

Review

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PERFORMANCE ANALYSIS OF DIPOLE ANTENNA APPLICATIONS : A LITERATURE REVIEW

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Review

Performance Analysis of Dipole Antenna

Applications: A Literature Review

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Abstract: Dipole antennas, fundamental components in wireless communication systems, have garnered significant attention due to their versatility and efficiency across various applications. This literature review explores the performance analysis of dipole antennas, focusing on recent advancements and methodologies from 2019 to 2024. Employing a systematic approach, the review synthesizes findings from multiple databases, emphasizing peer-reviewed studies that delve into dipole antenna designs and applications. Through meticulous data extraction, key parameters influencing dipole antenna performance, such as material properties and operating frequency, are identified and analyzed. Results highlight the widespread utilization of dipole antennas in wireless communication systems, including indoor positioning, mobile communication, and antenna calibration, among others. Discussions underscore the evolution of dipole antennas in base station environments and their role in filtering applications. The review concludes by emphasizing the continued relevance and evolution of dipole antennas, showcasing their adaptability and potential across diverse wireless communication contexts.

Keywords: dipole antennas; performance analysis; wireless communication; impedance matching; optimization techniques

I. Introduction

Dipole antennas, a fundamental type of antenna, are widely used in various applications due to their simplicity and versatility in telecommunication applications which consist of two identical conductive metal wires. [1]. Dipole antenna performance is dependent on many parameters such as metal conductivity, length, radius of wire, surrounding medium, feeding point and etc. These antennas consist of two conductive elements, typically rods, that are fed with a sinusoidal voltage differential [2]. The frequency of operation can be adjusted by changing the distance between the two elements [3]. This adjustability makes them suitable for a range of applications, including RF energy harvesting [4]. Building on this basic structure, dipole antennas can be enhanced with additional features, such as p-i-n diodes for frequency reconfigurability [5]. Furthermore, they are also widely used in wireless communication due to their compact size and efficient impedance matching [6]. Recent advancements have focused on reducing their dimensions while maintaining performance [7], and enhancing their reconfigurability for different frequency bands [5].

Reflectors have been introduced to improve their radiating characteristics, particularly for 5G applications [8]. In addition, compact printed dipole antennas have been developed for GPS/WiMAX applications [6], while V-shape dipole antennas have been designed for radio astronomical observation [9]. These advancements underscore the significance of dipole antennas in improving signal quality and system performance across different applications. The fundamental electromagnetic theory underlying dipole antennas has been extensively explored in recent research.

Investigations into the radiation characteristics of horizontal and vertical electric dipole antennas over dielectric-coated impedance surfaces have been conducted [10,11]. Transformation electromagnetics has been used to design a material that transforms the field from a horizontal dipole to that of a vertical dipole [12].

Impedance tuning and bandwidth enhancement are key areas of focus in the ongoing development of dipole antennas. A range of methods for impedance tuning and bandwidth enhancement have been proposed, including the use of wideband impedance matching balun for balanced two-arm antennas [13], and the design of an optimal matching stack that provides flat broadband transmission [14].

Finally, a range of optimization techniques have been proposed to improve the performance of dipole antennas. These include machine learning-based approaches [15], computationally-efficient design optimization methods using accelerated gradient search algorithms [16], and electromagnetic bottom-up optimization strategies for automated antenna designs [17]. These collectively demonstrate the potential of various numerical simulation, electromagnetic modeling, and optimization algorithms in enhancing the performance of dipole antennas. Through that, this literature review seeks to identify and analyze the various parameters that affect the performance of dipole antenna configurations, including material properties and operating frequency. Also, to summarize the existing gaps and challenges in the field of dipole antenna performance analysis and suggest avenues for future research.

II. Related Studies

A range of experimental validations of dipole antenna designs have been conducted, demonstrating the effectiveness of these designs in various applications. This part shows studies or practical applications showcasing the performance and effectiveness of dipole antennas in real-world scenarios.

