Computational Study of Frequency Steered Helical Antennas for High Power Application

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Abstract—The advancement of linear mode photoconductive semiconductor devices provides increased timing control capabilities for arrayed antenna systems, especially those requiring high power. The temporal response of the switch is dependent upon photonic energy and therefore is capable of yielding specific frequency content per excitation. The versatility with respect to frequency content provides differing center frequencies dependent upon the desired application and effects. This paper explores the effect of driving helical antennas with mesoband signals using two unique center frequencies. The simulated antennas range from 4 to 8 turns. This paper presents computational results for a proposed frequency steering technique designed to achieve greater electric fields off boresight than are possible with axial mode driven helical antennas.

Keywords—HPEM; Mesoband; Helix; Pulsed Power; Frequency Steer

I. INTRODUCTION

The goal of this paper is to compare the radiation properties of traveling wave helical antennas using two mesoband signals of differing center frequencies ($f_1$, $f_2$, $f_3$), where $f_1$ is 1 $\lambda$ per loop, and $f_2$ provides 1.5 $\lambda$ per loop. The intent is to provide a proof of concept with respect to frequency steering for helical antennas. The steering occurs without physical modification of the antenna.

Linear mode photoconductive semiconductor devices (PCSS) contained in the pulse forming stage (PFS) of high power electromagnetic (HPEM) systems provide the advantage of low jitter, as compared with conventional spark gap systems. The low jitter affords HPEM designers the precision to overcome the empirical one tenth rise time requirement necessary for coherent pulse formation in arrayed systems [1].

With precise optical control with respect to timing, true-time delay exists as an option for beam steering. The optical solution triggering the PCSS may rely on computer clock timing rather than physical delay lines, thus negating the need for additional waveguide structures included in typical time delayed systems [2]. The smaller required physical volume inherent in a PCSS encourages novel design possibilities for mobile HPEM systems.

The short rise-time of current through PCSS leads to a wideband signal. However, wideband signals create spectral dispersion. This dispersion of power detracts from directed signal applications. Options exist to transform the wideband signal into a mesoband signal through bipolar pulse formation; a mesoband signal exhibits spectral content congruent with directed signal applications. Options for mesoband generation include laser modulation, frozen wave generation, and quarter wave resonance in the PFS. The quarter wave resonator offers low complexity, and produces current signals described mathematically by a sinusoid with a decaying exponential of the form

$$V(t) = A\sin(2\pi ft)e^{-\alpha t},$$

where $A$ represents the amplitude, $f$ is the frequency, and $\alpha$ is a damping constant [3].

The elements comprising the array portion of a HPEM system must provide a low VSWR through the relevant bandwidth. In addition, the antenna orientation must provide a polarization match with the target. A polarization diverse antenna increases the likelihood of the emitted field coupling into the target. Lastly, a directive antenna provides high gain and may decrease the size of the prime power subsystem.

The helical antenna fits the above requirements. The relationship among gain, number of turns ($N$), and half power beam width (HPBW) for axial mode helical antenna radiation is a well known phenomena. As $N$ increases, the antenna more closely resembles an array of circular loops at quarter wave intervals. Therefore, increasing $N$ increases the gain is accomplished by increasing the number of turns as shown in

$$G = 6.2\left(\frac{C}{\lambda}\right)^2N\frac{S}{\lambda},$$

where $C$ represents circumference per loop, $S$ is the spacing between turns [3]. The increase in turns provides a longer path for the forward traveling wave and allows the wave to decay due to ohmic losses and radiation resistance. The increased path length leads to a smaller reflection from the tip, thus limiting standing waves. However, increasing $N$ decreases the HPBW of the element factor (EF) in accordance with conservation of energy.

In an arrayed case, the pattern multiplication between the array factor (AF) and EF predicts the steering capabilities, but the EF is the parameter limiting the steering performance of the system [3]. It is possible to change the EF of an antenna...
through deliberate selection of frequency content of the feed signals.

II. SIMULATION SETUP

A. Input Signal

The $f_1$ and $f_2$ signals are generated in MATLAB and imported into CST Microwave Studio (MWS). The signals exhibit damped sinusoidal behavior with fractional bandwidths (FBW) of approximately 25%. The $f_1$ signal, with $f_c$ of 667 MHz, excites the axial mode for maximum boresight radiation. The $f_2$ signal, with $f_c$ of 1.0 GHz, excites higher order modes, achieving peak radiation in off boresight directions.

B. Antenna

The antenna is designed for the axial mode frequency, $f_1$. The helical antenna is derivative of the ten turn helix design from [4]. The notable difference in this design involves the circular ground plane instead of the octagonal plane used in the Giri experiment. The dimensions of the helix are summarized in Table I.

### TABLE I. HELICAL ANTENNA GEOMETRY

| Parameter               | Value        |
|-------------------------|--------------|
| Helix diameter          | 44.95 cm     |
| Pitch angle             | 12.58°       |
| Number of turns         | 4-8          |
| Inner conductor diameter| 0.85 cm      |
| Ground plane radius     | 41.86 cm     |

III. SIMULATION EXECUTION

We designed the original helical antenna with Antenna Magus using the parameters shown in Table I. The antenna was exported into CST MWS and cloned with variations occurring in $N$ but other variables held constant. The final set of antennas consisted of 9 different antennas with $N$ spacing differential at half turns intervals. We set the boresight orientation in the $Z$ direction such that the axial mode occurs at $\theta = 0^\circ$ and the normal mode occurs at $\theta = 90^\circ$. The simulation required the Finite-Difference Time Domain solver to analyze the transient electric fields. We defined far field electric field probes at $10^\circ$ intervals in the azimuth and elevation planes. The probes form a hemisphere above the antenna and captured the time varying electric field values. We exported the probe values into ASCII files using CST post-processing, and then imported the data into MATLAB. The analysis in MATLAB provides the maximum field values in time for each probe, thus discerning the field values at particular locations. The field values were derived from the absolute values of the theta and phi directions as shown in

$$E_{\theta \phi} = \sqrt{E_{\phi}^2 + E_{\theta}^2},$$  \hspace{1cm} (3)

IV. SIMULATION RESULTS

The $f_1$ performs as expected: the boresight field value increases and the HPBW decreases with each turn. The $f_2$ excitation results show an inverse relationship between maximum field value and $N$ at boresight. An increase in $N$ for the $f_2$ case delineates a shift toward higher values of $\theta$, meaning the off-boresight performance is increasing as $N$ increases. For all $N$ values, we see the $f_2$ exceed $f_1$ in terms of maximum electric field value at $\theta = 40^\circ$. As steering increases in excess of $40^\circ$ off $\theta$, $f_2$ continues to exhibit superior electric field performance. Figure 1 shows the performance difference between the shortest and longest helix for both sets of frequencies.

V. CONCLUSION

This paper presents a dual frequency technique for achieving increased electric field maximum values off boresight without physical modification to the helical antenna. The results reveal improvement in the $40^\circ < \theta < 90^\circ$ range at secondary frequencies, meaning switching to a secondary frequency at the aforementioned steering angles leads to increased electric field strengths when compared with the axial mode excitation. In addition, the results showed the electric field generated in the $f_2$ case increased slightly as $N$ increased. Modifications to the ground plane shape and other variables with intent to enhance $f_2$ generated field strength and directivity require additional exploration. Additional analysis must occur to fully characterize the frequency steering improvement.

Figure 1. Frequency steering results for 4 and 8 turn antennas.

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