Transmit Antenna for Ionospheric Sounding Applications

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Abstract

Uniform illumination, over space and frequency, of the bottom-side ionosphere is important for a vertical incidence ionosonde. Ionospheric tilts and structures produce echoes several tens of degrees from vertical even under quiet conditions. Characteristics of traditional traveling wave Delta and Rhombic antennas offer poor frequency and spatial characteristics. An inverted log periodic antenna (LPA) was designed and built for the new vertical incidence VIPIR/Dynasonde ionosonde at the NASA Wallops Flight Facility. An ionosonde specific figure of merit was developed to optimize between the potential antenna designs. Using method of moments, a sensitivity analysis of the physically realized LPA showed the antenna to be a highly stable design. This paper presents the capabilities of the LPA design to more accurately sample ionospheric dynamics.

Objective

Vertical incidence ionosonde transmit antennas need to operate over a broad range of frequencies, ideally 300kHz to 30MHz, to cover the natural range of ionosphere plasma frequencies. It is also important to illuminate the sky over a broad range of angles around station zenith, ideally ±60°, to observe the reflections the dynamic ionosphere can produce **[1][2]**. Uniform polarization allows equal excitation of ordinary and extraordinary propagation modes. Consistent performance in all of these domains is desired, so as to provide unbiased data that are easier to interpret.

The size of a transmit antenna is generally the limiting factor to how well it can meet the desired performance objectives. Transmit antennas and their installation are typically the largest, most expensive and most limiting component of an ionosonde field site. It is our objective to optimize the performance of this system component.

Approach

Vertical incidence ionosondes historically use traveling wave antennas of the Delta or Rhombic design. These antennas often exist from previous installations, and have the significant logistical advantages of being simple to design and easy to build. Empirical studies **[3]** have compared Delta and Rhombic antennas with other designs.

The basic concept of the Apex-down Zig-Zag Log Periodic Antenna (ZZLPA) is embodied in the transmitting antenna used for the EISCAT Dynasonde operating at Tromsø, Norway. This antenna was designed using scale models **[4]** and has performed well over the years. The opportunity to build a similar antenna at Wallops allowed us to optimize the design using finite element numerical antenna modeling in the Numerical Electromagnetics Code Version 2 (NEC2).

Key to selecting between good and poor antenna designs from the population of possible designs is a Figure Of Merit (FOM) which compares the computed electrical performance of any specific antenna model against a desired set of performance standards. Our desired antenna achieves a high vertical gain over as wide a frequency band as possible, which varies minimally with frequency. It is also important that the impedance of the antenna is matched to the feed transmission line and the Standing Wave Ratio (SWR) does not exceed the limits of the transmitter. It is desirable to have equal illumination in both ordinary and extraordinary polarizations, so as to equally excite both propagation modes.

The FOM algorithm selects antenna gain in the zenith direction from NEC and corrects this for reflected power loss due to driving point impedance mismatch, including a penalty when the mismatch exceeds the transmitter limits. The mean $\bar{G}_{eff}$ and standard deviation σ_{Geff} of this effective vertical gain is computed across the intended frequencies of operation using Equation 1

$$FOM = 10 * \frac{\bar{G}_{eff}}{(1 + \sigma_{Geff})} \tag{1}$$

This is the algorithm used to optimize the design of the Wallops ZZLPA, which makes the assumption that the gain in the zenith direction is a representative metric of the performance objectives of the ionosonde.

