Inverted "V"-Shaped Grid Plate Dipole Antenna Design Postprint

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Abstract

Radio astronomy employs antenna arraying for observations in the HF-VHF band. According to the requirements of the Square Kilometre Array (SKA), each array element antenna must achieve high specifications in gain, structural consistency, stability, impedance variation characteristics, and polarization purity to satisfy the demands of various measurements—including solar, Jovian, and Epoch of Reionization observations—for polarization measurement, antenna tracking stability, and receiver broadband matching. Based on the performance requirements specified in SKA requirement 2165: polarization purity (2135-38) and sensitivity per polarization (2814-15), and drawing upon lessons learned from previous designs, a novel inverted "V" type grid-plate dipole antenna has been designed for the HF-VHF band covering 10-90 MHz. This antenna offers advantages such as light weight and low wind resistance, while exhibiting slow impedance variation and excellent polarization purity across the ultra-wideband 10-90 MHz frequency range. In terms of impedance variation, the real part of the antenna impedance ranges from 0.8 Ω to 631.132 Ω, outperforming the low-frequency array antenna of the Low Frequency Array (LOFAR) and thereby reducing receiver matching difficulty and noise. Regarding polarization purity, the antenna achieves an overall axial ratio of less than 0.41 dB, providing excellent polarization isolation for strongly polarized signals such as solar radio bursts.

Full Text

Design of Inverted "V" Grid Dipole Antenna

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Abstract: Radio astronomy employs antenna arrays for observations in the HF-VHF frequency band. According to Square Kilometre Array (SKA) requirements, each array element must achieve high performance in gain, structural consistency, stability, impedance characteristics, and polarization purity to meet the demands of solar, Jovian, and Epoch of Reionization measurements for polarization accuracy, antenna tracking stability, and receiver broadband matching. Based on SKA Requirement 2165—covering polarization purity (2135-38) and sensitivity per polarization (2814-15)—and drawing from prior design experience, this paper presents a novel inverted "V" grid dipole antenna for the 10-90 MHz HF-VHF band. The design offers advantages of light weight and low wind resistance while exhibiting gradual impedance variation and excellent polarization purity across the ultra-wideband. Specifically, the antenna' s impedance real part varies from approximately 0.8 Ω to 631.132 Ω, outperforming the Low Frequency Array (LOFAR) low-frequency antenna and reducing receiver matching difficulty and noise. The antenna achieves an overall axial ratio below 0.41 dB, providing good polarization isolation for strongly polarized signals such as solar radio bursts.

Keywords: inverted "V" grid dipole antenna; HF-VHF radio array; ultra-wideband; polarization purity; antenna impedance

Celestial bodies radiate abundant electromagnetic waves that penetrate clouds to reach Earth' s surface. By receiving and processing these radio signals, we can study cosmic phenomena and explore natural mysteries. However, these signals are extremely weak, requiring larger telescope apertures and higher sensitivity for detection. As the next-generation meter-to-centimeter-wave radio telescope, SKA will deploy three receiver arrays—low-frequency aperture arrays, mid-frequency aperture arrays, and mid-frequency reflector arrays—with a total collecting area of one square kilometer. Upon completion, SKA will achieve 50 times the sensitivity and 10,000 times the survey speed of the current largest centimeter-wave interferometer, the Jansky Very Large Array (JVLA). With nanosecond-level sampling for fine temporal structure and data rates of 10 petabits per second—exceeding global internet traffic—SKA' s wide-field, multibeam, high-dynamic-range, high-resolution, and big-data concepts will revolutionize traditional radio astronomy research methods.

The rapid development of high-speed digital devices in the early 21st century, coupled with the evolution of radar technology from passive to active to digital arrays, has provided new approaches for SKA. Around 2000, Dutch scientists pioneered the development of LOFAR, a new digital beamforming architecture for low-frequency radio telescopes, which became operational in 2013 and validated the superior performance of digital array architectures in wide-field imaging, flexibility, and imaging capabilities. During this developmental phase, SKA gradually established a technical roadmap based on multi-antenna small-aperture arrays. Consequently, two of its three major telescope architectures—the sparse aperture array and dense aperture array—adopt digital array systems, with the sparse aperture array drawing on LOFAR technology for larger-scale deployment.

LOFAR enables flexible multi-beam imaging and beamforming measurements for deep, high-angular-resolution radio surveys of outer space, operating in two primary bands: LOFAR Low-Band Antenna (LOFAR-LBA, 10–90 MHz) and LOFAR High-Band Antenna (LOFAR-HBA, 110–250 MHz). The LOFAR-LBA covers the HF-VHF band, which holds significant research value for space weather, solar radio bursts, planetary emissions within the solar system, pulsars and transients, and cosmic reionization. In solar radio astronomy, for instance, low-frequency observations of the corona at 1–2 solar radii can effectively provide early warnings for space weather events such as energetic particles, geomagnetic storms, and ionospheric disturbances associated with coronal mass ejections (CMEs). In pulsar studies, the low-frequency radio band has become increasingly popular with the emergence of new observational facilities.

According to antenna array beamforming principles, stable tracking performance depends on favorable impedance characteristics of array elements, requiring good impedance matching without degradation across the operating band. Additionally, elements must maintain stable radiation patterns throughout the tracking range without sudden drops in radiated energy. Finally, mutual coupling between array elements should be relatively small to avoid scanning blind spots caused by strong coupling.

