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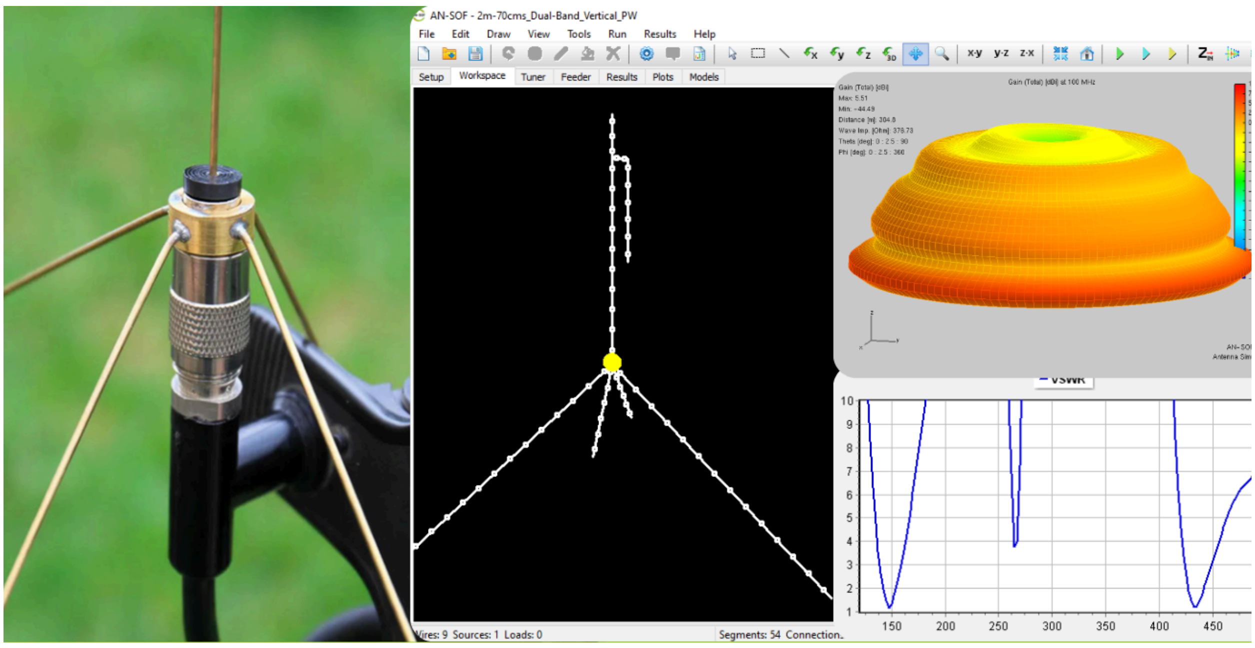
June 30, 2025



Top 5 Most-Read Articles in June 2025

In this edition of *Antennas and Beyond!*, we're excited to share the top 5 most-read articles from June. We greatly appreciate your continuous feedback and support. Your engagement helps us improve and tailor our content to your interests.

Tony Golden

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Efficient NOAA Satellite Signal Reception with the Quadrifilar Helix Antenna

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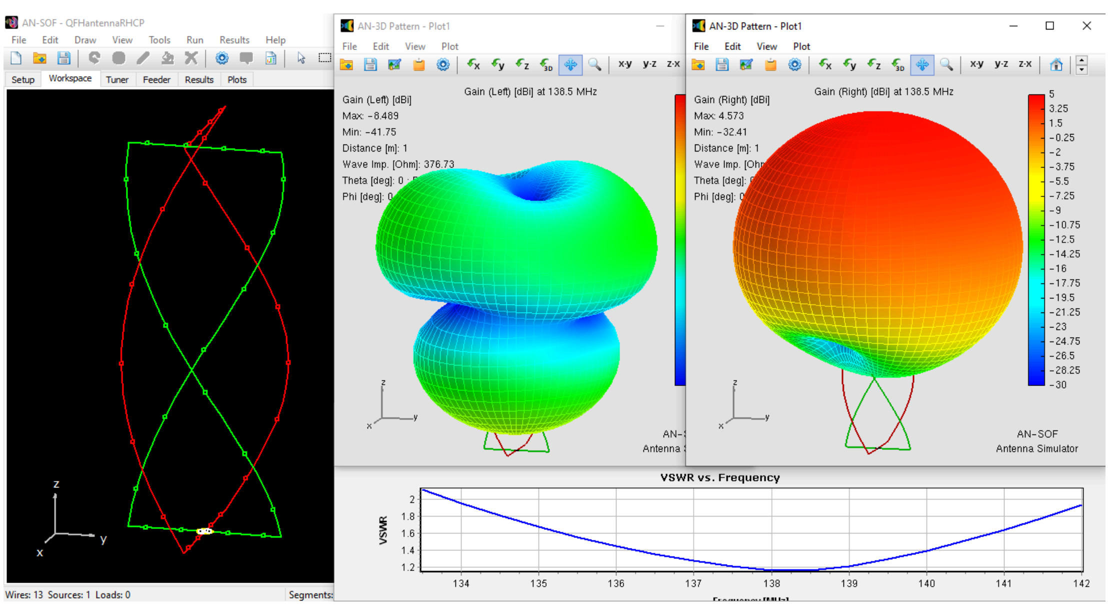
The Quadrifilar Helix (QFH) antenna, with its unique design and circular polarization, ensures efficient NOAA satellite signal reception. This article explores the history, key characteristics, and practical modeling of QFH antennas using AN-SOF, providing valuable insights for RF engineers and enthusiasts.



Introduction

The **Quadrifilar Helix (QFH)** antenna, also known as the **QHA**, is an excellent choice for receiving signals from the **National Oceanic and Atmospheric Administration (NOAA) satellites**. This antenna configuration consists of four helically wound monofilar wires that intertwine to form a quadrifilar helix (Fig. 1). This intricate geometric arrangement gives the antenna unique properties in **a compact size:** a directional radiation pattern, circular polarization, and self-resonance with **a feedpoint impedance close to 50 Ohms**. While the QFH antenna's bandwidth is narrower compared to a traveling-wave axial mode helix, its compact form factor makes up for this limitation.

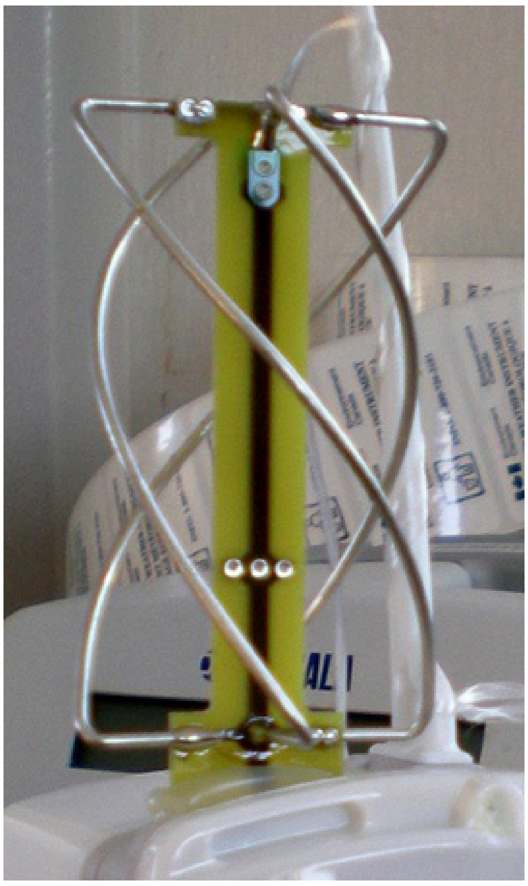


Fig. 1: Quadrifilar Helix Antennas (QFH or QHA) (images licensed under Creative Commons).

