International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Dig. Sys.13, No.1 (May-23)

http://dx.doi.org/10.12785/ijcds/130196

Bandwidth Improvment of Dualband mm-wave Microstrip Antenna Using Genetic Algorithm

Arebu Dejen[1], Jaume Anguera[2,3], Jeevani Jayasinghe[4] and Murad Ridwan[1]

[1]*School of Electrical and Computer Engineering, Addis Ababa University, Addis Ababa, Ethiopia*
[2]*Telecommunication Engineering, Universitat Ramon LLull, Barcelona, Spain*
[3]*Ignion, Barcelona, Spain*
[4]*Department of Electronics, Wayamba university of Sri Lanka, Kuliyapitiya, Sri Lanka*

Received 20 Apr. 2022, Revised 4 May. 2023, Accepted 14 May. 2023, Published 30 May. 2023

Abstract: The necessity for multi-functional antennas with achievable performance from a single device is increasing dramatically. At the same, dual-band rectangular microstrip antennas are essential for a varieties of applications in mm-wave communication. This study aims to use a genetic algorithm to enhance the operating bandwidth of a dualband mm-wave microstrip antenna for wireless communication with binary-coded scheme. The patch surface was optimized by gridding it into $10X10$ tiny rectangular blocks and designing them as non-conducting and conducting features to them. The proposed method has iteratively modeled the antenna using a Ansys HFSS and MATLAB to identify best fitted antenna. The optimized antenna has resonated at 39.1 GHz center frequency with 7.6 dB peak gain with 1.6 GHz bandwidth and at 50.2 GHz center frequency with 7.3 dB peak gain and 3.3 GHz bandwidth. The antenna's total efficiency is 71.4 % at 39.1 GHz and 92.8 % at 50.2 GHz.

Keywords: mm-wave antenna, dualband antenna, genetic algorithm , microstrip antenna

1. INTRODUCTION

The importance of wireless technology is growing rapidly in the sector. Specifically, mobile communication technologies have undergone significant changes before reaching the present 5G standard. A newly deployed 5G technologies will have a substantial effect in wireless communication. It is anticipated that it will provide high data rates and connect billions of users to the network [1]. This necessitates a wide bandwidth, which is available at the mm-wave frequency. Figure 1 depicts the estimated mm-wave spectrum available for wireless communication. This band, however, is sensitive to a number of difficulties, including significant propagation loss, obstruction, and atmospheric loss. Antenna optimization is critical for overcoming propagation problems and optimizing the available spectrum, bandwidth, directivity, and gain of mm-waves.

Especially, the investigation of multi-band antennas with relative effective qualities of bandwidth, efficiency, directivity and gain can meet the needs of communication.This form of antenna is required to provide a low profile, planar construction, and multi-band properties. Thus, patch antenna technologies are an appealing alternative because of their simple planar configuration, reduced size, cheap cost, ease of fabrication, and lightweight [3]. Nevertheless, typical microstrip antennas have limited bandwidth, low gain, and weak directivity [4], [5]. As a result, creating multi-band microstrip patch antennas is always a challenging problem.

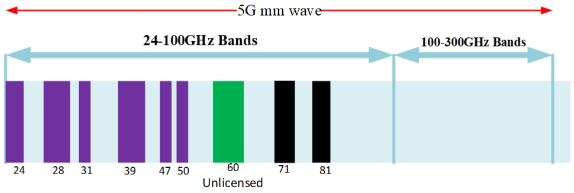


Figure 1. Predicted spectrum for mm-wave mobile communication [2]

Several methods for enhancing patch antennas with dualband operation have been documented in the literature. In dual band antenna were designed in various mechanisms among them based on artificial magnetic conductor [6], and C and O slot structure [7] were presented. U-shaped slot dualband patch antenna resonates at 28GHZ and 38GHz is described [8]. A dualband elliptically slotted circular radiating patch with resonant frequencies of 28 and 45 GHz is proposed [9]. Dual-band antenna also designed using branch fractal bionic antenna as described in[10]. In [11], the authors introduced a dualband single antenna by a band switching mechanism

E-mail address: arebu.dejen@aastu.edu.et, jaume.anguera@salle.url.edu, jeevani@wyb.ac.lk, murad.ridwan@aait.edu.et

