Analytical Model for the HPEM Radiation from Helical Antennas

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Abstract

Axial radiation from a helical antenna looks somewhat like a damped sinusoid in time domain, with some important distinction. It has been observed that the radiated waveform initially grows in time and then starts to decay. Consequently a simple damped sinusoidal model for the radiated field is inadequate. In this paper, we cite some examples of the observed radiation from helical antennas and offer an analytical model that well explains the behavior of helical antennas.

1. Introduction

We start with some examples of high-power electromagnetic (HPEM) radiation from helical antennas [1] that have been reported in the literature [2-4]. Mays et al. used a Marx generator in energizing a helical antenna configured for axial radiation. The voltage waveform launched into the helical antenna is shown in Figure 1.

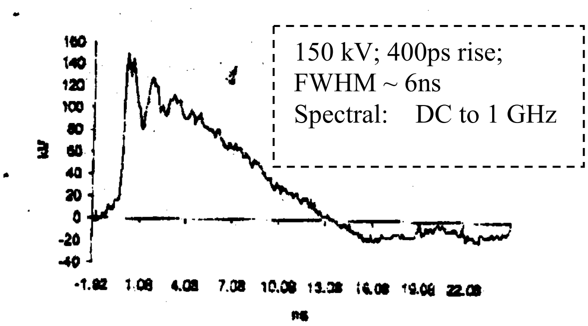
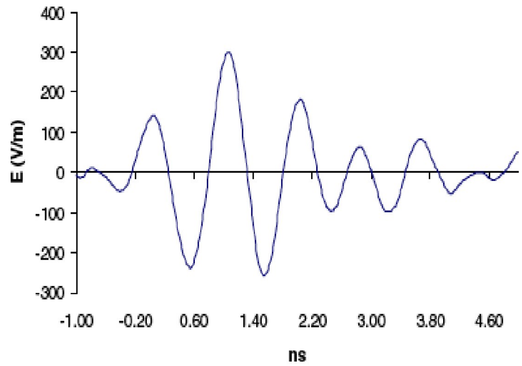


Figure 1. Voltage waveform into the helical antenna [1]

Parameter	Mayes' Helix [1]
Axial length L	77.0 cm
Diameter D	9.5 cm
Circumference: C = πD	30.24 cm
Spacing (pitch) S	7.70 cm
Pitch angle α	14.29°
Length of 1 turn L_T	31.20 cm
Number of turns N	10
Wire radius r	1.5 mm (guess)

TABLE 1: Helical antenna designed to radiate 1 GHz

The voltage waveform has spectral content from DC to over 1 GHz. The helical antenna [2] designed for 1 GHz has its parameters listed in Table 1. Radiated field measured at a distance of 100m reported by Mayes is shown Figure 2.



Radiated Field:
Temporal
300V/m peak at 100m
r E_p / V_0
~ 100m x 300(V/m)/150 kV
~ 0.20
Spectral Max: ~ 1 GHz

Figure 2. Measured electric field on axis at a distance of 100m [1]

If we model the radiated field by a damped sinusoid as shown in Figure 3, the radiated spectrum deviates excessively from the observed spectrum and this comparison is shown in Figure 3.

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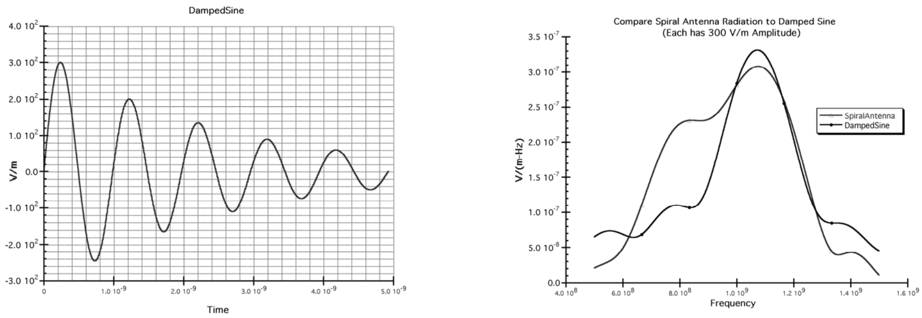