Axial Mode Helical Antennas: History and Fundamentals

The **axial mode helical antenna** was invented in 1946 by John Kraus. Inspiration can come when we least expect it:

> *I attended an afternoon lecture on traveling-wave tubes by a famous scientist… In these tubes an electron beam is fired down the inside of a long wire helix for amplification of waves traveling along the helix. The helix is only a small fraction of a wavelength in diameter and acts as a guiding structure. … I asked the visitor if he thought a helix could be used as an antenna. 'No,' he replied, 'I've tried it and it doesn't work.' The finality of his answer set me thinking. If the helix were larger in diameter than in a traveling-wave tube, I felt that it would have to radiate in some way, but how, I did not know. I determined to find out.*
>
> **Dr. John D. Kraus, in "Antennas," 2nd Ed. McGraw-Hill, 1988.**

Today, helical antennas can be easily simulated (Fig. 2). Being **wire antennas**, the most efficient way to simulate them is through **the Method of Moments (MoM)**. However, a poor convergence rate is often obtained for the input impedance when the helix is approximated by straight segments, as is customary. Using **curved segments** that exactly follow the helix contour overcomes this problem.

The axial mode helical antenna is one of the most widely used antennas for UHF and microwave communications. Its robust design makes it ideal for both space and ground applications, contributing significantly to the explosive growth of satellite-based services.

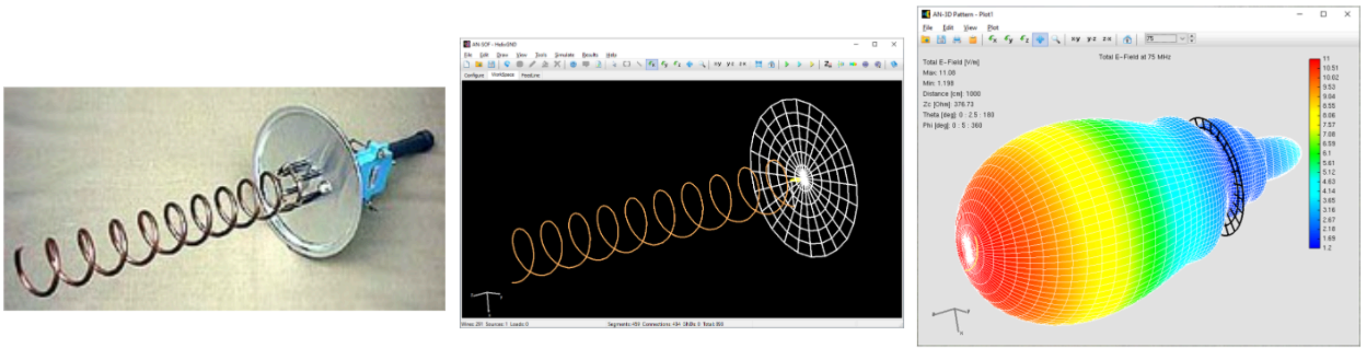


Fig. 2: Axial Mode Helical Antenna. The antenna radiates a beam along its axis. The feedpoint is located between the helix base and the ground plane.

Traveling-Wave Antennas and Axial-Mode Helix: Traveling-wave antennas are a class of antennas where the radio frequency (RF) energy travels along a structure, such as a wire, in a continuous wave. The axial mode helix is a specific type of traveling-wave antenna designed to operate in the axial mode. For a helix to operate in this mode, **the circumference of the helix should be close to one wavelength** of the operating frequency. Additionally, **a metallic ground plane**, often of circular shape, is added to the helix base, as shown in Fig. 2. These conditions allow the antenna to produce a directional radiation pattern with a main beam along the axis of the helix.

Circular Polarization: The axial-mode helical antenna exhibits circular polarization, which can be either right-hand circular polarization (RHCP) or left-hand circular polarization (LHCP), depending on the winding sense of the helix. Circular polarization is achieved when the electric field of the wave rotates in a circular motion as it propagates. The sense of rotation—RHCP or LHCP—is determined by the direction in which the helix is wound. RHCP helical antennas are typically used for transmitting WEFAX pictures due to their reliable performance in space communications.

Importance of Circular Polarization: Circular polarization is crucial in both space communications and terrestrial mobile applications. In space communications, circular polarization helps to mitigate the effects of **Faraday rotation**, an unpredictable phenomenon caused by the ionosphere, which can alter the polarization of the signal. By using circular polarization, satellite communications can maintain consistent signal quality despite these changes. In terrestrial mobile applications, circular polarization helps to reduce signal degradation caused by multipath interference, where signals bounce off various obstacles before reaching the receiver.

Key Characteristics of Quadrifilar Helical Antennas

The axial-mode helix antenna exhibits a consistent input impedance over a wide bandwidth, thanks to its nature as a traveling-wave antenna. For optimal performance, a ground plane with a diameter of about half to one wavelength is required. This antenna type can achieve a gain of 10-17 dBi over a 60% fractional bandwidth. However, with feedpoint impedances ranging from 150 to 300 Ohms, impedance matching is necessary for efficient operation in 50 Ohm systems.

By adding **extra windings**, the radiation pattern of the axial-mode helix can be tightened, and sidelobes can be reduced compared to a monofilar helix. The **Quadrifilar Helix (QFH)** antenna comprises **four windings of equal torsion**. Unlike long traveling-wave antennas, the QFH can be shortened to sizes commensurate with half a wavelength and operate as a **resonant antenna**, similar to a resonant dipole or loop antenna.

As a resonant antenna, **the QFH has a narrow bandwidth**, requiring careful attention to its dimensions and construction details. Its compactness and ease of integration with mobile systems make the short resonant QFH ideal for portable applications.

Each component helix of a QFH is excited in a **90-degree progression**, either clockwise or counterclockwise, depending on the desired polarization and lobe direction. QFHs can operate in either **endfire** or **backfire** modes, producing a hemispherical directional pattern (Fig. 3). For long quadrifilar antennas, a quadrature feeding network is necessary to generate the 90° phase progressions. This can be achieved using quadrature hybrids and power splitters. For the small resonant helix, using two co-wound half helices with slightly different dimensions can induce quadrature excitation, similar to the "nearly square" method of generating circular polarization in a microstrip patch antenna.

