Coupled monopole antenna array for IoT-based smart home devices and sensors

Saleem, I., Abbas, S. M., Mukhopadhyay, S., & Abbasi, M. A. B. (2023). Coupled monopole antenna array for IoT-based smart home devices and sensors. In N. K. Suryadevara, B. George, K. P. Jayasundera, & S. C. Mukhopadhyay (Eds.), *Sensing technology: proceedings of the 15th International Conference on Sensing Technology, ICST 2022* (pp. 414–420). (Lecture Notes in Electrical Engineering; Vol. 1035). Springer. https://doi.org/10.1007/978-3-031-29871-4_42

Published in:
Sensing technology: proceedings of the 15th International Conference on Sensing Technology, ICST 2022

Document Version:
Peer reviewed version

Queen's University Belfast - Research Portal:
Link to publication record in Queen's University Belfast Research Portal

Publisher rights
© 2023 Springer.
This work is made available online in accordance with the publisher's policies. Please refer to any applicable terms of use of the publisher.

General rights
Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.

Open Access
This research has been made openly available by Queen's academics and its Open Research team. We would love to hear how access to this research benefits you. – Share your feedback with us: http://go.qub.ac.uk/oa-feedback

Download date:10. Jul. 2024

Coupled Monopole Antenna Array for IoT-based Smart Home Devices and Sensors

Ilyas Saleem[1], Syed Muzahir Abbas[1], Subhas Mukhopadhyay[1], M. A. B. Abbasi[2]

[1] School of Engineering, Macquarie University, Sydney, NSW 2109, Australia
[2] Centre for Wireless Innovation, Institute of Electronics, Communications & IT, Queen's University Belfast, United Kingdom

ilyas.saleem@hdr.mq.edu.au, syed.abbas@mq.edu.au,
subhas.mukhopadhyay@mq.edu.au, m.abbasi@qub.ac.uk

Abstract. A compact, dual-band 1 × 2 coupled monopole printed antenna array design is proposed in this paper for indoor IoT-based smart home devices and sensors. With an overall dimension of $30 \times 70 \times 1.5$ mm^3, the presented design is operational at two frequency bands ranging from 3.6 to 4.3 GHz and from 5.6 to 6.6 GHz with stable impedance matching. The coupled planar monopole configuration ensures a consistent radiation performance over a wide bandwidth. To verify the practical implementation of the antenna on an IoT platform's device, the effects of dielectric height and ground plane variation on impedance matching over a wide frequency of operation are also discussed.

Keywords: Coupled Monopole, Printed Antenna, Mutual Coupling, Ground Plane Configuration, IoT, Smart Home.

1 Introduction

When multiple sensors, objects, nodes or devices connects wirelessly to each other as well as to an internet-enabled network, their online accessibility for a user becomes possible. Such devices are then known as the Internet of Things (IoT) [1, 2]. The multi-layer service which allows users to manage, monitor, and automate IoT is called IoT platform [3, 4]. Through IoT platforms, multiple devices collaborate and interact with each other [5] to collect and analyze data; to optimize and predict patterns [6]. Within the next 2 years, there will be more than 80 billion IoT connections [7] resulting in a better-connected world. Millions of these connections will originate from smart home devices and with many IoT-based wireless hardware systems; integrated sensors and antennas become an integral element for optimum performance.

Printed antennas have been extensively used in wireless communication systems. They are simple in structure, small, easy to fabricate, economical to produce, exhibit reasonable gain & have reliable radiation performance, generally for a wide bandwidth [8-10]. Implementation of multiband printed antennas in smart home devices is always preferred in order to support 5G, LTE, Wi-Fi, Bluetooth, and Zigbee technologies simultaneously [11, 12]. On the other hand, due to their compact size; smart home devices has limited space for antenna installation. This proximity of the antenna with electronic circuitry results in cross-coupling and degradation of performance. It is desired to reduce this coupling effect and subsequently reduce the co-channel interferences [13]. Multiple antenna configurations have been proposed to fulfill the demands of higher data rates over multiple wireless technologies [14-16], however, the stability of antenna elements in the presence of other electronic components and relatively high mutual coupling between the radiating surfaces is still one of the major issues revolving around IoT services and applications [17, 18]. Also, co-channel interferences has direct impact on communication system data rate performance because multiple radiating elements operates over adjacent frequencies [19].

