Mutual Coupling Reduction Using Metamaterial Supersubstrate for High Performance & Densely Packed Planar Phased Arrays

Mohammad Alibakhshikenari[1]*, Alessandro Salvucci[1], Giorgio Polli[1], Bal S. Virdee[2], Chan H. See[3], Raed Abd-Alhameed[4], Francisco Falcone[5], Aurora Andújar[6], Jaume Anguera[6,7] and Ernesto Limiti[1]

[1]Electronics Engineering Department, University of Rome "Tor Vergata", Via del politecnico 1, 00133, Rome, ITALY
[2]London Metropolitan University, Center for Communications Technology, School of Computing & Digital Media, London N7 8DB, UK
[3]School of Engineering, University of Bolton, Deane Road, Bolton, BL3 5AB, UK
[4]School of Electrical Engineering & Computer Science, University of Bradford, UK
[5]Electric and Electronic Engineering Department, Universidad Pública de Navarra, SPAIN
[6]Technology Department, Fractus, 08174 Barcelona, SPAIN
[7]Department of Electronics and Telecommunication, Universitat Ramon Llull, Barcelona08022, SPAIN

*alibakhshikenari@ing.uniroma2.it

Abstract: **This paper proposes on an effective mutual coupling suppression technique for planar phased array. This is achieved locating a metamaterial superstrate patch between radiation elements of phased array. The superstrate patch is realised by incorporating slots inside the patch, where the slots are arranged in 2×3 array column. The proposed mutual radiation decoupling technique is implemented on FR-4 substrate. Average coupling suppression of 5 dB is achieved on a low permittivity substrate over its operational frequency band. The proposed technique is (i) simple to implement; (ii) planar design; (iii) easily realised in practice; (iv) overcomes the shortcomings of poor front-to-back ratio previously reported in other radiation suppression techniques; and (v) applicable for densely packed microstrip. Furthermore, the proposed planar technique is highly versatile for various applications having stringent performance requirements.**

Keywords: **Mutual coupling, metamaterial decoupling strip, antennas, phased array.**

I. Introduction

Microstrip antennas have become popular in wireless communication systems, because of their light weight, low profile, and ease to design antenna array [1-15]. Array antenna offer advantages of high gain and beamforming ability that is important for EMI immunity and radar applications [16]. However, with the growing needs for compact array antennas, the footprint of the array antenna becomes smaller and consequently the performance of the array antennas such as radiation pattern and antenna gain is significantly degraded by strong mutual coupling and cross talks between neighboring antenna elements.

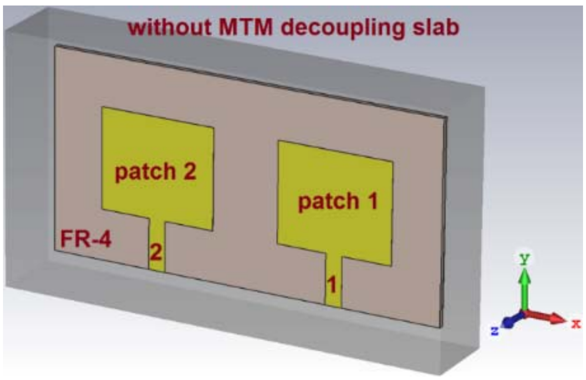
Various techniques have been investigated previously to reduce the mutual coupling between antenna elements by using periodic structure [17-19]. In paper [20] [21], mutual coupling reduction is achieved by introducing walls with mushroom PBG etched on them that are located between antenna elements. Mushroom-like electromagnetic band-gap (EBG) has also been used to reduce mutual coupling reduction in [22] [23]. In [24], DGS is etched off in the ground plane to reduce mutual coupling between two parallel individual planar inverted F antennas (PIFAs). In another technique presented in [25] complementary split-ring resonators (CSRRs) are etched away from the substrate ground plane in a location between two patch antennas.