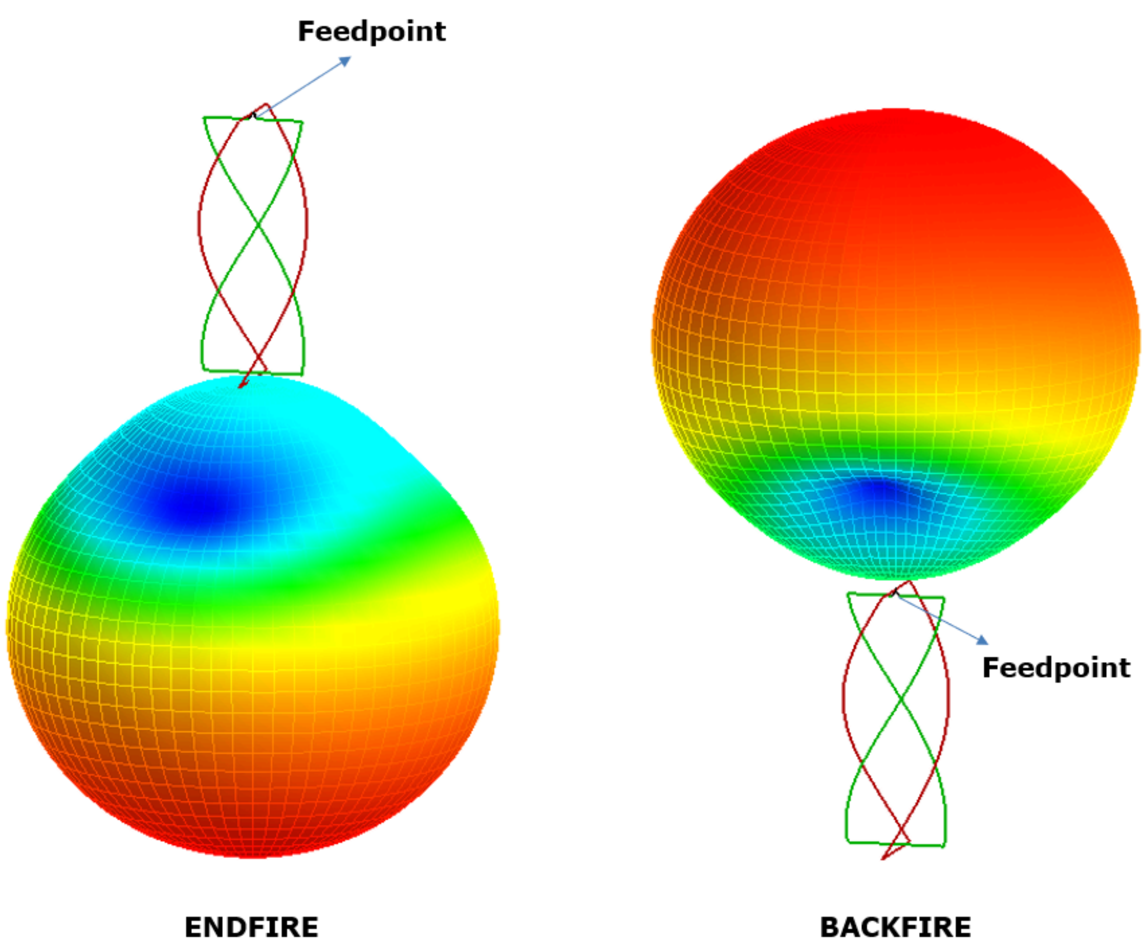


Fig. 3: Endfire (left) and backfire (right) modes of operation of QFH antennas.

The feed phasing sense relative to the QFH winding sense determines the radiation mode: if they match, the antenna will be backfire; if they oppose, the antenna will be endfire. The circular polarization sense of the radiation is always opposite to the helix winding sense, regardless of the feed phasing sense. However, if a backfire helix antenna is used with a reflector or ground plane at the feed, the sense of the circular polarization is reversed, making the antenna endfire with the polarization sense corresponding to the helix winding.

Summary:

- The helix winding sense is opposed to the desired circular polarization sense. That is to say, left-hand wound helices in a QFH will generate right-hand circular polarization.
- Careful adjustment of the helix dimensions will produce a 50 Ohm feedpoint impedance without the need for external quadrature generating circuits or impedance matching networks.
- The backfire resonant quadrifilar helix antenna is popular for GNSS, communication, and weather satellite receiving stations. This antenna is configured for right-hand circular polarization, with a left-hand winding sense and the feedpoint at the top of the antenna.
- The QFH antenna's ability to provide circular polarization and its compact form factor make it an essential tool for modern communication systems, ensuring reliable performance in a variety of challenging environments.

Input Parameters for Drawing a Helix in AN-SOF

AN-SOF allows you to draw helices quickly. **Right-click on the workspace screen and choose Helix**. There are two options for drawing a helix:

1. **Start – Radius – Pitch – Turns:** In this option, the helix is generated from a starting point along an axis with a defined pitch (distance between turns) and number of turns. The number of turns does not need to be an integer.

- When the pitch is positive, the helix is right-handed, running from the starting point along the +z axis, with the endpoint at z > 0.
- When the pitch is negative, the helix is left-handed, running along the -z axis, with the endpoint at z < 0.

Starting from **AN-SOF version 9.50**, you can enter the helix **diameter**, **pitch angle**, and **filar length** instead of the Radius-Pitch-Turns combination. The **axial height** is automatically calculated. The software warns when the wire diameter is greater than the pitch, preventing the overlapping of the windings.

2. **Start – End – Radius – Turns:** In this option, a helix with an integer number of turns connects the specified start and end points. The straight line connecting these points defines the axis of the helix. Only a helix with an integer number of turns can be mathematically defined between two given points, ensuring that the axis is parallel to the straight line joining them. The helix is right-handed if the number of turns is positive and left-handed if the number of turns is negative. Note that in this option, a pitch cannot be specified, as its value is determined by dividing the distance between the given start and end points (the axial height) by the number of turns (an integer).

A QFH Model for NOAA Satellite Signal Reception

The design depicted in Figure 4 showcases an endfire QFH configuration with a diameter of approximately 0.14 times the wavelength (λ) and helix lengths of 0.4λ. It exhibits a resonant frequency of 138.5 MHz and a fractional bandwidth of 6% (VSWR < 2). The helices composing the QFH antenna are **left-handed**, resulting in a **right-hand circularly polarized (RHCP) field**. This design serves a dual purpose: enabling efficient signal reception from NOAA satellites while effectively mitigating external interference.

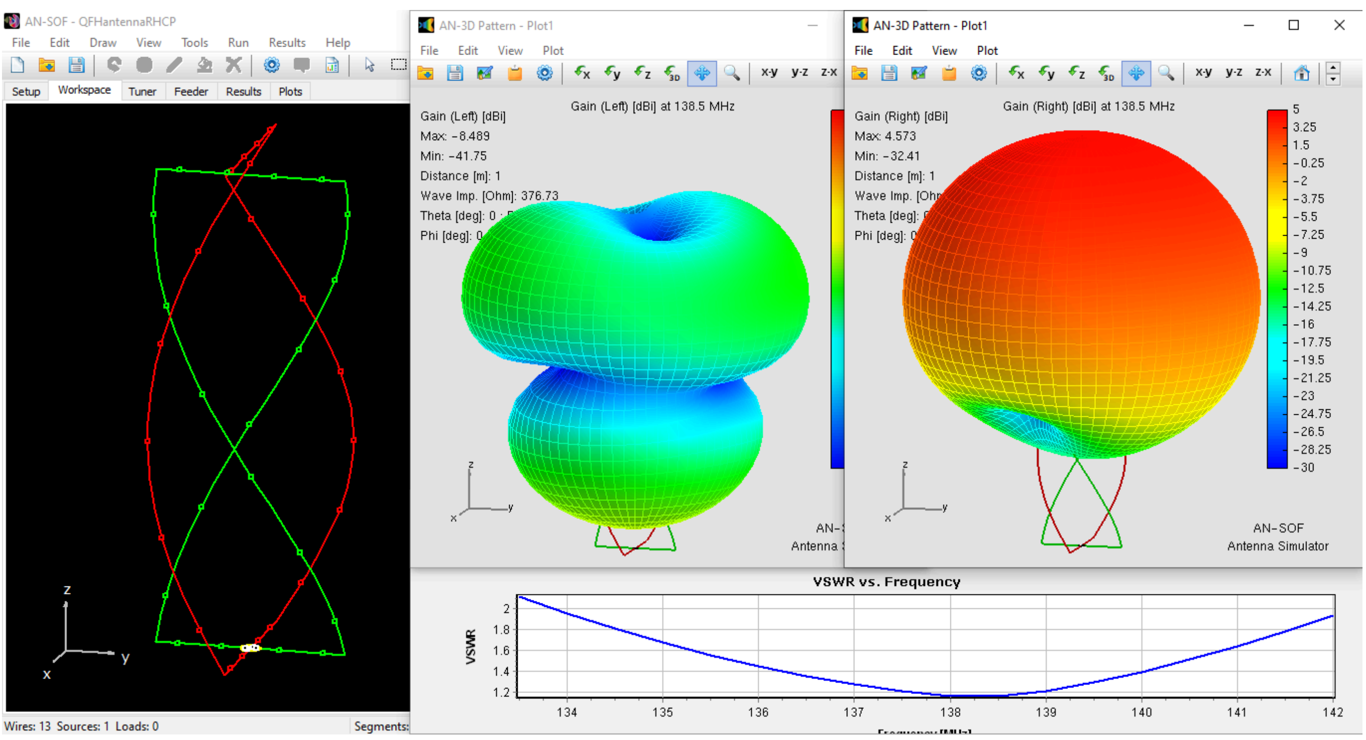


Fig. 4: QFH antenna model in the AN-SOF interface, with the LHCP (center) and RHCP (right) components of the Gain radiation patterns, and the VSWR curve.

Download Model

In free space, the radiation pattern orients upward when the coaxial cable, simulated as a voltage source in the model, connects to the antenna's bottom (endfire mode). **The total gain is 4.6 dBi**. AN-SOF allows for decomposing the gain into right-handed and left-handed polarizations, demonstrating that **the radiated field is RHCP** since the right-hand gain practically equals the total gain and **the left-hand gain is below -8.5 dBi**. The resultant pattern in this configuration is omnidirectional within the azimuth plane, which is invaluable for effectively capturing signals from a variety of satellite orientations.

