Bulletin of Electrical Engineering and Informatics
Vol. 13, No. 2, April 2024, pp. 955~962
ISSN: 2302-9285, DOI: 10.11591/eei.v13i2.5515 ❒ 955

Microstrip antenna with reflector and air gap for short range communication in 900 MHz band

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Article Info

Article history:

Received Dec 14, 2022
Revised Oct 10, 2023
Accepted Oct 21, 2023

Keywords:

Antenna
Communication
Effective isotropic radiated power
Microwave
Short range communication

ABSTRACT

This paper proposes a microstrip antenna that was made of a microstrip fed slot with a complimentary stub on a single dielectric medium. This antenna was integrated with a reflector and air gap for the application of short range communication (SRC) in a 900 MHz band. Analyses were made on the dimension of the reflector and the height of the air gap towards the antenna performance. Besides, an antenna field test was done for the propagation distance of the proposed antenna. As a result, with the antenna size of 13,770 mm^2, the measured return loss was -10.79 dB and the directivity gain was 7.44 dBi. Besides, with the effective isotropic radiated power (EIRP) of 7.44 dBm, it was predicted that at 100 m, the received signal would be around 60 to 70 dBm. Therefore, a high gain was produced by using a reflector with air gap and a compact size was achieved if compared to conventional high gain antenna designs such as Yagi Uda. Thus, it is suitable for a communication device such as the SRC application.

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1. INTRODUCTION

In short range communication (SRC), the performance of a wireless communication is depending on the several requirements such as communication range (longer distance), transmit power (low power), and antenna gains (high gain) [1], [2]. It should have a low capability in causing harmful interference towards the other radio equipment as well. In the antenna design, by making the antenna more directional (increasing the antenna gain), RF signals will be more focused either to increase the communication range or to reduce the transmit power (due to power amplifier) in the SRC system, as required in any regulatory body [3]. On the other hand, there is a lot of extensive research that has been going on to improve the performance of microstrip antennas in order to meet the current technologies such as 5G [4] and IoT [5].

Therefore, in this paper, a microstrip antenna with air gap and reflector is proposed for SRC in 900 MHz band. This antenna was made of a microstrip fed slot with a complimentary stub on a single dielectric medium. A high gain was produced by using a reflector with air gap and a compact size was achieved if compared to convensional high gain antenna design such as Yagi Uda [6], [7]. This antenna performance was validated by integrating with the SRC transmitter and receiver for the field test, a similar method applied in [8], [9].

2. THEORY AND DESIGN

There is a requirement of high gain performance of antenna in order to increase signal strength on certain directions and in the same time increases the communication distance. Therefore, in order to increase gain, certain element need to be added to the antenna but unfortunately will increase the size of the antenna. Meanwhile, there are several research works on the compact and high gain in microstrip antenna design as reported in [10]–[16]. Therefore, it can be used in any portable device such as in the application of SRC. Certain regulatories has limited the maximum effective isotropic radiated power (EIRP) for the SRC [3]. Therefore, the use of high gain antenna can reduce the power consumption in the SRC transmitter as depicted in Figure 1. This can be calculated from (1):

$$EIRP = P_T - L_C + G_A \tag{1}$$

where P_T is the transmit power from SRC transmitter, L_C is the losses from cable and connector and G_A is the SRC antenna gain. Thus, several research works were done by other researchers on how the high gain antenna can reduce power consumption as reported in [17], [18].

