Simulations on the effects of an optimized bowtie dipole antenna with an adaptive FIR filter

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ABSTRACT

In the evolution of technology through the years, antennas are use in varying wireless systems have been in demand. Antennas play a great role in transmitting and receiving signals. As its application is heavily used in many days to day activities, it is important to create a cost-efficient and quick way to analyze its performance, characteristics, and relationship to different variables. As many radiation pattern acquisition devices are expensive, this simulation proposes a quick, reliable, and cost-friendly way to simulate 2D patterns in the E-plane and H-plane of a bowtie dipole antenna with an adaptive finite impulse response (FIR) filter. Through this study, the software MATLAB will be utilized to successfully simulate the radiation patterns of antennas with varying lengths. With the use of MATLAB toolboxes, the researchers aim to be able to compare different antenna lengths and determine the relationship and effect of it in the obtained 2D radiation pattern. If this method is successful various antenna applications may be implemented in the future with the use of 2D radiation pattern results.

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1. INTRODUCTION

Antennas are used worldwide to propagate and receive various forms of signals from one place to another. The types of signals they propagate can be of numerous kinds. From TV channels to cellular data to wifi to radar to radio [1], [2]. These forms of signals vary in their functions and purposes, and they also vary in their frequencies. Some TV channels make use of frequencies in the ultra high frequency (UHF) range, cellphones make use of frequencies in the UHF range as well, and radar makes use of frequencies in the UHF range too [3]-[5]. The UHF range has a variety of purposes [6] and radio makes use of frequencies in either the low frequency (LF), medium frequency (MF), or high frequency (HF) range for shortwave, AM radio, FM radio [7]. One of the most common types of antennas used for signal propagation and reception is the dipole antenna. This is because designing a dipole antenna is a simple process from a theoretical perspective [8]. The designer only needs to know what frequency/wavelength the antenna will be operating at to design the antenna. To design a dipole antenna for a specific frequency range, the ideal length of the antenna must be half of the wavelength. These parameters can be inputted in the MATLAB software [9]. This is the ideal design for a bowtie dipole antenna. But what if this rule is not followed? That is what this study will explore. This study will explore the effects of varying the length and width of a dipole antenna whilst operating under the same frequency. The study will explore the effects by looking at the E-plane and H-plane characteristics of the antenna via simulations in MATLAB. The study will explore lengths ranging from the ideal half-wavelength, whole wavelength, and double wavelength, until ten times the wavelength. The study will observe the peak gains and radiation patterns in the E-plane and H-plane, while also observing the beamwidth of the simulated antennas. The study will only focus on the 2D radiation patterns of the antennas simulated. A study focusing on the 3D radiation patterns will be conducted soon.

2. BACKGROUND OF THE STUDY

Various studies related to antennas focus on designing antennas for different purposes. Some focus on designing antennas optimized for a specific purpose, some studies focus on designing antennas optimized for a general purpose, while some studies focus on optimizing existing designs with tweaks and revisions. What these studies all have in common is the desire to create something that will better perform its function. What this study seeks to do is show how various design decisions can affect the outcomes of antenna design. The study will explore various design outcomes. Although this study will focus specifically on dipole antenna design. Antennas have this characteristic called directionality. Directionality can be described as the bias an antenna may or may not have towards a specific direction with regards to its signal propagation or reception, depending on the antenna's function [10]. There are many types of antennas concerning directionality. There is the omnidirectional antenna, an antenna that propagates equally in all directions [11]. There is the directional antenna, an antenna that propagates more towards one specific direction [12]. There is the bidirectional antenna, an antenna that propagates in two specific directions. Various other types of antenna propagation types can be observed. One such example includes the cardioid pattern, which could be counted as a directional pattern based on its behavior [13]. This study will attempt to observe an antenna's directionality across the different simulation parameters to be attempted. The advantage of simulating these different antenna designs is the ease. The researchers will not have to create dozens of different antennas. The software will be able to do so more efficiently and effectively. This is the advantage of using optimized software for antenna design. To proceed with the study, the MATLAB antenna library will be necessary as the functions used will be unavailable otherwise.

3. STATEMENT OF THE PROBLEM

The researchers of this study seek to understand the effects of varying the length and width of a dipole antenna from the perspective of the same operating frequency. The researchers seek to comprehend the varying effects of various parameters on a dipole antenna. The researchers will do so by observing the 2D radiation patterns, namely the E-plane and H-plane patterns, plus the resulting peaks and beamwidth values. This study attempts to observe any possible outcomes resulting from the varying dipole parameters. The researchers will be on the lookout for any possible special use cases with the various parameters as keeping an open mind sometimes proves beneficial to scientific research. The study will do so by presenting the code settings and the various radiation graphs produced, and the researchers will then analyze and discuss their findings. The researchers will conduct this study with the use of MATLAB and MATLAB's antenna library.

4. SIGNIFICANCE OF THE STUDY

This study will attempt to discuss the effects of various antenna lengths and widths on a dipole antenna by observing the effects from the perspective of the E-plane, H-plane, the peak values in each plane, and the beamwidth of the major lobe. As such, this study will prove useful to those that seek to learn more about dipole antenna characteristics. This study will also prove relevant to those attempting to design dipole antennas. Especially to those with various specific characteristics in mind. This study will also prove relevant to dipole antenna-related literature as well as this study will perform dozens of simulations related to various dipole parameters. This study will also prove relevant to those attempting to perform their dipole antenna simulations in MATLAB as this study will discuss the process required to perform dipole antenna radiation pattern simulations.