Thanks to the implementation of **the Conformal Method of Moments (CMoM) in AN-SOF**, we can accurately model the behavior of the QFH **with just 5 segments per helix**, as the **wire segments are curved** and faithfully represent the contour of the helices.

In summary, this Quadrifilar Helix (QFH) antenna model stands as an ingeniously designed configuration. It features a compact form factor, self-resonance, and RHCP, making it adept at capturing signals from NOAA satellites.

Conclusions

The **Quadrifilar Helix antenna (QFH or QHA)** has proven to be an exceptional choice for UHF and microwave communication, particularly in satellite signal reception. Its design, featuring **circular polarization** and **a compact form factor**, ensures reliable performance in various applications, from weather satellite data acquisition to advanced GNSS systems. The historical evolution of the helical antenna highlights its versatility and enduring significance in the field of antenna design.

Utilizing AN-SOF's advanced simulation tools, users can efficiently design and optimize QFH antennas, achieving **precise impedance matching** and robust signal reception. The comprehensive exploration of input parameters and practical examples equips engineers and enthusiasts with the necessary knowledge to fully leverage QFH antennas for their specific needs, cementing their role in the advancement of communication technologies.

See Also:

- **Advantages of AN-SOF for Simulating 433 MHz Spring Helical Antennas for ISM & LoRa Applications**
- **DIY Helix High Gain Directional Antenna: From Simulation to 3D Printing**

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The 17m Band 2-Element Delta Loop Beam: A Compact, High-Gain Antenna for DX Enthusiasts

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Conquer the 17-meter band with the 2-element Delta Loop Beam antenna. This compact, high-gain design boasts near-perfect impedance matching, making it perfect for DX enthusiasts. Download the AN-SOF model and unlock its potential!

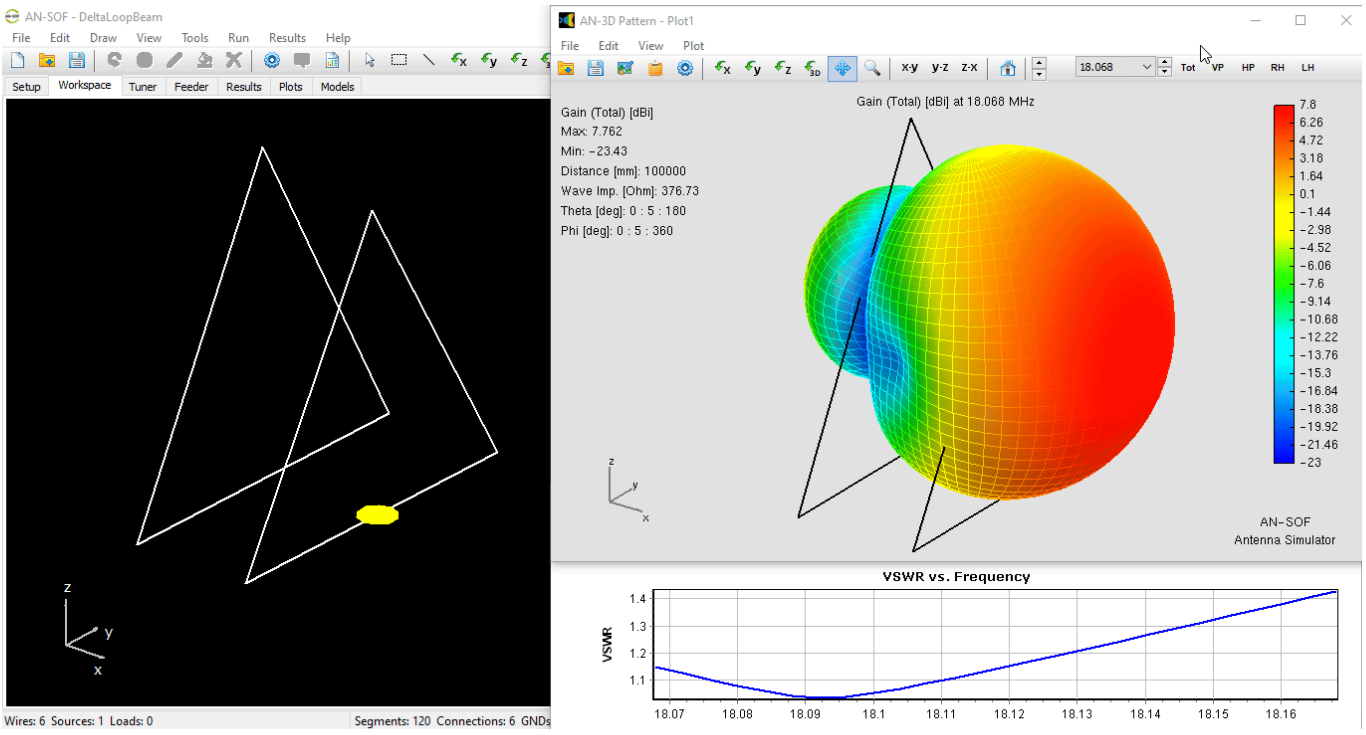
The **17-meter band** presents a unique set of design challenges for radio antenna designers targeting **DX applications**. Achieving high directivity while maintaining portability and ease of deployment requires careful consideration. This article presents a **2-element Delta Loop Beam** antenna that addresses these challenges head-on. The antenna boasts a compact form factor, exceptional gain, and **near-perfect impedance matching**, making it an ideal choice for DX enthusiasts.

Minimalist Design, Maximum Performance

The design philosophy behind this antenna is one of elegant simplicity. It represents the **minimum viable configuration** for a **directional** Delta Loop array, consisting of just two elements: a **driven element** at the front (where the feed line connects) and a **passive reflector** element behind, reminiscent of the Yagi-Uda architecture. Both elements are **equilateral triangles** with perimeters of approximately **one wavelength** on the 17-meter band. To achieve optimal forward directivity, the driven element is deliberately crafted slightly smaller than the reflector. The element spacing is tuned to 0.12 wavelengths, ensuring optimal performance.

Impedance Harmony: Eliminating Matching Networks

With these carefully chosen dimensions, the array exhibits an almost **purely resistive** input impedance of approximately **50 Ohms**. This remarkable characteristic eliminates the need for an additional impedance matching network, simplifying construction. This feature is particularly advantageous for portable DX applications.



Visualizing the 17m band Delta Loop Beam's potential: AN-SOF model, 3D radiation pattern, and VSWR curve. Download the model and explore!

Download Model

Visualizing Performance: The Power of Modeling

The figure above showcases the Delta Loop Beam model within the AN-SOF simulation workspace. It depicts the antenna geometry, its radiation pattern, and the VSWR across a range of frequencies. The radiation pattern, plotted in dBi, reveals a **peak gain of 7.7 dBi**. The animation demonstrates how the radiation lobes dynamically change with frequency. Notably, the **VSWR remains below 2** throughout the analyzed frequency range, indicating excellent impedance matching across the band.

Modeling with Confidence: Capturing Sharp Angles

To accurately capture the **acute angles** of the Delta Loops, it is recommended to activate the **Exact Kernel** option within AN-SOF's Setup window. This ensures accurate results even for intricate geometries, guaranteeing reliable simulation data.

Beyond Theory: Exploring Real-World Scenarios

While the model depicts the antenna in an ideal **free-space environment**, real-world deployments often involve ground planes and environmental factors. We encourage you to download the AN-SOF model (button below the figure) and delve into how the antenna behaves when incorporating realistic **ground planes** into the simulation. AN-SOF conveniently provides a library of **soil constants** (conductivity and permittivity) to facilitate this research.

Feel empowered to experiment! **Resize the antenna**, tweak the element spacing, and observe how these adjustments affect gain and resonant frequency. You might discover the perfect configuration for your specific DX needs, whether it be maximizing gain for weak signal reception or fine-tuning the resonant frequency for a particular contest.