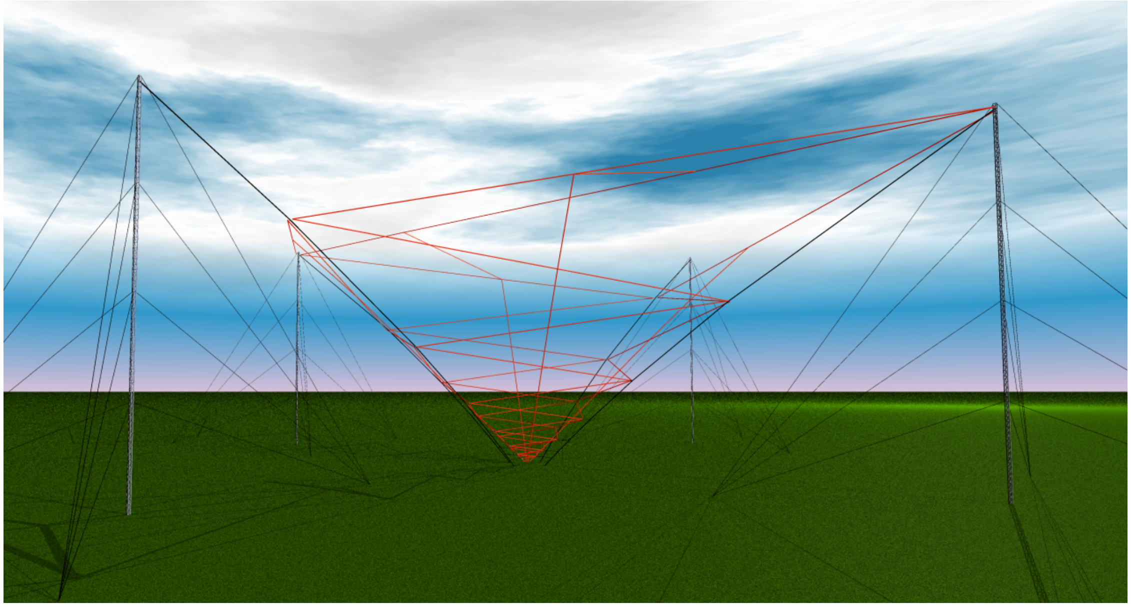

Figure 1: Visualization of the radiating wires in the Wallops ZZLPA antenna.

The Wallops ZZLPA consists of over 1.5km of wire in 4 zig-zag planes. The site constraints, 4 towers of 36m located on a square 76m per side, limit the actual log periodic performance of the design to above ≈2MHz. Below this frequency there is an adaptation which behaves approximately like a terminated or traveling wave dipole. The configuration of the radiating wires is shown in Figure 1.

Results

The modeled values of effective vertical gain and SWR for this design are plotted in Figure 2a. A typical elevation gain pattern from the ZZLPA is shown in Figure 2b. The ZZLPA gain varies slowly about zenith and the 10dB full beamwidth is 120°. The FOM for this design is 38. This beam pattern is very uniform with frequency. The polarization is largely linear in the log periodic portion of the antenna, but shows a significant bias toward right hand circular polarization (RHCP) below 2MHz. This bias towards RHCP is undesirable but the orientation of our ZZLPA at Wallops is such that the ordinary mode of ionosphere propagation is predominantly excited. The plane of polarization also rotates through 65 degrees from 1 to 2 MHz before settling. These effects are quantified by the antenna axial ratio and E-plane curves shown in Figure 3a. The blue curve shows the rotation of the plane of polarization as a function of frequency. The red curve shows the frequency dependency of the axial ratio. Note the sub optimum axial ratio below 2.5 MHz. As aforementioned, this is due to the top wire radiator that was necessary to optimize low frequency gain given land and tower height constraints.