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 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. [18]

Design, simulation, and measurement of printed dipole array antennas are presented. The dipole element is fed by a log-periodic microstrip balun. The balun converts the unbalanced microstrip line into a balanced two-wire line feeding the dipole. Two-element and four-element dipole arrays are designed by using Wilkinson power divider parallel feeding networks. The arrays are designed using an inexpensive FR4 dielectric material. The height of the dielectric substrate is 1.6mm and its dielectric constant is 4.5. The proposed antennas are simulated using CST MWS electromagnetic simulator. The simulated impedance bandwidths are 27.5%, 29.5%, and 28.6% whereas the realized gains are 4.2dB, 7.2 dB, and 9.7dB for the single element, two-element, and four-element designs respectively. The two-element array has been manufactured and tested. The simulated results agree well with the measured ones. The obtained bandwidths are 29.5% and 27.9% from simulation and measurement respectively. The centre frequency of the measurement result is slightly shifted up towards 2.15GHz. This is mainly due to the dielectric constant which is not well-defined and can take any value from 4 to 5. [19]

This paper proposes an array antenna at 28 GHz that can be used to measure polarimetric omnidirectional pathloss. The array consists of a printed microstrip dipole and loop with an integrated tapered balun structure. The design and experimental results of low profile microstrip dipole and loop antenna show wideband matching and radiation performance. Over 6 GHz of -10 dB impedance matching bandwidth has been achieved for the dipole, whereas the loop shows 0.2 GHz ranging from 27.9 to 28.1 GHz. A fairly-good agreement between the simulated and measured radiation pattern validates their simulation method. The omnidirectional behaviors of both dipole and loop make it suitable as a reference antenna for over-the-air antenna testing at 28 GHz [20].

This paper presents two compact textile-based planar dipole and loop antennas for wearable communication applications operating in the 2.4 GHz industrial, scientific, and medical radio (ISM) bands. The antennas were fabricated on a 0.44 mm thin camouflaged-military print, cotton jean cloth using conductive copper threads, and sewing embroidery technique to create the radiating structure. Design and performance analyses of the antennas were carried out using simulations; further experiments were performed in anechoic chamber and indoor environment to validate the designs. The experiments were carried out in a free space scenario and on the various locations of the human subject such as the torso and limb joints. The performance of the antennas was investigated based on the reflection coefficient in normal and bent conditions corresponding to the different radii of the locations of the human limbs. The antennas perform well in free space and on-body scenarios in flat and bend conditions providing return loss below -10 dB in all cases with an acceptable resonant frequency close to 2.4 GHz due to the antenna bending and body effects. The radiation pattern measurements are also reported in this work for free space and on-body scenarios. It is observed that the presence of the human body significantly influences the antenna radiation pattern which leads to an increase in the front-to-back ratio and also makes the antenna more directive. Overall, the performance of the fabricated embroidered textile antennas was found suitable for various wearable body-centric applications in indoor environments. [21]

Ideal dipole antennas are desirable for antenna calibration. However, real-world implementation issues introduce inevitable nonideal effects that can significantly affect the quality of calibration. In this communication, a 2 GHz standard dipole (SD) antenna is presented with an excellent overall performance. This result is achieved by an innovative design with an optimized element shape and an embedded (shielded) balun. The designed feeding structure is a balanced structure that transitions from parallel strip lines to coaxial lines. The feeding method avoids the impact of electromagnetic environment asymmetry while achieving an appropriate balance. The measured relative bandwidth of the dipole exceeds 15%, and the antenna gain is approximately 2 dBi. The cross-polarization ratio is greater than 27 dB in the horizontal plane, and the horizontal gain variation is less than 0.2 dB. The dipole has a symmetrical vertical plane pattern, and the maximum gain point does not deviate from the horizontal plane. The high performance of this SD makes it suitable for antenna calibration [22].