And for those interested in the intricacies of **EMF compliance** and **RF exposure regulations**, this Delta Loop Beam model has been featured as a case study in our recent article, **"Evaluating EMF Compliance – Part 1: A Guide to Far-Field RF Exposure Assessments."** Dive into the details and gain valuable insights into ensuring safe and responsible antenna deployment.

See Also:

- **Evaluating EMF Compliance – Part 1: A Guide to Far-Field RF Exposure Assessments**
- **Evaluating EMF Compliance – Part 2: Using Near-Field Calculations to Determine Exclusion Zones**

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Advantages of AN-SOF for Simulating 433 MHz Spring Helical Antennas for ISM & LoRa Applications

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Accurate antenna simulation is crucial for designing high-performance antennas for various applications, including **ISM** and **LoRa**. AN-SOF software offers significant advantages over traditional methods for simulating 433 MHz spring helical antennas, enabling designers to achieve optimal antenna performance.

Challenges of Modeling Helical Antennas with Traditional Methods

Traditional antenna simulation techniques, such as the **Numerical Electromagnetics Code (NEC)**, often encounter limitations when modeling helical antennas. These limitations stem from the inherent assumptions made in the **integral equation's kernel**, such as the **thin-wire approximation**. This approximation breaks down for **small, compact helical antennas** with their complex geometries of **closely spaced, curved, and thick wires**.

Advantages of AN-SOF for Helical Antenna Simulation

AN-SOF overcomes the limitations of traditional methods by employing a more robust and versatile approach with an **exact kernel formulation**. Here's how AN-SOF benefits antenna designers:

- **Accurate Modeling of Complex Geometries:** AN-SOF eliminates the need for simplifications by accurately modeling the complex geometry of spring helical antennas, including **tight bends**, **thick wires**, and **curved sections**. This ensures accurate current distribution and radiation patterns.
- **Superior Handling of Curved Wires:** AN-SOF is adept at handling **curved wires**, a key characteristic of helical antennas, by employing the **Conformal Method of Moments (CMoM)**. This ensures that the current distribution and radiation patterns are precisely simulated.
- **Precise Simulation of Closely Spaced Wires:** The **tight coil spacing** in the 433 MHz compact helical antennas can be accurately modeled by AN-SOF. This

capability is essential for capturing the electrical interactions between the antenna windings, which significantly affect its performance.

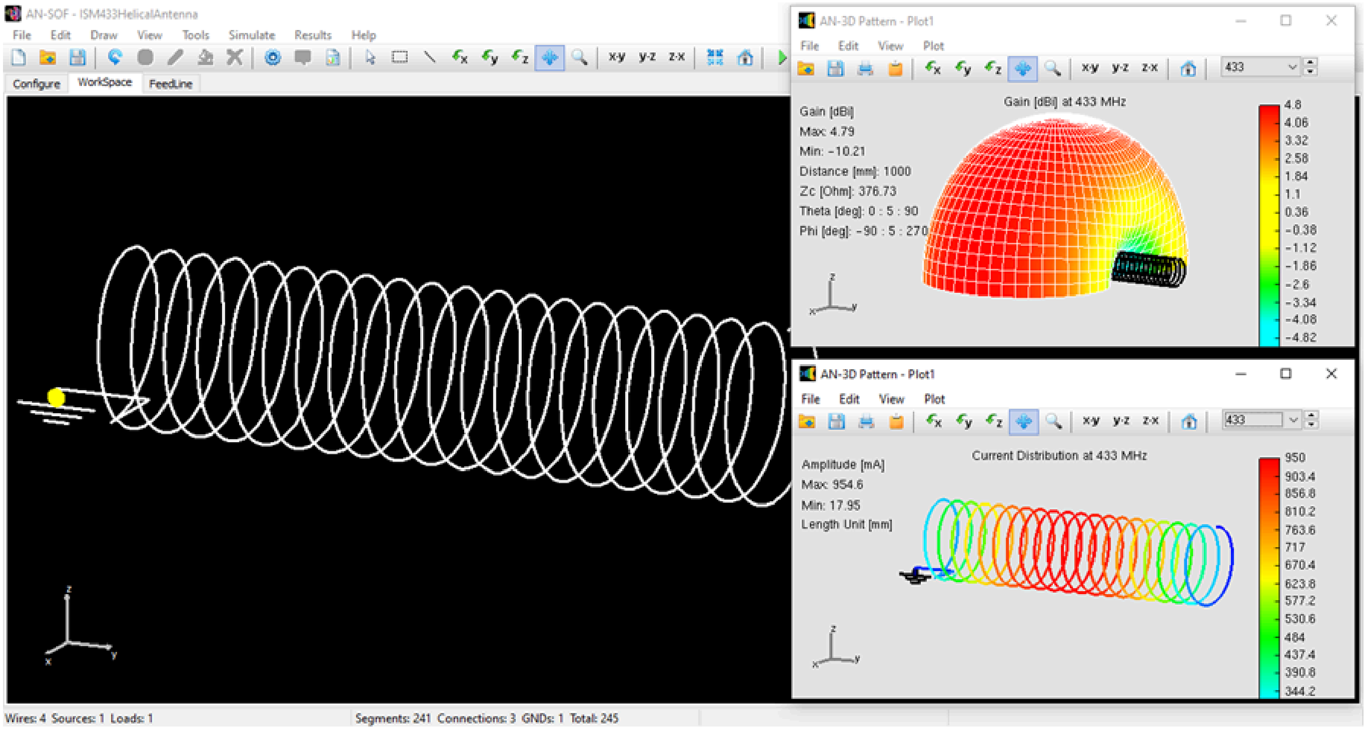
- **Modeling of Short Segments:** AN-SOF can effectively represent the **short curved segments** that must be used in helical antenna models. This characteristic is crucial for simulating the antenna's resonant behavior and input impedance.

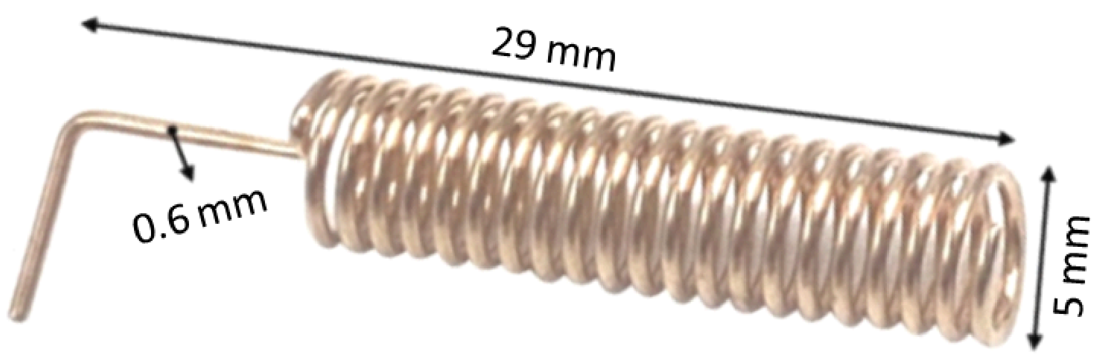
Case Study: Using AN-SOF for 433 MHz Helical Antenna Simulation

Consider a 433 MHz spring helical antenna designed for LoRa applications, as specified in the datasheet available here. This antenna is **physically short compared to the wavelength** (around 4-5% in this case). Consequently, its inherent radiation resistance is low. The helical turns compensate for this by effectively increasing the electrical length of the antenna, boosting radiation resistance to usable values. AN-SOF software is particularly adept at simulating such antennas due to its ability to handle complex geometries. This allows for accurate modeling of the electrical behavior, including input impedance, radiation pattern, and gain.

An important aspect to consider during the simulation is the inclusion of a **ground plane** below the antenna. In real-world applications, helical antennas typically operate over a ground plane or with a nearby PCB, which influences their performance. By incorporating a ground plane in the AN-SOF simulation, designers can obtain results that closely match the actual antenna's behavior, including its input impedance and gain values specified in the datasheet.