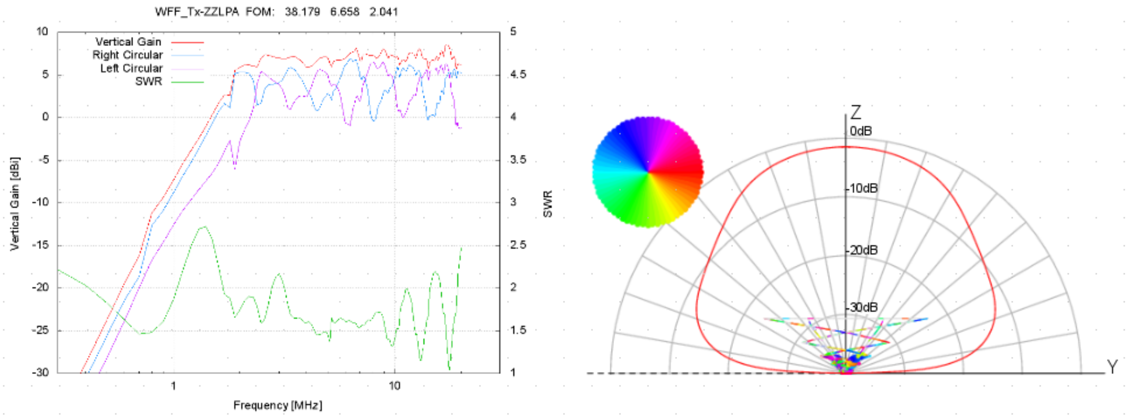

Figure 2: Modeled results for the Wallops ZZLPA. Corrected Vertical Gain: Total, Left Circular and Right Circular polarization components, and Standing Wave Ratio are shown in the left panel(a). The polarization varies with frequency. The elevation pattern of vertical gain at 8.3 MHz is shown in the right panel(b). This pattern is smooth and very similar for all frequencies. The current amplitude is represented by color and the phase by thickness. Zero dB represents maximum gain over all frequencies.

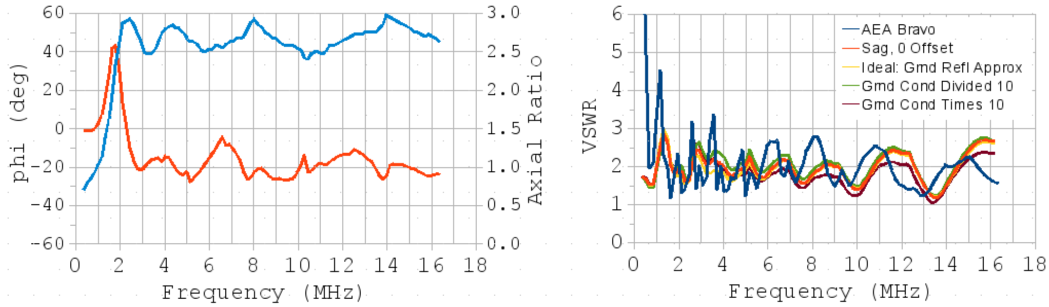

Figure 3: E-plane direction (blue) and Axial Ratio (red) versus frequency are shown in the left panel (a). The right panel (b), is a comparison of the real measured VSWR and model sensitivity to a variety of realistic perturbations.

After construction, a number of undesirable mechanical characteristics were present. Due to limited catenary tension, the feed and radiating element segments showed levels of vertical sag up to 14 feet and the feed connections were noticeably out of plane from their modeled design. Questions regarding the effects of these artifacts to the basic ZZLPA antenna parameters such as impedance and radiation pattern arose. Our figure of merit FOM and method of moments antenna analysis techniques were employed to carry out a sensitivity study of the effects of element sagging, feed offsets, ground plane conductivity and permittivity and corrosion, to the basic properties of this antenna including impedance, voltage standing wave ratio (VSWR), polarization and gain. Modelling proved the ZZLPA's antenna parameters to be insensitive to these perturbations. Stability of the ZZLPA design's VSWR is shown in Figure 3b where: AEA Bravo = measured VSWR after construction, Ideal Grnd Refl Approx = idealized ZZLPA as control, Sag 0 offset = model VSWR including measured (photometric) radiating element sag, Grnd Cond Divided 10 = Sag 0 offset + ground plane conductivity / 10, Grnd Cond Times 10 = Sag 0 offset + ground plane conductivity * 10. This study was performed on a model which embodied all visual aberrations of the physically constructed antenna at the Wallops Flight Facility.

