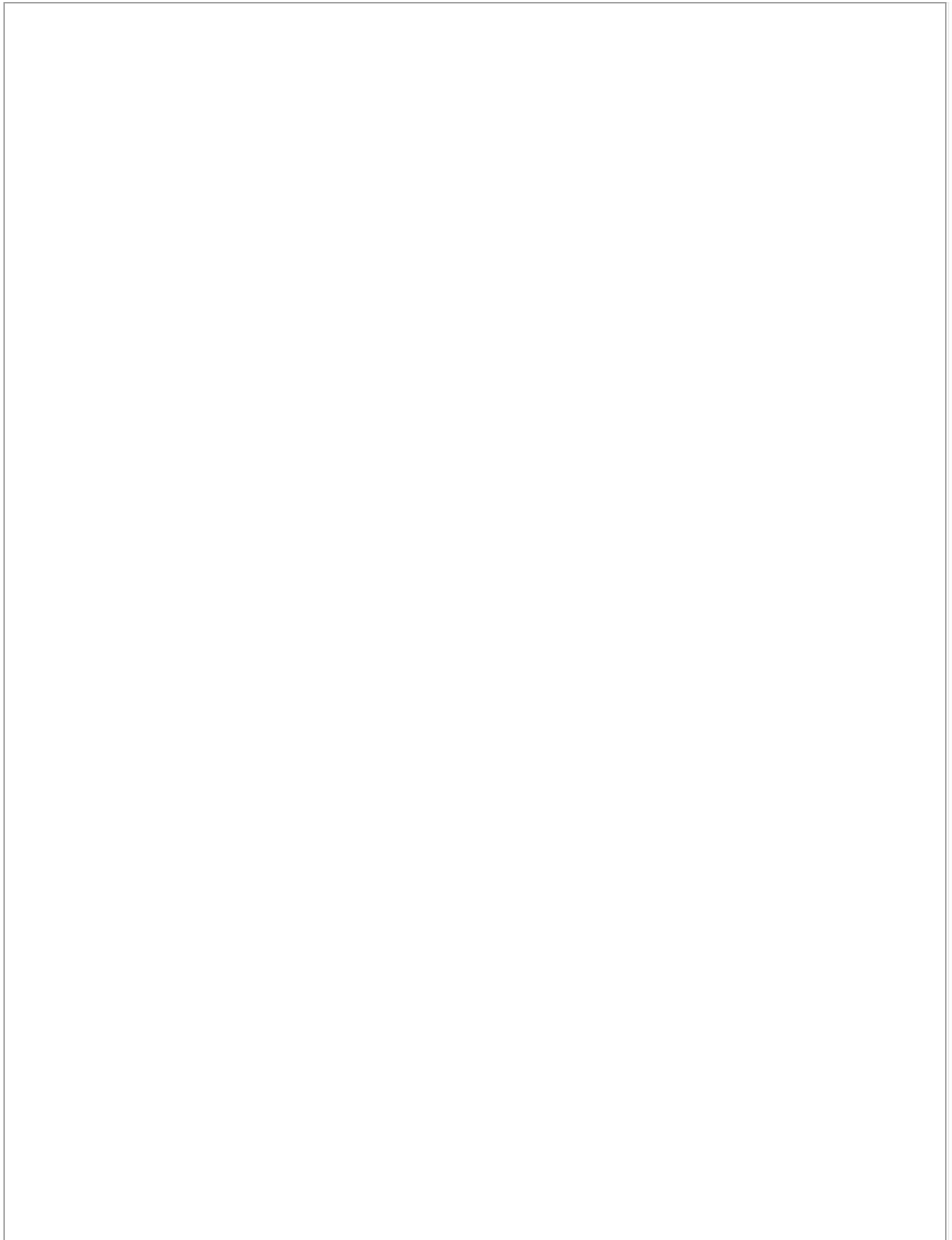


## Documents



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**Analysis, Optimization, and Hardware Implementation of Dipole Antenna Array for Wireless Applications**  
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### Abstract