The impact of the ground plane can be illustrated by considering the example shown below. Here, a perfect ground plane is used in the AN-SOF simulation, resulting in an input impedance of **48 Ohms**, very close to the 50 Ohms specified in the antenna's datasheet. This close match highlights the importance of including a ground plane for accurate simulations.





This image shows an AN-SOF simulation of a 433 MHz spring helical antenna. The color map represents the current distribution along the helical wire, and the 3D plot depicts the antenna's radiation pattern.

Download Model

The gain simulated with the ground plane is higher compared to the gain the antenna would achieve in free space (without any surrounding objects). This difference is of 3 dB in this example. To estimate the antenna's performance in free space, we can subtract 3 dB from the simulated gain, resulting in a **free-space gain of 1.8 dBi**. This value is closer to what might be specified in the datasheet, which typically refers to free-space performance. While this is a simplified model, it demonstrates AN-SOF's ability to capture the real-world influence of the environment on antenna performance.

Conclusion

AN-SOF software offers distinct advantages for simulating 433 MHz spring helical antennas for ISM and LoRa applications. Its ability to handle **complex geometries**, **closely spaced wires**, and **short curved segments** makes it a powerful tool for achieving accurate antenna design. Additionally, incorporating a ground plane in the simulation is essential for obtaining realistic results that match the antenna's datasheet specifications.

By leveraging AN-SOF's capabilities, antenna designers can optimize the performance of their helical antennas, leading to successful implementations in various wireless applications.

See Also:

- **Solving the Rounded Corner Challenge in Antenna Simulations**
- **DIY Helix High Gain Directional Antenna: From Simulation to 3D Printing**

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Transmission Line Feeding in Antenna Design: Exploring the Four-Square Array

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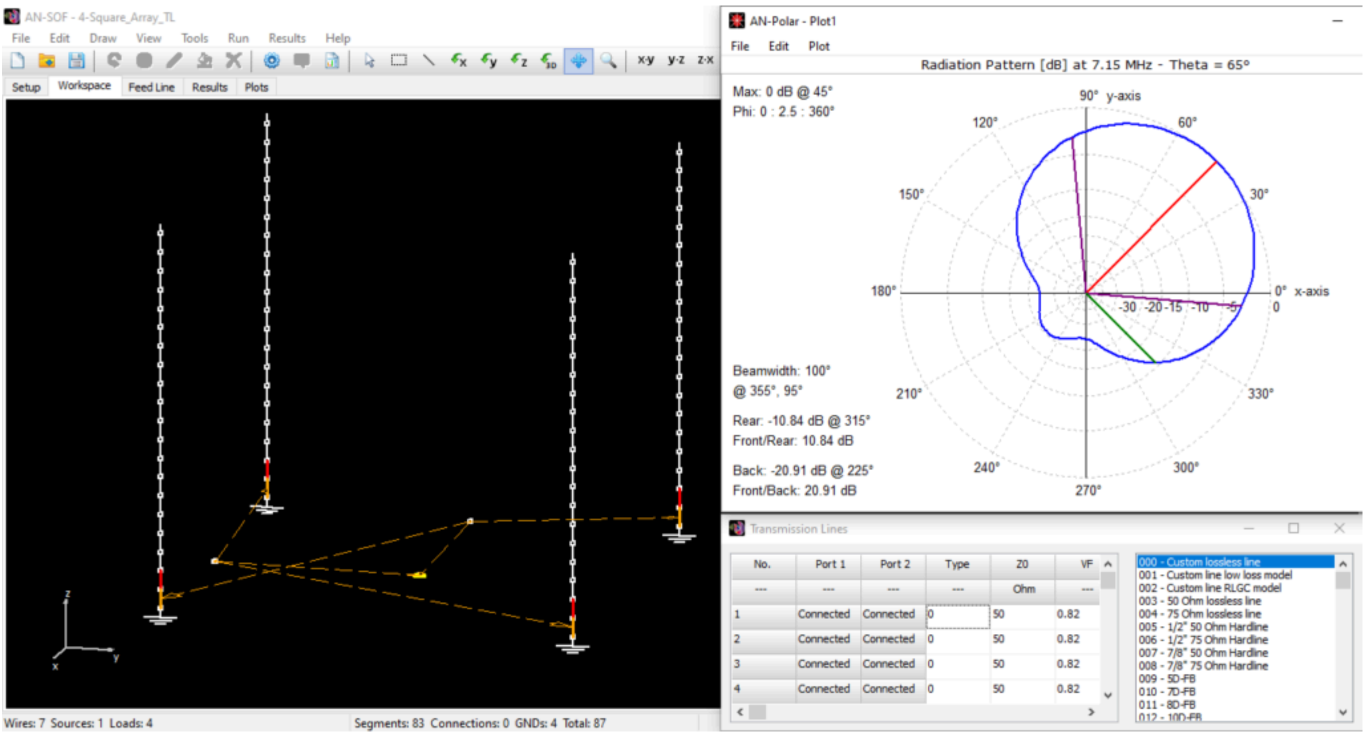
Explore the Four-Square Array: a phased array using six transmission lines in its feeding system. Perfect for directional control, it combines simplicity and performance for RF engineers, ham operators, and antenna designers.

As the **AN-SOF Antenna Simulator** enables implicit modeling of **transmission lines**, this feature allows users to define a transmission line by specifying its characteristic impedance, velocity factor, length, connection ports, and losses. One particularly valuable application of this transmission line modeling capability is in the design and analysis of feeding systems for **phased arrays**. A prime example of a versatile phased array that leverages transmission lines in its feeding system is the **four-square array**. This configuration consists of four vertical elements, each measuring **1/4-wavelength** in height and arranged in a square formation. It serves as an excellent tool for both radio enthusiasts and professionals seeking a straightforward yet effective phased array for controlling the main lobe direction of the antenna's radiation pattern.

The figure below illustrates the layout of the four-square array and its corresponding radiation pattern. When treating the four vertical elements as a **4-port network**, calculations indicate that an **18-Ohm resistor** must be added at the base of each monopole to achieve the desired directional radiation pattern. Additionally, the feeding system of this array incorporates **six transmission lines**, each meticulously configured for specific lengths and interconnections. Detailed specifications for this setup can be found in **Chapter 8, Section "The Four-Square Array,"** of the **19th edition of the ARRL Antenna Book**.



Four-Square Array antenna configuration with a radiation pattern slice at θ = 65º (elevation 25º). The window in the bottom right corner displays settings for the transmission lines used in the antenna's feeding system.

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Here are some of the key properties that make the four-square array an attractive choice for antenna enthusiasts and professionals:

1. **Forward Gain**: 3.3 dBi, assuming an average ground.
2. **Beamwidth**: The array provides a **3 dB beamwidth of 100º**.
3. **Horizontal Front-to-Back Ratio**: 20 dB or better over a **130º angular range**.
4. **Symmetry for Directional Switching**: Due to its symmetric design, the four-square array allows for directional switching in **90º increments**.

By implementing the feeding system described in this model, the four-square array demonstrates excellent performance characteristics, with any limitations primarily arising from environmental factors. Moreover, the array's design facilitates the integration of a **remote switching mechanism**, enabling seamless adjustment of the array's direction as needed.

Whether you are a **ham radio operator**, a **DXer**, or a professional in the field, the four-square array represents a compelling and versatile option for your next antenna project. Its combination of simplicity, performance, and adaptability makes it a standout choice for applications requiring precise control over radiation patterns.