Emerging wireless applications call for flexible antenna designs that operate efficiently regardless of their host structures. A study of the performance of an inkjet printed dipole antenna for blood irradiation applications is presented. Simulations and measurements show that a blood environment can significantly impact antenna performance. The radiation pattern of the dipole antenna is significantly degraded when placed on a host blood bag, with a simulated maximum gain of -18 dBi at 2.45 GHz. To isolate the antenna from the host structure, the dipole antenna is integrated with an AMC structure operating at 2.45 GHz. In spite of the presence of the lossy host, simulations and measurements show a significant improvement in the antenna gain. Simulated and measured gains of 6.4 dBi and 4.1 dBi are attained by integrating the AMC ground plane [23]

A folded planar dipole antenna was designed and customized to operate close to the human body. Backward radiation was reduced to protect the human body from unwanted electromagnetic (EM) emissions and increase the antenna's operating range. The antenna design was based on the concept of a folded planar dipole, which presents favorable impedance bandwidth (BW) characteristics. For integrability and robustness during usage in real environments, the antenna was completely covered by resin, taking into account the tradeoff between the antenna's radiation

performance, protection, and isolation. Measurements demonstrated a 10-dB impedance BW of 470 MHz (18.76%) covering the 2.27–2.74-GHz band. The maximum gain at 2.45 GHz was 1.4 dB isotropic (dBi). The antenna has a nearly omnidirectional pattern, occupies $77 \times 35 \times 11.15$ mm, and weighs 120 g, making it easy to integrate with clothes. The resin packaging increased the mechanical robustness and improved the design's isolation from external interference and perturbations; however, it reduced the radiation efficiency to 48.35%. The presented antenna is an excellent candidate for many wireless applications, in particular, applications where withstanding exposure to external mechanical strains and EM perturbations is required [24]

The radiation performance of a dipole antenna on a diamond-structured photonic crystal (PC) substrate with point defects fabricated using three-dimensional (3D) printing technology has been investigated. Meanwhile, according to the reflection properties of the PCs, corresponding dipole antennas were fabricated and packaged with standard coaxial lines. The experimental results showed a strong radiation frequency of the dipole antenna at about 13 GHz, in basic agreement with the strongest reflection frequency of the PCs with point defects. The experimental results also show that the maximum gain of the major lobe in the dipole antenna was close to -67 dB, while the angular range of the major lobe was 5 – 55° . The maximum gain of the major lobe increased to -60 dB in the composite antenna, representing an improvement of 7 dB compared with the dipole antenna, while the width range of the major lobe was 240 – 270° . These results show that the use of such substrates based on diamond-structure PCs with point defects could significantly improve the gain and directivity of the antenna, providing a basis for engineering applications [25]

III. Methodology

This review employs a systematic and detailed method to examine the performance analysis of dipole antennas. The following specific techniques are used to guarantee a thorough assessment.

A. Strategy for Literature Search

The search strategy is structured to discover and scrutinize the latest progress in dipole antenna setups. This strategy emphasizes two primary elements:

- **Time Frame:** The focus is on studies published from 2019 to 2024 to encompass the most recent advancements in the analysis of dipole antenna performance.
- **Choice of Database:** A range of databases and platforms, such as IEEE Xplore, ScienceDirect, ResearchGate, Scopus, Litmaps, and Google Scholar, are methodically searched. Search results are refined using keywords like "dipole antenna," "dipole antenna performance analysis," and "printed dipole arrays". Boolean operators are employed to strike a balance between breadth and precision.

B. Setting Inclusion and Exclusion Criteria

Strict criteria are established to assure the quality and pertinence of the studies reviewed, with a focus on impactful and meticulously conducted research.

Criteria for Inclusion:

- Priority is given to peer-reviewed articles, conference papers, and pertinent reviews that concentrate on the performance analysis of dipole antennas.
- Studies that investigate a broad array of dipole antenna designs and uses are included to provide a complete understanding of the current state-of-the-art.

Criteria for Exclusion:

- Studies that lack well-defined methodologies or in-depth performance analysis are excluded to keep the focus on robust research.
- Publications not in English are excluded to maintain consistency and clarity.