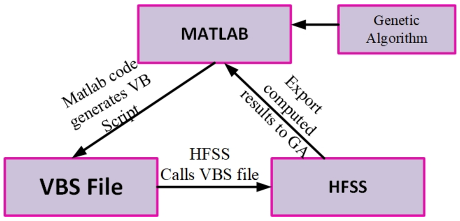


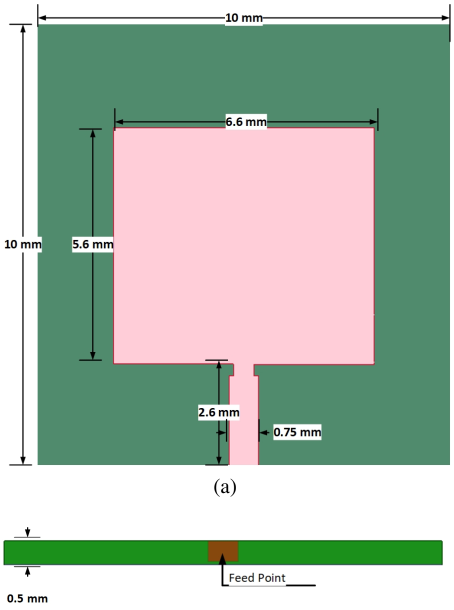
Figure 2. Combination of MATLAB and HFSS in optimization procedure for single execution

that resonates at 27.5 GHz and 39GHz. For dualband operation at 28 GHz and 38 GHz, a slot patch antenna was presented [12]. Dualband antenna also modeled using varaties of autonomous algorithm such as auto-context system learning [13], Gaussian's deep learning process [14], as well as evolutionary algorithms like genetic [15]. In [16], a dualband optimization of a patch antenna in microwave frequency using a genetic algorithm is described.The author of [17] describes a dualband antenna using genetic algorithm at mm-wave with a circular cell.

This study uses a binary-coded genetic algorithm to enhance the impedance bandwidth of a dualband microstrip antenna for mm-wave mobile applications.The procedure is carried out on the patch surface to produce a new geometry by altering the gridded rectangular blocks. The combination of MATLAB and HFSS was utilized to simulate and model the antenna. HFSS employed to model, compute and exporting the results of parameters to MATLAB's main function [18]. The optimized antenna's revealed performances are transferred to the algorithm for additional fitness computation, and the algorithm performs parent selection for continuous generation. As shown in Figure 2 , the optimizer code is written in MATLAB, and HFSS receives the details of the antenna from the VBS file generated by MATLAB.

2. ANTENNA MODELING

The proposed antenna was first modeled to have a rectangular radiating patch on a $10{\times}10mm^2$ Roger substrate. The substrate has a 2.2 dielectric strength , 0.5 mm thick and very low tangent-loss approximately 0.009. The starting dimension of a reference model, rectangular microstrip antenna, was determined using the fundamental method provided in[19]. The anticipated dimensions, however, do not provide appropriate performance at the desired center frequencies and bands. Thus, para-metrics analysis was applied to determine the actual length and width of the patch. When the resonance frequency is desired at 39 GHz, the optimal patch length was 5.6 mm and the width was 6.6 mm. A 50 Ω microstrip feed line having 2.6mm length and 0.75mm width is connected to the patch. Figure 3 presents the dimension of reference model, which is ready for patch geometry optimization.



(a)

(b)

Figure 3. (a) Reference model designed to operate at 39.0GHz (b) side view.

3. GENETIC ALGORITHM PROCEDURE

In genetic algorithm(GA) optimization, the next offspring is reproduced from best fitted chromosomes, which is mimics the procedure of natural selection [20]. In GA, each individual is symbolized by chromosomal or a sequence of bits [21].The algorithm starts from random generation and reproduces the next generations iteratively until the halting criteria is reached. [22]. The flowchart diagram of a genetic algorithm is presented in Figure 4.

Figure 5 illustrates the segmentation of patch surface into 10 × 10 tiny random rectangular blocks, which is suitable for optimization. The cell's properties may be simply specified as non-conducting and conducting using a binary-coded approach. Boolean "1" is given to the corresponding gene if the cell is conductive, whereas a binary "0" is attributed to a non-conducting genes. [23]. The goal of this optimization is to look into improving the operating bandwidth with dual-band resonance. As a consequence, the objective functions is built as follows:

