

Typical Constructs in Unveiling the Horizontal Wire Antenna

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ABSTRACT

Horizontal wire antennas represent a fundamental yet versatile class of antennas widely used in radio communication and broadcasting applications. In this extensive review, we delve into the design principles, operational characteristics, and diverse applications of horizontal wire antennas. We explore the fundamental concepts of antenna theory, the factors influencing antenna performance, and the various configurations and implementations of horizontal wire antennas. Additionally, we discuss advanced techniques, optimizations, and emerging trends in horizontal wire antenna design and deployment. By elucidating the intricacies of horizontal wire antennas, this review aims to provide engineers, researchers, and enthusiasts with valuable insights into maximizing the potential of these antennas across different communication scenarios and frequency bands.

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INTRODUCTION

INTRODUCTION TO HORIZONTAL WIRE ANTENNAS

Horizontal wire antennas are among the simplest and most widely used types of antennas in radio communication systems. They consist of a horizontal wire or wire array suspended above the ground, typically at a certain height above the Earth's surface. Horizontal wire antennas are favored for their simplicity, versatility, and effectiveness across a wide range of frequency bands and applications. Horizontal wire antennas, also known as dipole antennas, are one of the simplest and most widely used types of antennas in radio communication.^[1-19]

As the name suggests, these antennas consist of a conductive wire that is typically oriented horizontally. They are commonly deployed for short- to medium-range communication applications, including amateur radio, shortwave broadcasting, and Wi-Fi networks as shown in Fig. 1.

The basic structure of a horizontal wire antenna consists of a straight wire element that is typically half of the wavelength of the intended operating frequency. This wire is connected to a transmission line, such as coaxial cable, at its center point, creating a balanced feed configuration. The antenna can be suspended between two supporting structures, such as poles or towers, or

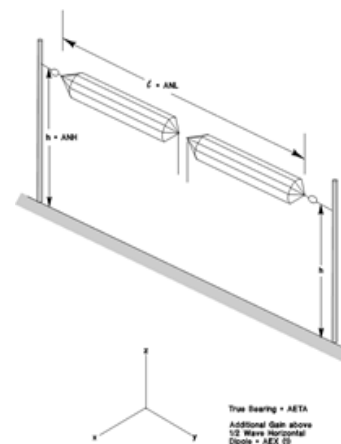


Fig. 1: Basic structure of a horizontal wire antenna

it can be installed horizontally along a rooftop or other elevated surface.

Horizontal wire antennas are known for their simplicity, low cost, and ease of installation. They exhibit a relatively omnidirectional radiation pattern in the horizontal plane, making them suitable for applications where coverage in multiple directions is desired. Additionally, horizontal wire antennas are relatively broadband and can be easily tuned to operate over a wide range of frequencies by adjusting the length of the wire element.

Despite their simplicity, horizontal wire antennas have certain limitations. They are typically less efficient than more complex antenna designs, and their performance can be affected by nearby objects, terrain, and atmospheric conditions. However, with proper installation and tuning, horizontal wire antennas can provide reliable communication over short to medium distances and remain a popular choice for amateur radio operators, broadcast stations, and other users requiring cost-effective and straightforward antenna solutions.

DESIGN PRINCIPLES OF HORIZONTAL WIRE ANTENNAS

The design of horizontal wire antennas is governed by fundamental principles of antenna theory, including resonance, radiation pattern, impedance matching, and efficiency. Key design considerations include the length and height of the wire, the choice of supporting structures, the ground plane configuration, and the feed mechanism [20]-[32]. Understanding these principles is essential for optimizing the performance of horizontal wire antennas in different operating conditions and frequency bands. Designing horizontal wire antennas involves considering various principles to optimize their performance for specific applications. Here are some key design principles as shown in Fig. 2:

1. Length

The length of the wire element is crucial and directly related to the operating frequency of the antenna. For a half-wave dipole antenna, the length of each element is approximately half of the wavelength of the desired frequency. Adjusting the length allows for resonance at the operating frequency, maximizing antenna efficiency.