The antenna pattern synthesis is one of the significant problems in the phased array antenna. Pattern synthesis refers to the optimized weight excitation of each antenna element in order to steer the beam electronically without mechanically rotating the antenna. It can be achieved by using a combination of phase shifters and attenuator circuits. In this paper, a 2 by 2 dipole antennas with an RF beamforming circuit has been designed to steer the main beam along the azimuth plane. The main beam coverage from 100° to 140° with a step size of 10° has been successfully optimized using a hybrid of the induced EMF method and a genetic algorithm. The optimization results were compared to the full-wave simulation technique implemented in Empire XCCel. The design is realistically implemented at 2.45 GHz, with both simulation and measurement results shown. The measured reflection coefficient of the phased array antenna is -48 dB at 2.56 GHz. The feasibility of the beam synthesis has been validated successfully with the main beam being steered at 110°. The possibility of a fabrication discrepancy resulting in minor radiation degradation is also discussed in this research. The dipole antenna system with RF beamformer circuit can be applied to indoor positioning systems such as Wi-Fi, wireless local area network (WLAN), and fifth-generation. © 2022 Norun Abdul Malek et al.

### Index Keywords

Beam forming networks, Beamforming, Dipole antennas, Directional patterns (antenna), Genetic algorithms, Microwave antennas, Wi-Fi, Wireless local area networks (WLAN); Antenna element, Dipole antenna arrays, Hardware implementations, Main beams, Optimisations, Pattern synthesis, Phase-shifters, Phased array antennas, RF beamforming, Wireless application; Antenna phased arrays

### References

- Akdeniz, M.R., Liu, Y., Samimi, M.K., Sun, S., Rangan, S., Rappaport, T.S., Erkip, E.  
**Millimeter wave channel modeling and cellular capacity evaluation**  
(2014) *IEEE Journal on Selected Areas in Communications*, 32 (6), pp. 1164-1179.  
2-s2.0-84904966620
- Al-Saman, A.M., Cheffena, M., Mohamed, M., Azmi, M.H., Ai, Y.  
**Statistical analysis of rain at millimeter waves in tropical Area**  
(2020) *IEEE Access*, 8, pp. 51044-51061.
- Rappaport, T.S., Gutierrez, F., Ben-Dor, E., Murdock, J.N., Qiao, Y., Tamir, J.I.  
**Broadband millimeter-wave propagation measurements and models using adaptive beam antennas for outdoor urban cellular communications**  
(2013) *IEEE Transactions on Antennas and Propagation*, 61 (4), pp. 1850-1859.  
2-s2.0-84876046476
- Roh, W., Seol, J.-Y., Park, J., Lee, B., Lee, J., Kim, Y., Cho, J., Aryanfar, F.  
**Millimeter-wave beamforming as an enabling technology for 5G cellular communications: Theoretical feasibility and prototype results**  
(2014) *IEEE Communications Magazine*, 52 (2), pp. 106-113.  
2-s2.0-84896874339
- Rangan, S., Rappaport, T.S., Erkip, E.  
**Millimeter-wave cellular wireless networks: Potentials and challenges**  
(2014) *Proceedings of the IEEE*, 102 (3), pp. 366-385.  
2-s2.0-84897656084
- Ngo, H.Q., Larsson, E.G., Marzetta, T.L.  
**Energy and spectral efficiency of very large multiuser MIMO systems**  
(2013) *IEEE Transactions on Communications*, 61 (4), pp. 1436-1449.  
2-s2.0-84877926659