C. Process for Detailed Data Extraction

Once relevant studies are identified, a careful data extraction process is carried out, which includes the following steps:

- **Development of an Extensive Extraction Grid:** An extraction grid is created to enable consistent data extraction, including crucial data elements.
- **In-depth Information Extraction:** Important details such as bibliographic information, antenna design parameters, simulation and measurement techniques, and key performance metrics are extracted from each chosen study.
- **Recording Performance Metrics and Limitations:** Performance metrics and any cited limitations are recorded to facilitate a comparative analysis of various dipole antenna setups and pinpoint potential research challenges.

This methodological approach uses a multi-dimensional exploration to discover and analyze the latest progress in dipole antenna performance analysis, ensuring a thorough understanding of the field.

IV. Results and Discussion

A.

Table 1 shows the studies included in the literature review after the identification and screening techniques. From the table, it is shown that dipole antenna applications highlight their widespread use in various industries and technologies. At the top are wireless communication systems, followed by RFID applications, GPS, and WiMAX. Mobile communications and directional finding systems come next, with specialized uses including wireless body area networks, RF energy harvesting, and radio astronomy. Lastly, dipole antennas serve in infrared sensing and antenna calibration

Table 1. Synthesized Studies.

Ref	Lead Author	Year	Title	Application	Analysis
[24]	Benmahmoud	2023	Wearable Folded Planar Dipole Antenna: Design and assessment for on-body wireless communication devices	Wireless communication devices designed to operate close to the human body.	<ul style="list-style-type: none"> - Utilizes folded planar dipole concept for favorable impedance bandwidth characteristics. - Achieves a 10-dB impedance bandwidth of 470 MHz covering the 2.27–2.74-GHz band. - Nearly omnidirectional radiation pattern. - Suitable for wireless applications requiring exposure to external mechanical strains and electromagnetic perturbations.

[26]	Berdnik	2021	Triple-Band Dipole Antenna for Wireless Communication Systems	- Mobile communications operating in GSM 900, GSM 1800, and WiMAX ranges.	- Designed based on optimization modeling with three resonant frequencies.
[6]	Patel	2021	Surface Mountable Compact Printed Dipole Antenna for Gps/Wimax Applications	- GPS and WiMAX applications.	- Low-profile, electrically compact, and cost-effective antenna design. - Self-complementary dipole elements for efficient impedance matching. - Covers 1.57 GHz and 3.65 GHz frequencies with measured impedance bandwidths.
[27]	Firdaus	2020	Study on Impedance Matching of 2.4 GHz Dipole Antenna	- Impedance matching of a 2.4 GHz dipole antenna to a feedline using bazooka and balun.	- Optimization of antenna and feedline length for impedance adjustment. - Antenna length optimized to 0.35λ and feedline length to 0.5λ . - Bazooka and balun lengths for best impedance adjustment are 0.25λ and 0.2λ , respectively.
[28]	Ismail	2020	Meander Dipole Antenna for Low Frequency Applications	- Dual-band printed Meander dipole antenna for low frequency and Ground Penetrating Radar (GPR) applications.	- Operates at 73 MHz and 145.75 MHz with a 70% reduction in length compared to a regular dipole. - Achieves reflection coefficient of -15 dB and -18.5 dB with bandwidths of 2 MHz and 6.6 MHz, respectively. - Exhibits omnidirectional radiation characteristics with

					high radiation efficiency up to 87%.
[29]	Adjali	2020	Matching Evaluation of Highly Coupled Dipoles Quantified by a Statistical Approach	- Analysis of electromagnetic coupling between randomly distributed dipole antennas.	Utilizes statistical approach to assess input impedance of surrounded dipole under various loading conditions. - Focuses on UHF RFID use cases where tag antennas are concentrated in reduced volumes.
[15]	Neelamraju	2023	Machine Learning based Low-Scale Dipole Antenna Optimization using Bootstrap Aggregation	- Optimization of dipole antenna parameters using Machine Learning (ML) algorithms.	- Tests ML algorithms for elucidating minor trends in device profiles. - Proposes a bootstrap aggregation model concatenating Linear Regression, Support Vector Regression, and Decision Tree Regression algorithms.
[30]	Moreno	2021	Impedance-Matching Technique for an Infrared Folded Dipole Antenna	- Solution for the impedance mismatch challenge in antenna-coupled infrared detectors.	- Modifications of folded dipole antenna geometry to increase input impedance. - Numerical simulations and experimental measurements confirm input impedance of 1 k Ω or above.
[23]	Sanusi	2020	Impact of Blood Environment on Integrated Antenna Performance	- Study of inkjet printed dipole antenna performance for blood irradiation applications.	- Blood environment significantly impacts antenna performance, degrading radiation pattern. - Integration with an artificial magnetic conductor (AMC) structure improves antenna gain despite the lossy host.

