HELICAL ANTENNAS FOR HIGH POWERED RF

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Abstract

Radiating high power RF below 1 GHz can be difficult. Large structures are preferred for high voltage operation; however, large structures are difficult to deploy. Conversely, small geometries are more easily deployed, but insulating the high voltage can be difficult. Dipole structures have made their way into use due to the relatively simple and compact implementation; however, their radiation pattern is not desirable, since they radiate in a donut pattern, which can disrupt, or even destroy one's own electronic controls. Impulse Radiating Antennas have been configured for wideband operation; however, their large geometry is very difficult to deploy. Helical antennas offer many advantages over other methods. The helical antenna is relatively compact, with its cylindrical geometry. The antenna's geometry is wavelength dependent, but is acceptable from several hundred MHz and higher, with the upper limit being dominated by the high voltage operation. It offers a good gain factor and can be operated as a narrow band, or wide band device. Applied Physical Electronics, L.C. has been developing high voltage helical antennas for narrow band and wide band applications. This paper describes the fundamental operation of a 400 MHz helical antenna driven by Marx generators. Simulation and experimental results are provided.

I. INTRODUCTION

High powered RF is desired in a number of fields, including defense for disrupting electronically-controlled system, medical for cell manipulation, and biological for food and water purification. Defense requirements are the most prevalent. There are a number of ongoing high power RF efforts, and an equal number of geometries being pursued. Example geometries generally include the Impulse Radiating Antenna (IRA)[1], dipoles and bicones[2-4], and traditional TEM horns, among others. However, most of these geometries are either large and not deployable, or they a radiate with undesirable radiation pattern (i.e. donut-shaped). Furthermore, generating very large electric field strengths is difficult, since extremely high voltages are required. Insulating the high voltage increases the complexity of the antenna design, and typically results in larger volumes.

Helical antennas are being studied for high power RF applications[5,6]. The helical geometry is very appealing for is relatively small and conformal geometry, which makes it suitable for air platforms. Furthermore, the antenna is very directive, with typical beam widths of 20 – 40 degrees, and offering relatively good values of gain, from 8 – 15 dB.

This paper describes developments by Applied Physical Electronics, L.C. on high powered helical antennas. Particular attention is paid toward a 400 MHz design, directly driven by a high voltage Marx generator.

II. BACKGROUND

In 2001, APELC reported on the first shock-excited helical antenna for generating high powered RF[7]. The helical antenna was directly connected to an ultrafast Marx generator, which shock excited the physical elements of the antenna. The relaxing of the antenna resulted in a 1 GHz signal, as defined by the antenna's geometry. A 300 V/m signal, reproduced in Figure 1, was measured at a 100 m range, which reduces to an rE_p (range x electric field strength at the range) of 300 kV. The understanding of the results was not explored beyond the simple demonstration.

Kraus' Helical Antenna

In 1947, J.D. Kraus invented the helical antenna in his basement, using basic helix structures and simple measurement tools. Kraus went on to develop a large knowledge base surrounding the helical antenna, for a wide variety of applications. However, Kraus' work, as well as complimentary work, seems to employ the helical antenna for continuous wave radiation[8].

The design of a simple helical antenna follows from Figure 2, in which the circumference of the helix is one wavelength (λ) so that diameter d equals λ/π; the length of the helix is given by $N*\lambda/4$, where N is the number of helix turns and $\lambda/4$ is the turn-to-turn spacing. The ground plane diameter (D) is approximately ¾ λ.

However, as APELC recently discovered, the simple model does not truly encompass the design of the helical antenna. APELC has developed an understanding of the helical antenna, which can be divided into four distinct components, as illustrated in Figure 3. The coaxial feed section, A, should be closely match to the impedance of the Marx generator (or other source). The coaxial section should naturally blend into a conductor-over-a-ground plane geometry, B, with a minimal amount of impedance mismatch as possible. This section departs from Kraus' abrupt junction from a straight rod feed to the helix, as Figure 2 describes. Next, the a quarter wave section, C, closely follows the ground plane, acting as an impedance transformer, but also as the element that is being shock excited. Finally, the helix, D, as defined by Kraus, completes the structure [8].