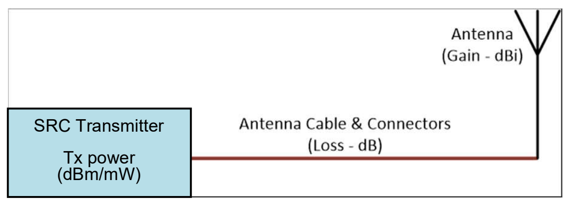
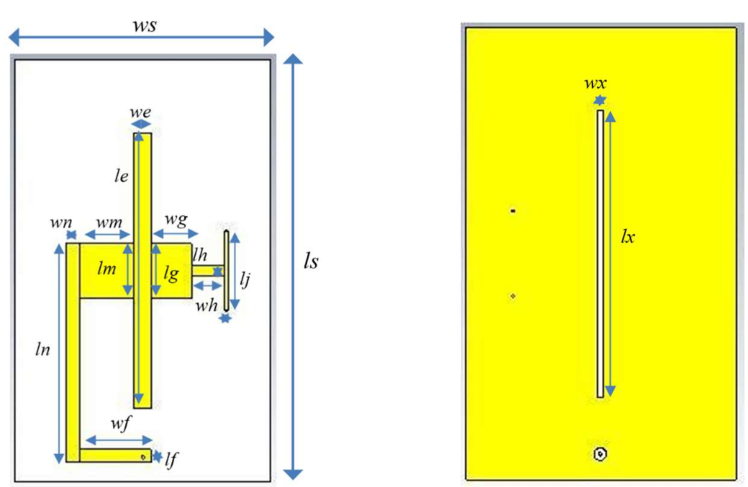


Figure 1. Diagram for the EIRP of SRC

The proposed microstrip antenna was made of a microstrip fed slot with a complimentary stub on a single dielectric medium that was modified based on the design in [19]. This is shown in Figure 2(a) for the top layer and Figure 2(b) for the bottom layer. This design was selected due to a directive and high gain of the antenna and compact in size. The fed slot with a complementary stub (*wx*, *lx*, *we* and *le*) is a slot radiating element (SRE) that was reported in [20].

As depicted in Figure 3, a reflecting ground plane was employed to achieve a unidirectional radiation pattern and also to increase the gain. This reflector was placed at the bottom of microstrip antenna as shown in Figure 4 with the air gap height (h_{air}). There are several research works on the study of air gap between antenna and reflector for the high gain antenna [21]–[25]. Thus, some of these parameters in Figures 2 and 3 are simulated, analyzed and discussed in section 3.



(a) (b)

Figure 2. The dimension of the microstrip antenna, (a) top layer and (b) bottom layer

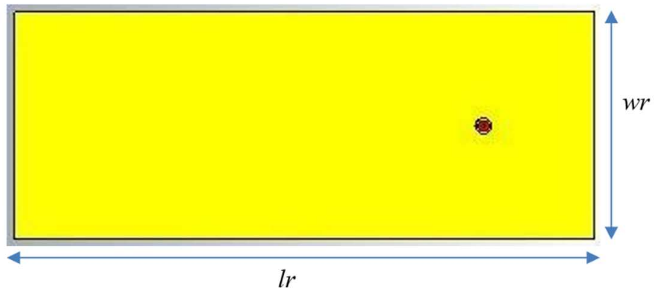


Figure 3. The dimension of reflector for microstrip antenna

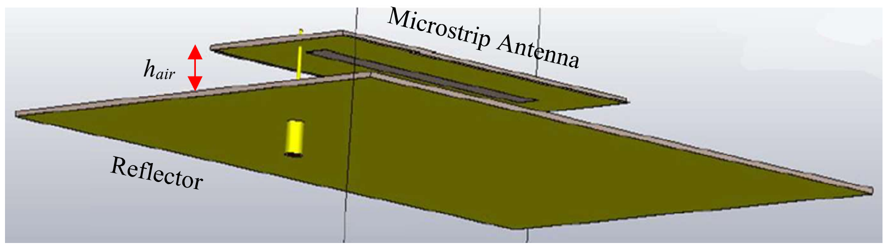
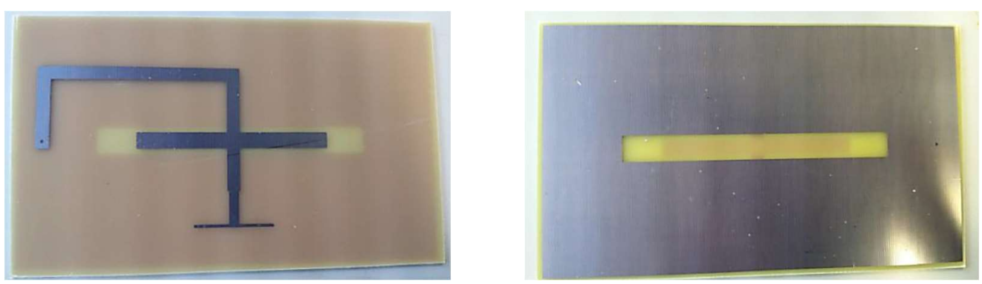


Figure 4. The air gap between microstrip antenna and reflector

The microstrip antenna part was fabricated as shown in Figure 5(a) for top layer and Figure 5(b) for bottom layer using FR4 substrate (dielectric constant=4.7 and thickness=1.6 mm). The reflector (using FR4) was just cut in size and assembled with the fabricated microstrip antenna and SMA connector as depicted in Figure 6. The fabricated and assembled antenna was then performed for the measurement for verification with simulation results.



