotted patch, Defected Microstrip Structure (DMS)

I. Introduction

Antenna arrays are highly valued in various wireless communications applications, including satellites, radar, and 5G due to their high gain, beamforming capability, and ability to direct signal to a specific direction, providing high directivity. However, the array antenna occupies large footprint, which becomes a limiting factor for compact portable applications such as a drone, a mobile phone, etc.. On the other hand, a compact array, where the gap between neighboring patches is reduced, suffers from mutual coupling and deterioration in antenna performance such as antenna efficiency, radiation pattern, and matching characteristics. To minimize mutual coupling and grating lobes in antenna arrays, it is recommended to increase the pitch between patch elements to more than $0.5\lambda_0$, which leads back to an increase in the overall size of the antenna. In addition, the electrical size of modern wireless communication devices, like mobile phones and RFID-based cards operating in the low-frequency range, needs to be reduced to comply with the trend towards the miniaturization of actual devices.

To achieve a small pitch (under 0.5 λ_0) between elements in antenna arrays, many studies have reported the use of techniques such as a defected ground structure [1] and an electromagnetic band gap (EBG) design [2] as a decoupling structure to improve isolation between antennas. In [2], a uniplanar compact electromagnetic bandgap (UC-EBG) is introduced, showing a reduction of mutual coupling by 10 dB in a 2x1 array design. However, the unit cell of the UC-EBG structure is not small enough to be considered compact for an array antenna. In [3], meander-line (ML) slots serving as a band stop filter loaded on the ground plane, greatly reduce mutual coupling in a 2x1 patch array antenna with a small gap of 0.06 λ_g. However, this design suffers from a high back lobe radiation loss through the ML on the ground plane.

Many approaches for reducing the electrical size of antennas have been reported in recent years. A high permittivity substrate is commonly used to miniaturize antenna size while it tends to also reduce radiation efficiency, and increase undesired surface waves [4]. Inserting shorting pins or using defected ground substrates (DGS) is widely used for antenna miniaturization. However, its design is quite complicated, showing some challenges such as increased mutual coupling between neighboring elements and backside radiation [5].

In this work, a highly compact 2 x 2 patch array antenna is introduced where ML slots are included on each patch instead of the ground plane as shown in Fig. 1(a), i.e. a defected microstrip structure (DMS) is selected for choosing the resonance frequency we want. With the DMS, size reduction of each patch is obtained, where the narrowly patterned ML helps increase the electrical length and effective inductance and capacitance of a microstrip patch, to lower the resonance frequency [6]. Hence, the proposed antenna design has simultaneously obtained ease of design and exceptional antenna performance. The simulation analysis for the characteristics of a 2 x 2 patch array antenna with and without ML slots has been conducted using High Frequency Structure Simulator (HFSS, ANSYS Inc.).

II. Mutual Coupling In 2 x 2 Patch Array

Fig. 1 shows the three-dimensional view and top view of the 2 x 2 patch array without ML slots. The antenna is implemented on an FR4 substrate with a dielectric constant of 4.4 and a loss tangent of 0.02. The 2 x 2 antenna array antenna has a total size of $l_1 \times \omega_1 = 60 \times 60\ \text{mm}^2$ and a thickness of 3.175 mm. Each patch has a width ω_2 of 19.4 mm and a length l_2 of 19.4 mm, with a 2 mm edge-to-edge distance. Fig. 2 shows the current density on the patch antenna, with a distance of 2 mm between the antennas. The square geometry of the patch antenna leads to an even distribution of current on all four edges of the patch

2377-5726/23/$31.00 ©2023 IEEE
DOI 10.1109/ECTC51909.2023.00329

antenna. Port 1 is activated with 1V while ports 2, 3, and 4 are terminated to 50 ohms. It is observed that a substantial amount of electromagnetic interference occurs at this distance, as the 2 mm $(0.023\lambda_0)$ gap between each antenna is less than 0.5 λ_0.

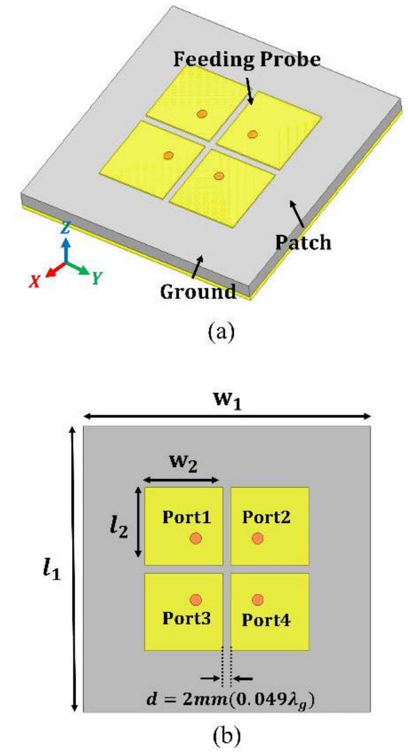

Fig. 1. Configuration of a 2 x 2 patch array antenna: (a) 3-D view. (b) Top view. The geometrical parameters are: w_1 = 60 mm, l_1 = 60 mm, w_2 = 19.4 mm, l_2 = 19.4 mm, and d = 2 mm.