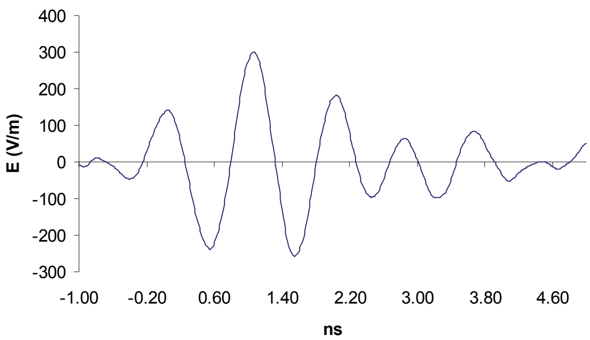

Figure 1. Radiated Waveform From a 1 GHz Helical Antenna, by APELC in 2001[7]

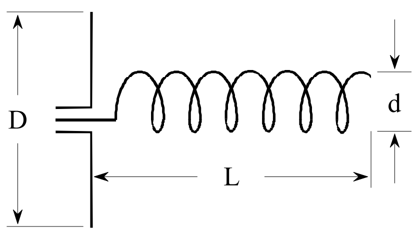

Figure 2. Simple Helical Antenna Geometry

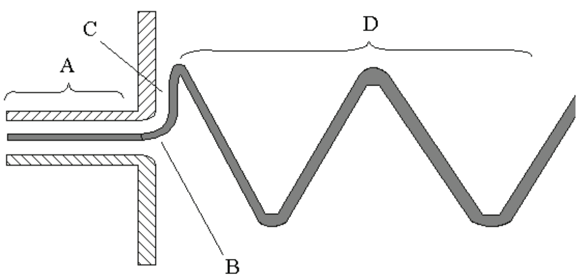

Figure 3. Key Sections of the Helical Antenna

The design of the coaxial section follows from simple coaxial transmission line theory. The blend radius is best simulated using field codes, such as CST Microwave Studio or Maxwell 3D. However, two guidelines are followed: 1) the bend radius should be gradual to minimize corona emission points, as well as to minimize unwanted inductance, and 2) the center conductor should grow in diameter, as it rolls across (and above) the ground plane. The equation for the impedance of a rod-over-a-ground plane, as illustrated in Figure 4, is found as follows:

$$Z = \frac{1}{2\pi} \sqrt{\frac{\mu}{\epsilon}} \cosh^{-1}\left(\frac{h}{a}\right) \quad (1)$$

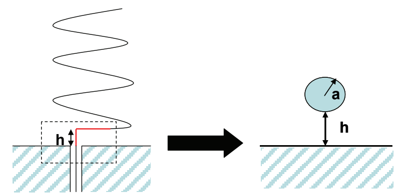

Figure 4. Illustration of the Rod-Over-a-Ground Plane with Definitions

Finally, the helix can also be viewed as a transmission line. Each turn of the helix represents the series inductance, while the inter coil capacitance describes the shunt capacitance.

$$Z = \sqrt{\frac{L}{C}} \quad (2)$$

Where L is calculated as the inductance for a single loop, and C is calculated as the capacitance between two conductors through a single turn. So, the impedance is calculated as

$$Z = \sqrt{\frac{\frac{\mu N^2 A}{l}}{\frac{\varepsilon A}{d}}} = \sqrt{\frac{\frac{\mu_0 \lambda}{4\pi}}{\frac{\epsilon_0 d\lambda}{S}}} = 377\sqrt{\frac{S}{4\pi d}} \quad (3)$$

Where S is the spacing between the helix turns and d is the diameter of the helix tubing.

Kraus' Helical Antenna with a Cupped Ground Plane

Kraus provides a very good example of a cupped helical antenna, as described with definitions by Figure 5. Dimensions a and b define the cup geometry, with a = ¾ λ, and b = a/2. *D* defines the helix diameter, and *d* defines the helix's material diameter. The spacing between the helix turns is defined as 0.225 λ, and *C* is the circumference, which for the end fire mode is chosen to be equal to λ[8].