When logistical constraints, such as the height of an existing tower, antenna cost, or limited land, compel a Delta antenna, it is desirable to use a similar optimization process as for the ZZLPA to obtain the best performance possible, and to understand the impacts of the design choices. For this comparison, we chose a Delta design with gain similar to the ZZLPA at 1MHz and performed no other optimization. Figure 4a shows the vertical gain and SWR for a Delta antenna with a single 36m high tower, the same height tower as for the ZZLPA. The horizontal extent of this antenna is ±55m. Figure 4b shows that the gain pattern at 8MHz varies substantially near zenith. This pattern varies dramatically with frequency. There is a vertical null in the antenna pattern between 9 and 12 MHz. The polarization is strictly linear at all frequencies. The FOM for this design is a non-optimum value of -6. This is the consequence of the design choice to obtain low frequency performance similar to the ZZLPA.

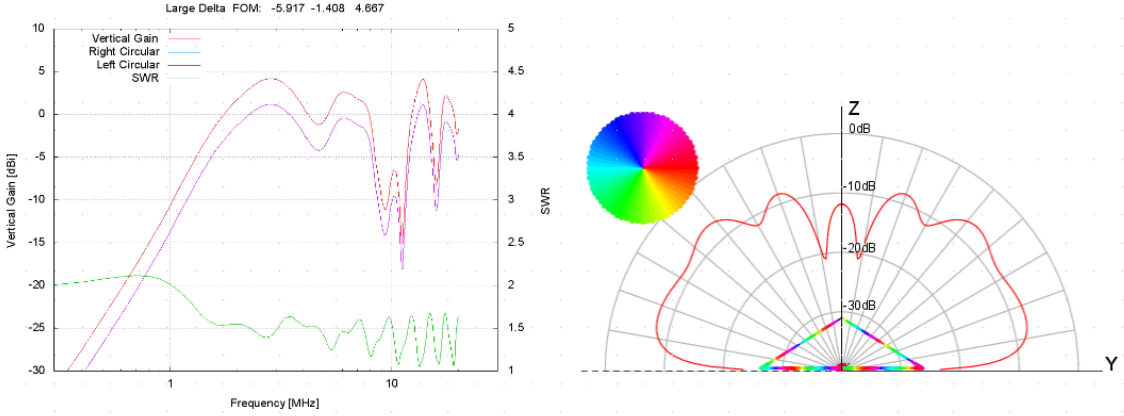

Figure 4: Modeled results for a large Delta antenna. Corrected Vertical Gain: Total, Left Circular and Right Circular polarization components, and Standing Wave Ratio are shown in the left panel(a). The polarization is uniformly linear. The elevation pattern of vertical gain at 8MHz is shown in the right panel(b). This pattern is highly structured and varies strongly with frequency. The current amplitude is represented by color and the phase by thickness. Zero dB represents maximum gain over all frequencies.

The two dimensional structure of the illumination pattern for the Delta and the ZZLPA is shown in

Figure 5 as all-sky gain plots. The spatial non-uniformity of the Delta near zenith is large compared to that of the ZZLPA.