5. DESCRIPTION OF THE SYSTEM

Several simulations will be performed in the system. These parameters are important for us to know the effectiveness of the antenna design. The simulations will function based on the following defined antenna parameters: the operating frequency, velocity propagation constant, wavelength based on the operating frequency and velocity propagation constant, length based on wavelength, and width based on the length.

6. METHOD

This study will use MATLAB and MATLAB's antenna library. Test will be done using different parameters. This is important to determine the system's proficiency. The dipole antenna used in this study will have the following parameters. First, an operating frequency of 480 MHz. This operating frequency is an arbitrary value. It was chosen for this study with the assumed scenario that the study is designing an antenna for UHF TV channel signal reception. Second, the velocity propagation constant was set to 3×108, which is the speed of light in free space. Third, the wavelength was obtained by dividing the velocity propagation constant by the operating frequency. Fourth, the length of the antenna will be defined by the equation wavelength*n, where n will have varying values. The values used for this study will start with ½, to one, and then increment to 10. This will simulate the varying lengths of the antenna. Last, the width of the antenna will be relative to the length. The study will have two runs. The first will be where the width is 1/100 of the length, and the second will be where the width is 1/10 of the length. The researchers will then plot the E-plane, H-plane, and beamwidth of the resulting antennas. MATLAB will be used as a tool for the research. Figure 1 shows the flow of the method process.

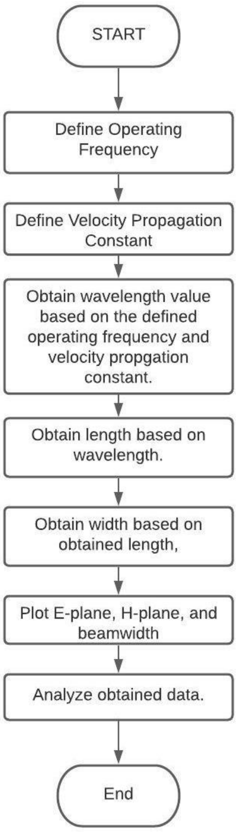

Figure 1. The flowchart for the method process

7. REVIEW OF RELATED LITERATURE

In a study on 2D and 3D far-field radiation patterns reconstruction based on compressive sensing, the 2D and 3D radiation patterns were obtained to be able to measure far-field radiation patterns with the use of several algorithms [14]. This study was very successful in obtaining its results with the use of 2D radiation pattern analysis. This study involved testing on three different types of antennas namely the half-wave dipole, Vivaldi antenna, and the horn antenna. 2D radiation patterns were then observed and analyzed with the use of the RMSE method to ensure simulated results were accurate to the expected results. Abdullah *et al.* [15], emphasize the importance of H-plane and E-plane analysis to be able to study the omnidirectional and directional antennas in wearable systems. The study encompasses the human-body phantom assuming that the wearable device will be worn on the wrist, torso, or arms. The antenna is now tested at different positions and different lengths and afterward, the radiation pattern is observed. In a study by Mahlaoui *et al.* [16] on the analysis of the character mode to the design of a radiation pattern reconfigurable antenna, a good radiation pattern was obtained in the XZ plane by simulating the 2D radiation pattern. This study observed the XYZ plane by studying the radiation pattern in the XZ plane and YZ plane to be able to determine if the reconfigurable antenna is successful. Not only was this study able to obtain simulated results, but a prototype was also adapted. Once the results of the prototype were obtained, the software was used to analyze the radiation pattern. This study was successful in obtaining its goals; however, it is suggested that more studies need to focus on avoiding cable effects on the antenna's radiation pattern as seen in the 2D radiation patterns obtained in the study to ensure that the design has minimal errors and can be easily adapted in real-life applications. Antennas play a significant role in wireless systems which is why to ensure that the quality and efficiency are maintained optimum performance must be employed in the design. In the study conducted by Saied [17], the evaluation of phone base station antennas was done to measure their performance with the use of the software MATLAB. This study utilized various antenna equations such as the field pattern, gain, and power density where the distance and direction of the base station antenna were varied. The 2D radiation patterns of broadside, collinear, end-fire, and pattern of the antenna used in the site were obtained to conduct multiple sets of analysis and comparison. The obtained 2D radiation pattern was vital in determining the best antenna for mobile phone base stations, in this case, results showed that the best pattern is the collinear array antenna. As radiation pattern acquisition is costly due to the special devices needed, Rea *et al.* [18] create a low measuring system to obtain an approximate radiation pattern. This prototype utilizes a USRP, arduino, current driver, antenna support, cables, and other basic equipment which results in a much more cost-effective acquisition system. This study utilizes measurements at different angles to ensure that the design is fully functional. A reference 2D radiation pattern was created as a basis to compare with the obtained results in the study. Reconfigurable radiation patterns in antennas have become an advent in wireless communication. As the use of telecommunication systems continues to increase over the years, the quality and capacity demands continue to increase as well. By studying the characteristics of the antenna and utilizing various algorithms, Trad *et al.* [19] were able to create a prototype with an efficiency of 75%. The 2D radiation pattern played a vital role in analyzing the performance of the antenna deeming this study a success. The analysis of the dipole antenna radiation pattern using a low-frequency model was obtained with simulations through the software, MATLAB. This study heavily relies on the two-dimensional segment of the radiation pattern's initial 3-dimensional patterns observing both perpendicular and parallel planes. Through this study, it was concluded that the relationship between the length of the antenna and the transmission frequency is that it is inversely proportional to each other. This is significant as technology continues to innovate throughout the years, and the range of frequencies continues to move up causing the antenna used in this device to become smaller and smaller [20]. In this day and age, broadband omnidirectional antennas are essential in applications such as radio broadcasting and wireless local area networks [21]. For such an application, an omnidirectional pattern is ideal but due to various interferences such as thin wires causing narrow bandwidths as the quality factor is significantly high; thus communication systems must have larger bandwidths with greater gains [22]. With this, Li and Li [23] propose a prototype to solve this issue ensuring that the bandwidths of the dipole antenna are enhanced through various approaches. The study was successful as it observed the 2D radiation patterns determining that the gain of 2.0-4.0 dBi was present in the azimuthal plane while achieving an omnidirectional pattern. In a similar study done by Yang *et al.* [24], the dipole was designed to use in 5G applications to implement a multiband omnidirectional antenna by obtaining the proper length for the feed line, improving selectivity without altering the performance. In addition, Khalifa *et al.* [25] were also able to implement this type of antenna in a 4G/5G system obtaining 80% antenna efficiency where the Fairfield directivity was observed based on the simulated 2D radiation patterns at different operating frequencies. In a study by Abdelmottaleb and Shen [26], the analysis of compact and wideband dipole antennas was done by analyzing two dipoles one at the high-frequency band and one at the low-frequency band where the group was able to obtain physical results consistent with the simulated results. This study focuses on the importance of antenna design to be able to employ an antenna that is both compact and wideband. Technology has innovated quickly over the past few years paving the way for various IoT devices. As various devices require wireless power transfer, Lin and Ziolkowski [27] developed an antenna array that has high directivity and is omnidirectional in the H-plane. An omnidirectional polarization is ideal in this case as it should be able to power sensors 360 degrees surrounding it to optimize the use and ensure that the system is indeed smart. This simulation was able to create an OHP and requires future in-depth studies to use its application in real environments. A method of testing in this study was measuring the 2D radiation pattern to observe whether an omnidirectional pattern is achieved. This was done by testing the set-up at various frequencies in the H-plane and E-plane. Similarly, Liu *et al.* [28] prove that analysis in the 2D radiation plot observing the H-plane is an effective means to be able to improving antenna design and exploration. The study conducted by Liu *et al.* [29] proves that MATLAB is an efficient tool for simulating and designing antennas. This was confirmed by the group as the software contains both local and global optimization methods compatible with antenna exploration. This was further confirmed by conducting a study on microwave antennas deeming the software cost-friendly, efficient, and convenient for antenna exploration. Likewise in a study on sidelobe level reduction, the MATLAB software was confirmed to be efficient and accurate in graphing and plotting 2D and 3D radiation patterns making it easier to observe and analyze patterns present in the H-plane and E-plane as the obtain results from the testing the fabricated sample and simulation results were at a good agreement [30].