See Also:

- **Extended Double Zepp (EDZ): A Phased Array Solution for Directional Antenna Applications**

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Linear Antenna Theory: Historical Approximations and Numerical Validation

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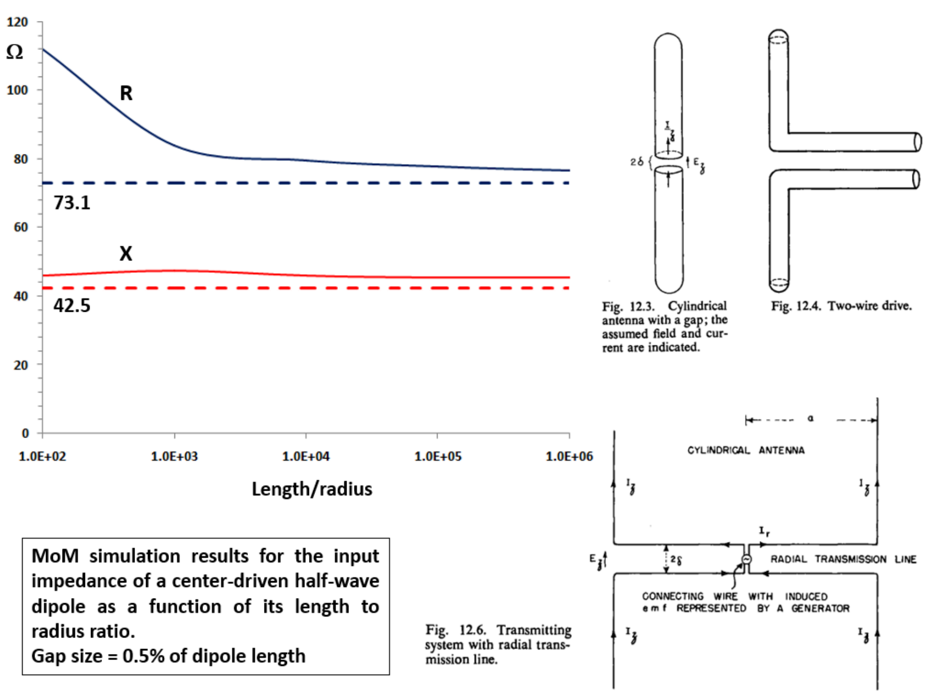
Discover the vital role of historical theoretical results alongside advanced numerical calculations in accurately approximating current distribution on linear antennas.



This article provides a comprehensive review of the theoretical approximations to the current distribution on **linear antennas** that were analytically derived during the first half of the 20th century. While the advancements in computing and numerical calculation methods have enabled higher precision, the historical theoretical results continue to serve as vital references for **validating calculation methods** implemented in algorithms. By examining these approximations, researchers can ensure the accuracy and reliability of modern numerical techniques used in antenna analysis and design.

Historical Theoretical Results: Approximations to Current Distribution

In 1956, Ronold W. P. King published his monumental work titled *"The Theory of Linear Antennas,"* which laid the foundation for understanding linear antennas and became a benchmark for future research. This section explores the significant contributions of

King's work, specifically focusing on the first four approximations to the current distribution on cylindrical antennas derived through an iterative method.

- **0th-Order Approximation > Perfect Sinusoid for Infinitely Thin Antennas**: The 0th-order approximation considers infinitely thin antennas (wire radius = 0) with a delta-gap source (zero gap width between the antenna terminals at the source position). This approximation involves a perfect sinusoidal current distribution.
- **1st-Order Approximation > Accounting for Finite Radius Effect**: The 1st-order approximation incorporates the finite radius effect (wire radius > 0) into the current distribution calculation. In this case, it is necessary to incorporate an additional term to the perfect sinusoidal function in order to obtain the 1st-order current distribution.
- **2nd-Order Approximation > Controversies Surrounding Finite Gap at the Source**: The 2nd-order approximation takes into account the finite gap at the source position, which has historically sparked controversies and debates.
- **3rd-Order Approximation > Considering Feedline Effect**: The 3rd-order approximation considers the feedline effect, which accounts for the boundary conditions at the feeding point resulting from the connection of a transmission line to feed the antenna.

Current Distribution Along a Half-Wave Dipole

To illustrate the aforementioned approximations, this section focuses on the current distribution in amplitude along a center-fed half-wave dipole. Figure 1 provides a graphical representation of the normalized current, $i(s)$, as a function of position in wavelengths, s/λ. It should be noted that the actual current distribution exhibits a sign change in its derivative, $\partial i/\partial s$ (the electric charge), at the dipole center due to the excitation source.

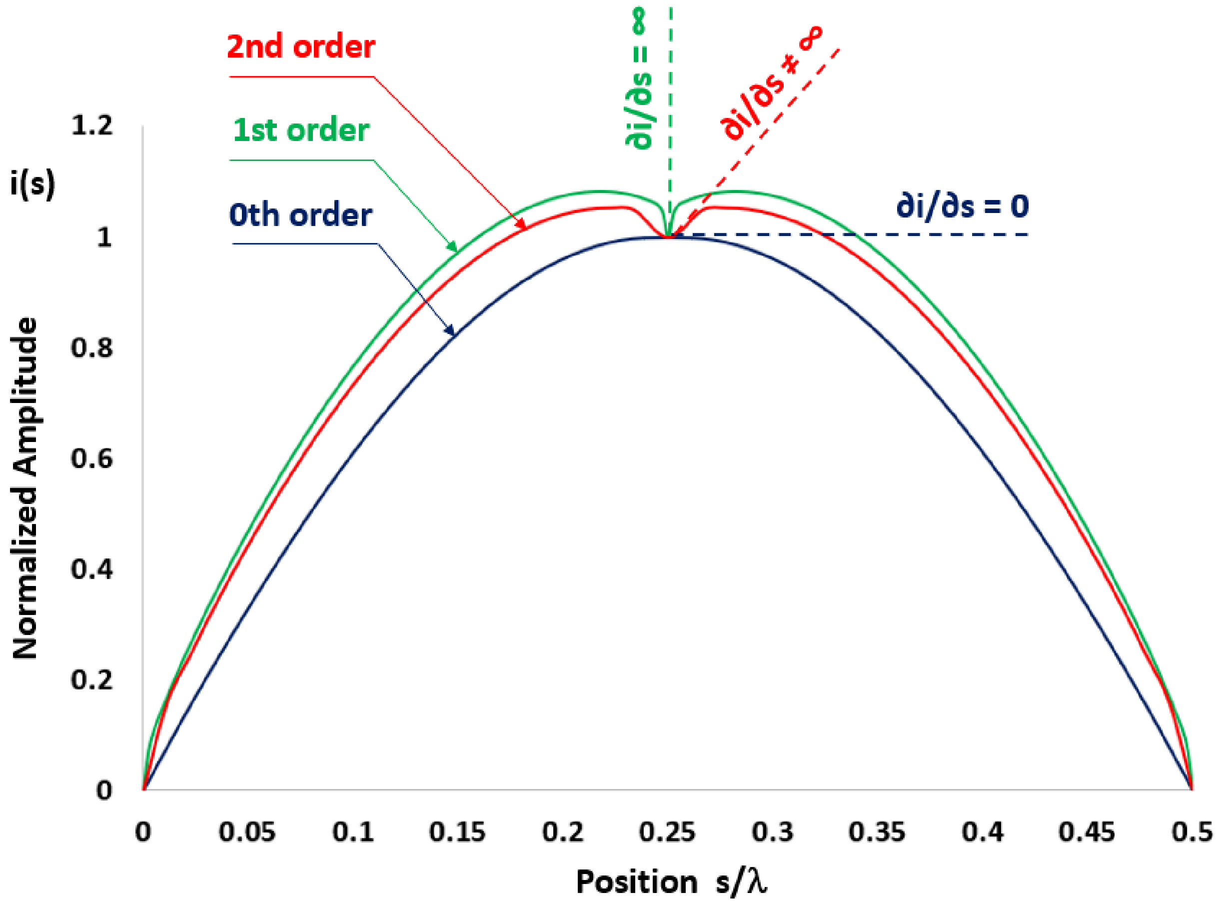


Fig. 1: Normalized amplitude current distribution along a center-fed half-wave dipole. The figure illustrates the 0th, 1st, and 2nd order approximations, highlighting the discontinuity of the current derivative at the feed point.