2. Height and Elevation

The height above ground and the orientation of the antenna play significant roles in its performance. Generally, mounting the antenna higher improves its coverage and reduces signal interference from nearby

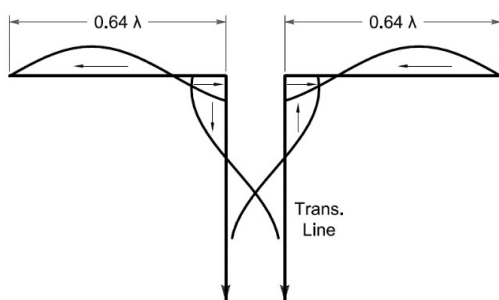


Fig. 2: Wire Antennas

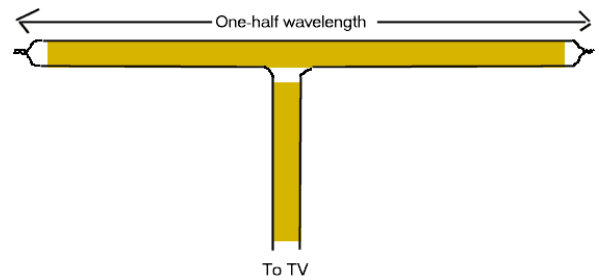


Fig. 3: A cheap and 5 TV 5 antenna

objects and terrain. For optimal performance, the antenna should be positioned as horizontally as possible, although slight deviations may be acceptable depending on the applications as shown in Fig. 3.

3. Feed Mechanism

Horizontal wire antennas are commonly fed using balanced transmission lines, such as coaxial cable or twin-lead. The feed point, where the transmission line connects to the antenna, can significantly affect impedance matching and radiation characteristics. Proper matching techniques, such as using baluns or impedance transformers, ensure efficient power transfer and minimize signal reflections.

4. Grounding

Grounding plays a crucial role in horizontal wire antenna design, especially for antennas installed close to the ground. Grounding systems, such as ground radials or a ground plane, help establish a low-impedance path for RF currents and improve antenna efficiency and radiation patterns.

5. Bandwidth and Tuning

Horizontal wire antennas typically have a broad frequency bandwidth, allowing them to operate over multiple frequency ranges with minimal adjustment. However, fine-tuning may be necessary to optimize performance for specific frequencies or to match impedance across the operating bandwidth.

By carefully considering these design principles, engineers can develop horizontal wire antennas tailored to meet the requirements of various communication systems, ensuring efficient and reliable performance in diverse operating environments.

OPERATIONAL CHARACTERISTICS OF HORIZONTAL WIRE ANTENNAS

Horizontal wire antennas exhibit unique operational characteristics that make them suitable for various



Fig. 4: Vertical Dipole Antenna

communication scenarios as shown in Fig. 4. These include:

- Omni-directional Radiation Pattern:** Horizontal wire antennas typically exhibit an omni-directional radiation pattern, meaning they radiate or receive electromagnetic waves equally in all directions around the horizontal plane. This makes them suitable for applications where communication with multiple stations or coverage over a wide area is desired. An omni-directional radiation pattern is characteristic of antennas that radiate or receive electromagnetic waves equally in all directions within a given plane, typically the horizontal plane for antennas used in terrestrial communication. This radiation pattern resembles a three-dimensional sphere, with the antenna at its center.

Omni-directional antennas are commonly used in applications where coverage in all directions is desired, such as Wi-Fi routers, broadcast antennas, and mobile communication systems. These antennas provide uniform signal distribution, allowing for seamless connectivity and communication with devices located in any direction around the antenna.

Achieving an omni-directional radiation pattern requires careful design and optimization of the antenna structure and feed mechanism. Symmetrical antenna configurations, such as monopoles, dipole antennas, and vertical antennas with ground planes, are commonly used to achieve omni-directional radiation patterns. Additionally, proper impedance matching and grounding techniques are essential to ensure uniform signal propagation and minimize signal distortion.

Omni-directional antennas offer several advantages, including simplicity, versatility, and ease of installation. However, their coverage range and signal strength may vary depending on factors such as antenna height,

surrounding terrain, and interference sources. Overall, omni-directional radiation patterns play a crucial role in enabling widespread connectivity and communication in modern wireless networks.

- Low Elevation Angle:** Horizontal wire antennas tend to have a low elevation angle of radiation, making them well-suited for long-distance communication, particularly in the HF (High Frequency) band. This characteristic enables horizontal wire antennas to propagate signals efficiently over the Earth's surface, minimizing signal attenuation and maximizing communication range. The term "low elevation angle" refers to the angle at which electromagnetic waves propagate or are received relative to the horizontal plane. In antenna systems, elevation angle is crucial as it determines the coverage area and the effectiveness of communication links, particularly in applications such as satellite communication, radar, and terrestrial point-to-point communication.

A low elevation angle indicates that the waves are traveling close to the Earth's surface, typically within the range of 0 to 30 degrees above the horizon. In satellite communication, low elevation angles refer to the angle between the satellite's position in the sky and the observer's location on the Earth's surface. Low elevation angles are often associated with satellite communication systems operating in geostationary or low Earth orbit (LEO) satellites.