In this paper, a dual-band 1 × 2 MIMO printed antenna is presented. The proposed antenna is relatively small and has sufficient bandwidth and gain over the entire operating band which is achieved using coupled monopole technique. Two planar radiating strips (monopoles) facing each other are simultaneously excited via a transmission line, making antenna structure. The coupling is prominent along the vertical axis. When two copies of the same antennas are replicated in the horizontal axis, reduction in cross-coupling between the antennas is realized. Implementation of the proposed antenna array structure in an IoT device is also verified by detailed full-wave electromagnetic analysis.

2 Antenna Design

The design of the printed antenna is shown in Fig. 1. The quasi-rectangular antenna structure is fed by a 50 Ω microstrip feed line backed by a partial ground plane structure. Two matched radiation strips of lengths 22 mm and varying widths are excited by the transmission line, while the impedance of the planar monopole is controlled for simultaneous matching in two frequency bands. The planar monopole and transmission line is devised on an FR4 substrate, widely used in smart home hardware, making the antenna easy-to-mounted.

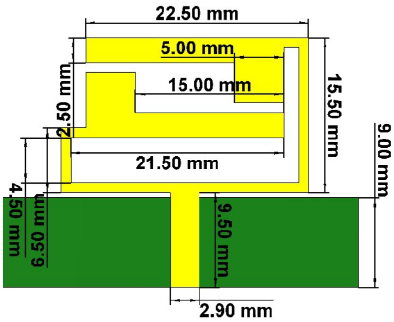


Fig. 1. Antenna Geometry

3 Analysis and Results

3.1 Effect of Substrate Dimensions

Height of substrate (H = 1.5) is added ~5 times with the length and width of the patch to have the length and width of substrate respectively [20]. We have modified this assumption for our analysis and halved it for length, as given below:

$$\text{Substrate Length} = \text{Patch Length} + 3.3 \times H \quad (1)$$

$$\text{Substrate Width} = \text{Patch Width} + 6.6 \times H \quad (2)$$

Fig. 2 shows effect of substrate dimensions on impedance bandwidth when H is varied with a step size of 1 mm. It was observed that resonating bands in lower frequencies were negatively affected when H increased from 1.5, whereas the higher frequency resonant bands started shifting towards lower frequencies with an overall reduced operating bandwidth but with improved return loss.

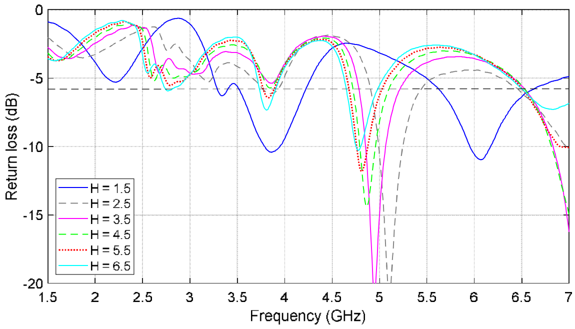


Fig. 2. Frequency responses for different *H* values

3.2 2 × 1 Array Configuration

The proposed antenna shows reasonable characteristics to be employed as an array antenna. The major issue in multi-antenna configurations is the mutual coupling. With high coupling values, communication between IoT hardware and the remote access point becomes weaker since radiating elements would have more interference.