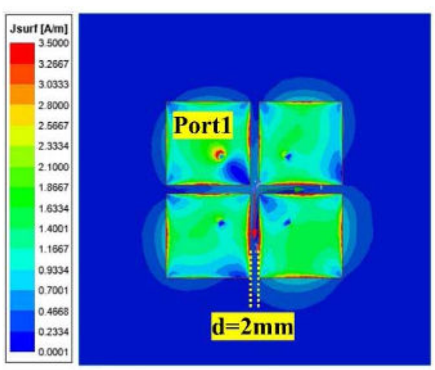

Fig. 2. Current distribution of the 2 x 2 array antenna with a distance of 2 mm.

Fig.3. shows the simulation results of return loss (S11) and all the mutual coupling factors (S12, S13, S14) between neighboring antennas. A strong insertion loss of 6.16 dB is plotted for S14 where the patch antenna is positioned diagonally. An insertion loss of 11.9 dB from S12 and S13 has been observed. Additionally, the resonant frequency of the antenna experiences a slight shift, which is attributed to the increased mutual coupling between neighboring patches.

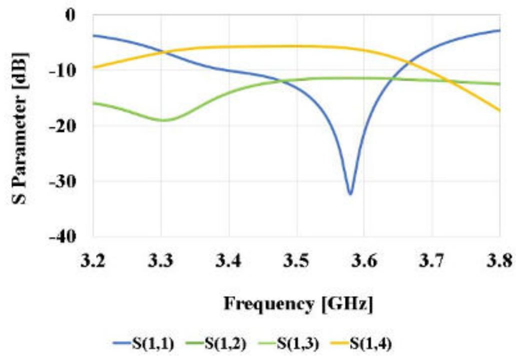

Fig. 3. Simulated return loss (S11) and mutual coupling factors (S12, S13, S14) of the 2 x 2 array antenna with a distance of 2 mm between patches.

III. ANTENNA DESIGN

Figure. 4 shows the configuration of the proposed miniaturized 2 x 2 patch array antenna. An ML slot is loaded diagonally on each microstrip patch to resonate at a target frequency. The slotted patch antenna is realized on an FR-4 substrate with a dielectric loss tangent tan δ of 0.02, a dielectric constant D_k of 4.4, and a thickness h of 3.175 mm. The coaxial cable is utilized for feeding. Each antenna is arranged in a 2 x 2 array type at a pitch of 2 mm $(0.023\lambda_0)$. Port 1 has been energized with a voltage of 1V, whereas ports 2, 3, and 4 have been terminated to 50 ohms.

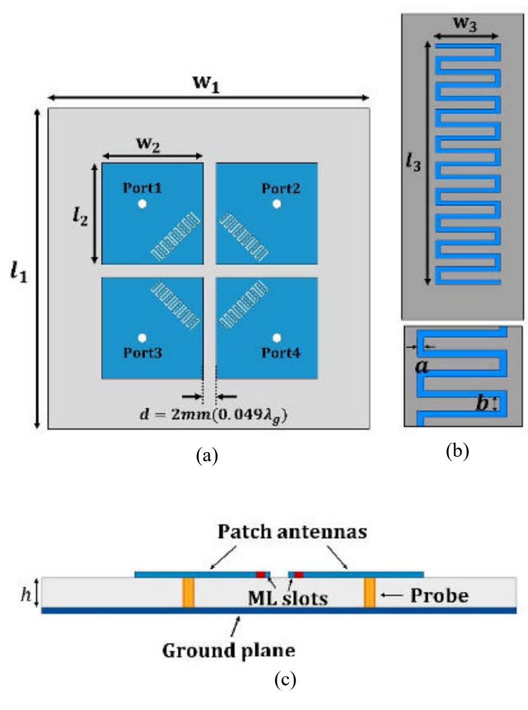

Fig. 4. The configuration of a proposed 2 x 2 slotted antenna array with integrated ML slots: (a) top view, (b) magnified ML slot on patch antenna, and (c) cross-section view. The dimensions of the proposed antenna are: ω_1 = 40 mm , l_1 = 40 mm , ω_2 = 14.75 mm l_2 = 14.75 mm, ω_3 = 2.05 mm, l_3 = 8.25 mm, a = 0.15 mm, and b = 0.3 mm.