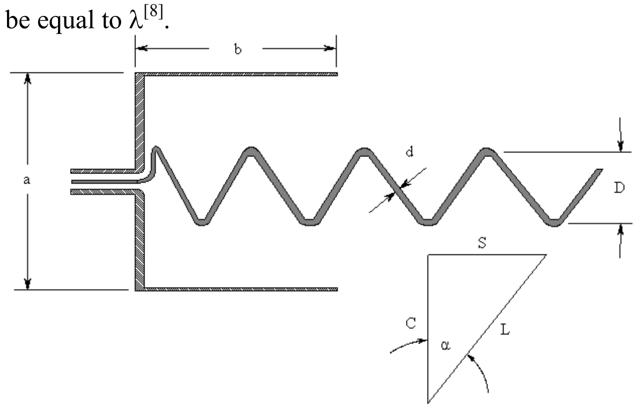

Figure 5. Cupped Ground Helical Antenna Defined by Kraus

III. DESIGN AND SIMULATION

For this effort, a 400 MHz geometry is chosen. Table 1 provides a listing of the designed geometrical parameters. The design was simulated with CST Microwave studio. The VSWR is provided in Figure 6. The antenna appears to have a good match from 300 MHz to 700 MHz, with VSWR values ranging from approximately 1.5 to 2.5. The simulated far field gain is illustrated in Figure 7, which predicts a gain factor of more than 11 (linear scale), on axis. The simulated beam pattern is provided in Figure 8, and predicts a full beam width of approximately 55 degrees. Finally, the impedance is measured with a simulated TDR. In this case, the Coaxial transition appears to have an impedance of 50 Ohms, and cleanly transitions to an approximate 60 Ohms, before transitioning out to the free space impedance of 377 Ohms.

Table 1. Derived Design Parameters for a 400 MHz Helical Antenna with a Cupped Ground Plane

Parameter	Definition	Value	Unit
f_0		400	MHz
λ		0.75	m
D	λ/π	0.238	m
S	$0.225\ \lambda$	0.168	m
C	λ	0.75	m
a	$0.75\ \lambda$	0.562	m
b	a/2	0.281	m
N	Turns	6	
Z_{coax}		60	Ω
$Z_{rod/ground}$		128	Ω
Z_{helix}		273	Ω

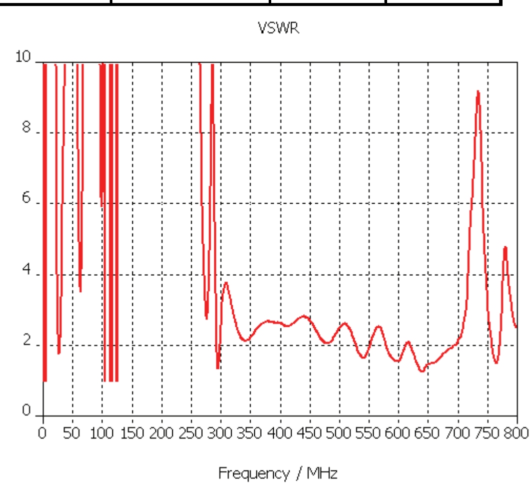

Figure 6. Simulated VSWR for the 400 MHz Helical Antenna

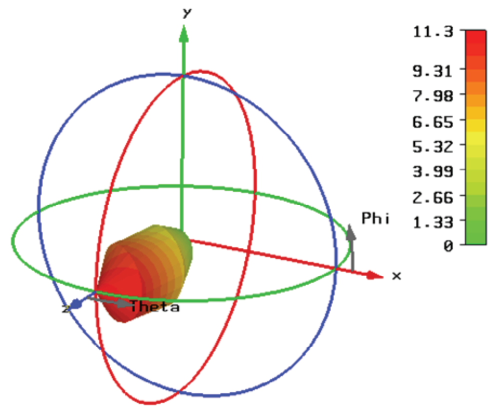

Figure 7. Simulated Gain for the 400 MHz Helical Antenna (Linear Scale)