8. THEORETICAL CONSIDERATIONS

This study will assume that the dipole antenna being simulated is in ideal scenarios. External factors such as physical and spatial constraints will not be considered as the simulations will assume that the researchers have all the space they need for the antennas. The MATLAB antenna library will be used to process the data in this research. This library is a toolbox that provides functions and GUI tools for the design, analysis, and visualization of antenna elements and arrays. It includes antennas for various applications, including mobile communications, wireless LANs, radar, and satellite systems. The library also provides tools for antenna array synthesis and optimization. This library provides a wide range of functions for antenna designers, including built-in support for importing and visualizing antenna geometry, analyzing antenna performance, and working with electromagnetic field data. The library also includes a comprehensive set of tools for optimizing antenna designs.

9. DATA AND RESULTS

This section shows the data and results for the optimized bowtie dipole antenna with an finite-impulse-response (FIR) filter. In batch 1 simulations the width set to length/100 was used. Figure 2 shows the radiation pattern of the E-plane in Length=Lambda/2. Figure 3 shows the radiation pattern of the H-plane in Length=Lambda/2. Figure 4 shows the radiation pattern of the E-plane in Length=Lambda. Figure 5 shows the radiation pattern of the H-plane in Length=Lambda. Figure 6 shows the radiation pattern of the E-plane in Length=Lambda*2. Figure 7 shows the radiation pattern of the H-plane in Length=Lambda*2. Figure 8 shows the radiation pattern of the E-plane in Length=Lambda*10. Figure 9 shows the radiation pattern of the H-plane in Length=Lambda*10. In batch 2 simulations the width set to Length/10 was used. Figure 10 shows the radiation pattern of the E-plane in Length=Lambda/2. Figure 11 shows the radiation pattern of the H-plane in Length=Lambda/2. Figure 12 shows the radiation pattern of the E-plane in Length=Lambda. Figure 13 shows the radiation pattern of the H-plane in Length=Lambda. Figure 14 shows the radiation pattern of the E-plane in Length=Lambda*2. Figure 15 shows the radiation pattern of the H-plane in Length=Lambda*2. Figure 16 shows the radiation pattern of the E-plane in Length=Lambda*9. Figure 17 shows the radiation pattern of the H-plane in Length=Lambda*9.

