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 VIPR/Dynasonde ionosonde at the 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.

Summary

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 $\pm 60°$, to observe the reflections the dynamic ionosphere can produce [**1**][**2**]. Uniform polarization allows consistent 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 station. It is sensible to optimize the performance of this system component.

Vertical incidence ionosondes historically use traveling wave antennas of the Delta or Rhombic design. These antennas are often existing 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 on 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 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) algorithm which compares the computed electrical performance of any specific antenna model against a desired set of performance standards. The desired antenna characteristics are to obtain a vertical gain which is high, over as wide a frequency band as possible, and does not vary with frequency. It is also important that the impedance of the antenna are 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.

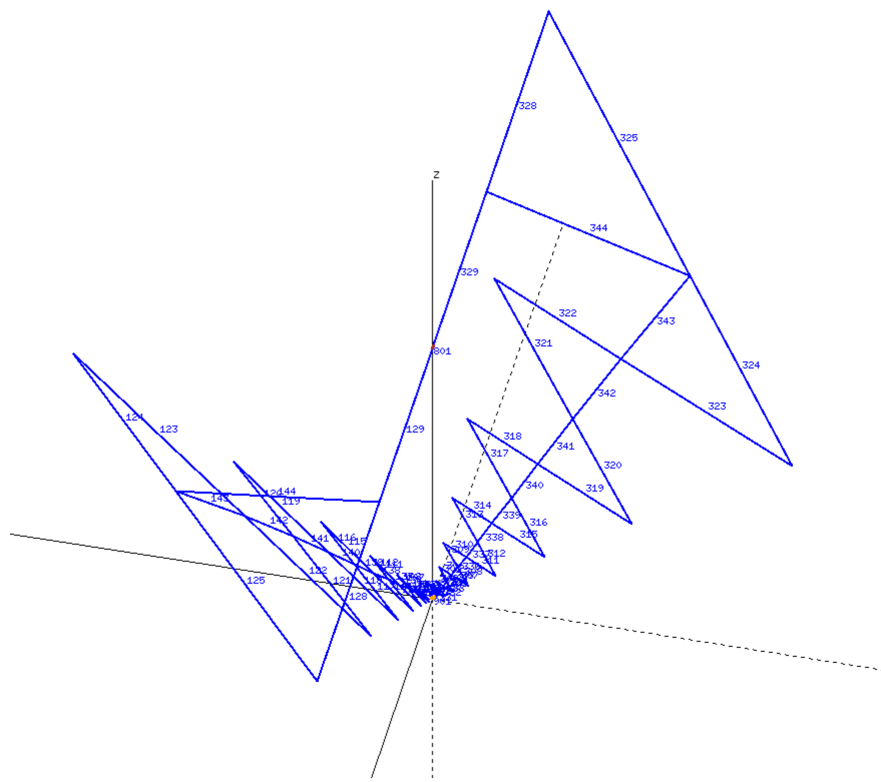

Figure 1: Visualization of the radiating wires in the Wallops ZZLPA antenna. Note that only two of the four planes are shown, for clarity.

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.