$$FitnessFunction = \frac{-1}{N}\sum_{i=1}^{N}(Bw - S_{11}(f_{ii})) \tag{1}$$

$$Bw = Bw_1 + Bw_2 \tag{2}$$

where

$$Bw_2 = f_{H2} - f_{L2} \tag{3}$$

$$Bw_2 = f_{H2} - f_{L2} \tag{4}$$

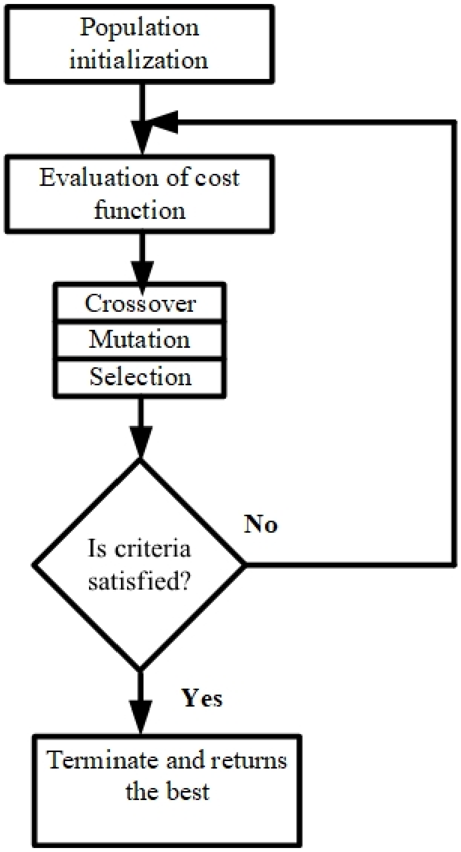


Figure 4. Flowchart of genetic algorithm

$$Bw = \begin{cases} 5GHz & if Bw \geq 5GHz \\ Bw & if Bw \leq 5GHz \end{cases}$$

Where $S_{11}(f_{ii})$ is designed as.

$$S_{11}(f_{ii}) = \begin{cases} S_{11}(f_{ii}) & if \quad S_{11}(f_{ii}) \geq -10dB \\ -10dB & if \quad S_{11}(f_{ii}) \leq -10dB \end{cases}$$

where
f_{ii}: sampling frequency in the interval of 100 MHz
$S_{11}(f_{ii})$: reflection coefficient in dB
Bw: total operating bandwidth of antenna
Bw_1 : bandwidth of antenna at the first operating band
Bw_2 : bandwidth of antenna at the second operating band
f_{H1}:higher operating frequency in a first band
f_{H2}:higher operating frequency in a second band
f_{L1}:Lower operating frequency in a first band
f_{L2}:higher operating frequency in a second band
N: Number of sampling frequencies in a given band

The genetic algorithm optimization setup has been arranged and summarized in Table I.

The solution-space has a total of $2^{100} = 1.3x10^{30}$ individuals. If each individual computational time is 1 second, the total computing required to identify the best-fitted individual will be $1.2x10^{24}$years. However, owing to the algorithm, the fitted one was selected about 44.86 hours by a RAM of 8GB and 2.7 GHz processor computer. The iteration were conducted for 125 generations and stared to converge after 48 iterations as illustrated in 6(a). The final optimized geometry is presented in Figure 6(6).