Figure 3. A damped sinusoidal model of the measurement in Figure 2 (left)
Magnitude spectrum of the electric field at 100m (Spectral magnitudes of Figures 2 and 3) (right)

From Figure 3, it is evident that the damped sinusoidal signal does not accurately model the radiated spectrum of a helical antenna. The radiated temporal field grows for some time, before it decays and hence cannot be represented by a damped sinusoid. A similar behavior of the helical antenna was seen in the WBTS system [3-4]. WBTS (Wide-Band Threat Systems) is a high-power, repetitively pulsed, wide-band microwave generator capable of 100Hz burst operation. The WBTS HPM microwave capability covers the range of 200 MHz to 6 GHz in nine frequency bands. The system is transportable, capable of being set up at remote sites and operation on generator power. The system is operated remotely via a fiber-optic linked lap-top computer. The system incorporates built-in diagnostics and data acquisition capability. The WBTS HPM pulser produces a short (<1ns FWHM) >2MV negative pulse with a rise-time of <300ps (10-90%) into the antenna load. The WBTS HPM is capable of operation at 100Hz with burst lengths of up to 500 pulses. WBTS is basically one Marx source working into nine "switch in-switch out" helical antennas. The lowest band (1^{st}) was from 200 MHz to 225 MHz and the highest (9^{th}) band was from 4 GHz to 6 GHz. The nine helical antennas that were included in the WBTS system have been analyzed, built and tested. The axially radiated temporal waveforms are similar to what has been seen in Figure 2 above.

2. Modeling the Mayes [1] Helical Antenna by NEC Code

NEC is a wire model that segments the antenna into small linear sections, applies the proper integral equation for the current on each segment and gets the current on the antenna. From the current distribution on the antenna, one can obtain the radiated fields in frequency domain for each frequency. The frequency domain results (magnitude and phase) are then Fourier inverted to obtain transient data. It is noted that we do not know the radius of the wire used in the Mayes' helical antenna and have assumed a number of 1.5 mm for the wire radius. Also, the NEC model has an infinite ground plane while the ground plane in the experimental configuration is necessarily finite.
The calculated results are summarized below.

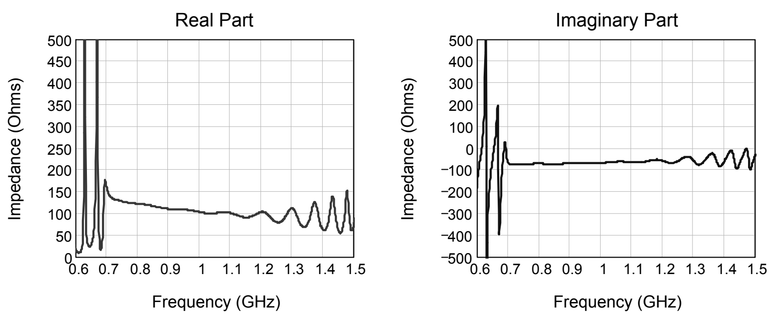

Figure 4. Input Impedance (real and imaginary parts)

The resulting *un-normalized* E-field spectrum and waveform have been calculated here and are shown below.

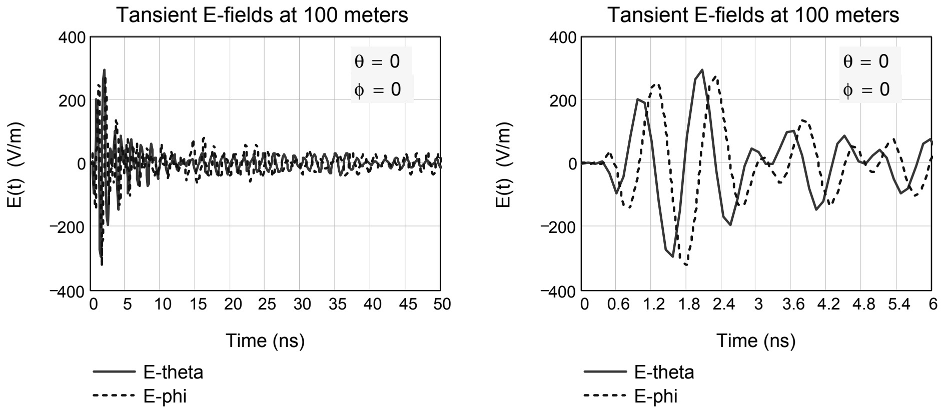

Figure 5. Transient electric field (NEC simulation) at a distance of 100m

A damped sinusoidal waveform has a DC component in it and cannot represent the radiated far field of any antenna. We develop an appropriate model in the next section.