- **0th-Order Approximation › Perfect Sine Function with Zero Derivative:** Figure 1 demonstrates that the 0th-order approximation, representing a wire radius of 0, yields a perfect sine function. Consequently, the derivative at the source position is zero, $\partial i/\partial s = 0$. However, King's analytical solution results in a finite input impedance of 73.1 + j42.5 Ω, which has been widely accepted and corroborated by other methods.
- **1st-Order Approximation › Finite Wire Radius and Divergent Input Impedance:** The 1st-order approximation considers a finite wire radius and exhibits an infinite derivative, $\partial i/\partial s = \infty$, at the source position. This singularity arises from the zero gap at the antenna terminals and has generated extensive debates throughout the history of linear antennas. As a consequence, the input impedance diverges.
- **2nd-Order Approximation › Finite Source Gap and Converging Input Impedance:** Incorporating a finite source gap, the 2nd-order approximation yields a finite derivative at the source position. As a result, the input impedance converges to a finite value, dependent on the dipole wire thickness and the separation between its feeding terminals.
- **3rd-Order Approximation › Consideration of Transmission Line Feed:** Although not visually distinguishable from the 2nd order on a graph, the 3rd-order approximation accounts for the characteristic impedance of the transmission line at the feed point. This effect, though small, can be accurately calculated using the **Method of Moments** with an **exact Kernel**.

Validating Numerical Methods: Impedance Convergence

Validating numerical methods is a critical step in ensuring their accuracy, achieved by examining the limiting cases predicted by theory. As demonstrated, the 0th-order input impedance (wire radius = 0) of a center-fed half-wave dipole is determined to be **73.1 + j42.5 Ω**. Consequently, this value should serve as a **horizontal asymptote** for the input impedance when the dipole length-to-radius ratio tends to infinity.

Figure 2 presents simulation results obtained using **AN-SOF**, which utilizes the **Method of Moments with an exact Kernel**. The figures from King's book illustrate the antenna terminals in detail, where a radial transmission line was considered to account for 3rd-order effects. **Notably, the calculated input impedance indeed converges to the theoretical value as predicted.**

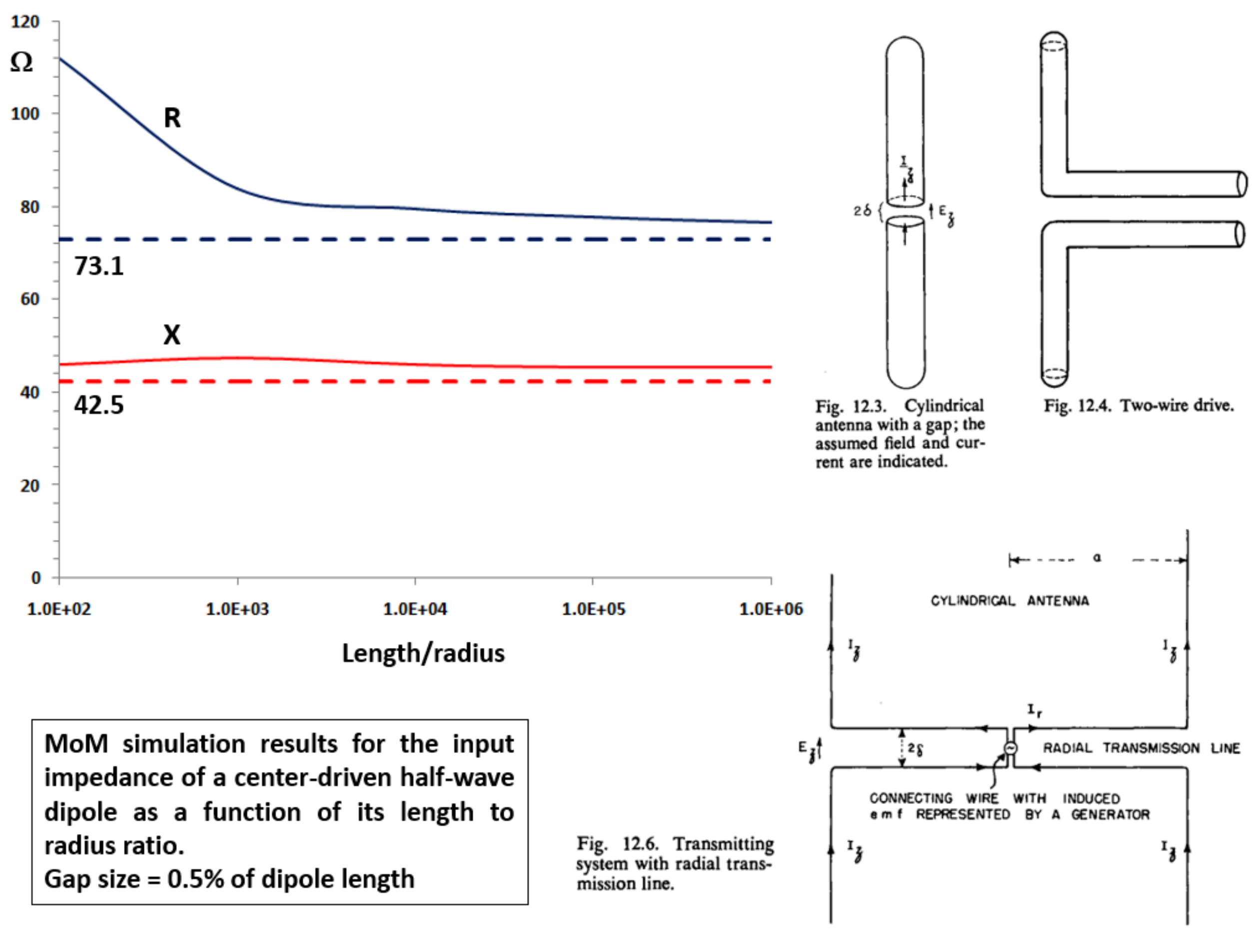


Fig. 2: Simulation results using the Method of Moments with an exact kernel, depicting the input impedance of a center-fed half-wave dipole as a function of its length-to-radius ratio. The figure also includes a comparison with the theoretical asymptotes. The cylindrical antenna illustrations are taken from King's book.

For a more comprehensive investigation into the impedance convergence of cylindrical antennas, **a detailed study on the validation of AN-SOF can be accessed through this link**.

Conclusions

This article has reviewed the historical approximations of current distribution on linear antennas as presented in Ronold W. P. King's book. The four approximations, namely the 0th, 1st, 2nd, and 3rd-order approximations, have been thoroughly examined. These approximations progressively refine the theoretical model of a cylindrical antenna by considering factors such as the finite wire radius, the finite gap at the feed point, and the incorporation of the connected transmission line.

Moreover, the article has highlighted the importance of **numerical validation** in establishing the reliability of modern methods. The validation process involved comparing the numerical results to the limiting cases predicted by theory. Through the **AN-SOF** simulation, which utilizes the **Method of Moments with an exact kernel**, the calculated input impedance successfully demonstrated convergence to the theoretical values.

Further Reading

- For further reading, we highly recommend the book *"The Theory of Linear Antennas"* by Ronold W. P. King, Harvard University Press, 1956. This seminal work provides a comprehensive understanding of linear antennas and serves as a benchmark for research in the field.
- In the paper *"Currents, Charges, and Near Fields of Cylindrical Antennas"* by R.W.P. King and Tai Tsun Wu, Radio Science Journal of Research NBS/USNC-URSI, Vol. 69D, No. 3, pp. 429-446, March 1965, the authors compare the sinusoidal current distribution with measured data and identify the need for an additional term in the model.
- To delve deeper into the source gap problem, we refer to *"The Influence of the Width of The Gap Upon The Theory of Antennas"* by L. Infeld, Quarterly of Applied Mathematics, Vol. V, No. 2, pp. 113-132, July 1947. This study provides valuable insights into the effects of gap width on antenna theory.

See Also:

- **Pi Day Special: A Short Dipole with Radiation Resistance of 3.14 Ohms**
- **Modeling a Center-Fed Cylindrical Antenna with AN-SOF**

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About the Author

Tony Golden

ANTENNA SIMULATION ENGINEER & PHYSICS PH.D. With over 25 years of experience in Computational Electromagnetics, I'm a dedicated researcher specializing in antenna modeling and design. As the founder of Golden Engineering LLC, I develop intuitive yet powerful simulation tools to help RF engineers optimize designs, educators demonstrate concepts, and hobbyists bring antenna projects to life. Through technical content on simulation methods and antenna theory, I empower professionals and enthusiasts to overcome practical challenges in radiating systems.

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