(a) (b)

Figure 5. Fabricated microstrip antenna, (a) top layer and (b) bottom layer

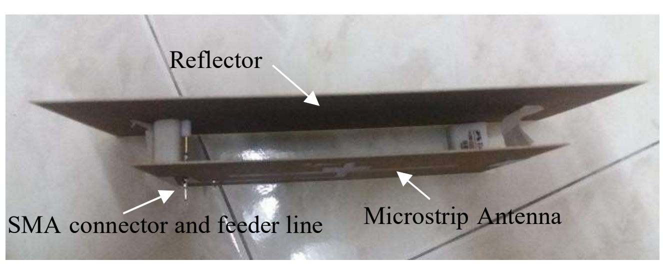


Figure 6. A complete assemble of the proposed antenna for SRC

3. RESULTS AND DISCUSSION

3.1. Effect of air gap height

The return loss (S11) for different height of the air gap was investigated in order to see the effect of the air gap towards the antenna's return loss. Therefore, the height of air gap was varied from 0, 13.33, 23, 26.67, and 40 mm and the return loss simulation result is plotted in Figure 7. It showed that the S11 was shifted to the lower frequencies by increasing the height of air gap. This is due to the increasing of capacitance between microstrip antenna and the reflector. On the other hand, without any modification of the microstrip antenna dimensions, the height of 26.67 mm is the best for the return loss. This means that the microstrip antenna is the best match with 50 Ω impedance at this height value. However, since the targeted antenna design is centered at 915 MHz, the best solution is to choose 23 mm which is very close to the 915 MHz frequency and was selected for the antenna design and fabricated for performance verification.

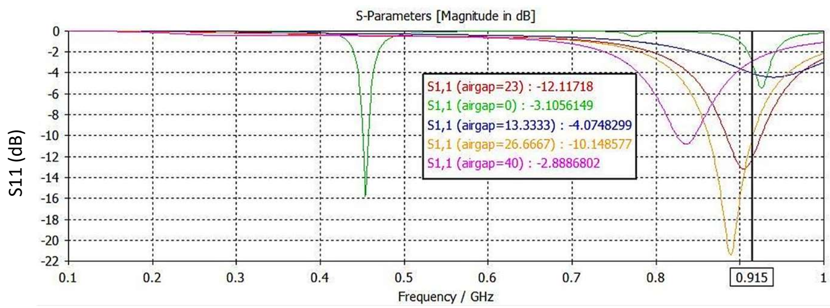


Figure 7. Simulation result for return loss with the effect of different air gap heights

3.2. Effect of length and width of reflector

The effect on the reflector size towards the return loss (S11) of the microstrip antenna was investigated. Therefore, different lengths and widths of the reflector were simulated for the analysis. First, twelve different values of length were selected and simulated as shown in Figure 8. It showed that the reflector length of 250 mm was the best S11 of -15.18 dB than the other lengths. The S11 result showed that less than -10 dB for the length lower than 206.67 mm. That means, antenna matching is not good for the length lower than that value. Therefore, more than 206.67 mm length should be selected for a good impedance matching between the antenna and the reflector. Second, the different width of the reflector was simulated where five different width values were selected as shown in Figure 9. It can be seen that not much difference in the return loss performance when increasing the width of the reflector. The starting width of 90 mm was selected due to the width of the antenna substrate. Furthermore, detailed results showed that the width of 90 mm is the best return loss of -13.33 dB compared to other width sizes. Therefore, in the final design, 90 mm width was selected for the reflector size and the length of 220 mm was found to be the best between return loss and size. Take note that, a larger size of reflector is not recommended for any portable device.