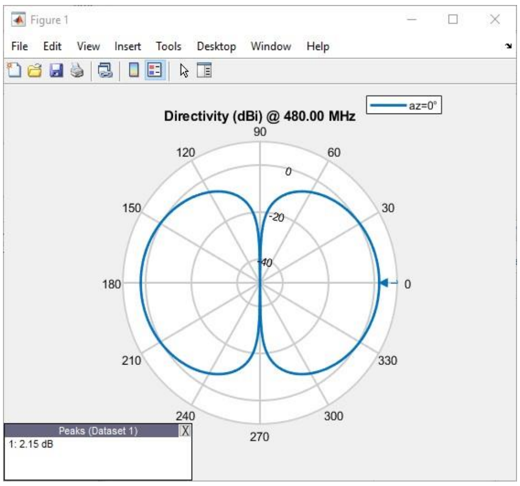

Figure 2. E-plane radiation pattern of batch 1 Length=Lambda/2

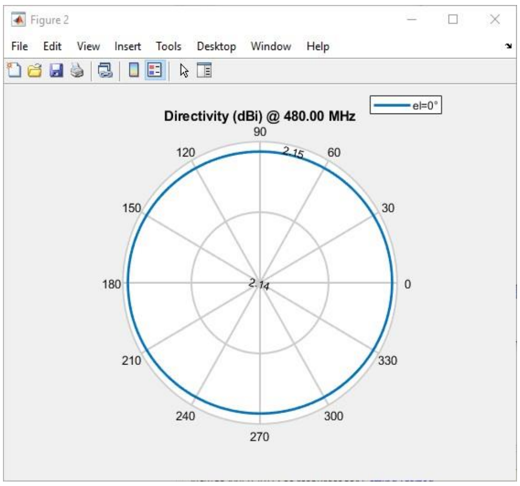

Figure 3. H-plane radiation pattern of batch 1 Length=Lambda/2

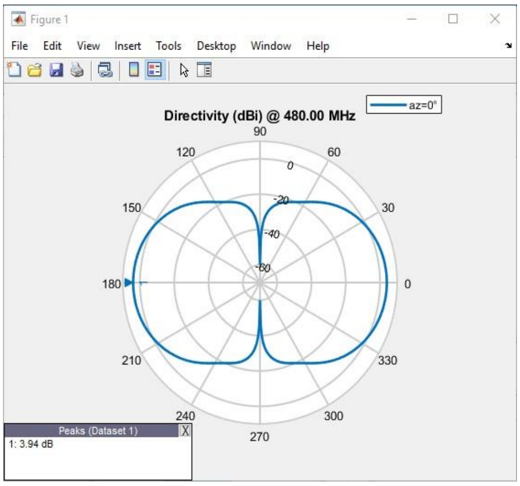

Figure 4. E-plane radiation pattern of batch 1 Length=Lambda

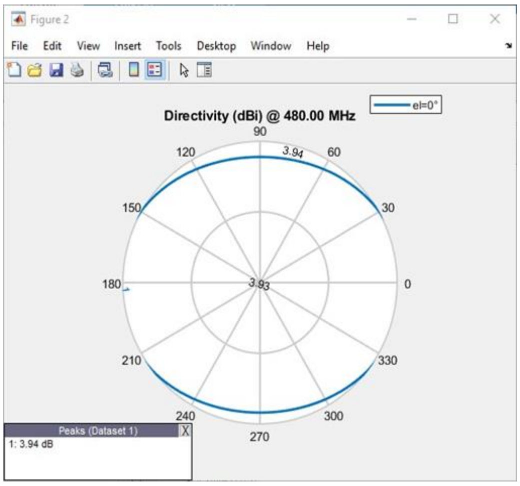

Figure 5. H-plane radiation pattern of batch 1 Length=Lambda

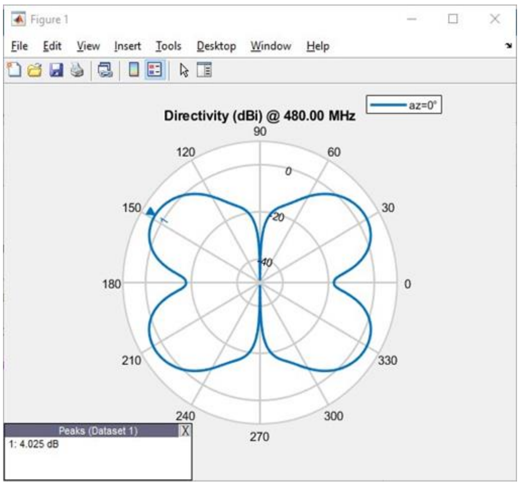

Figure 6. E-plane radiation pattern of batch 1 Length=Lambda*2

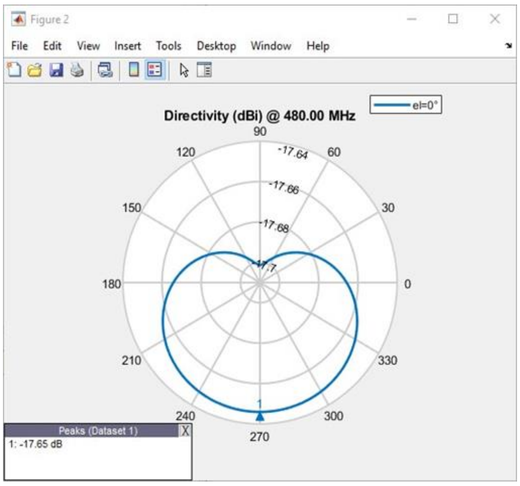

Figure 7. H-plane radiation pattern of batch 1 Length=Lambda*2

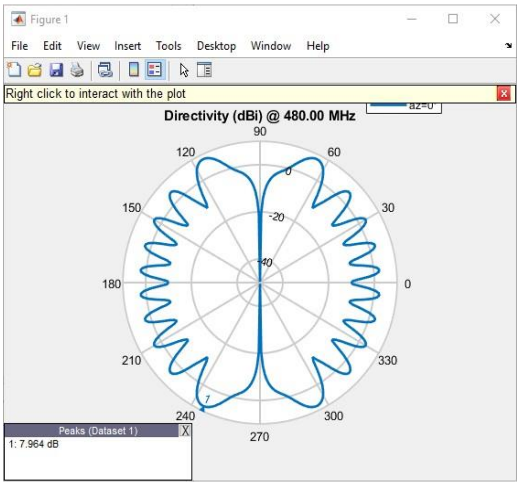

Figure 8. E-plane radiation pattern of batch 1 Length=Lambda*10

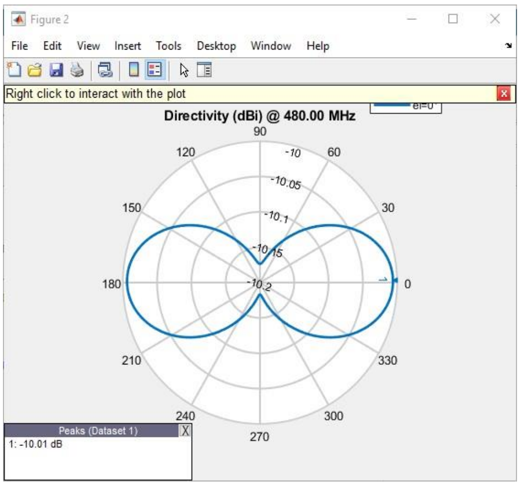

Figure 9. H-plane radiation pattern of batch 1 Length=Lambda*10

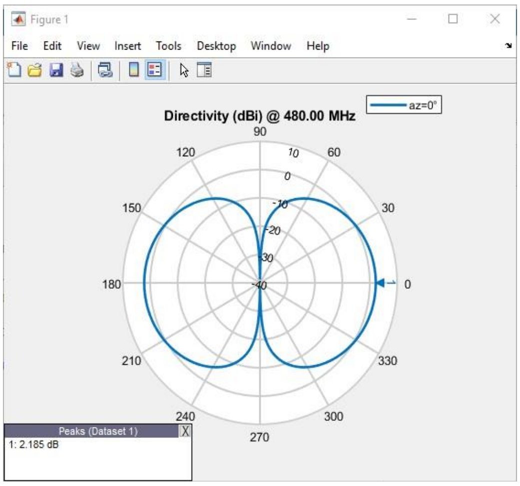

Figure 10. E-plane radiation pattern of batch 2 Length=Lambda/2

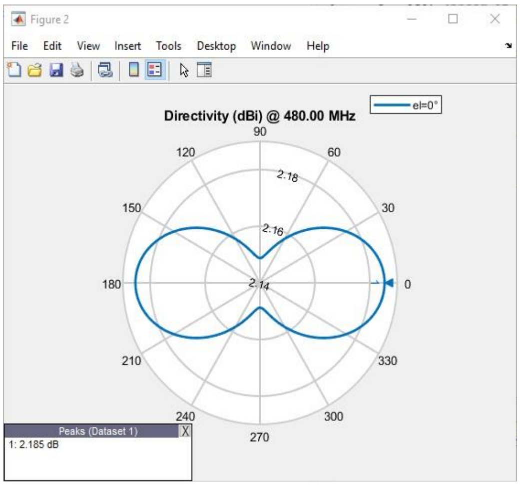

Figure 11. H-plane radiation pattern of batch 2 Length=Lambda/2