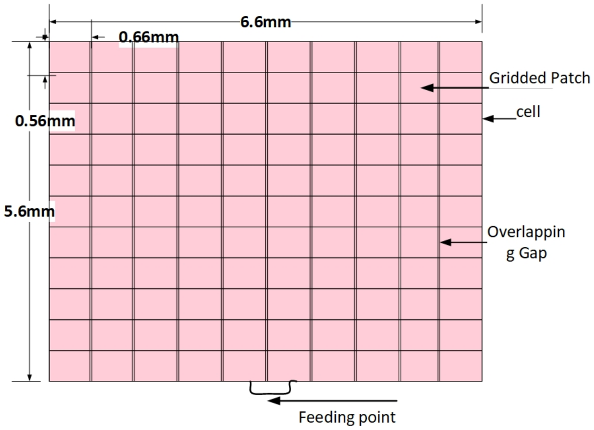


Figure 5. Distribution of 100 rectangular blocks on reference patch surface

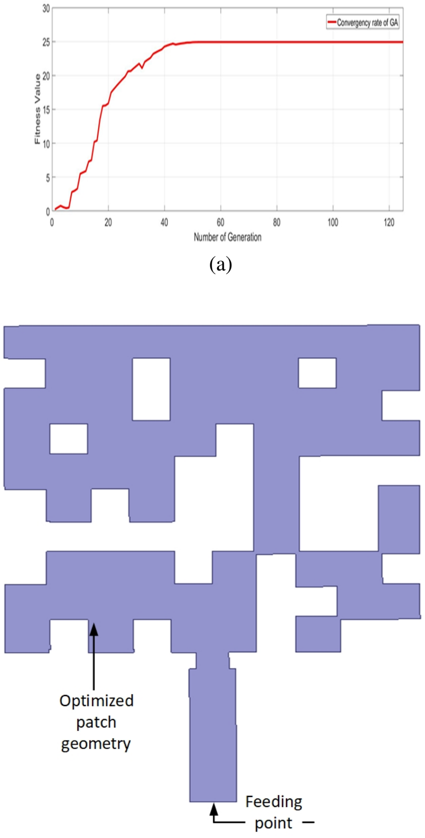
TABLE I. Optimization setup for genetic algorithms

No.	Parameters	Set up figures
1	Clustered population	30
2	No. of Cells	100
3	No. of generation	125
4	Crossover	Single-point
5	Crossover Probability	0.7
6	Mutation	Single-bit
7	Mutation-rate	0.02
8	Kind of Selection	Tournament

4. RESULTS AND DISCUSSION

ANSYS HFSS was used to simulate the reference and the genetic modified antennas. The baseline antenna operates in a single band and has a covering impedance bandwidth of 1.2 GHz at 39 GHz. The reference model's peak S_{11} value at 39 GHz is -17.6 dB, where the antenna's greatest actual gain is 5.4 dB.The suggested genetically engineered antenna, nevertheless, operates at two separate frequencies: 39.1 GHz and 50.2 GHz.The frequent slots produced by the algorithm aid in the patch surface's ability to remove uncorrelated current distribution, which improves the antenna's radiation characteristics. The slots also lengthen the current flow on the area of radiating patch, which facilitating the antenna's capability to operate at dualband frequencies.

The results revealed that the bandwidth of the antenna has improved in both frequency spectrum. The directivity and gain of the antenna are also acceptable for mm-wave cellular systems.The antenna resonates at 39.1 GHz and 50.2 GHz, as shown in Figure 7, with the return loss values of S_{11} =-12.6 dB and S_{11} =-26.0 dB, respectively. With the engineered antenna, there was a noticeable increment in overall bandwidth when $S_{11} \leq -10dB$ was considered.



(a)

(b)

Figure 6. a) average fitness-value vs number of generation, b) Fittest patch geometry

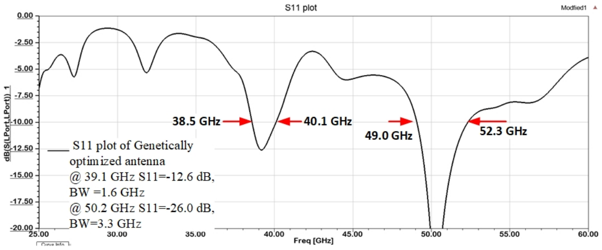


Figure 7. S_{11} result for the engineered antenna

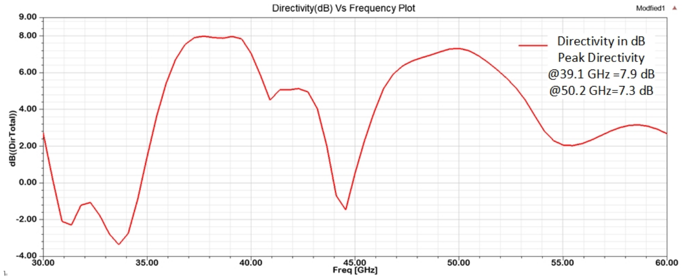
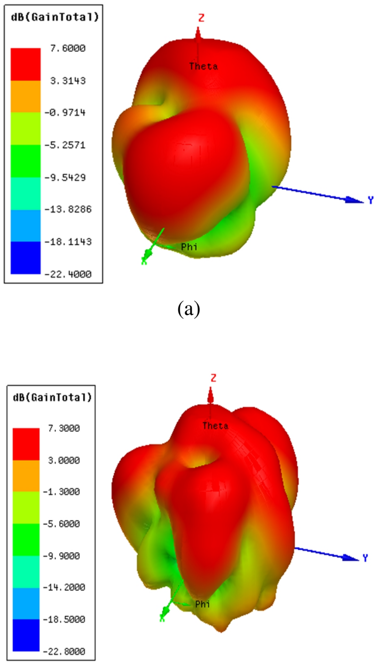


Figure 8. Directivity versus frequency plot of genetically optimized antenna ϕ='90^0' and θ='0^0'



(a)

(b)

Figure 9. The 3D gain plot of engineered antenna (a) 39.1 GHz (b) 50.2 GHz.