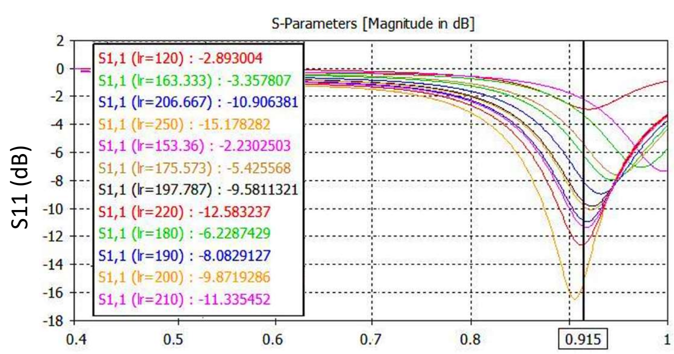


Figure 8. Simulation result for return loss with the effect of different lengths of the reflector

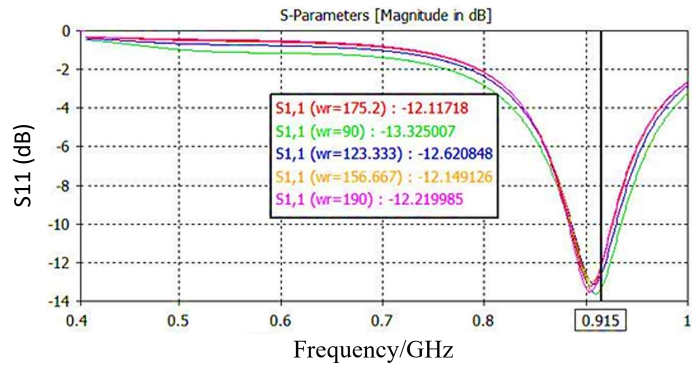


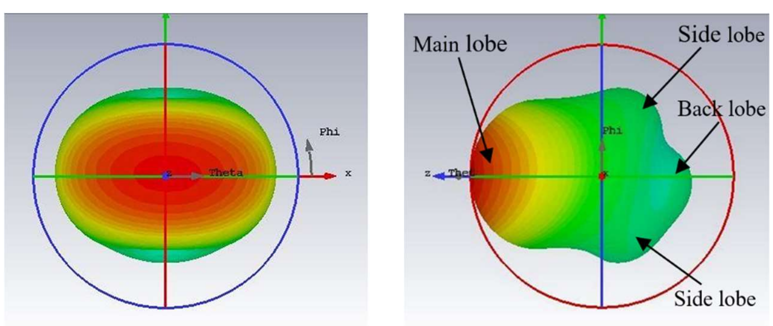
Figure 9. Simulation result for return loss (S11) with the effect of different widths of the reflector

3.3. Radiation pattern, antenna gain and measured return loss

The simulated three-dimensional radiation pattern of the optimized microstrip antenna for the front view is shown in Figure 10(a) and the side view is shown in Figure 10(b). As can be seen to the red color of the radiation pattern, the antenna radiation was directed to the z-axis which is toward the front view of the microstrip antenna. Beside that, it is proven that the reflector changes the microstrip antenna to be a directive gain. However, there is a small side lobe and back lobe that would be an unwanted radiation pattern for the directive antenna.

Figure 11 shows the two-dimensional view of the radiation pattern for the microstrip antenna. This is another way of plotting and analyzing the radiation pattern of the antenna. The plotted radiation pattern is in a realized gain (dB). As can be seen, the realized gain of the main lobe is higher than 0 dB and the side and back lobes are lower than 0 dB. The microstrip antenna produced 7.32 dB realized gain and 7.44 dBi directive gain. It was proven that the reflector changed the normal microstrip antenna to be a directive gain.

Figure 12 shows a simulated and measured result of the S11 of microstrip antenna in the frequency of 900 MHz band. It can be seen that the measured return loss is comparable with the simulated result. The simulated S11 was -12.84 dB. Meanwhile the measured return loss was -10.79 dB with the difference of 2.05 dB. However, there was unwanted return loss at 0.63 GHz for another resonance of the antenna in the measurement result. This could be an unwanted parasitic parallel inductance and capacitance that created this resonance. Further investigation needs to be done to find the source of this unwanted return loss. On the other hand, this unwanted return loss is operated out of 900 MHz band, thus any received RF signal at 0.63 GHz, will be easily attenuated using bandpass filter in the SRC system.