Low elevation angles present challenges in communication systems, as they can result in signal attenuation due to atmospheric effects, terrain obstacles, and signal blockages from buildings or vegetation. However, low elevation angles also offer advantages in certain scenarios, such as minimizing signal interference and maximizing coverage in densely populated urban areas.

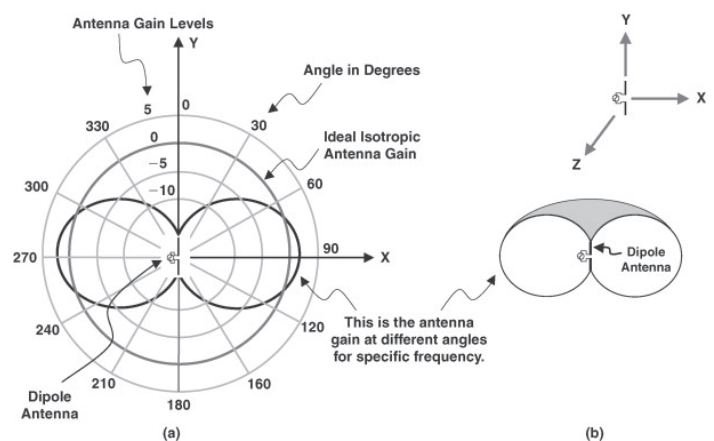


Fig. 5: Designing antenna systems

Designing antenna systems and communication protocols to accommodate low elevation angles requires careful consideration of factors such as antenna height, propagation characteristics, and signal processing techniques. By optimizing antenna placement and system parameters, engineers can ensure reliable communication links and maximize the effectiveness of low elevation angle propagation in various applications as shown in Fig. 5.

- ♦ **Broadband Performance:** Horizontal wire antennas can be designed to operate over a wide frequency range, offering broadband performance across multiple bands. This versatility makes them suitable for multi-band and wideband communication systems, where flexibility and adaptability to changing operating conditions are essential. Broadband performance in antennas refers to their ability to operate efficiently over a wide range of frequencies within a specified bandwidth. Antennas with broadband performance can transmit or receive signals across multiple frequency bands without significant degradation in efficiency or signal quality. This characteristic is crucial in modern communication systems, where flexibility and versatility are essential.

Achieving broadband performance in antennas involves careful design and optimization to ensure impedance matching, radiation efficiency, and gain across the desired frequency range. Various techniques are employed to broaden the antenna's bandwidth, including the use of wideband elements, innovative feed structures, and advanced matching networks. Additionally, broadband antennas may incorporate frequency-independent or frequency-selective components to enhance performance over specific frequency ranges.

Broadband antennas find applications in a wide range of communication systems, including wireless networks, cellular systems, radar systems, and satellite communication. By providing reliable communication capabilities across diverse frequency bands, broadband antennas enable seamless connectivity, interoperability, and compatibility with different communication standards and protocols. Overall, broadband performance is a key consideration in antenna design, ensuring optimal performance and versatility in today's rapidly evolving communication landscape.

TYPES AND CONFIGURATIONS OF HORIZONTAL WIRE ANTENNAS

Horizontal wire antennas come in various types and configurations, each tailored to specific applications and operating requirements. Common types of horizontal wire antennas include:

- ♦ **Dipole Antennas:** Dipole antennas consist of a straight wire element split at the center, with each half connected to a transmission line or feedline. Dipole antennas are among the simplest and most widely used horizontal wire antennas, offering balanced radiation patterns and efficient performance across a broad frequency range. Dipole antennas are one of the simplest and most commonly used types of antennas in radio communication. They consist of a conductive element that is typically split into two halves and connected to a transmission line at its center. Dipole antennas are symmetrical and omnidirectional, meaning they radiate or receive electromagnetic waves equally in all directions within the horizontal plane. They are often used for short- to medium-range communication applications, including amateur radio, broadcasting, and Wi-Fi networks. Dipole antennas exhibit a fundamental resonant frequency determined by their physical length, making them versatile and easily tunable to operate across various frequency bands as shown in Fig. 6.
- ♦ **Folded Dipole Antennas:** Folded dipole antennas feature a modified dipole configuration where the two halves of the antenna element are folded back on themselves. This design enhances the antenna's impedance bandwidth and radiation characteristics, making it suitable for wideband applications and impedance matching. Folded dipole antennas are variants of dipole antennas designed to improve their impedance matching and bandwidth characteristics. They consist of two conductive elements, typically metal rods or wires, folded back upon themselves