3. Modeling the Radiated Field of a Helical Antenna by a Waveform with a Second Order Pole

Let us consider a canonical temporal waveform of a second order pole

$$E(t) = E_0 \ (\omega_0 t) \ e^{-\alpha t} \sin(\omega_0 \ t \ ) \ u(t) \qquad \text{(V/m)} \qquad (1)$$

Here we have chosen ω_0 as the normalization constant in front. For example, by choosing E_0 = 100 (V/m), $f_0 = (\omega_0 /(2\pi))$ = 1.05 GHz and α = 8 x 10^8 rad/s in (1), the resulting time domain waveform is shown plotted in Figure 1.

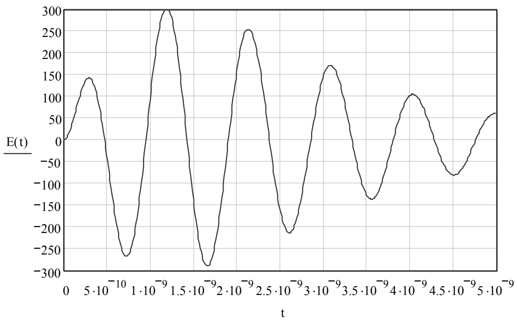

Figure 1. Temporal electric field waveform with a second order pole

The above waveform looks like the measured waveform shown in Figure2. Let us look at this model in frequency domain.

The Laplace transform of (1) can be written as

$$\tilde{E}(s) = \frac{E_0\,\omega_0}{2j}\left[\frac{1}{(s-s_0)^2} - \frac{1}{(s-s_0^*)^2}\right] \quad \text{with } s_0 = -\alpha + j\omega_0 \text{ and its conjugate } s_0^* = -\alpha - j\omega_0 \tag{2}$$

By setting $s = j\omega$, we get the Fourier transform to be

$$\tilde{E}(f) = \frac{2\,E_0\omega_0^2\,\alpha}{\left[(j\omega+\alpha)^2+\omega_0^2\right]^2} \qquad \frac{V}{m\,Hz} \tag{3}$$

From (2), by setting the frequency = 0, we have a ***non-zero*** dc component of the field given by

$$|\,\tilde{E}(0)| = \frac{2\;E_0\,\omega_0^2\,\alpha}{\left(\alpha^2+\omega_0^2\right)^2} \qquad \frac{V}{m\,Hz} \tag{4}$$

We note that this waveform has a dc component in its spectrum and cannot, by itself represent a radiated electric field, since no antenna can radiate dc into the far field. It is possible to introduce a phase term in the waveform of (1), such that the dc component could vanish. So, let us consider a waveform with a second order pole as in (1), but with an added phase term. It is convenient to renormalize and write

$$E(t) = E_0\,(\alpha\,t)\;e^{(1-\alpha t)}\sin(\omega_0 t + \phi)u(t) \qquad \text{(V/m)} \tag{5}$$

We can solve for ϕ and our time domain waveform now becomes

$$E(t) = E_0\,\alpha\;t\;e^{(1-\alpha t)}\sin\left[\omega_0 t\; + \arctan\left(\frac{2\alpha\omega_0}{\omega_0^2-\alpha^2}\right)\right] \tag{6}$$

This temporal waveform has the characteristics: a) A double pole at $-\alpha + j\,\omega_0$ along with its complex conjugate, b) no dc component, c) no jump at time t = 0 (the function is zero at t = 0).

4. Summary

We have investigated the axially radiated, transient field of a helical antenna. Measured waveforms are available in the literature. The helical antenna is modeled by NEC Code and that can predict the performance characteristics of the helical antenna. Furthermore, we find that a waveform with a second order pole, properly normalized can accurately model; the radiated field.

5. References

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