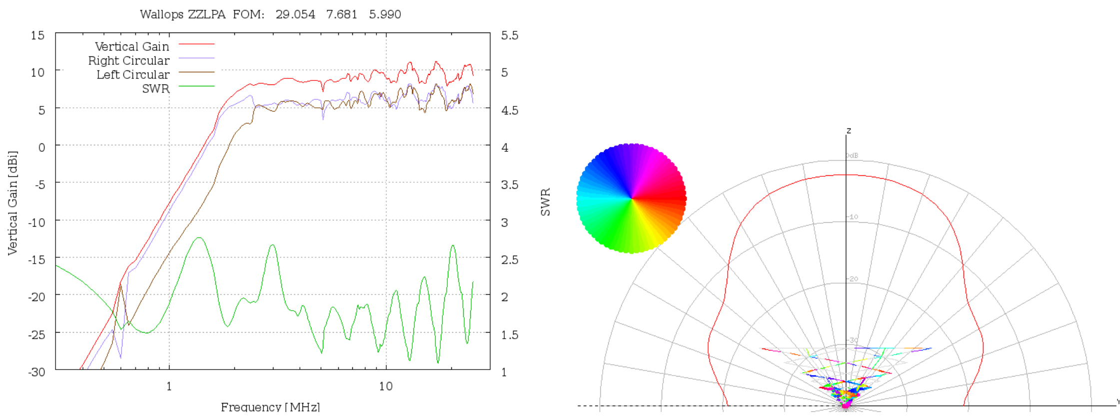

Figure 2: Modeled results for the Wallops ZZLPA. Corrected Vertical Gain, Total, Left Circular and Right Circular polarization components, and Standing Wave Ratio are shown in the left panel(a). The polarization varies with frequency. The elevation pattern of vertical gain at 8 MHz is shown in the right panel(b). This pattern is smooth and very similar for all frequencies. Colors represent current amplitudes and phases.

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 in Figure 2b. The ZZLPA gain varies slowly about zenith and the beamwidth is typically 90°. 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 below 2MHz. The FOM for this design is 29.05.

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 affects of these artifacts to the basic LPA antenna parameters such as impedance and radiation pattern arose. Our figure of merit FOM and method of moments antenna analysis techniques and were employed to carry out a sensitivity study to of the effects of element sagging, feed offsets, ground plane characteristics and corrosion, to the basic properties of this antenna including impedance, SWR, polarization and gain. This shows the LPA performance to be insensitive to these effects.

When logistical constraints, such 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. Figure 3a shows the vertical gain and SWR for a Delta antenna with a single tower the same 36m height tower as for the ZZLPA, with approximately the same gain at 1MHz. The horizontal extent of this antenna is ±55m. Figure 3b shows the gain pattern at 8MHz varies substantially near zenith. This pattern varies dramatically with frequency. There is a vertical null in the antenna pattern around 10MHz. The polarization is strictly linear at all frequencies. The FOM for this design is a non-optimum value of 8.25. This is the consequence of a design to obtain low frequency performance similar to the ZZLPA.

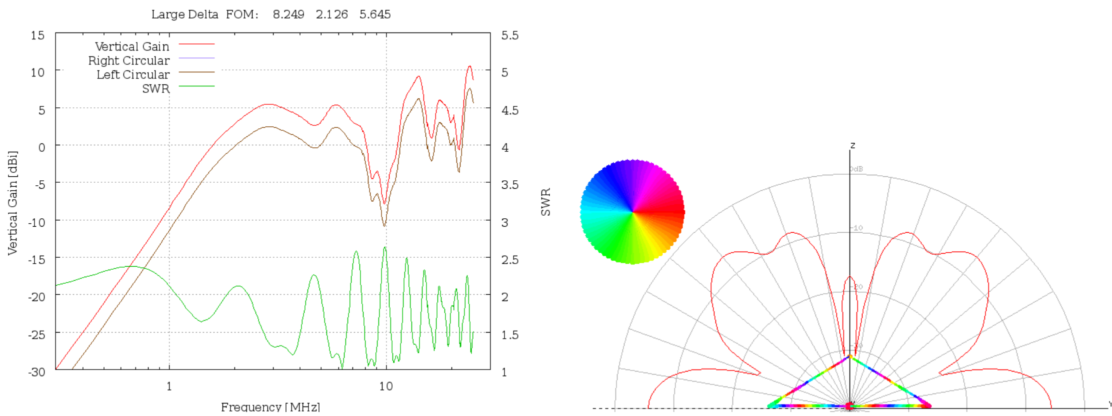

Figure 3: Modeled results for a large Delta antenna. Corrected Vertical Gain, Total, Left Circular and Right Circular polarization components, and Standing Wave Ratio are shown in the left panel(a). The polarization is uniformly linear. The elevation pattern of vertical gain at 8MHz is shown in the right panel(b). This pattern is highly structured and varies strongly with frequency. Colors represent current amplitudes and phases.

The variability of the a transmit antenna's spatial illumination pattern and its variation with frequency results in a selective and non-uniform sampling of the ionosphere under observation. Echos in the direction of a transmit antenna null, which otherwise would have bee been observed, dissapear 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 illuminaton.

References

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