IV. Simulation Results

The proposed 2 x 2 patch array surface current distribution at 3.5 GHz, as shown in Fig. 5, displays a substantial flow of current near the ML of the patch antenna. This property of current concentration near the ML slots improves the isolation between antenna elements, whereas a normal patch antenna experiences severe electromagnetic interference because of the current flow to the edge of the patch antenna.

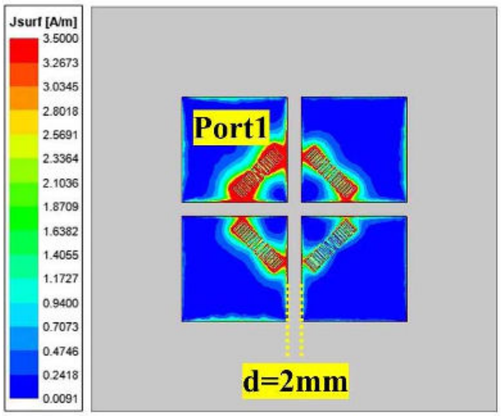

Fig. 5. Simulated current distribution of the proposed 2 x 2 patch arrays ML loading and pitch is 2 mm at 3.5 GHz.

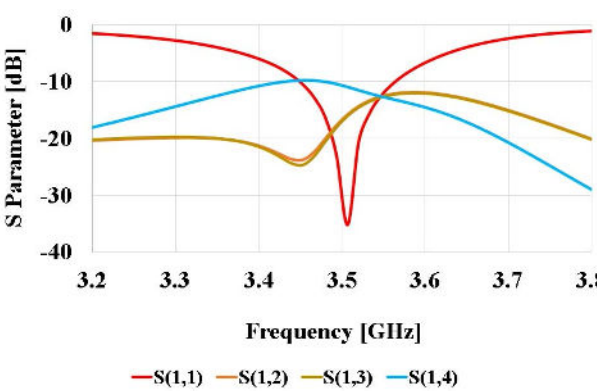

Fig. 6. Simulated return loss and insertion loss of the proposed 2 x 2 patch arrays ML loading and pitch is 2 mm at 3.5 GHz.

Fig.6 shows the simulated S parameters of the proposed antenna array. The overall improvement in insertion loss of S12, S13, and S14 has been obtained. The insertion loss of S14 is improved to 11.14 dB when the patch antenna is positioned diagonally. An improved insertion loss of 14.94 dB is reported for the remaining ports (S12 and S13). By inserting ML slot on the microstrip patch antenna, a great reduction of the mutual coupling in the array antenna has been proved, where four patches are placed closely each other with a distance of 2 mm. The antenna-slotted ML loading operates at 3.51 GHz without the need of a decoupling structure for reducing mutual coupling. Moreover, the antenna miniaturization is achievable using ML slot loading on the patch antenna. Since the flow of surface current on ML slots increases the electrical length of the patch antenna, allowing the antenna to resonate at a low frequency. In other words, the patch antenna with ML slots can be miniaturized without variation in frequency.

Fig. 7 shows the simulated radiation pattern at 3.58 GHz without ML slots and 3.51 GHz with ML slots, respectively. The undesired radiation pattern of the patch antenna is shown in Fig. 7(a) due to the critical mutual coupling. The proposed antenna with ML slots on patch exhibits a stable xz-plane and yz-plane radiation pattern with high realized gain, which represents mutual coupling is greatly mitigated by the insertion of ML slots on the patch antenna in Fig. 7(b).

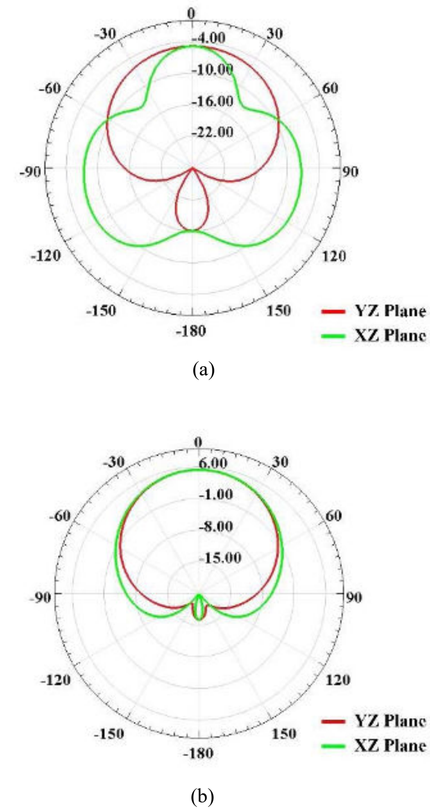

Fig. 7. Simulated radiation pattern of the proposed 2 x 2 patch array antenna. (a) Without ML slots (b) With ML slots