[4]	Mansour	2020	High-Gain Simple Printed Dipole-Loop Antenna for RF-Energy Harvesting Applications	- Compact dual-band antenna for RF energy harvesting applications.	- Combination of dipole and loop antenna structures operating at 900 MHz and 1600 MHz. - Measured fractional bandwidth and peak gain, compact size compared to similar designs. - Prototype fabrication, testing, and comparison of measurements with simulation results.
[31]	Tang	2022	Enhancing the Directivity of Antennas Using Plasma Rings	- Improving the radiation directivity of dipole antennas by placing plasma rings in close proximity.	- Simulation results show appreciable enhancement in gain without affecting antenna impedance matching characteristics. - Dependency of gain enhancement on plasma parameters is analyzed. - Experimental validation using an inexpensive commercial fluorescent lamp.
[25]	Chen	2020	Enhanced Transmission Performance of a Dipole Antenna Based on a Ceramic Diamond-Structure PBG Substrate with a Defect Cavity	- Investigating radiation performance of dipole antenna on a diamond-structured photonic crystal (PC) substrate with point defects.	- Experimental results demonstrate strong radiation frequency at about 13 GHz and improved gain and directivity. - Use of diamond-structure PCs with point defects significantly enhances antenna performance.
[32]	Gil	2019	Embroidery manufacturing techniques for textile dipole antenna	- Design and testing of textile dipole antennas for wireless body area network applications.	- Medium stitch density embroidery patterns, satin fill, and contour fill, impact

			applied to wireless body area network		dipole performance in cotton and felt textile substrates. - Notable antenna parameter results in terms of return loss, radiation pattern, realized gain, and efficiency.
[3]	Hashemi	2019	Dipole Antenna Based on Forward-Coupling Multilayer Ring Resonators (MRR)	- Novel compact dipole antennas based on forward-coupling configuration of multilayer ring resonators (MRR) structure.	- Structure allows for tunable frequency of operation by changing distance between two radiating elements. - Bidirectional radiation pattern with peak gain of 2.8 dBi. - Good impedance matching and return loss better than 35 dB obtained.
[5]	Jin	2020	Differential Frequency-Reconfigurable Antenna Based on Dipoles for Sub-6 GHz 5G and WLAN Applications	- New differential frequency-reconfigurable antenna based on dipoles.	- Resonates at two states, centered at 3.5 and 5.5 GHz, respectively, achieved by switching p-i-n diodes. - Similar radiation patterns for both states, wide bandwidth, and good impedance matching.
[9]	Anwar	2019	Development of V-Shape Dipole Antenna for 20 MHz Astronomical Observation	- V-shape dipole antenna for 20 MHz radio astronomical observation.	- Low SWR, wide beamwidth, and achievable maximum gain of 7.85 dBi. - Prototype constructed and installed for radio astronomy research.
[8]	Ramanujam	2022	Design of reflector-based dipole antenna for sub-6GHz 5G applications	- Reflector-based printed dual dipole antenna for 5G sub-6 GHz applications.	- Wide bandwidth of 44.2%, power reflection coefficient of < -10 dB, average gain of 7.23 dBi, and radiation efficiency > 83%.