Based on LOFAR and SKA requirements for low-frequency array elements, antennas must provide ultra-wideband operation and excellent polarization purity, with impedance variation remaining moderate. The antennas require dual-linear polarization reception, enabling dual-circular polarization through backend digital synthesis to facilitate weak signal detection in radio astronomy. During tracking, real-time optimization of array beamwidth, pointing angle, and tracking algorithms is necessary for adaptive stable tracking of weak radio astronomical signals.

1 Antenna Element Design

The inverted “V” antenna offers wide bandwidth, simple structure, and easy installation. Building upon the inverted “V”dipole antenna described in reference [11], we transformed the wire dipole into a plate dipole to broaden bandwidth and smooth impedance variation. The model and impedance characteristics of the inverted “V” plate dipole antenna are shown in [Figure 1: see original paper] and [Figure 2: see original paper], with impedance data provided in .

To reduce weight and wind resistance while simplifying transport and assembly, we replaced the radiating plates with copper wires and grid structures. We compared the electrical performance of antennas with plate, cable, and grid radiators to determine the optimal number and dimensions of cables and grids that could equivalent the plate dipole performance.

1.1 Equivalent Plate Using Multiple Cables

We replaced the plates in the inverted "V" plate dipole model with multiple cables as dipole radiators, connecting them at the bottom with a parallel plate. With cable diameter set to 5 mm and connection plate width to 50 mm, we simulated impedance characteristics while varying the number of cables. The cable-replacement model is shown in [Figure 3: see original paper], impedance variations for different cable counts in [Figure 4: see original paper] (with the red curve representing the plate dipole), and detailed data in .

The results show that using cables shifts the impedance extrema to lower frequencies. As cable count increases from 3 to 17, the maximum real part of impedance decreases progressively, reducing impedance variation across the 10-90 MHz band. With 17 cables, impedance variation approaches that of the plate dipole, though transport and assembly become significantly more complex.

1.2 Equivalent Plate Using Grid Structures

Considering manufacturing complexity and structural simplicity, we simulated an inverted "V" grid dipole antenna comprising five grid bars. The simulation model appears in [Figure 5: see original paper], with real impedance characteristics for grid bar widths of 24 mm, 30 mm, and 35 mm shown in [Figure 6: see original paper] and data in .

Analysis of [Figure 6: see original paper] reveals that increasing grid bar width reduces the maximum real impedance and decreases impedance variation across the band. However, wider bars increase weight. Balancing performance and weight, we selected 30 mm-wide grid bars as optimal.

2 Inverted "V" Grid Dipole Antenna

[Figure 7: see original paper] shows the overall structure of the inverted "V" grid dipole antenna, with impedance characteristics depicted in [Figure 8: see original paper].

2.1 Antenna Structure

The final design replaces the radiating plates with five grid plates, adding horizontal cross-members for structural stability. The antenna body is supported by insulating dielectric columns, with the radiating grids connected via insulators to a bottom cross-shaped metal structure. The RF feed module mounts near the top of the support column. For lightning protection, a lightning rod installed above the antenna channels high currents to ground through a grounding wire, while an insulating dielectric plate isolates the rod from the antenna to prevent radiation pattern distortion. The complete structure is shown in [Figure 7: see original paper], where orange indicates metal components and red indicates dielectric material (fiberglass, relative permittivity _r = 3.5, loss tangent tanδ = 0.0035). Grid bars are 30 mm wide, with total grid width of 300 mm and length of 1800 mm. The bottom connection plate is 10 mm wide, and the distance between the antenna top and insulating plate is 10 mm. Compared with the plate dipole, the grid dipole reduces weight by 53% while the grid openings decrease instantaneous wind loading.

2.2 Antenna Performance

We simulated the electrical performance—impedance, radiation pattern, and axial ratio—using the full-wave electromagnetic simulation software FEKO.

2.2.1 Antenna Impedance Impedance variation is shown in [Figure 8: see original paper], with the real part in green and imaginary part in blue. Detailed data appears in . The real part varies from approximately 0.8 Ω to 631.132 Ω, showing reduced variation compared with the plate dipole and easing backend RF circuit matching. The plate dipole exhibits two resonance points in the imaginary part because the wide bandwidth causes the arms to exceed $\lambda/2$ at high frequencies, creating reverse currents. The grid dipole similarly suppresses these reverse currents, yielding smoother imaginary impedance characteristics.

2.2.2 Antenna Radiation Pattern Phase modulation of the two ports enables circular polarization. [Figure 9: see original paper] shows right-hand circular polarization (blue) and left-hand circular polarization (green), with the shaded blue region indicating the 3 dB beamwidth for right-hand polarization. Maximum gain and 3 dB beamwidth data are provided in . The pattern exhibits a cosine-like radiation characteristic.

2.2.3 Antenna Axial Ratio Axial ratio data in show values below 0.41 dB across the band, demonstrating excellent polarization purity and multipath interference suppression for weak signal detection.

2.3 Performance Comparison

We compared the inverted "V" grid dipole with two previously developed HF-VHF antennas, as summarized in . The grid dipole demonstrates superior performance in polarization isolation, in-band frequency response smoothness, and antenna-receiver matching.

Conclusion

Based on the inverted "V" plate dipole, we analyzed cable and grid alternatives for the radiating elements. Prioritizing electrical performance and transportability, we selected a five-grid-bar design. Compared with the plate dipole, the grid dipole achieves a 53% weight reduction while maintaining gradual impedance variation and excellent polarization purity. Lightning protection design further ensures operational safety in practical environments.

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Note: Figure translations are in progress. See original paper for figures.