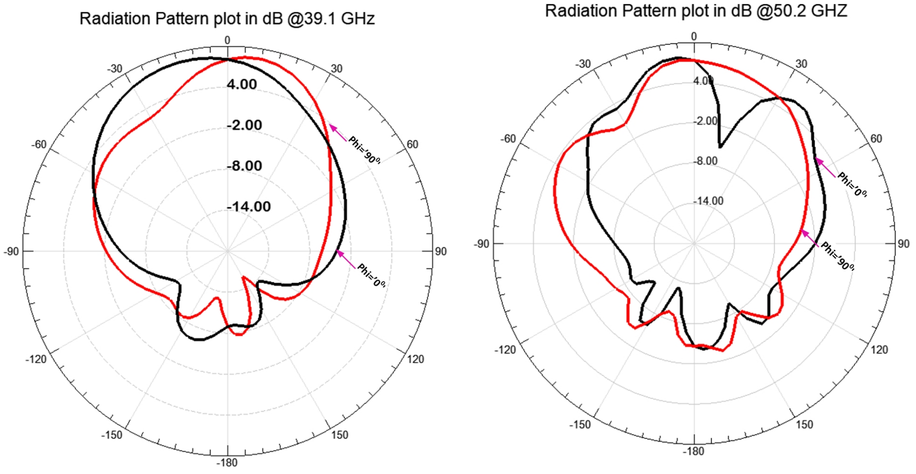
At 39.1 GHz, it has achieved 1.6GHz or 4.1% bandwidth. A 3.3GHz or 6.6 % bandwidth was also attained at 50.2GHz frequency with the improved antenna. This increased bandwidth capabilities are crucial for mobile broadband services. VSWR is less than 2 in both operational bands (38.5 GHz – 40.1 GHz) and (49.0 GHz – 52.3 GHz).

Furthermore, directivity enhancement in both working bands was seen in Figure 8. At 39.1 GHz, broadside direction peak directivity was 7.9 dB, while at 50.2 GHz, directivity was 7.4 dB.

At two operational frequencies, the 3D antenna's gain plot is shown in Figure 9. At 39.1 GHz, the max gain of optimized antenna is 7.6 dB. And at 50.2 GHz the peak gain of antenna was resulted approximately 7.3 dB. In Figure 10, the radiation pattern of optimized antenna was presented and it shows that radiation pattern was directed in a broadside orientation. The antenna has an overall efficiency of 89.3% at 39.1 GHz and 98.8% at 50.2 GHz as presented in Figure 11.

. The distribution of current on the radiating surface of the engineered antenna is displayed in Figure 12 at 39.1 GHz and 50.2 GHz resonance bands. On the edges of cells and around the junction points between the feed line and the optimized patch, a greater degree of current dispersion is visible.

As indicated in Table II, the antenna performance parameter was compared to several relevant works. The double bow-tie approach in [24] had a comparable bandwidth with this result. The antenna's bandwidth, on the other hand,



(a) (b)

Figure 10. The 2D radiation pattern plot in dB of proposed antenna (a) at 39.1 GHz (b) at 50.2 GHz.

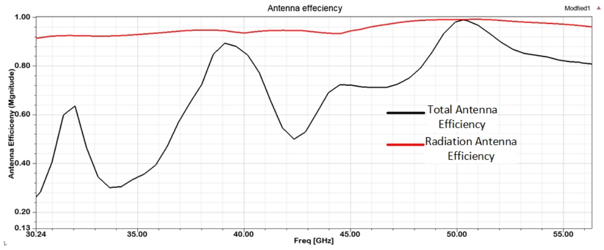
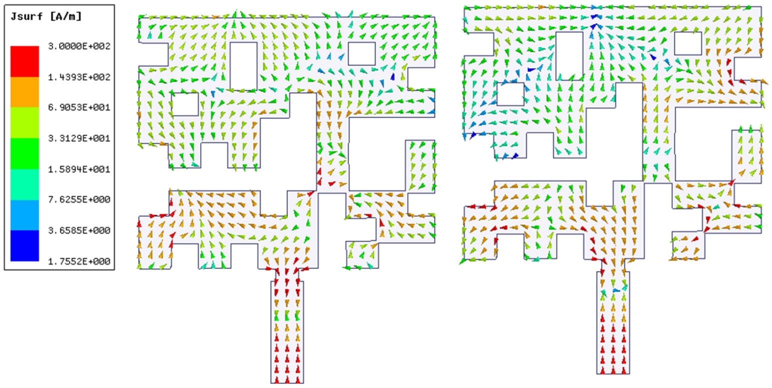