[33]	Sharma	2022	Design of antenna by amalgamating staircase and hexagonal ring-shaped structures with the modified ground plane for multi-standard wireless applications	- Antenna designed for multi-standard wireless applications.	- Enhanced bandwidth and reflection coefficient with resonances at multiple frequency bands. - Satisfactory parameters such as gain, radiation efficiency, and radiation patterns for wireless operations.
[20]	Miah	2019	Design of a Reference Dipole-Loop Antenna Array at 28 GHz	- Array antenna for measuring polarimetric omni-directional pathloss at 28 GHz.	- Wideband matching and radiation performance achieved for both dipole and loop. - Impedance matching bandwidth of over 6 GHz for the dipole and 0.2 GHz for the loop.
[34]	Park	2019	Design and fabrication of triple-band folded dipole antenna for GPS/DCS/WLAN/WiMAX applications	- Triple-band folded dipole antenna for GPS/DCS/WLAN/WiMAX applications.	- Bilateral symmetric structure and coupling by adding stubs enable triple-band operation. - Stable radiation pattern with moderate gain achieved at desired frequency bands.
[35]	El Bekkali	2021	Crossed Dipole Antenna for RFID applications	- Crossed dipole antenna for 2.45 GHz ISM band RFID readers.	- Symmetric radiation pattern with high return loss, good impedance matching, and efficiency >95%. - Low profile, low cost, and good performances suitable for microwave RFID readers.
[36]	Perez-Miguel	2020	Comparison of Four High Performance Dual Polar	- Comparison of cross-dipole antennas for base	- Evaluation based on parameters such as mutual coupling, return losses, gain

			Antennas for Base Stations	stations of cellular systems.	stability, beamwidth, cross-pol discrimination, and tracking error. - Each antenna type has advantages and limitations depending on specific application requirements.
[37]	Aliakbari	2019	Characteristic Mode Analysis of Planar Dipole Antennas	- Analysis of planar monopole antennas based on image theory and dipole counterparts.	- Study of bandwidth and radiation pattern of planar dipoles using characteristic mode analysis. - Tradeoff observed between pattern stability and impedance bandwidth with varying dipole width. - Offset in feed point leads to degradation in both modal and impedance bandwidths.
[19]	Mansour	2023	Broadband Printed Dipole Array Antennas	Design, simulation, and measurement of printed dipole array antennas for broadband applications.	Simulated impedance bandwidths: 27.5%, 29.5%, and 28.6% for single element, two-element, and four-element designs respectively. - Realized gains: 4.2dB, 7.2 dB, and 9.7dB for single element, two-element, and four-element designs respectively. - Good agreement between simulated and measured results.
[38]	Wu	2021	Bandwidth Enhancement of Broadband Dual-Polarized Dipole Antenna for 5G Base Station	- Bandwidth enhancement method for broadband dual-polarized dipole antenna aimed at	- Antenna element in the shape of a four-leaf clover. - Wide impedance bandwidth of 72.4%

				5G base station applications.	achieved with (from 1.32 to 2.82 GHz). - High isolation (>30dB) within the bandwidth. - Stable radiation pattern with maximum half-power beamwidth of 76.3° at horizontal plane and stable gain of 8.4 dBi obtained over the working frequency band.
[18]	Abdul Malek	2022	Analysis, Optimization, and Hardware Implementation of Dipole Antenna Array for Wireless Applications	- Dipole antenna array designed for wireless applications, particularly for indoor positioning systems like Wi-Fi, WLAN, and 5G.	- Main beam coverage optimized from 100° to 140° with step size of 10°. - Feasibility of beam synthesis validated successfully, with main beam steered at 110°. - Measured reflection coefficient of phased array antenna is -48 dB at 2.56 GHz.
[39]	Velicheti	2021	An Analytical Review on Log Periodic Dipole Antennas with Different Shapes of Dipole Elements	- Log periodic dipole array antennas studied for various communication applications including direction-finding systems, 5G, air-borne applications, UWB radar, and mobile imaging.	- Various LPDA structures studied with respect to operating frequency, bandwidth, substrate type, gain, and dimensions. - High gain and VSWR values (<2) achieved using miniaturization techniques.
[22]	Cai	2021	A High-Performance Standard Dipole Antenna Suitable for Antenna Calibration	- Standard dipole (SD) antenna designed for antenna calibration.	- Measured relative bandwidth exceeds 15%. - Antenna gain approximately 2 dBi. - Cross-polarization ratio greater than 27 dB in horizontal plane.