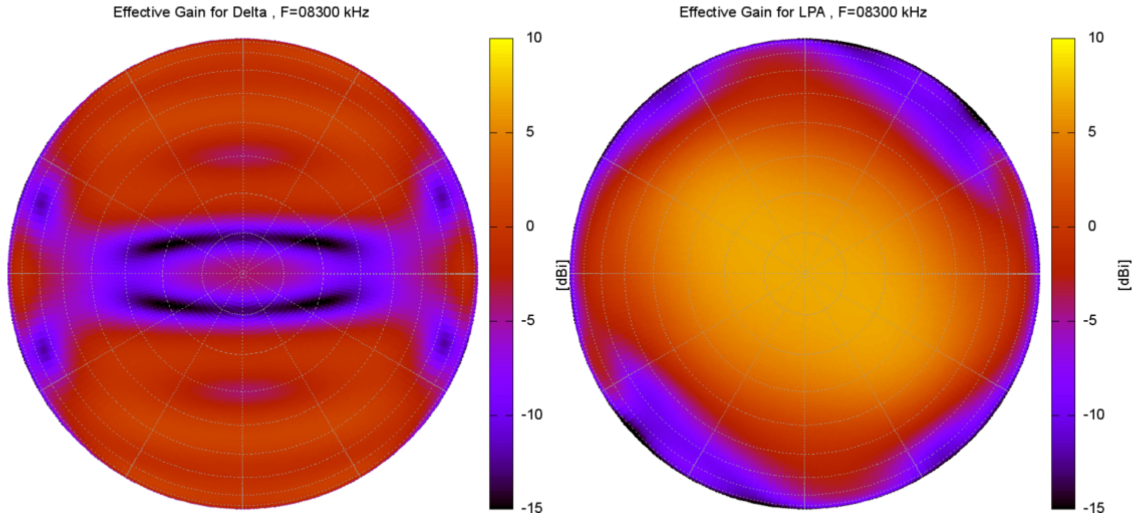

Figure 5: Modeled all-sky gain plots for the Delta (left) and the ZZLPA (right) antenna designs at 8.3 MHz. Zenith is in the center of each circular plot and the horizon is at the outer edge.

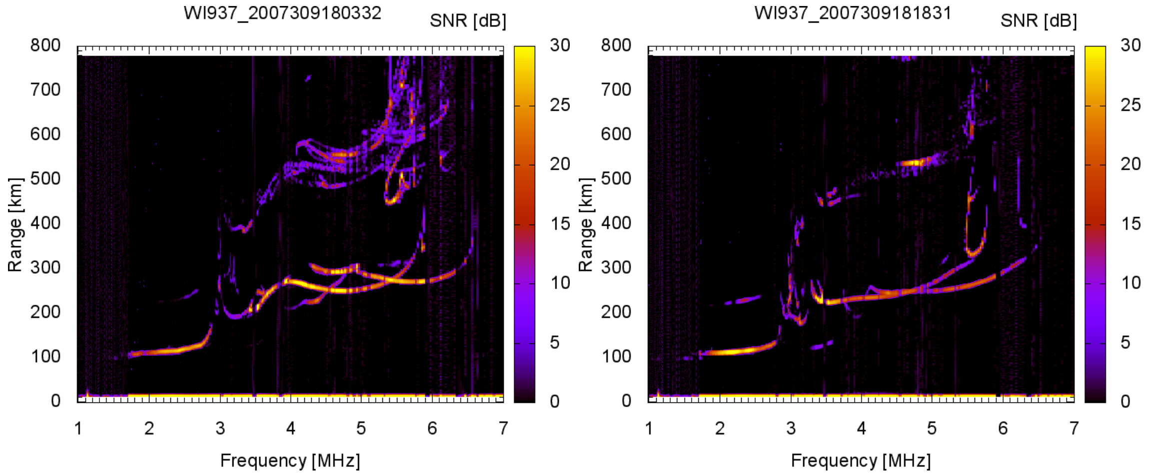

Figure 6: Two ionograms from the Wallops Island VIPIR taken on 05 November 2007 at 13LT, 15 minutes apart. The received power signal to noise ratio, in dB, is displayed. These ionogram traces indicate the presence of strong temporal and spatial gradients in the ionosphere.

Ionograms in Figure 6 were taken by the Wallops VIPIR using the ZZLPA. The left hand ionogram (18:03:32UT) features a signature between 5.4 and 5.8 MHz and 420-500 km range that is likely a first order reflection from a strong horizontal gradient at F region altitudes. The observed ranges indicate that this feature is coming from as much as 50 degrees off zenith. Angle of arrival information for these echoes have not yet been extracted from the raw data to confirm this approximation. Without a broad, uniform transmitted beam, this dynamic feature might not have been observed.

Conclusion

The variability of a transmit antenna's spatial illumination pattern and the variation of that pattern with frequency results in a selective and non-uniform sampling of the ionosphere under observation. Echoes in the direction of a transmit antenna null, which otherwise would have been observed, disappear or are weak. As this effect varies with frequency, this can induce a false appearance of structure in the observed data. The more uniform the antenna pattern, the more accurately the observations represent true ionosphere structure and the simpler the determination of the nature of this structure. The log periodic design provides very uniform vertical incidence ionosphere illumination.

References

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