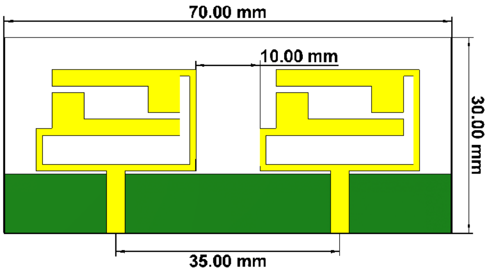
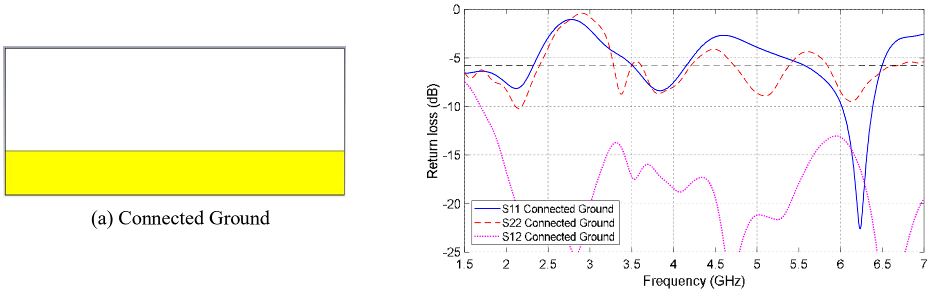


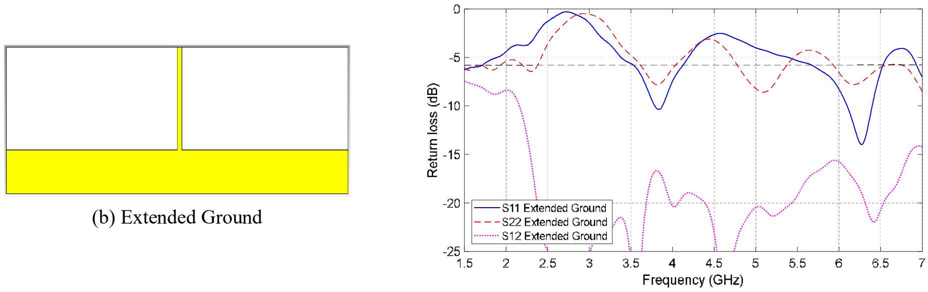
Fig. 3. Antenna Array Geometry

Therefore, the distance at which radiating patches are placed is critical, increasing the distance rectifies the coupling problem but introduces issues related to required footprint since portable devices always have limited space to fit antenna into. To cater this dilemma, the distance (in terms of λ, i.e., wavelength at the highest frequency of operation) between the transmission lines is kept constant to 35 mm. Three ground plane configurations namely, Connected ground, Extended ground and Separated ground shown in Fig. 4 are applied to investigate low-complexity mutual-coupling reduction options selectable depending upon the IoT platform. From Fig. 4 it can be deduced that in connected and extended ground configurations, array behavior in terms of resonating frequency was similar to single antenna element but return loss for 2nd band improved in connected ground structure. Whereas, in separated ground configuration, return loss improved for both frequency bands.



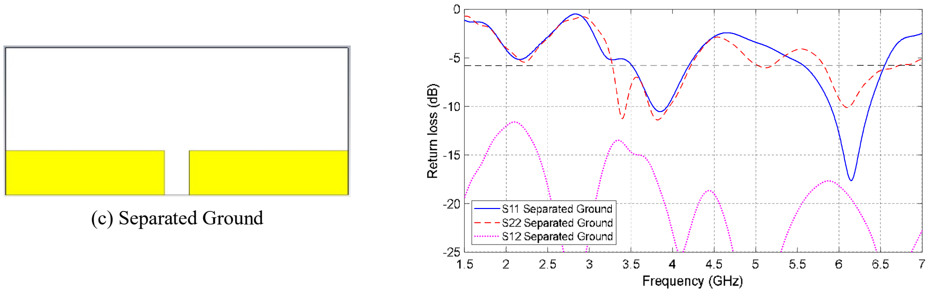
(a) Connected Ground

S parameters variation with (a)



(b) Extended Ground

S parameters variation with (b)



(c) Separated Ground

S parameters variation with (c)

Fig. 4. Ground Plane Configurations and their corresponding S parameters variation

Note that MIMO configuration is also implementable if separate ground structure is used (Fig. 4 (c)); low coupling of the order of < –12 dB can be expected.