(a) (b)

Figure 10. Simulated result for the 3-dimensional of radiation pattern, (a) front view and (b) side view

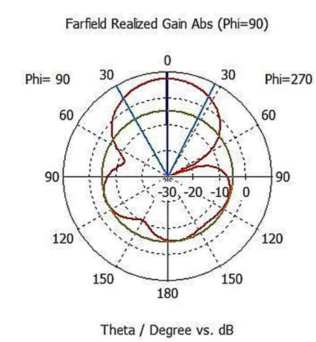


Figure 11. Simulated result of the antenna for the 2-dimensional of radiation pattern

3.4. Antenna field test results and overall performances

In the antenna field test, a distance between the SRC transmitter (with microstrip antenna) and receiver (using Fieldfox) was setup with the power transmit of 0 dBm. By neglecting the cable and connector losses, the calculated EIRP using (1) was 7.44 dBm. The measured received signals from Fieldfox were recorded and plotted as shown in Figure 13. It showed that at 5 m distance, the received signal was -25 dBm and then gradually decreased due to signal fading. At 50 m, the received signal was -35 dBm and indicated that the signal was still strong at 50 m distance. Based on these results, it can be predicted that at 100 m, the received signal would be around 60 to 70 dBm. Take note that, for simple communication (small data), the received information is still can be captured for a signal as low as -100 dBm. Therefore, in this field test results, it can be concluded that more than 100 m distance can be reached for the proposed microstrip antenna in the SRC application. Finally, the overall performances of the antenna are listed in Table 1.

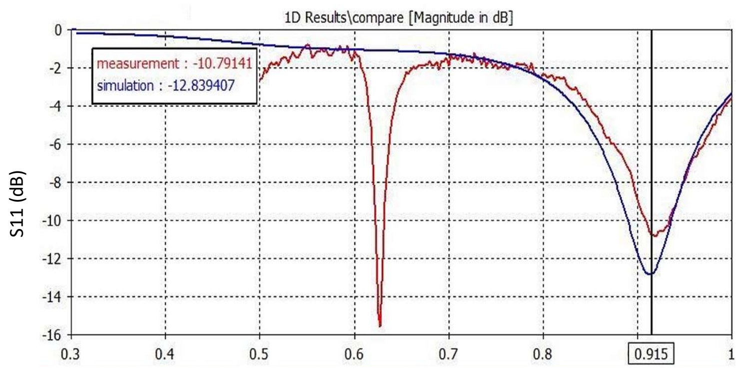


Figure 12. Measured return loss of the microstrip antenna and comparison with the simulated result

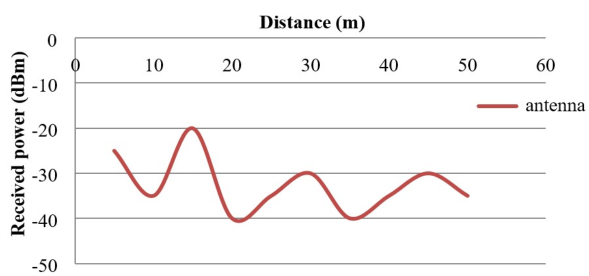


Figure 13. Measured received power versus distance of the microstrip antenna

Table 1. Summarize of microstrip antenna performances

Size	Return loss (dB)	Realized gain (dB)	Directive gain (dBi)
90 mm x 153 mm=13,770 mm^2	-10.79 (meas)	7.32 (sim)	7.44 (sim)

4. CONCLUSION

From the initial design, optimization and verification through measurement and field tests, the microstrip antenna with the air gap and reflector was successfully developed for SRC application in 900 MHz band. Results showed that with the antenna size of 13,770 mm^2, the measured return loss was -10.79 dB and the directivity gain was 7.44 dBi. It was predicted that at 100 m for the EIRP of 7.44 dBm, the received signal would be around 60 to 70 dBm. Thus, for the overall performance, this antenna works well in 900 MHz band by integrating it with the SRC system. Therefore, it is suitable for communication devices such as the SRC application.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Centre for Research and Innovation Management (CRIM) and Universiti Teknikal Malaysia Melaka (UTeM) for financing this project. We also would like to thank Nur Syahirah binti Eshah Budin Shah for his contribution to this research work at UTeM.