Figure 11. Efficiency of engineered antenna



(a) (b)

Figure 12. Surface Current distribution of genetically optimized antenna (a) at 39.1 GHz and (b) 50.2 GHz

is investigated as $S_{11} \leq -6dB$ and the antenna exhibits low gain when compared to this research. Additionally, this work achieves a gain of 7.6 dB, which is 3 dB greater than the maximum gain reported in the literature. The novelty of this paper may be noticed in bandwidth improvement, directivity and gain augmentation from a single antenna with dualband operating abilities. These results show that the engineered antenna is appropriate for mm-wave cellular communication, and they were achieved using genetic algorithm.

TABLE II. A comparison of this work with previous literature

No.	Paper	Patch size in terms of λ^2	Resonant frequency	Bandwidth in GHz (S11≤-10 dB)	Directivities (dB)	Gains (dB)	Methods
1	[3]	0.74 X 0.79	28 GHz 38 GHz	0.3 0.5	6.7 7.9	- -	U-shaped slot
2	[9]	0.56 X 0.56	28 GHz 45 GHz	1.3 1	7.6 7.2	- -	elliptical slot
3	[25]	0.29 X 0.31	14 GHz 17 GHz	1.8 0.6	7.9 7.3	- -	slot optimization
4	[12]	0.93 X 0.93	28 GHz 38 GHz	1 3	- -	4.7 5.13	slot
5	[24]	0.26 x 0.14	28 GHz 60 GHz	0.4 3.1	- -	3.5 4.6	Double Bow-tie
6	This Paper	0.73 X 0.86	39.2 GHz 50.2 GHz	1.6 3.3	7.9 7.4	7.6 7.3	genetic algorithm

5. CONCLUSION

Using a binary-coded genetic algorithm, this article revealed a dualband microstrip antenna optimization for mm-wave mobile applications.The engineered antenna was resonated at 39.1 GHz and 50.2 GHz whereas the reference model was resonated only at 39.0 GHz. To that purpose, a genetically modified microstrip antenna performed admirably in the operating band of interest. The optimized antenna have achieved 1.6 GHz bandwidth and 7.6 dB gain at 39.1 GHz and 3.3 GHz bandwidth, 7.4 dB gain at 50.2 GHz center frequency. This work can also compared with other related works and the proposed reference antenna in mm-wave frequency. The proposed antenna performs brilliantly in terms of bandwidth and other far-field properties, which makes the antenna practical for mm-wave communication.

References

[1] S. S. Filipa, Fernandes, C. Rom, A. Rodrigues, S. Svendsen, and O. Jagielski, "Two-step method for millimeter-wave antenna performance assessment in 5g smartphones," *International Journal of Antennas and Propagation*, pp. 1–18, 2021.

[2] A. Dejen, J. Jayasinghe, M. Ridwan, and J. Anguera, "Optimization of dual-band microstrip mm-wave antenna with improved directivity for mobile application using genetic algorithm," *9th EAI International Conference on Advancements of Science and Technology Bahirdar,Ethiopia*, vol. 411, pp. 331–340, 2022.

[3] T. S. Rappaport, Y. Xing, G. R. MacCartney, J. A. F. Molisch, E. Mellios, and J. Zhang, "Overview of millimeter wave communications for fifth-generation (5g) wireless networks-with a focus on propagation models," *IEEE Transactions on Antennas and Propagation*, vol. Special Issue, 2017.

[4] C.-N. Hu, D.-C. Chang, C.-H. Yu, T.-W. Hsaio, and D.-P. Lin, "Millimeter-wave microstrip antenna array design and an adaptive algorithm for future 5g wireless communication systems," *International Journal of Antennas and Propagation*, vol. 10, pp. 1–12, 2016.

[5] J. Wu, J. Sun, and J. Fang, "Directivity enhancement of a broadband printed antenna by using two closely spaced strips," *International Journal of Antennas and Propagation*, vol. 2021, pp. 1–9, 2021.