Radiation Efficiency, 3dB Beamwidth, Gain and Isotropic Sensitivity of the antennas in array configuration are illustrated in Fig. 5. First, each radiating patch element was excited separately while the second patch was terminated to 50 Ω load, and then both were excited simultaneously to confirm that the proposed design is radiating with reasonable radiation efficiency. 3dB Beamwidth and Gain are also adequate over the entire operational frequency range. Total Isotropic Sensitivity (TIS) is receiving antenna's average sensitivity when measured across an entire 360° spherical coverage. The simulated TIS in both azimuth and elevation is favorable enough for the IoT devices to operate in any orientation.

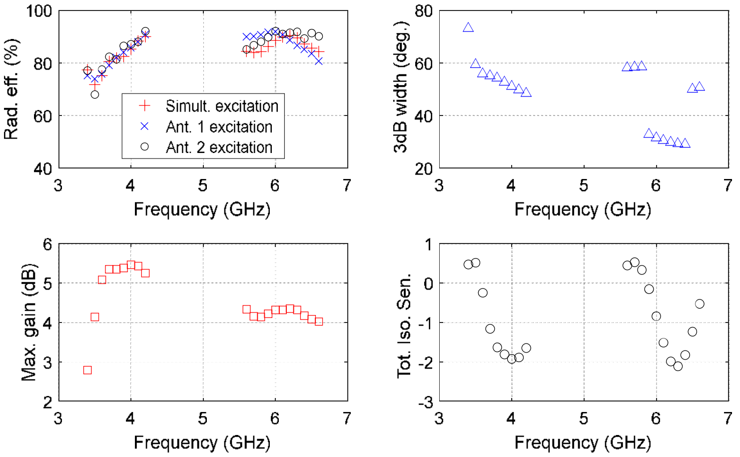
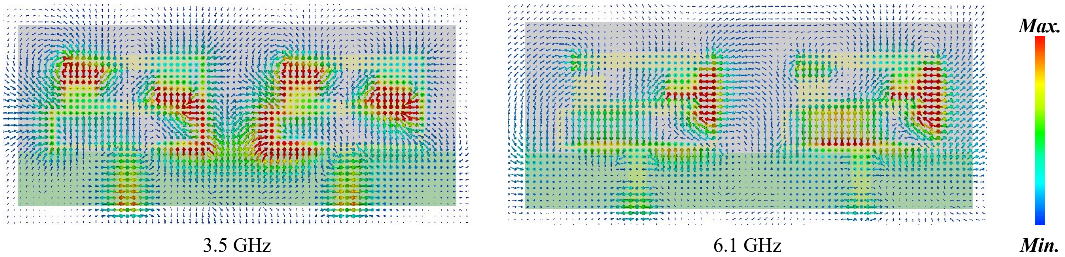


Fig. 5. Radiation Efficiency, 3dB Width, Gain, Isotropic Sensitivity



3.5 GHz

6.1 GHz

Fig. 6. E-field at 2 mm above the ground floor. Color scale mapped from 0 - 5000 V/m.

Finally, the operational resilience of the antenna can be affirmed by observing the involvement of the coupled planar monopoles in maintaining high radiation efficiency of the antenna. The *E*-field was analyzed to validate the surface current density as shown in Fig. 6. Here, it can be observed that for the lower frequency band, entire coupling monopole structure is assisting in radiation, while smaller footprint of coupling monopoles is radiating at higher frequencies.

4 CONCLUSION

In this work, we proposed a microstrip line fed, coupled monopole printed antenna array operating over two bands which are suitable for almost all applications functional in C-band (4-8 GHz); making this design a good solution to be integrated in an IoT-based smart home devices and sensors. The mutual coupling was also analyzed, while three operations to reduce coupling are provided based on the IoT platform that the antenna is expected to be mounted on.