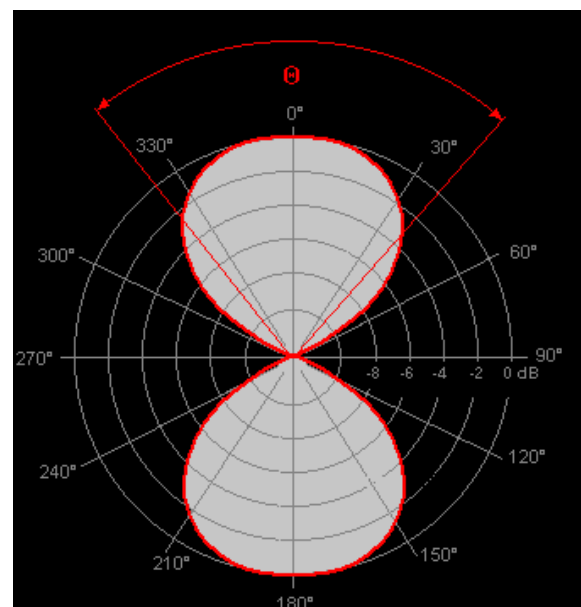


Fig. 6: Half-wave Antenna

to form a symmetrical structure. This configuration increases the electrical length of the antenna, resulting in a lower resonant frequency and improved impedance matching. Folded dipole antennas offer broader bandwidth and higher efficiency compared to traditional dipole antennas, making them well-suited for applications requiring wideband operation and improved performance. They are commonly used in communication systems, broadcasting, and RFID applications due to their versatility and robustness.

- ♦ **Inverted V Antennas:** Inverted V antennas consist of a horizontal wire element supported by two vertical mast structures, forming an inverted V shape. This configuration provides improved elevation angle and low-angle radiation, making it suitable for long-distance communication and NVIS (Near Vertical Incidence Skywave) propagation. Inverted V antennas are a type of dipole antenna configuration where the two arms of the dipole are sloped downward, resembling an inverted letter "V". This design allows for a compact and space-efficient antenna installation, particularly in limited-height environments. Inverted V antennas exhibit similar radiation patterns and characteristics to traditional horizontal dipole antennas but offer the advantage of reduced height requirements. They are commonly used in portable and mobile communication systems, amateur radio operations, and military applications where space or height constraints are a concern. Inverted V antennas provide a practical solution for achieving reliable communication performance in constrained environments.
- ♦ **Wire Arrays:** Wire arrays comprise multiple horizontal wire elements arranged in parallel or in a grid pattern. Wire arrays offer increased gain, directivity, and bandwidth compared to single-wire antennas, making them suitable for high-performance communication systems and directional applications. Wire arrays are antenna configurations consisting of multiple conductive elements arranged in a specific geometric pattern. These elements can be wires, rods, or other conductive structures, spaced apart at regular intervals. Wire arrays are versatile and can exhibit various radiation patterns depending on their geometry and arrangement. They are often used in applications requiring directional radiation, such as Yagi-Uda antennas and phased arrays. Wire arrays offer advantages such as ease of construction, scalability, and adaptability to different frequency bands and operating environments. They are commonly deployed in communication systems, radar systems, and radio astronomy for their reliability and performance.

ADVANCEMENTS AND OPTIMIZATION TECHNIQUES

Advancements in horizontal wire antenna design and optimization have led to improved performance, efficiency, and versatility [33]-[38].

- ♦ **Computer-Aided Design (CAD) Tools:** CAD tools and electromagnetic simulation software enable accurate modeling and optimization of horizontal wire antennas, allowing engineers to analyze antenna performance, predict radiation patterns, and optimize antenna parameters for specific applications.
- ♦ **Material Selection and Coating:** Advances in antenna materials and coatings enhance the durability, weather resistance, and electrical performance of horizontal wire antennas, particularly in outdoor or harsh environments. Antenna materials with low-loss and high-conductivity properties improve efficiency and signal transmission/reception.
- ♦ **Feeding Techniques:** Innovative feeding techniques, such as baluns, impedance transformers, and matching networks, improve impedance matching and reduce feedline losses in horizontal wire antennas. Proper feeding is crucial for maximizing antenna efficiency and minimizing signal degradation as shown in Fig. 7.
- ♦ **Ground Plane Optimization:** Optimization of the ground plane configuration, including ground plane size, conductivity, and dielectric properties, enhances the performance of horizontal wire antennas, particularly in ground-mounted or elevated installations. Ground plane effects significantly influence antenna radiation patterns and efficiency.

