Genetic Algorithm Optimization of a Military Ionosonde Antenna

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Abstract: The application of genetic algorithms to advanced forms of military antenna design have been studied at the Air Force Research Laboratory Antenna Technology Branch for many years. We were recently asked to apply our research in this area to a real-world problem – the redesign of a hybrid transmit antenna used for ionospheric measurements as part of the DISS system. In this poster, we describe the antenna application and the genetic algorithm approach used to optimize the new hybrid antenna configuration.

1 Digital Ionospheric Sounding System (DISS)

The Digital Ionospheric Sounding System (DISS) network is operated by the US Air Force Weather Agency (AFWA) and the Air Force Research Laboratory (AFRL) to observe and specify the global ionosphere in real time. Eighteen digital ionosondes are deployed worldwide by the Air Force to provide data for many atmospheric weather products.

DISS was originally built using an off-the-shelf TCI model 613F communications antenna (Fig 1a). This antenna transmits radio signals of different frequencies across a specified sweep (2-30 MHz) in a vertical direction; these are then reflected, absorbed, or distorted by the ionosphere. Co-located receive antennas intercept

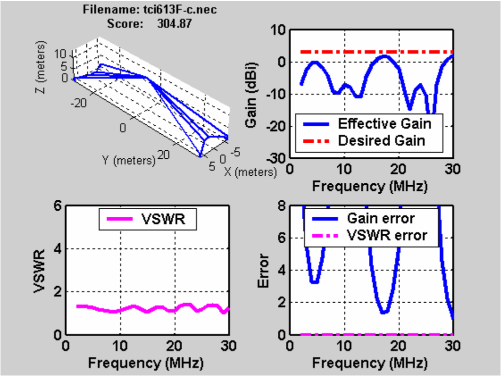

Fig. 1. Original TCI DISS Tx Antenna.

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the returning signals for algorithmic processing. The current transmit antenna does not exhibit a consistent gain in the vertical direction for all desired frequencies (Fig 1b) although the VSWR (in Fig 1c) matched at 450Ω is excellent across the entire frequency band. Our goal was to determine if a simple hybrid augmentation to the antenna could increase gain across the bandwidth without prohibitive costs.

2 Genetic DISS Hybrid Antenna

Conventional antenna wisdom suggested the addition of a six-element log-periodic dipole array (LPDA) as a complement to the existing TCI antenna. Although that hybrid looked promising in simulation, it proved mechanically difficult and cost prohibitive to create and assemble with sufficient robustness to survive at the variety of world-wide DISS locations. We therefore decided to augment the TCI with six new pairs of wire elements, with one end of each wire connected to the feed line running up the tower, the other end open and angled towards one of two new ground stakes. To reduce complexity, we used only four additional stakes, two per side, leading to the hybrid configuration in Fig. 2a. Following the active wire length, we transitioned to an insulator to complete the mechanical connection. The three highest new wires (L2, L3, and L4) are connected to stake 1, with the lowest three wires (L5, L6, and L7) connected to stake 2. The distances of the stakes from the tower and their azimuth angles relative to the TCI antenna were optimized, along with the active lengths of each wire and the height of the wire on the tower. We constrained the distance of the stakes to a reasonable value and set a minimum distance criterion between all wires to avoid sparking conditions.

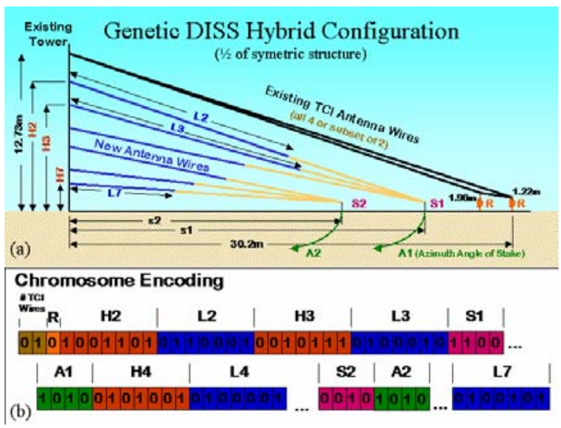

Fig. 2. Genetic DISS hybrid antenna & chromosome

We modified the antenna hybrid and associated chromosome over time, as our genetic optimizations pointed out strong points and weak points in our hybrid model and as construction requirements changed. We had initially connected the highest wire (L2) mechanically to the edge of the TCI curtain [1], however our GA continually minimized this wire to almost zero in length, removing it or rendering it only viable for high frequency contributions. We subsequently connected L2 to stake 1 (with L3 and L4) and achieved much better performance. We also did not know whether all of the existing TCI antenna wires were needed or if only a subset would suffice, until our optimizations constantly converged to using the entire TCI curtain. We initially varied the load resistance from the original 600Ω resistors to a variety of values. However, while our optimizations determined that a higher resistance (1350Ω) increased the overall performance, these were not readily available for our power requirements, so we decided to either maintain the existing resistors or remove the entirely. When a new operational constraint was discovered which required the antenna to be well-behaved down to 1MHz, the option of removing the resistors was then discarded as unfeasible. We also compared feeding the new antenna elements as 1) six independent bent dipoles, 2) two pairs of 3-element LPDAs or 3) as a six-element LPDA. We found that the independent bent dipole configurations performed similarly to the LPDA-wired structures and were easier to model and build.

3 Genetic Algorithm and Optimization Goals

For this antenna optimization, a simple genetic algorithm proved sufficient in obtaining a good solution. We encoded the chromosome shown in Fig. 2b into a cyclic grey-code binary representation to avoid the Hamming cliffs typical in binary representations. While one could argue that a real-valued GA would have provided greater accuracy, when considering our wire lengths in terms of wavelengths for the given frequency band and our field construction tolerances, the granularity of a binary representation was not a limiting factor. Our cost function consisted of a weighted sum of both the effective gain error (< 3dBi) and VSWR error (> 3) across the entire bandwidth and their standard deviations. The standard deviation was used to avoid large error spikes in either effective gain or VSWR. As shown in Fig 1a, using this figure of merit, the TCI antenna scored ~305.

4 Results

In Figure 3a, we show a genetic DISS Tx antenna resulting from the optimization. With the 600Ω resistors permanently included, our optimization runs converged to this basic shape, with minor variations as we balanced the cost function between gain and VSWR error. This solution is similar in structure to the LPDA-augmented TCI, in the orthogonal nature of the new elements. However, where the former had lower-frequency elements higher up, the genetically designed hybrid places them lower on the tower. The score of the genetic DISS hybrid greatly exceeds the simulated scores of the TCI , with or without LPDA augmentation, and this hybrid antenna structure should prove an easy retrofit.

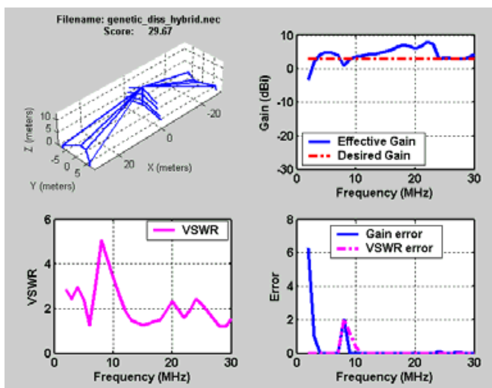

Fig. 3. Genetic DISS Tx Antenna.

References

1. T. O'Donnell, S. Best, E. Altshuler, J. Hunter, T. Bullett, R. Barton, "Genetic Algorithm Optimization: A Tale of Two Chromosomes", 2003 Antenna Applications Symposium, Monticello, IL Sept 2003, pp 131 – 146.