[6] S. Wang and H. Gao, "A dual-band wearable conformal antenna based on artificial magnetic conductor," *International Journal of Antennas and Propagation*, vol. 2022, pp. 1–8, 2022.

[7] T. Xie, J. Y. Z. Lin, Y. Li, G. Zhang, and Z. Yu, "A novel dual-band "c+o" structure antenna," *International Journal of Antennas and Propagation*, vol. 2021, p. Article ID 7974349, 2022.

[8] W. Hussain, M. Khattak, and M. A.K.Khattak, "Multiband microstrip patch antenna for 5g wireless communication," *International Journal of Engineering Works*, vol. 7, pp. 15–21, 2020.

[9] M. I. Khattak, A. Sohail, U. Khan, Z. Ullah, and G. Witjaksono, "Elliptical slot circular patch antenna array with dual band behaviour for future 5g mobile communication networks," *Progress In Electromagnetics Research C*, vol. 89, pp. 133–147, 2019.

[10] X. Ran, Z. Yu, T. Xie, Y. Li, X. Wang, and P. Huang, "A novel dual-band binary branch fractal bionic antenna for mobile terminals," *International Journal of Antennas and Propagation*, vol. 2020, p. Article ID 6109093, 2020.

[11] H.-C. Huang, R. Ma, X. Jian, Y. Wang, and Z. Zhu, "A miniaturized band-switching multiband dual-polarized 5g mm-wave antenna-in-package (aip) array for cellular phones," *2019 International Symposium on Antennas and Propagation (ISAP)*, p. 19296338, 2019.

[12] M. B.Almashhdany, O. A. Al-Ani, and A. M. A. Sabaawi, "Design of multi-band slotted mm-wave antenna for 5g mobile applications," *23rd International Conference on Sustainable Engineering Techniques (ICSET 2020)*, 2020.

[13] W.-T. Ding, F. Meng, Y.-B. Tian, and H.-N. Yuan, "Antenna optimization based on auto-context broad learning system," *International Journal of Antennas and Propagation*, vol. 2022, p. Article ID 7338164, 2022.

[14] X.-Y. Zhang, Y.-B. Tian, and X. Zheng, "Antenna optimization design based on deep gaussian process model," *International Journal of Antennas and Propagation*, vol. 2020, p. Article ID 2154928, 2020.

[15] A. Kapoor and R. Mishra, "Genetic algorithm optimized gain augmented dual band printed antenna for cognitive ehealth care (iomt) applications," *11th International Conference on Communication Systems and Network Technologies*, vol. CSNT, pp. 6–11, 2022.

[16] J. M. J. W. Jayasinghe, D. Uduwawala, and J. Anguera, "Design of dual band patch antennas for cellular communications by genetic algorithm optimization," *International Journal of Engineering and Technology*, vol. 1, pp. 26–43, 2012.

[17] A. Dejen, J. Anguera, M. Ridwan, and J. Jayasinghe, "Genetically engineered dual-band microstrip antenna with improved directivity for 5g mm-wave mobile applications," *1st IEEE Women in Engineering Symposium, Sri lanka*, 2020.

[18] A. Dejen, J. Jayasinghe, M. Ridwan, and J. Anguera, "Genetically optimized quad-band mm-wave microstrip patch antenna," 7^{th} *International Conference on Micro-Electronics, Electromagnetics and Telecommunications, Andhra Pradesh, India*, p. presented, 2022.

[19] C. Balanis., "Modern antenna handbook," *A JOHN WILEY and SONS INC*, 2013.

[20] R. L. Haupt, "An introduction to genetic algorithms for electromagnetics," *Antennas and Propagation Magazine*, vol. 37, 1995.

[21] O. A. Saraereh, A. A. A. Saraira, Q. H. Alsafasfeh, and A. Arfoa, "Bio-inspired algorithms applied on microstrip patch antennas: a review," *International Journal on Communications Antenna and Propagation*, vol. 6, 2016.

[22] J. M. Johnson and Y. Rahmat-Samii, "Genetic algorithms in engineering electromagnetics," *Antennas and Propagation Magazine*, vol. 39, 1997.

[23] J. M. J. W. Jayasinghe, J. Anguera, and D. Uduwawala, "A simple design of multi band microstrip patch antennas robust to fabrication tolerances for gsm, umts, lte, and bluetooth applications by using genetic algorithm optimization," *Antennas and Propagation Magazine*, vol. 27, pp. 255–269, 2012.