REFERENCES

[1] Q. Li, "Brief Analysis of Short-distance Wireless Communication Technology and Its Convergence Development," *2021 4th International Conference on Advanced Electronic Materials, Computers and Software Engineering (AEMCSE)*, Changsha, China, 2021, pp. 1043-1046, doi: 10.1109/AEMCSE51986.2021.00213.

[2] C. Park and T. Rappaport, "Short-Range Wireless Communications for Next-Generation Networks: UWB, 60 GHz Millimeter-Wave WPAN, And ZigBee," *IEEE Wireless Communications*, vol. 14, no. 4, pp. 70–78, Aug. 2007, doi: 10.1109/MWC.2007.4300986.

[3] "IEEE Standard for Low-Rate Wireless Networks," in IEEE Std 802.15.4-2015 (Revision of IEEE Std 802.15.4-2011), 22 April 2016, doi: 10.1109/IEEESTD.2016.7460875.

[4] D. A. Outerelo, A. V. Alejos, M. G. Sanchez, and M. V. Isasa, "Microstrip antenna for 5G broadband communications: Overview of design issues," in *2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, Jul. 2015, pp. 2443–2444, doi: 10.1109/APS.2015.7305610.

[5] A. A. Elijah and M. Mokayef, "Miniature microstrip antenna for IoT application," *Materials Today: Proceedings*, vol. 29, pp. 43–47, 2020, doi: 10.1016/j.matpr.2020.05.678.

[6] R. Reddy and R. Swaminathan, "Directivity Improvement of 9-Element Yagi Uda Antenna by increasing director elements in comparison with 7-Element Yagi Uda Antenna," in *2022 3rd International Conference on Intelligent Engineering and Management (ICIEM)*, Apr. 2022, pp. 561–564, doi: 10.1109/ICIEM54221.2022.9853131.

[7] A. Zabri, M. Kamal A. Rahim, F. Zubir, N. M. Nadzir, and H. A. Majid, "Video Monitoring Application using Wireless Sensor Node with Various External Antenna," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 6, no. 1, pp. 148–154, Apr. 2017, doi: 10.11591/ijeecs.v6.i1.pp148-154.

[8] D. Kremer, A. Morris, R. Blake, T. Park, and J. Proctor, "Outdoor far-field antenna measurements system for testing of large vehicles," in *2012 6th European Conference on Antennas and Propagation (EUCAP)*, Mar. 2012, pp. 2256–2260, doi: 10.1109/EuCAP.2012.6206720.

[9] J. M. Miller, Y. Hussein, C. Jin, and E. Decrossas, "VHF Antenna Far-Field Pattern Measurements at 60 MHz Using an Outdoor Antenna Range for Europa Clipper Mission," in *2019 IEEE Conference on Antenna Measurements & Applications (CAMA)*, Oct. 2019, pp. 65–68, doi: 10.1109/CAMA47423.2019.8959580.

[10] H. Yon, N. H. A. Rahman, M. A. Aris, and H. Jumaat, "Developed high gain microstrip antenna like microphone structure for 5G application," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 3, pp. 3086–3094, Jun. 2020, doi: 10.11591/ijece.v10i3.pp3086-3094.

[11] K. Mandal and P. P. Sarkar, "A compact high gain microstrip antenna for wireless applications," *AEU - International Journal of Electronics and Communications*, vol. 67, no. 12, pp. 1010–1014, Dec. 2013, doi: 10.1016/j.aeue.2013.06.001.

[12] B. K. Kanaujia, M. K. Khandelwal, S. Dwari, S. Kumar, and A. K. Gautam, "Analysis and Design of Compact High Gain Microstrip Patch Antenna with Defected Ground Structure for Wireless Applications," *Wireless Personal Communications*, vol. 91, no. 2, pp. 661–678, Nov. 2016, doi: 10.1007/s11277-016-3486-3.