In this paper a mutual coupling suppression technique is described that is applicable for densely packed microstrip array antennas. Reduction in mutual coupling is realised by inserting a metamaterial superstrate patch between adjacent radiation elements. The superstrate patch includes dielectric slots. The proposed technique is shown to accomplish 5 dB reduction in the mutual coupling between two patch antennas with no degradation in radiation characteristics.

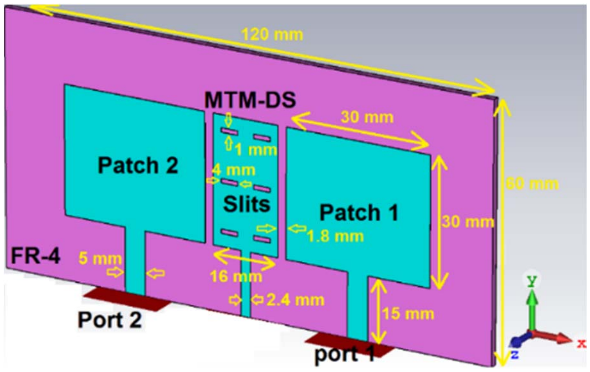
II. Metamaterial Decoupling Slab Design

The initial design consists of 2×1 array of square patches arranged symmetrically on the dielectric substrate as shown in Fig. 1(a). The structure is implemented on FR-4 substrate with thickness of 1.6 mm and dielectric constant of 4.3 and tanδ of 0.025. The S-parameter response of the 2×1 antenna array is shown in Fig. 2. The antenna has a bandwidth from 9.55 GHz to 10.65 GHz, and resonance is observed at 9.76 GHz and 10.23 GHz with impedance matching of -42 dB and -27 dB, respectively. The maximum transmission coefficient S_{12} representing the degree of mutual coupling is around -19 dB between 10.2 GHz to 10.7 GHz. The mutual coupling at the resonance frequencies of 9.76 GHz and 10.23 GHz are -31 dB and -23 dB, respectively.

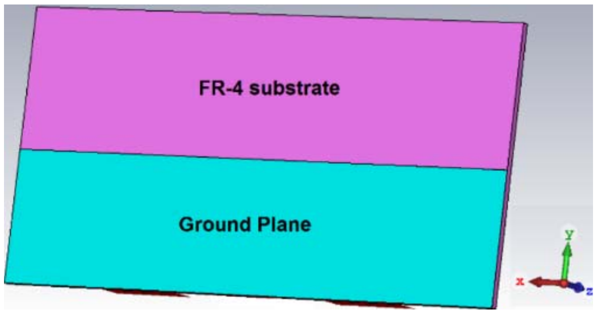
Fig. 1(b) shows the 2×1 array of square patches with the proposed metamaterial supersubstrate patch that is inserted between the two patches. The superstrate decoupling patch is realised by incorporating slots inside the patch, where the slots are arranged in 2×3 array column. It is evident from Fig. 2 the mutual coupling between the two main patches is reduced by 5 dB over the antenna's operating frequency band. It is also observed with the inclusion of the decoupling patch the operating bandwidth increases by 160 MHz. The frequency bandwidth of the 2×1 array is from 9.55 GHz to 10.81 GHz, which corresponds to a fractional bandwidth of 12.38%. Radiation characteristics of the proposed antenna at the two resonant frequencies are shown in Fig. 3, which shows the antenna offers acceptable gain and directivity at its resonant frequencies.



(a) Antenna array without metamaterial decoupling supersubstrate (MTM-DS)



(b) Proposed design with MTM-DS



(c) Bottom view of antenna ground plane

Fig.1. Layout of the proposed antenna with and without metamaterial decoupling supersubstrate.