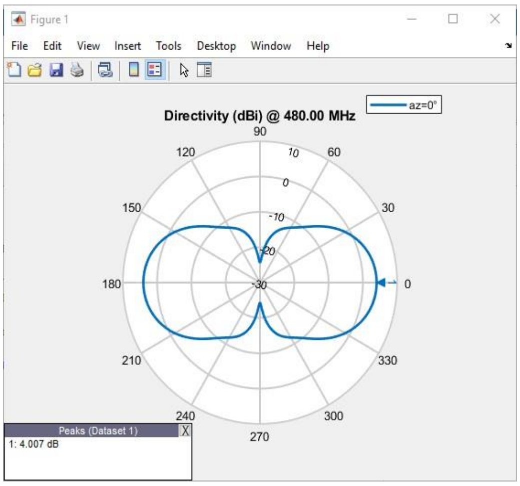

Figure 12. E-plane radiation pattern of batch 2 Length=Lambda

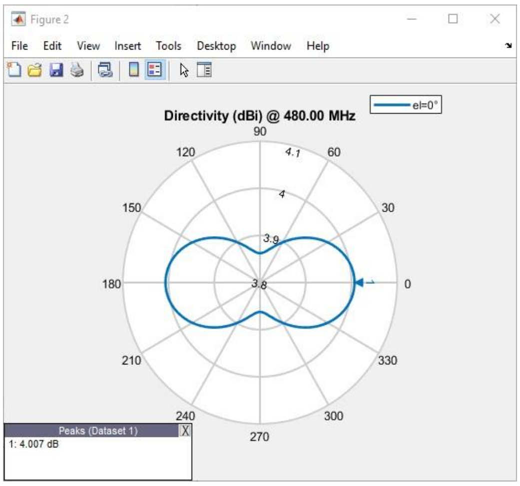

Figure 13. H-plane radiation pattern of batch 2 Length=Lambda

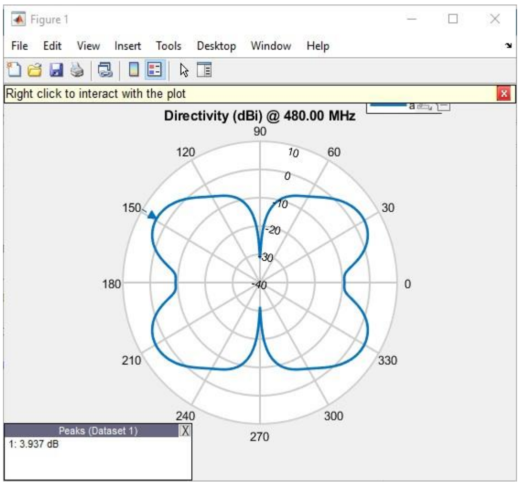

Figure 14. E-plane radiation pattern of batch 2 Length=Lambda*2

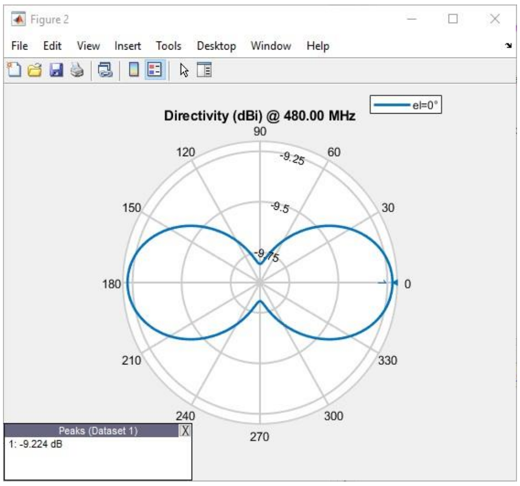

Figure 15. H-plane radiation pattern of batch 2 Length=Lambda*2

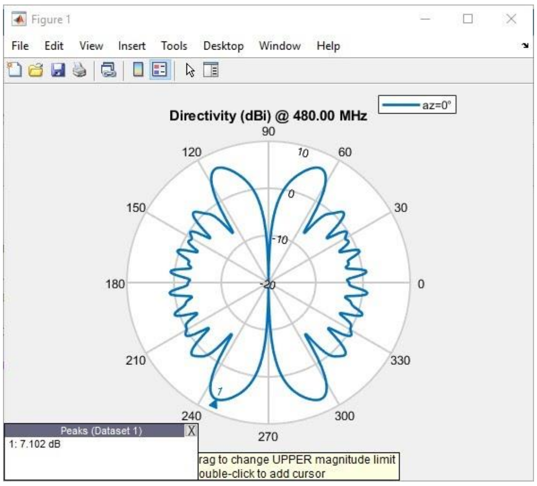

Figure 16. E-plane radiation pattern of batch 2 Length=Lambda*9

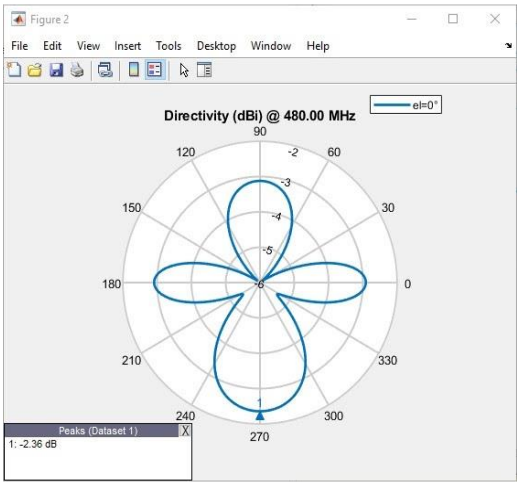

Figure 17. H-plane radiation pattern of batch 2 Length=Lambda*9

10. ANALYSIS OF DATA

For the first batch with an antenna width 1/100 of the length, the initial simulation made use of the ideal length of half of the wavelength. The resulting antenna had an omnidirectional propagation. This can be observed in Figure 2, the H-plane radiation pattern. Increasing the length of the antenna affected the shape of the radiation pattern in both the E-plane and H-plane. The peak value of the E-plane increased, but the shape became more and more distorted as more and more lobes grew out. The number of lobes seemed to coincide with the integer value length of the length. An antenna with a length 4 times the wavelength would have an E-plane radiation pattern with 4 lobes on each side, and an antenna with a length 10 times the wavelength would have an E-plane radiation pattern with 10 lobes on each side. The H-plane radiation pattern, on the other hand, would have significantly varying outcomes depending on the length. At the ideal length of half the wavelength, the H-plane radiation pattern is omnidirectional with a peak value of 2.15 dB. At a length twice the wavelength, the H-plane radiation pattern is directional with a cardioid pattern, but the peak value is very low at -17.65 dB. This can be seen in Figure 7. But at a length thrice the wavelength, the H-plane radiation pattern is somewhat bidirectional with a peak value of 2.422 dB.