[13] A. M. Ibrahim, I. M. Ibrahim, and N. A. Shairi, "Design a compact wide bandwidth of a printed antenna using defected ground structure," *Journal of Advanced Research in Dynamical and Control Systems*, vol. 11, no. 2, pp. 1065–1076, 2019.

[14] A. Kumar, S. Dwari, and G. P. Pandey, "A dual-band high-gain microstrip antenna with a defective frequency selective surface for wireless applications," *Journal of Electromagnetic Waves and Applications*, vol. 35, no. 12, pp. 1637–1651, Aug. 2021, doi: 10.1080/09205071.2021.1914195.

[15] S. A. Md Ali, M. Abu, and S. N. Zabri, "Improvements of trapezoid antenna gain using artificial magnetic conductor and frequency selective surface," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 20, no. 1, pp. 281–286, Oct. 2020, doi: 10.11591/ijeecs.v20.i1.pp281-286.

[16] M. El Bakkali, M. El Bekkali, G. S. Gaba, J. M. Guerrero, L. Kansal, and M. Masud, "Fully Integrated High Gain S-Band Triangular Slot Antenna for CubeSat Communications," *Electronics*, vol. 10, no. 2, Jan. 2021, doi: 10.3390/electronics10020156.

[17] C.-L. Yang, C.-L. Tsai, K.-T. Cheng, and S.-H. Chen, "Low-Invasive Implantable Devices of Low-Power Consumption Using High-Efficiency Antennas for Cloud Health Care," *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, vol. 2, no. 1, pp. 14–23, Mar. 2012, doi: 10.1109/JETCAS.2012.2187469.

[18] A. Nasipuri, K. Li, and U. R. Sappidi, "Power consumption and throughput in mobile ad hoc networks using directional antennas," in *Proceedings Eleventh International Conference on Computer Communications and Networks*, 2002, pp. 620–626, doi: 10.1109/ICCCN.2002.1043137.

[19] M. van Rooyen, J. W. Odendaal, and J. Joubert, "High-Gain Directional Antenna for WLAN and WiMAX Applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 286–289, 2017, doi: 10.1109/LAWP.2016.2573594.

[20] E. A.-Sanchez, J. E. Page, T. M. M.-Guerrero, J. Esteban, and C. Camacho-Penalosa, "Planar Broadband Slot Radiating Element Based on Microstrip-Slot Coupling for Series-fed Arrays," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 12, pp. 6037–6042, Dec. 2012, doi: 10.1109/TAP.2012.2211558.

[21] M. T. Nguyen, B. Kim, H. Choo, and I. Park, "Effects of ground plane size on a square microstrip patch antenna designed on a low-permittivity substrate with an air gap," in *2010 International Workshop on Antenna Technology (iWAT)*, Mar. 2010, pp. 1–4, doi: 10.1109/IWAT.2010.5464869.

[22] A. S. Mekki, M. N. Hamidon, A. Ismail, and A. R. H. Alhawari, "Gain Enhancement of a Microstrip Patch Antenna Using a Reflecting Layer," *International Journal of Antennas and Propagation*, vol. 2015, pp. 1–7, 2015, doi: 10.1155/2015/975263.

[23] M. Mrnka and Z. Raida, "Gain improvement of higher order mode dielectric resonator antenna by thin air gap," in *2016 International Conference on Broadband Communications for Next Generation Networks and Multimedia Applications (CoBCom)*, Sep. 2016, pp. 1–3, doi: 10.1109/COBCOM.2016.7593494.

[24] N. Melouki *et al.*, "High-Gain Wideband Circularly Polarised Fabry–Perot Resonator Array Antenna Using a Single-Layered Pixelated PRS for Millimetre-Wave Applications," *Micromachines*, vol. 13, no. 10, Oct. 2022, doi: 10.3390/mi13101658.

[25] S. Tanveer, A. Rashid, and M. Ur-Rehman, "A Millimeter-wave Broadband Magneto-electric Dipole Antenna Using Complementary Back Reflectors and Air-gaps," in *2021 1st International Conference on Microwave, Antennas & Circuits (ICMAC)*, Dec. 2021, pp. 1–4, doi: 10.1109/ICMAC54080.2021.9678296.

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