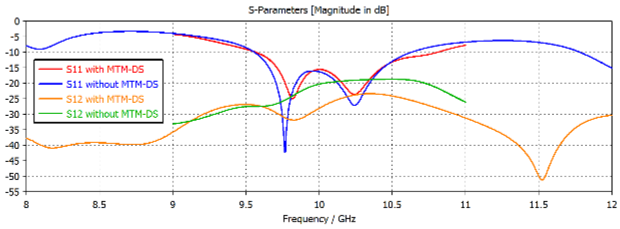
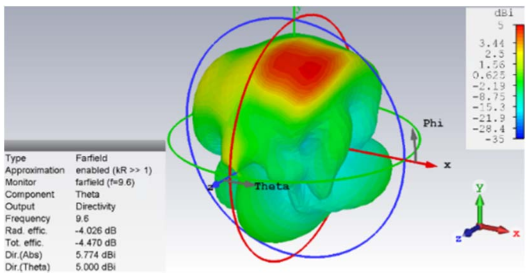
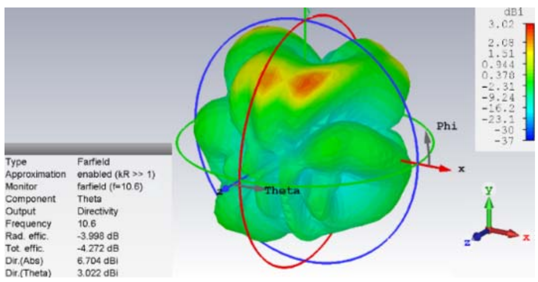


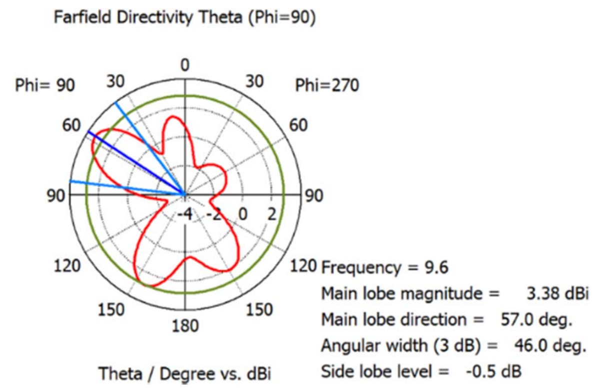
Fig. 2. Antenna transmission and reflection-coefficient S-parameters.



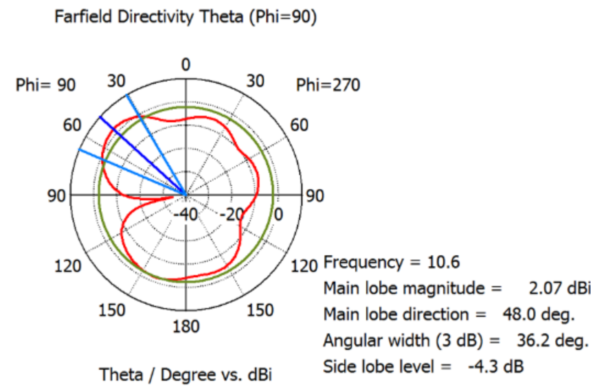
(a)



(b)



(c)



(d)

Fig. 3. Radiation characteristics of the proposed antenna with MTM-DS.

III. Conclusion

An innovative metamaterial supersubstrate is shown to decouple mutual coupling that is caused by surface and space waves in a 2×1 patch array by 5 dB. The supersubstrate comprised a rectangular patch with 2×3 array of slots. The proposed technique is shown to enhance the antenna's bandwidth by 160 MHz without degrading its gain performance. Its features include easy design and implementation that is suitable for densely packed planar phased array antennas.

References

[1] Alibakhshikenari M, Virdee B S, Ali A, Limiti E. "A Novel Monofilar-Archimedean Metamaterial Inspired Leaky-Wave Antenna for Scanning Application for Passive Radar Systems", Microw Opt Technol Lett., Accepted Manuscript, 17. March. 2018, In Press.

[2] Alibakhshikenari M, Virdee B S, Limiti E. "Triple-band planar dipole antenna for omnidirectional radiation", Microw Opt Technol Lett. 2018; 60: 1048–1051. https://doi.org/10.1002/mop.31098.