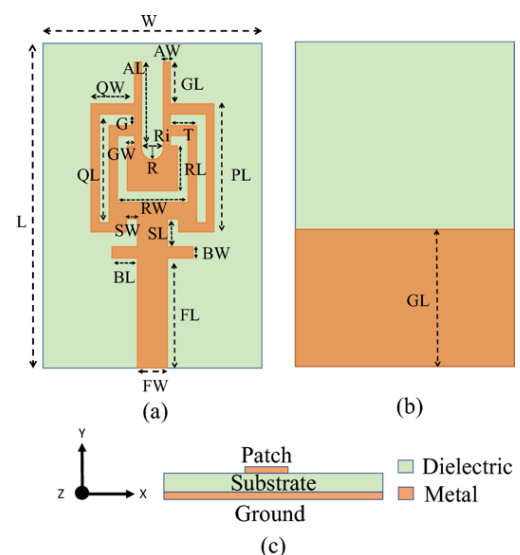


Fig. 7: Dual-band 5G MIMO antenna

APPLICATIONS OF HORIZONTAL WIRE ANTENNAS

Horizontal wire antennas find diverse applications across various communication systems and frequency bands :^{[39]-[49]}

- ♦ **Amateur Radio:** Horizontal wire antennas are popular among amateur radio operators (hams) for their simplicity, versatility, and cost-effectiveness. They are used for HF (High Frequency) communication, VHF (Very High Frequency) and UHF (Ultra High Frequency) bands, and satellite communication.
- ♦ **Shortwave Broadcasting:** Horizontal wire antennas are commonly used in shortwave broadcasting stations to transmit radio signals over long distances. They provide efficient coverage and propagation characteristics suitable for international broadcasting and long-range communication.
- ♦ **Military and Defense:** Horizontal wire antennas are employed in military communication systems, radar systems, and surveillance applications for their robustness, reliability, and compatibility with portable and mobile platforms. They provide essential connectivity for tactical and strategic communications in battlefield environments.
- ♦ **Wireless Sensor Networks:** Horizontal wire antennas are used in wireless sensor networks for environmental monitoring, remote sensing, and IoT (Internet of Things) applications. They provide reliable communication links for collecting and transmitting sensor data over extended distances.

FUTURE DIRECTIONS AND EMERGING TRENDS

Emerging trends and future directions in horizontal wire antenna research and development include:

- ♦ **Smart Antenna Technologies:** Integration of smart antenna technologies, such as beamforming, MIMO (Multiple-Input Multiple-Output), and cognitive radio, into horizontal wire antennas enhances their performance, adaptability, and interference rejection capabilities in dynamic and congested RF environments as shown in Fig. 8.

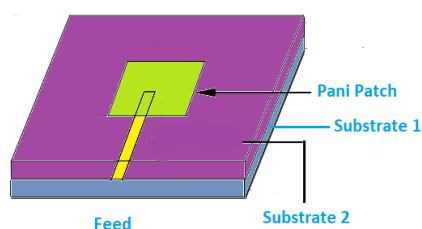


Fig. 8: Conductive polymer microstrip fed patch antenna

- ♦ **Miniaturization and Integration:** Advances in miniaturization techniques and integration technologies enable the development of compact and lightweight horizontal wire antennas for portable, wearable, and embedded applications. Miniaturized antennas offer improved mobility and flexibility in communication systems.
- ♦ **Energy Harvesting:** Integration of energy harvesting technologies, such as solar cells and RF energy harvesting circuits, into horizontal wire antennas enables self-powered and autonomous operation in remote or energy-constrained environments. Energy harvesting antennas provide sustainable power sources for wireless sensor networks and IoT devices.
- ♦ **5G and Beyond:** Horizontal wire antennas play a crucial role in next-generation 5G communication networks, providing coverage, capacity, and connectivity for high-speed data transmission and low-latency applications. Advances in antenna design and optimization support the deployment of 5G mmWave and sub-6 GHz bands.

CONCLUSION

Horizontal wire antennas represent a foundational element in radio communication systems, offering simplicity, versatility, and effectiveness across a wide range of applications and frequency bands. By understanding the design principles, operational characteristics, and advancements in horizontal wire antenna technology, engineers and researchers can harness the full potential of these antennas for diverse communication scenarios and emerging applications. Continued research and innovation in horizontal wire antenna design, optimization, and integration will drive advancements in wireless communication, connectivity, and information technology, shaping the future of global connectivity and digital transformation.

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