TABLE I. Comparision of Antenna Performance

	Normal antenna	**Proposed antenna**
Material	FR4	FR4
ML slots	Without	With
Center Freq	3.58 GHz	3.51 GHz
Return loss	32.25 to 31.68 dB	35.8 dB
Insertion loss	11.42 to 6.16 dB	14.93 to 11.34 dB
Realized Gain	-1.3 dB	5.37 dB
Radiation Efficiency	0.32	0.64
Single patch antenna size	19.4 mm x 19.4 mm	14.75 mm x 14.75 mm
Overall antenna size	81.4 mm x 81.4 mm	56.75 mm x 56.75 mm

Table I shows a comparison between the antenna performance of the proposed antenna and that of a conventional patch antenna. To make a precise comparison of the performance parameters between the proposed antenna and the traditional patch antenna, the substrates of both antennas were analyzed using FR-4 material. The antenna on the FR-4, which exhibits a high loss tangent of 0.02, shows low radiation efficiency. However, the use of patch antenna ML slot loading provides enhanced antenna performance in terms of a high peak gain of 5.37 dB, even without a mutual decoupling structure to block unwanted signal transmission at very small gap between patch antennas. In [7], a decoupling structure designed as a band-stop filter is loaded on the ground plane. This structure shows a reduced mutual coupling and degraded gain, attributed to the back radiation of ML slots that are etched from the ground plane. In this design, ML slots tilted to 45º loaded on the patch antenna does not induce undesirable lobes on the ground plane. Moreover, the proposed 2x2 array antenna shows 51% size reduction compared with a conventional half-wavelength based 2x2 patch array antenna operating at the same frequency.

V. CONCLUSION

We report a highly compact and high gain 2 x 2 antenna array with each patch loaded with an ML slot. The diagonal placement of ML slots induces a high current density on the ML, which contributes to the reduction of mutual coupling between adjacent patches and even decoupling structure is not mounted. In addition, the increased electrical length of the patch antenna can lower the operating frequency and thus miniaturize the antenna. It has been shown with simulation that the proposed antenna shows good antenna performance in radiation patterns, S parameters, and resonant frequencies.

ACKNOWLEDGMENT

This material is based upon work supported by the National Science Foundation under Grant Number 2030122. The device has been fabricated by the Multidisciplinary nano and Microsystems (MnM) Laboratory at the University of Florida.

REFERENCES

[1] H. S. Farahani, M. Veysi, M. Kamyab and A. Tadjalli, "Mutual coupling reduction in patch antenna arrays using a UC-EBG superstrate," in IEEE ntennas and Wireless Propagation Letters, vol. 9, pp. 57-59, 2010.

[2] R. O. Ouedraogo, E. J. Rothwell, A. R. Diaz, K. Fuchi and A. Temme, "Miniaturization of patch antennas using a metamaterial-inspired technique," in IEEE Transactions on Antennas and Propagation, vol. 60, no. 5, pp. 2175-2182, May 2012.

[3] S. Hwangbo, H. Y. Yang and Y. Yoon, "Mutual coupling reduction using micromachined complementary meander-line slots for a patch array antenna," IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 667-1670, 2017

[4] J. S. Colburn and Y. Rahmat-Samii, "Patch antennas on externally perforated high dielectric constant substrates," IEEE Trans. Antennas Propag., vol. 47, no. 12, pp. 1785–1794, Dec. 1999.

[5] A. A. Salih and M. S. Sharawi, "A dual-band highly miniaturized patch antenna", *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1783-1786, 2016.

[6] M. Kazerooni and A. Cheldavi, and M. Kamarei, "Comparing the performance of defected microstrip structures (DMS) and Defected Ground Structures (DGS) in microstrip miniature circuits," 17th ICEE, IUST, 2009.

[7] H. Cho and Y. Yoon, "Parallelly and diagonally placed Meander-Line Slot resonators for mutual coupling reduction in a 2x2 patch array antenna." *2021 IEEE 21st Annual Wireless and Microwave Technology Conference (WAMICON)*. IEEE, 2021.