[40]	Peng	2023	A Broadband Dual-Polarized Filtering Dipole Antenna with High Selectivity	- Dual-polarized filtering dipole antenna designed for enhanced bandwidth and high selectivity.	- Wide impedance bandwidth, high port isolation, flat in-band gain, sharp band-edge roll-off, and low cross-polarization level demonstrated through fabrication and measurements.
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B. Discussion

Dipole antennas have been extensively researched and applied across various communication systems, including indoor positioning, mobile communication, antenna calibration, and filtering applications. These antennas offer several advantages such as simplicity in design, cost-effectiveness, and versatility in performance, making them suitable for a wide range of wireless applications.

In the context of wireless applications, especially for indoor positioning systems like Wi-Fi, WLAN, and 5G, researchers have explored using dipole antenna arrays with RF beamforming circuits. By optimizing how each antenna element is excited, the main beam can be electronically steered without mechanical rotation, allowing flexible coverage patterns in different indoor environments. A hybrid approach combining induced EMF methods and genetic algorithms has successfully demonstrated beam synthesis, showing that such antenna configurations are practical for real-world deployment. The measured reflection coefficients and beam steering capabilities highlight the usefulness of dipole antenna arrays in indoor wireless communication systems.

Furthermore, the application of dipole antennas in base station environments has undergone significant evolution over the years. From primitive solutions to advanced designs, the performance of dipole antennas has continuously improved in terms of gain, directivity, bandwidth, and size. This evolution has been driven by the constant demand for enhanced mobile communication capabilities, emphasizing the importance of dipole antennas in providing reliable and efficient communication links between base stations and mobile users.

Additionally, high-performance standard dipole antennas play a critical role in antenna testing and verification. By optimizing element shapes and incorporating innovative feeding structures, these antennas achieve excellent overall performance with wide bandwidth, high gain, and low cross-polarization. They are ideal candidates for accurate antenna calibration processes.

In filtering applications, the design of broadband dual-polarized dipole antennas with enhanced bandwidth and high selectivity has shown promising results. By utilizing cross-dipole structures and optimized parasitic elements, these antennas can achieve wide impedance bandwidth, high port isolation, and sharp band-edge roll-off, meeting the stringent requirements of modern communication systems.

V. Conclusion

In conclusion, the analysis of dipole antennas across various applications and performance metrics reveals their versatility and significance in wireless communication systems. From wearable devices to base stations, dipole antennas offer solutions tailored to specific needs while maintaining favorable characteristics such as impedance matching, radiation pattern, and bandwidth. These antennas demonstrate adaptability to different environments and operating frequencies, ranging from low-frequency applications such as RFID to high-frequency bands for 5G communication.

The literature underscores the importance of impedance matching, radiation efficiency, and pattern stability in achieving optimal antenna performance. Additionally, studies on novel materials and structures, such as textile substrates and plasma rings, showcase innovative approaches to address challenges and improve antenna characteristics. Moreover, the application of dipole

antennas extends beyond traditional communication systems, encompassing fields like radio astronomy, RF energy harvesting, and biomedical applications. This diversity underscores the versatility and potential of dipole antennas in addressing a wide range of contemporary challenges.

With all that being stated, the comprehensive analysis presented in the literature underscores the continued relevance and evolution of dipole antennas in modern wireless communication systems. Through ongoing research and innovation, dipole antennas remain vital components in enabling efficient and reliable wireless connectivity across diverse applications and environments. Dipole antennas are fundamental components in wireless communication systems, serving various purposes from indoor positioning to base station setups. Ongoing research and innovation have led to their evolution, resulting in impressive performance features like wide bandwidth, high gain, and accurate beam steering. As wireless technology progresses, dipole antennas will remain crucial for reliable and efficient connectivity across different contexts.

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