[3] Mohammad Alibakhshikenari, Bal S. Virdee, Chan Hwang See, Raed Abd-Alhameed, Abdul Ali, Francisco Falcone, and Ernesto Limiti, "Wideband Printed Monopole Antenna for Application in Wireless Communication Systems" IET Microwaves, Antennas & Propagation, Accepted manuscript, 23. Jan. 2018, In Press.

[4] Mohammad Alibakhshikenari, Bal S. Virdee, Abdul Ali, and Ernesto Limiti, "Extended Aperture Miniature Antenna Based on CRLH Metamaterials for Wireless Communication Systems Operating Over UHF to C-Band" Radio Science, Volume 53, Issue 2, February 2018, Pages 154–165 DOI: 10.1002/2017RS006515.

[5] Mohammad Alibakhshikenari, Bal S. Virdee, Abdul Ali, and Ernesto Limiti, "Miniaturized Planar-Patch Antenna Based on Metamaterial L-shaped Unit-Cells for Broadband Portable Microwave Devices and Multiband Wireless Communication Systems" IET Microwaves, Antennas & Propagation, Accepted manuscript, 08. Jan. 2018, In Press.

[6] Mohammad Alibakhshikenari, Bal S. Virdee, and Ernesto Limiti, "Compact Single Layer Travelling-Wave Antenna Design Using Metamaterial Transmission-Lines" Radio Science, Volume 52, Issue 12 December 2017, Pages 1510–1521, DOI: 10.1002/2017RS006313.

[7] Mohammad Alibakhshikenari, Ernesto Limiti, Mohammad Naser-Moghadasi, Bal S. Virdee, and R. A. Sadeghzadeh "A New Wideband Planar Antenna with Band-Notch Functionality at GPS, Bluetooth and WiFi Bands for Integration in Portable Wireless Systems", AEUE Elsevier- International Journal of Electronics and Communications, Volume 72, February 2017, Pages 79–85.

[8] Mohammad Alibakhshikenari, Mohammad Naser-Moghadasi, R. A. Sadeghzadeh, Bal S. Virdee and Ernesto Limiti, "New CRLH-Based Planar Slotted Antennas with Helical Inductors for Wireless Communication Systems, RF-Circuits and Microwave Devices at UHF-SHF Bands", Wireless Personal Communications- Springer Journal, Wireless Personal Communications, February 2017, Volume 92, Issue 3, pp 1029–1038.

[9] Mohammad Alibakhshi-Kenari, Mohammad Naser-Moghadasi and Ramazan Ali Sadeghzadeh "Composite Right−Left-Handed-Based Antenna with Wide Applications in Very-High Frequency−Ultra-High Frequency Bands for Radio Transceivers" IET Microwaves, Antennas & Propagation, Volume 9, Issue 15, 10 December 2015, p. 1713 – 1726.

[10] Mohammad Alibakhshi-Kenari, Mohammad Naser-Moghadasi, Ramazan Ali Sadeghzadah, "Bandwidth and Radiation Specifications Enhancement of Monopole Antennas Loaded with Split Ring Resonators" IET Microwaves, Antennas & Propagation, Volume 9, Issue 14, 19 November 2015, p. 1487 – 1496.

[11] Mohammad Alibakhshi-Kenari, Mohammad Naser-Moghadasi and Ramazan Ali Sadeghzadah, "The Resonating MTM Based Miniaturized Antennas for Wide-band RF-Microwave Systems" Microwave and Optical Technology Letters, Volume 57, Issue 10, pages 2339–2344, October 2015.

[12] Mohammad Alibakhshi Kenari, "Design and Modeling of New UWB Metamaterial Planar Cavity Antennas with Shrinking of the Physical Size for Modern Transceivers," International Journal of Antennas and Propagation, vol. 2013, Article ID 562538, 12 pages, 2013. doi:10.1155/2013/562538.

[13] Mohammad Alibakhshi-Kenari and Mohammad Naser-Moghadasi,"Novel UWB Miniaturized Integrated Antenna Based on CRLH Metamaterial Transmission Lines" AEUE Elsevier-International Journal of Electronics and Communications, Volume 69, Issue 8, August 2015, Pages 1143–1149.