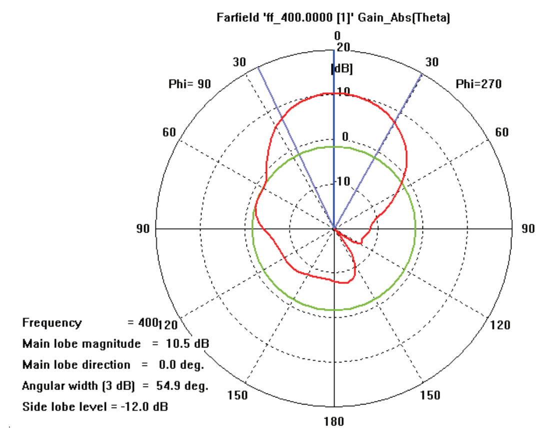

Figure 8. Simulated Beam Pattern for the 400 MHz Helical Antenna

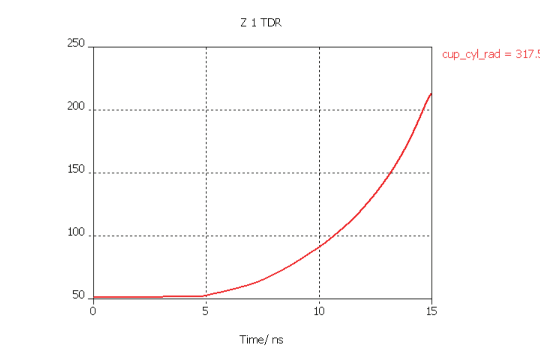

Figure 9. Simulated TDR Measurement for the 400 MHz Helical Antenna

IV. EXPERIMENTAL RESULTS

An experimental helical antenna was built, based on the design parameters previously described. The VSWR of the antenna, shown in Figure 10, was first measured.

While not as smooth as simulated, the VSWR ranges from approximately 1 to 4 through the range from 200 MHz to 1 GHz. The initial concern is that our design frequency, in which a VSWR value of approximately 3 is measured, seems high.

The gain of the antenna does not agree with the simulation, which was predicted at 10.5 dB in Figure 8. With a sweep from 200 MHz to 500 MHz, the measured gain approached 5 dB, but gradually decreases above 320 MHz. It is believed that the impedance mismatches cause some of the low gain measurements. As illustrated in Figure 12, the antenna has a number of impedance plateaus. The initial coaxial feed has a measured impedance of 60 Ohms, which transitions to the coaxial, air insulated section of 100 Ohms. The quarter wave section has a measured impedance of approximately 113 Ohms, which then grows out to the approximately designed 275 Ohms of the helix.

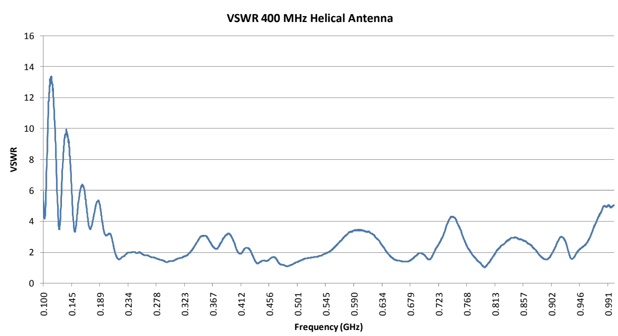

Figure 10. Measured VSWR for the 400 MHz Helical Antenna

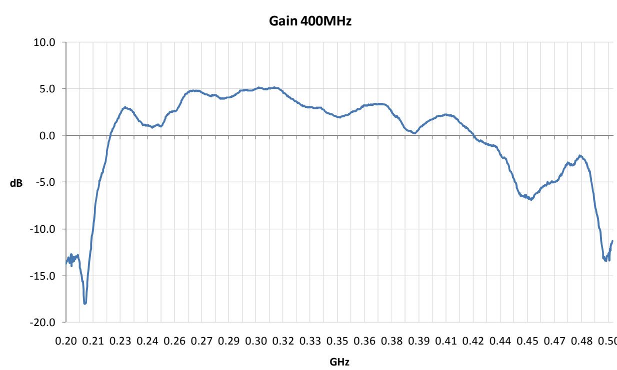

Figure 11. Gain Measurement of the Helical Antenna

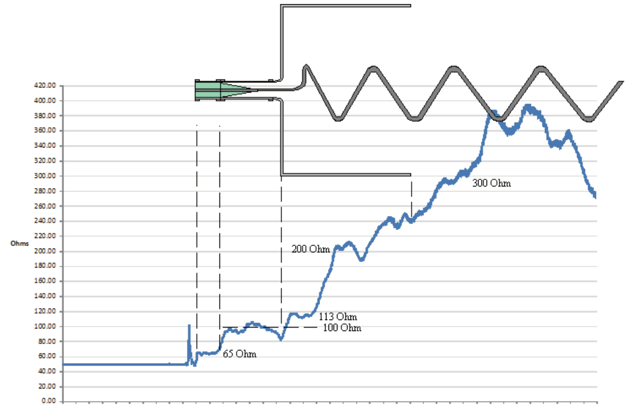

Figure 12. TDR Measurement of the Antenna

A 600 kV Marx generator was used to directly excite the antenna. A sample waveform is shown in Figure 13. Note that the fast rising portion has a magnitude of approximately 80 kV. The radiated waveform is provided in Figure 14, which was measured to be approximately 50 kV/m (at 1 m). Assuming that 80 kV excites the antenna, which is also assumed to have a 60 Ohm impedance, the radar equation can be used to calculate the expected field strength at 1 m.