[24] R. Rodríguez-Cano, S. Zhang, and G. F. Pedersen, "Beam-steerable multi-band mm-wave bow-tie antenna array for mobile terminals," *12th European Conference on Antennas and Propagation*, pp. 1–4, 2018.

[25] R. Kumar and M. Kartikeyan, "Design and simulation of multi band compact microstrip patch antenna," *Indian Conference on Antennas and Propogation*, pp. 1–4, 2019.

Arebu Dejen was born in 1989 in Wollo, Ethiopia. In 2010, he obtained a B.Sc. in Electrical Engineering from Mekelle University in Tigray, Ethiopia, and in 2013, he received an MSc in Communication Engineering from Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa, Ethiopia. He is now a PhD candidate at Addis Abeba University. He has been a lecturer in the School of Electri- cal and Computer Engineering, Kombolcha Insti- tute of Technology, Wollo University, since 2013 until 2017. He has several articles in his field of study. His primary research interests are in antenna design and optimization, antenna arrays, genetic algorithm optimization, mm-wave and terahertz wireless communication

Jaume Anguera IEEE Fellow, founder and CTO at the technology company Ignion (Barcelona, Spain). Associate Professor at Ramon LLull University and a member of the Smart Society research group. He is an inventor of more than 150 granted patents, most of them licensed to telecommunication companies. Among his most outstanding contributions is that of the inventor of Antenna Booster Technology, a technology that fostered the creation of Ignion. The wireless industry has adopted many of these products worldwide to allow wireless connectivity to IoT devices through a miniature component called an antenna booster that is ten times smaller than conventional antennas. Author of more than 280 widely cited scientific papers and international conferences (h-index 52). Author of 7 books. He has participated in more than 22 competitive research projects financed by the Spanish Ministry, CDTI, CIDEM (Generalitat de Catalunya), and the European Commission for an amount exceeding $ 13M as a principal researcher in most of them. He has taught over 40 antenna courses worldwide (USA, China, Korea, India, UK, France, Poland, Czech Republic, Tunisia, Perú, Brazil, Canada, Spain). With over 23 years of R&D experience, he has developed part of his professional experience with Fractus in South Korea in designing miniature antennas for large Korean companies such as Samsung and LG. Since 2017 he has been with Ignion in the role of CTO. He leads the company's R&D activity to create new products, envisage new technologies, technical evangelism, and provide technology strategy to scale the company's business. He has received several national and international awards (ex. 2004 Best Ph.D Thesis -two prizes, one given by Telefónica Mobile, 2004 IEEE New Faces of Engineering, 2014 Finalist European Patent Award). He has directed the master/doctorate thesis to more than 160 students, many of them have received awards for their thesis (COIT, COITT, Ministry of Education). His biography appears in Who'sWho in the World and Who'sWho in Science and Engineering. He is an associate editor of the IEEE Open Journal on Antennas and Propagation, Electronics Letters, and a reviewer in several IEEE and other scientific journals. He is an IEEE Antennas and Propagation Distinguished Lecturer and vice-chair of the working group "Software and Modeling" at EurAAP. More info at http://users.salleurl.edu/ jaume.anguera/

Jeevani Jayasinghe received Ph.D. in Engineering and B.Sc. (Hons.) in Engineering from the University of Peradeniya, Sri Lanka in 2014 and 2006 respectively. She was a Visiting Fellow of Macquarie University, Sydney, Australia in 2018 and a Research fellow of Ramon Llull University, Spain in 2013. She is working as a Professor of the Department of Electronics, Wayamba University of Sri Lanka. She has published more than 80 research articles in journals and conference proceedings. Prof. Jayasinghe is a Senior Member of IEEE, and an Associate Member of Institute of Engineers Sri Lanka. Her current Google scholar h-index is 13 and Scopus h-index is 11.

Murad Ridwan is from Ethiopia. He got his B.Sc. in Electrical Engineering from Addis Ababa University (AAU), Addis Ababa, Ethiopia in 1993, and his MSc and PhD in Communication Engineering from the same university in 2001 and 2013, respectively. He has worked as a satellite base-station and systems engineer, and then as a multimedia engineer at Ethiopian telecom's satellite communication. He has worked as an Assistant Professor at Addis Ababa Institute of Technology's School of Electrical and Computer Engineering since 2001. He has multiple articles published. His research interests lie primarily in the area of antennas, antenna arrays, beamforming, precoding techniques especially for 5G, electromagnetism, numerical electromagnetics, quantum mechanics and particle physics.