References

1. Abdulrahman Yarali: The Internet of Things (IoT). In: Intelligent Connectivity: AI, IoT, and 5G, Wiley-IEEE Press, pp.41-66, 2021.
2. A. Mahmood et al: Industrial IoT in 5G-and-Beyond Networks: Vision, Architecture, and Design Trends. In: IEEE Transactions on Industrial Informatics, vol. 18, no. 6, 2022.
3. A. Mijuskovic, I. Ullah, R. Bemthuis, N. Meratnia, P. Havinga: Comparing Apples and Oranges in IoT Context: A Deep Dive Into Methods for Comparing IoT Platforms. In: IEEE Internet of Things Journal, vol. 8, no. 3, 2021.
4. T. G. F. Barros, E. F. Neto, J. A. D. S. Neto, A. G. M. De Souza, V. B. Aquino, E. S. Teixeira: The Anatomy of IoT Platforms - A Systematic Multivocal Mapping Study In: IEEE Access, vol. 10, 2022.
5. N. S. Quadri, K. Yadav: Efficient Data Classification for IoT Devices using AWS Kinesis Platform. In: 21st Saudi Computer Society National Computer Conference 2018.
6. R. W. L. Coutinho, A. Boukerche: Transfer Learning for Disruptive 5G-Enabled Industrial Internet of Things. In: IEEE Transactions on Industrial Informatics, vol. 18, no. 6, 2022.
7. Juniper Research Whitepaper: IoT ~ The Internet of Transformation 2020. Available: https://www.juniperresearch.com/whitepapers/iot-the-internet-of-transformation-2020
8. Y. Chen et al: Landstorfer Printed Log-Periodic Dipole Array Antenna with Enhanced Stable High Gain for 5G Communication: In: IEEE Transactions on Antennas and Propagation, vol. 69, no. 12, 2021.
9. A. Nikkhah, H. Oraizi: Efficient 2×2 Printed Circuit Band-Gap Cavity-Backed Slot Antenna. In: IEEE Transactions on Antennas and Propagation, vol. 68, no. 4, 2020.
10. Y. Li et al: 3-D Printed High-Gain Wideband Waveguide Fed Horn Antenna Arrays for Millimeter-Wave Applications. In: IEEE Transactions on Antennas and Propagation, vol. 67, no. 5, 2019.
11. K. Cheng, Z. Liang, B. Hu: Design of Miniaturized Microstrip Antenna for Smart Home Wireless Sensor. In: IEEE 4th International Conference on Electronic Information and Communication Technology 2021.
12. C. Göçen, İ. Akdağ, M. Palandöken, A. Kaya: 2.4/5 GHz WLAN 4x4 MIMO Dual Band Antenna Box Design for Smart White Good Applications. In: 4th International Symposium on Multidisciplinary Studies & Innovative Technologies 2020.
13. S. Kim, S. Nam: A Compact and Wideband Linear Array Antenna with Low Mutual Coupling. In: IEEE Transactions on Antennas and Propagation, vol. 67, no. 8, 2019.

14. K. S. Vishvaksenan, K. Mithra, R. Kalaiarasan, K. S. Raj: Mutual Coupling Reduction in Microstrip Patch Antenna Arrays Using Parallel Coupled-Line Resonators. In: IEEE Antennas and Wireless Propagation Letters, vol. 16, 2017.
15. S. B. Sharma et al: A Novel U-slot Aperture Coupled Annular-Ring Microstrip Patch Antenna for Multiband GNSS Applications. In: 14th European Conference on Antennas and Propagation 2020.
16. P. Mukti, H. Farahani, H. Paulitsch, W. Bösch: Mutual Coupling Reduction of Aperture-Coupled Antenna Array Using UC-EBG Superstrate. In: 13th European Conference on Antennas and Propagation 2019.
17. A. Vamseekrishna, B. T. P. Madhav, T. Anilkumar, L. S. S. Reddy: An IoT Controlled Octahedron Frequency Reconfigurable Multiband Antenna for Microwave Sensing Applications, In: IEEE Sensors Letters, vol. 3, no. 10, 2019.
18. Abdulkawi M, Sheta A, Elshafiey I, Alkanhal A: Design of Low-Profile Single- and Dual-Band Antennas for IoT Applications. In: MDPI RF/Microwave Circuits for 5G and Beyond, Electronics 2021.
19. H. Qi, L. Liu, X. Yin, H. Zhao, W. J. Kulesza: Mutual Coupling Suppression between Two Closely Spaced Microstrip Antennas with an Asymmetrical Coplanar Strip Wall. In: IEEE Antennas and Wireless Propagation Letters, vol. 15, 2016.
20. K. L. Wong: Compact and Broadband Microstrip Antennas. John Wiley & Sons, 2002.