11. CONCLUSION AND RECOMMENDATIONS

The optimized bowtie dipole antenna with an FIR filter simulated in MATLAB is practical due to MATLAB's antenna library. With a few defined variables and functions, MATLAB was able to simulate an antenna with certain properties according to the desired perspectives. For this study, those perspectives were the E-plane, H-plane, and beamwidth. The functions MATLAB has allowed for an easy and specific definition of parameters. As observed in the study, the E-plane and H-plane characteristics of a dipole antenna vary depending on the lengths and widths used. When an ideal dipole antenna is designed, the antenna creates an omnidirectional pattern, but when the length is varied, the pattern becomes bidirectional, or sometimes directional. What is interesting is that the variations mostly maintain consistency except in certain scenarios where the radiation pattern varies drastically. It was interesting to observe how the E-plane developed more lobes as the length increased. Furthermore, the E-plane radiation patterns behavior did not have the abrupt variations the H-plane showed.

For future studies, the researchers suggest simulating the 3D radiation patterns as well. This is because some observable characteristics may not be easily seen from 2D perspectives. Furthermore, the researchers suggest future studies utilize more factors when simulating antenna dipoles to create more realistic results as the results obtained are for more ideal conditions.

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REFERENCES

[1] Y. Lu, J. Chen, and X. Yu, "Design of a Single Zero Compensation Dipole Antenna," in *2019 Photonics and Electromagnetics Research Symposium-Fall (PIERS-Fall)*, Dec. 2019, doi: 10.1109/piers-fall48861.2019.9021447.
[2] W. Fan, J. Han, L. Yao, F. Wu, and Y. Liu, "Latency-energy optimization for joint WiFi and cellular offloading in mobile edge computing networks," *Computer Networks*, vol. 181, 2020, doi: 10.1016/j.comnet.2020.107570.
[3] W. Lin and R. W. Ziolkowski, "High-Directivity, Compact, Omnidirectional Horizontally Polarized Antenna Array," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 8, pp. 6049–6058, Aug. 2020, doi: 10.1109/tap.2020.2983786.
[4] E. Li, X. J. Li, B.-C. Seet, and X. Lin, "Ink-printed flexible wideband dipole array antenna for 5G applications," *Physical Communication*, vol. 43, p. 101193, Dec. 2020, doi: 10.1016/j.phycom.2020.101193.
[5] I. Bouhassoune, H. Chaibi, A. Chehri, R. Saadane, and K. Menoui, "Review of Internet of Things and Design of New UHF RFID Folded Dipole with Double U Slot Tag," in *Human Centred Intelligent Systems*, Springer Singapore, 2020, pp. 281–291, doi: 10.1007/978-981-15-5784-2_23.
[6] N. Bourey, M. Darces, Y. Chatelon, and M. Hélier, "Near-field to far-field transformation applied to UHF antennas over lossy ground," *International Journal of Microwave and Wireless Technologies*, vol. 12, no. 3, pp. 227–232, Sep. 2019, doi: 10.1017/s1759078719001272.
[7] D. R. Kaufman, "Industrial Wireless Technology and Planning," in *Instrumentation Reference Book*, Elsevier, 2010, pp. 253–265, doi: 10.1016/b978-0-7506-8308-1.00020-6.
[8] A. Bensky, "Antennas and transmission lines," in *Short-range Wireless Communication*, Elsevier, 2019, pp. 43–83, doi: 10.1016/b978-0-12-815405-2.00003-8.
[9] "MATLAB - MathWorks." https://www.mathworks.com/products/matlab.html (accessed Dec. 29, 2022).
[10] D. Poljak and M. Cvetković, "Theoretical Background: an Outline of Computational Electromagnetics (CEM)," in *Human Interaction with Electromagnetic Fields*, Elsevier, 2019, pp. 21–52, doi: 10.1016/b978-0-12-816443-3.00010-8.
[11] J. Deepa, S. Santhanam, N. Vasudevan, and S. S. Chandran, "Substrate integrated waveguide antenna with dual rectangular slots for material characterization for ISM band applications," *Materials Today: Proceedings*, vol. 69, pp. 1493–1497, 2022, doi: 10.1016/j.matpr.2022.10.160.
[12] M. J. Chashmi, P. Rezaei, A. H. Haghparast, and D. Zarifi, "Dual circular polarization 2×2 slot array antenna based on printed ridge gap waveguide technology in Ka band," *AEU-International Journal of Electronics and Communications*, vol. 157, p. 154433, Dec. 2022, doi: 10.1016/j.aeue.2022.154433.
[13] K. Ghaemi and N. Behdad, "A low-profile, compact, wideband antenna array with cardioid-shaped radiation patterns in the azimuth plane," in *2015 International Workshop on Antenna Technology (iWAT)*, Mar. 2015, doi: 10.1109/iwat.2015.7365353.