- Rusek, F., Persson, D., Lau, B.K., Larsson, E.G., Marzetta, T.L., Tufvesson, F., Tufvesson, F.  
**Scaling up MIMO: Opportunities and challenges with very large arrays**  
(2013) *IEEE Signal Processing Magazine*, 30 (1), pp. 40-60.  
2-s2.0-85032752174
- Han, S., Chih-Lin, I., Xu, Z., Rowell, C.  
**Large-scale antenna systems with hybrid analog and digital beamforming for millimeter wave 5G**  
(2015) *IEEE Communications Magazine*, 53 (1), pp. 186-194.  
2-s2.0-84921504791
- Sun, Y., Qi, C.  
**Weighted sum-rate maximization for analog beamforming and combining in millimeter wave massive MIMO communications**  
(2017) *IEEE Communications Letters*, 21 (8), pp. 1883-1886.  
2-s2.0-85029535707
- Hu, R., Jiang, L., Li, P.  
**Hybrid beamforming with deep learning for large-scale Antenna arrays**  
(2021) *IEEE Access*, 9, pp. 54690-54699.
- Zhang, S., Guo, C., Wang, T., Zhang, W.  
**ON-OFF analog beamforming for massive MIMO**  
(2018) *IEEE Transactions on Vehicular Technology*, 67 (5), pp. 4113-4123.  
2-s2.0-85040077644
- Zhou, G.  
**Energy efficiency beamforming design for UAV communications with broadband hybrid polarization antenna arrays**  
(2019) *IEEE Access*, 7, pp. 34521-34532.  
2-s2.0-85063861369
- Kamal, M.M., Yang, S., Ren, X.-C., Altaf, A., Kiani, S.H., Anjum, M.R., Iqbal, A., Saeed, S.I.  
**Infinity shell shaped MIMO antenna array for mm-wave 5G applications**  
(2021) *Electronics*, 10 (2), p. 165.
- Di Serio, A., Hügler, P., Roos, F., Waldschmidt, C.  
**2-D MIMO radar: A method for array performance assessment and design of a planar antenna array**  
(2020) *IEEE Transactions on Antennas and Propagation*, 68 (6), pp. 4604-4616.
- Chou, H.T., Chang, Y.S., Huang, H.J., Yan, Z.D., Lertwiriayaprapa, T., Torrungrueng, D.  
**Two-dimensional multi-ring dielectric lens antenna to radiate fan-shaped multi beams with optimum adjacent-beam overlapping crossover by genetic algorithm**  
(2020) *IEEE Access*, 8, pp. 79124-79133.
- Liang, S., Fang, Z., Sun, G., Liu, Y., Qu, G., Zhang, Y.  
**Sidelobe reductions of antenna arrays via an improved chicken swarm optimization approach**  
(2020) *IEEE Access*, 8, pp. 37664-37683.
- Zhang, X., Lin, M., Zhang, X., Li, Y.  
**The design of microstrip array antenna and its optimization by a memetic method**  
(2019) *IEEE Access*, 7, pp. 96434-96443.  
2-s2.0-85070248167
- Mikki, S.M., Clauzier, S., Antar, Y.M.M.  
**Empirical geometrical bounds on MIMO antenna arrays for optimum diversity gain performance: An electromagnetic design approach**

(2018) *IEEE Access*, 6, pp. 39876-39894.  
2-s2.0-85048512090

- Chakraborty, A., Ram, G., Mandal, D.  
**Optimal pulse shifting in timed antenna array for simultaneous reduction of sidelobe and sideband level**  
(2020) *IEEE Access*, 8, pp. 131063-131075.
- Niccolai, A., Beccaria, M., Zich, R.E., Massaccesi, A., Pirinoli, P.  
**Social network optimization based procedure for beam-scanning reflectarray antenna design**  
(2020) *IEEE Open Journal of Antennas and Propagation*, 1, pp. 500-512.
- Greda, L.A., Winterstein, A., Lemes, D.L., Heckler, M.V.T.  
**Beamsteering and beamshaping using a linear antenna array based on particle swarm optimization**  
(2019) *IEEE Access*, 7, pp. 141562-141573.
- Holland, J.H.  
(1975) *Adaptation in Natural and Artificial Systems*,  
Ann Arbor, MI University of Michigan Press
- Balanis, C.A.  
(2005) *Linear Wire Antennas" in Antenna Theory: Analysis and Design*, pp. 151-219.  
Third New York Wiley-Interscience Chapter 4
- Stutzman, W.L., Thiel, G.A.  
(1998) *Arrays" in Antenna Theory and Design*, pp. 87-142.  
Second New York Wiley & Sons Chapter 3
- Thiele, G.A.  
**Analysis of yagi-uda type Antennas**  
(1969) *IEEE Transactions on Antennas and Propagation*, 17 (1), pp. 24-31.  
2-s2.0-0042660321
- Lewin, L.  
**Mutual impedance of wire aerial**  
(1951) *Wireless Engineer*, 28.  
352355
- Schmidt, K.E.  
**Simplified mutual impedance of nonplanar skew dipoles**  
(1996) *IEEE Transactions on Antennas and Propagation*, 44 (9), pp. 1298-1299.  
2-s2.0-0030242885
- Richmond, J., Geary, N.  
**Mutual impedance of nonplanar-skew sinusoidal dipoles**  
(1975) *IEEE Transactions on Antennas and Propagation*, 23 (3), pp. 412-414.  
2-s2.0-0016510173
- King, H.E.  
**Mutual impedance of unequal length antennas in echelon**  
(1957) *IRE Transactions on Antennas and Propagation*, 5 (3), pp. 306-313.  
2-s2.0-0006130873
- Baker, H., Lagrone, A.  
**Digital computation of the mutual independence between thin dipoles**  
(1962) *IRE Transactions on Antennas and Propagation*, 10 (2), pp. 172-178.  
2-s2.0-0038561744