[14] M. Alibakhshi-Kenari, M. Naser-Moghadasi, B. S.Virdee, A. Andújar and J. Anguera, "Compact Antenna based on a Composite Right/Left Handed Transmission Line" Microwave and Optical Technology Letters, Volume 57, Issue 8, pages 1785–1788, August 2015.

[15] Mohammad Alibakhshi-Kenari, Mohammad Naser-Moghadasi, R. A. Sadeghzadeh, Bal S. Virdee and Ernesto Limiti, "A New Planar Broadband Antenna Based on Meandered Line Loops for Portable Wireless Communication Devices" Radio Science, Volume 51, Issue 7, July 2016, Pages 1109–1117.

[16] R. Dale, A. Brown, and A. Reynolds, “Miniaturized GPS Antenna Array Technology and Predicted Anti-Jam Performance,” Proceedings of International Technical meeting of the Satellite Division of the Institute of Navigation, GPS-99, Nashville. 1999.
[17] Mohammad Alibakhshikenari, Bal S. Virdee, Chan Hwang See, Raed Abd-Alhameed, Francisco Falcone, and Ernesto Limiti, “Array Antenna for Synthetic Aperture Radar Operating in X and Ku-Bands: A Study to Enhance Isolation Between Radiation Elements", Accepted for inclusion in the 12th European Conference on Synthetic Aperture Radar (EUSAR), 4 -7 June, 2018, Aachen, Germany.
[18] Mohammad Alibakhshikenari, Bal Singh Virdee, and Ernesto Limiti, "A Technique to Suppress Mutual Coupling in Densely Packed Antenna Arrays Using Metamaterial Supersubstrate”, Accepted for inclusion in the 12th European Conference on Antennas and Propagation (EuCAP 2018), 9-13 April 2018,London, UK.
[19] Mohammad Alibakhshikenari, Marco Vittori, Sergio Colangeli, Bal Singh Virdee, Aurora Andújar, Jaume Anguera, and Ernesto Limiti, " EM Isolation Enhancement Based on Metamaterial Concept in Antenna Array System to Support Full-Duplex Application”, 2017 IEEE Asia Pacific Microwave Conference (APMC2017), pp. 740-742, 13-16 Nov 2017, Kuala Lumpur, Malaysia.
[20] A.A.L. Neyestanak, F. Jolani, M. Dadgarpour, “Mutual Coupling Reduction Between Two Microstrip Patch Antennas,” CCECE Canadian Conference on Electrical and Computer Engineering, 2008, pp. 739-742.
[21] F. Jolani, A.M. Dadgarpour, G. Dadashzadeh, “Reduction of Mutual Coupling between Dual-Element Antennas with New PBG Techniques,” 13th International Symposium on Antenna Technology and Applied Electromagnetics and the Canadian Radio Science Meeting, 2009, pp. 1-4.
[22] M. Ning, Z. Huiling, “Reduction of the Mutual Coupling between Aperture Coupled Microstrip Patch Antennas Using EBG Structure,” IEEE international Wireless Symposium (IWS), 2014, Xi'an, China, pp. 1-4.
[23] L. Qian, A.P. Feresidis, M. Mavridou, P.S. Hall, “Miniaturized Double-Layer EBG Structures for Broadband Mutual Coupling Reduction Between UWB Monopoles,” IEEE Trans. Antennas Propagat., vol. 63, 2015, pp. 1168-1171.
[24] F.G. Zhu, J.D. Xu, Q. Xu,, “reduction of mutual coupling between closely packed antenna elements using defected ground structure,” Electronics Lett., vol. 45, 2009, pp. 601-602.
[25] M.M. Bait-Suwailam, O.F. Siddiqui, M. Ramahi Omar, “Mutual Coupling Reduction Between Microstrip Patch Antennas Using Slotted-Complementary Split-Ring Resonators,” IEEE Antennas and Wireless Propagation Letter, Vol. 9, 2010, pp. 876-878.