[14] B. Verdin and P. Debroux, "2D and 3D far-field radiation patterns reconstruction based on compressive sensing," *Progress In Electromagnetics Research M*, vol. 46, pp. 47–56, 2016, doi: 10.2528/pierm15110306.
[15] M. W. Abdullah, X. Fafoutis, M. Klemm, and G. S. Hilton, "Radiation Pattern Analysis of Single and Multi-Antenna Wearable Systems," in *2016 IEEE 84th Vehicular Technology Conference (VTC-Fall)*, Sep. 2016, doi: 10.1109/vtcfall.2016.7881186.
[16] Z. Mahlaoui, E. A-Daviu, A. Latif, and M. F-Bataller, "From the Characteristic Modes Analysis to the Design of a Radiation Pattern Reconfigurable Antenna," in *2019 13th European Conference on Antennas and Propagation (EuCAP)*, Mar. 2019, pp. 1–4.
[17] S. H. Saeid, "Measurement-Based Analysis and Evaluation of Performance of Mobile Phones Base Stations Antenna," in *2015 IEEE International Conference on Computational Intelligence and Communication Technology*, Feb. 2015, doi: 10.1109/cict.2015.16.
[18] F. M. Rea, N. Tovar, M. F. Barba, and J. C. Aviles, "Approximate Antenna Radiation Pattern Determination Using a Low Cost Measuring System at 2.4 GHz," in *2018 IEEE 10th Latin-American Conference on Communications (LATINCOM)*, Nov. 2018, doi: 10.1109/latincom.2018.8613212.
[19] I. B. Trad, J. M. Floc'h, H. Rmili, M. Drissi, and F. Choubani, "A Planar Reconfigurable Radiation Pattern Dipole Antenna with Reflectors and Directors for Wireless Communication Applications," *International Journal of Antennas and Propagation*, vol. 2014, pp. 1–10, 2014, doi: 10.1155/2014/593259.
[20] T. Shejbal, M. Petkov, T. Zalabsky, J. Pidanic, and L. Zaplatilek, "The workplace for automatic measurement of antennas' radiation patterns," in *2014 24th International Conference Radioelektronika*, Apr. 2014, doi: 10.1109/radioelek.2014.6828490.
[21] H. Wang and I. Park, "Characteristics of the Angled Printed Dipole Array Antenna with Different Numbers of Dipole Elements," *Journal of Electromagnetic Engineering and Science*, vol. 20, no. 3, pp. 183–189, Jul. 2020, doi: 10.26866/jees.2020.20.3.183.
[22] Y. Shi and J. Liu, "Investigation of a Via-Loaded Microstrip Magnetic Dipole Antenna With Enhanced Bandwidth and Gain," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 7, pp. 4836–4841, Jul. 2019, doi: 10.1109/tap.2019.2913686.
[23] H. Li and Y. Li, "Mode Compression Method for Wideband Dipole Antenna by Dual-Point Capacitive Loadings," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 8, pp. 6424–6428, Aug. 2020, doi: 10.1109/tap.2020.2972642.
[24] S. J. Yang, H. F. Su, Y. Wu, and X. Y. Zhang, "Dual-polarized Low-profile Wideband Filtering Antenna for 5G Applications," in *2019 Photonics and Electromagnetics Research Symposium-Fall (PIERS-Fall)*, Dec. 2019, doi: 10.1109/piers-fall48861.2019.9021395.
[25] M. Khalifa, L. Khashan, H. Badawy, and F. Ibrahim, "Broadband Printed-Dipole Antenna for 4G/5G Smartphones," *Journal of Physics: Conference Series*, vol. 1447, no. 1, p. 012049, Jan. 2020, doi: 10.1088/1742-6596/1447/1/012049.
[26] A. A. Omar and Z. Shen, "Compact and Wideband Dipole Antennas," in *2019 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)*, Sep. 2019, doi: 10.1109/apwc.2019.8870425.
[27] W. Lin and R. W. Ziolkowski, "High Directivity, Omnidirectional Horizontally Polarized Antenna Array for Wireless Power Transfer in Internet-of-Things Applications," in *2020 14th European Conference on Antennas and Propagation (EuCAP)*, Mar. 2020, doi: 10.23919/eucap48036.2020.9135789.
[28] N.-W. Liu, L. Zhu, G. Fu, and Y. Liu, "A Low Profile Shorted-Patch Antenna With Enhanced Bandwidth and Reduced H-Plane Cross-Polarization," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 10, pp. 5602–5607, Oct. 2018, doi: 10.1109/tap.2018.2855730.
[29] B. Liu, A. Irvine, M. O. Akinsolu, O. Arabi, V. Grout, and N. Ali, "GUI design exploration software for microwave antennas," *Journal of Computational Design and Engineering*, vol. 4, no. 4, pp. 274–281, Apr. 2017, doi: 10.1016/j.jcde.2017.04.001.
[30] A. H. Hussein, M. A. Metawe'e, and H. H. Abdullah, "Hardware implementation of antenna array system for maximum SLL reduction," *Engineering Science and Technology, an International Journal*, vol. 20, no. 3, pp. 965–972, Jun. 2017, doi: 10.1016/j.jestch.2016.11.014.

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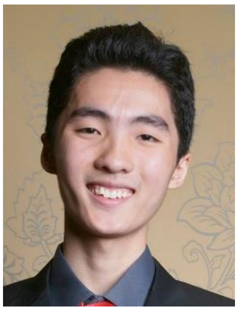

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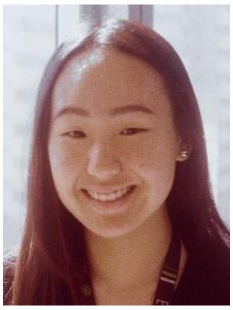

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