- Singh, H., Sneha, H.L., Jha, R.M.  
**Mutual coupling in phased arrays: A review**  
(2013) *International Journal of Antennas and Propagation*, 2013.  
348123 2-s2.0-84877958567
- Bracken, J.E.  
(2000) *Mutual Resistance in Spicelink*,  
Ph.D. Ansoft Corporation
- Fraser, A.S.  
**Simulation of genetic systems by automatic digital computers. II: Effects of linkage on rates under selection**  
(1957) *Australian Journal of Biological Sciences*, 10 (4), pp. 492-499.
- Bremermann, H.J.  
**The evolution of intelligence**  
(1958) *The Nervous System As A Model of Its Environment*,  
Seattle, WA Department of Mathematics, University of Washington Technical Report 1
- Farghaly, S.I., Seleem, H.E., Abd Elnaby, M.M., Hussein, A.H.  
**Pencil and shaped beam patterns synthesis using a hybrid GA/I optimization and its application to improve spectral efficiency of massive MIMO systems**  
(2021) *IEEE Access*, 9, pp. 38202-38220.
- Mohan, A., Raj, A.A.B.  
*Array Thinning of Beamformers Using Simple Genetic Algorithm*, pp. 1-4.  
Proceedings of the International Conference on Computational Intelligence for Smart Power System and Sustainable Energy (CISPSSE) July 2020 Keonjhar, India IEEE
- Hamza, A., Attia, H.  
**Fast beam steering and null placement in an adaptive circular antenna array**  
(2020) *IEEE Antennas and Wireless Propagation Letters*, 19 (9), pp. 1561-1565.
- Sun, G., Zhao, X., Shen, G., Liu, Y., Wang, A., Jayaprakasam, S., Zhang, Y., Leung, V.C.M.  
**Improving performance of distributed collaborative beamforming in mobile wireless sensor networks: A multiobjective optimization method**  
(2020) *IEEE Internet of Things Journal*, 7 (8), pp. 6787-6801.
- Jiang, X., Qin, J., Jiang, T.  
*Comparing the Failure Correction Ability between GA and Fa for Array Antenna*, pp. 737-740.  
Proceedings of the 2019 Joint International Symposium on Electromagnetic Compatibility, Sapporo and Asia-Pacific International Symposium on Electromagnetic Compatibility (EMC Sapporo/APEMC) November 2019 Sapporo, Japan IEEE
- Malek, N.A., Seager, R.D., Flint, J.A.  
*Beam Steering of Four Dipoles Antenna Array Using Genetic Algorithm*, pp. 146-151.  
Proceedings of the 2014 IEEE Symposium on Wireless Technology and Applications (ISWTA) October 2014 Kota Kinabalu, Malaysia IEEE
- Kundukulam, S.O., Beenamole, K.S.  
**Design of a linear array antenna for shaped beam using genetic algorithm**  
(2008) *International Journal of RF and Microwave Computer-Aided Engineering*, 18 (5), pp. 410-416.  
2-s2.0-51449097749
- Wilkinson, E.J.  
**An N-way hybrid power divider**  
(1960) *IEEE Transactions on Microwave Theory and Techniques*, 8 (1), pp. 116-118.  
2-s2.0-84902288524

- Malek, N.F.A.  
(2013) *3-D Antenna Array Analysis Using the Induced EMF Method*, Loughborough. UK Loughborough University Ph.D. dissertation, School of Electronic, Electrical and Software Engineering
- Circuits, M.  
(2021) *Surface Mount Voltage Variable Attenuator, EVA-3000+*, Brooklyn: NY <https://www.minicircuits.com/pdfs/EVA3000+.pdf>
- Circuits, M.  
(2021) *Surface Mount Phase Shifter, JPHPS-2484+*, Brooklyn: NY <https://www.minicircuits.com/pdfs/JSPHS2484+.pdf>
- Roberts, W.K.  
**A New wide-band balun**  
(1957) *Proceedings of the IRE*, 45 (12), pp. 1628-1631.  
2-s2.0-0001596224
- Dehghani Estarki, M., Xing, Y., Han, X., Vaughan, R.G.  
*The Effect of Gap Size on Dipole Impedance Using the Induced EMF Method*, pp. 373-376.  
Proceedings of the 2010 URSI International Symposium on Electromagnetic Theory  
August 2010 Berlin IEEE

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