$$E\,(r = 1\,m) = \sqrt{\frac{P_{antenna}}{4\pi\, r^2}\; x\; Gain\; x\; 377}\;\left(\frac{kV}{m}\right) \qquad (4)$$

Numerically, the electric field strength is calculated to be 70 kV/m, with an antenna peak power of 106 MW. Since the antenna is circularly polarized, the electric field in either the horizontal or vertical direction is calculated at the 3 dB point, which resolves to 50 kV/m.

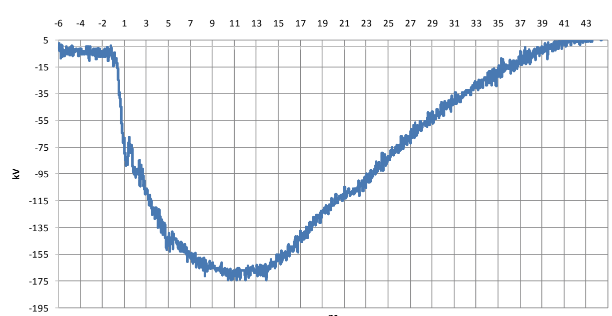

Figure 13. Driving Voltage Pulse From the Marx Generator

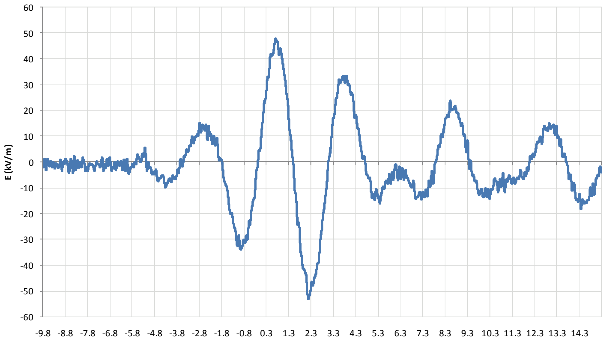

Figure 14. Radiated Signal From the Helical Antenna

V. SUMMARY

A 400 MHz helical antenna was designed, simulated fabricated and tested. A cupped ground plane was implemented to improve the performance. Simulation results predicted a good overall gain; however the experimental system will need to be improved. Problems with the VSWR and the impedance mismatches were apparent, as well as the performance with the source, which needs to have a faster rising edge.

VI. REFERENCES

[1] David V. Giri, et al, *Design, Fabrication and Testing of a Parabolic Reflecor Antenna and Pulser System for Impulse-Like Waveforms*, IEEE Transactions on Plasma Science, Vol. 25, No. 2, April 1997.

[2] William D. Prather, et al, *Survey of Worldwide High Power Widband Capabilities*, IEEE Transactions on Electromagnetic Compatibility, Vol. 46, No. 3, August 2004.

[3] Kevin D. Hong and Sean W. Braidwood, *Resonant Antenna-Source System for Generation of High-Power Wideband Pulses*, IEEE Transactions on Plasma Science, Vol. 30, No. 5, October 2002.

[4] W.S. Lee, et al, *Circuit Modeling of Spark-Gap Switch and Fat Dipole for DS Pulser,* 2007 IEEEAntennas and Propagation Society International Symposium.

[5] HPM Antennas, Phase II SBIR, Air Force contract number FA9451-07-C-0009.

[6] D.V. Giri, *Numerical Modeling of Helical Antenna Excited by Transient Waveforms*, 2007 Directed Energy Test and Evaluation Conference.

[7] J.R. Mayes, W.J. Carey, W.C. Nunnally and L.L. Altgilbers, *The Marx Generator as an Ultra Wideband Source*, The 13th IEEE International Pulsed Power Conference, 2001.

[8] John D. Kraus, Antennas 2nd Edition, McGraw-Hill, 1988.