Sensor and Simulation Notes

Note 577

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The Effect of Minor Radius on the Performance of a Helical Antenna

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Abstract

In this paper, we consider the effect of the conductor diameter on the performance of a helical antenna. The helical antenna considered here is an axial-beam type working in the frequency range of 300 to 500 MHz. We find that the conductor size has a significant effect on the realized gain of the antenna. Results of a numerical analysis of the antenna with varying conductor diameters are presented and compared with some available measurement data.

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1. Introduction

Krauss, the inventor of helical antennas has considered an axial beam helical antenna with three different conductor sizes [1 and 2] as shown in Figure 1.

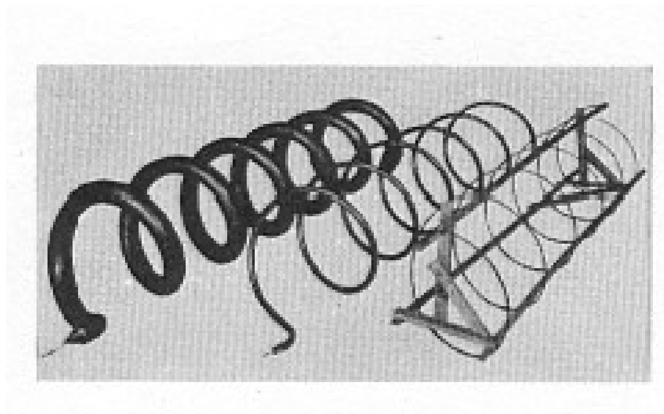


Figure 1. Helical antenna with varying wire radii

The three antennas in Figure 1 have conductor diameters of 0.317cm, 1.27cm and 4.13 cm, with a variation of 13 to 1. The antenna parameters [2] are major diameter D = 21.9 cm, pitch angle of 14 degrees and a spacing between turns S = 17.15 cm. The ground plane is a square 1.5 m x 1.5 m copper plate. The antenna is designed to work in the frequency range of 300 to 500 MHz.

We find that the length of one turn

$$L_1 = \sqrt{(\pi D)^2 + S^2} = 70.89 \text{ cm} \tag{1}$$

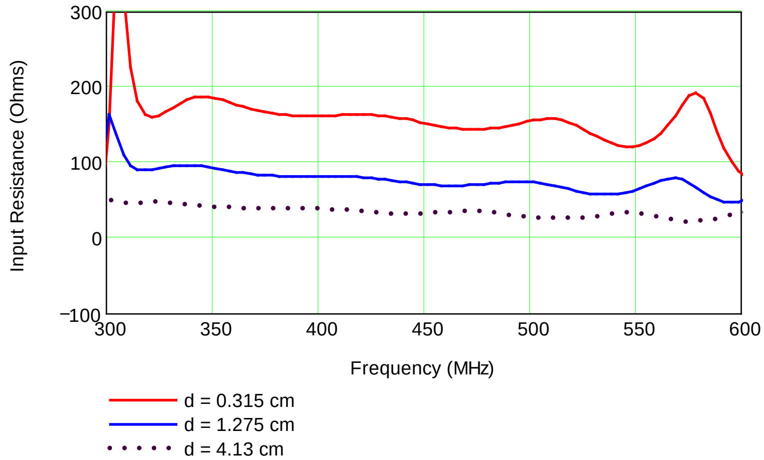
is a wavelength at 423 MHz. Tice and Krauss [2] consider the performance of these three antennas at a frequency of 400 MHz, and come to the following 5 conclusions.

1) The half power beam width varies only a few %
2) Ratio of the maximum main lobe to maximum side lobe varies only 8 %
3) The axial ratio is nearly the same for all three cases and within $\pm$ 4%
4) The terminal impedance is nearly resistive and the variation is $\pm$ 25 % and
5) Phase velocity is unaffected by conductor size.

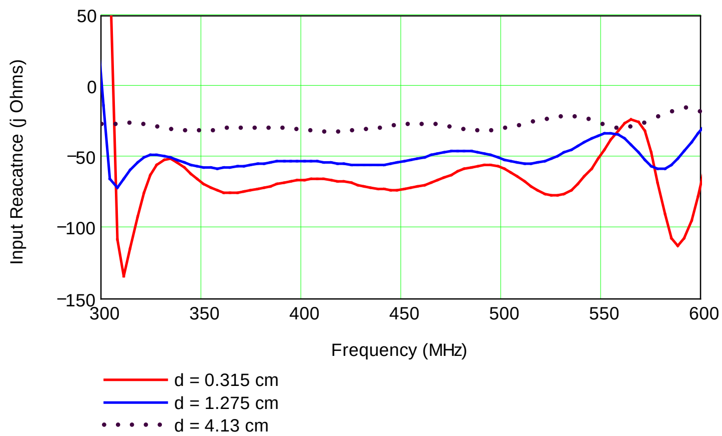
We wish to analyse these antennas using WIPL-D numerical code and examine the accuracy of some of the above conclusions.

2 WIPL-D Numerical Analysis

We have analyzed the above three antennas using WIPL-D (http:// www.wipl-d.com) and the results are presented in Figures 2 and 3.



(a) **Real part**



(b) Reactive part

Figure 2. Real and Imaginary Parts of the terminal Impedance

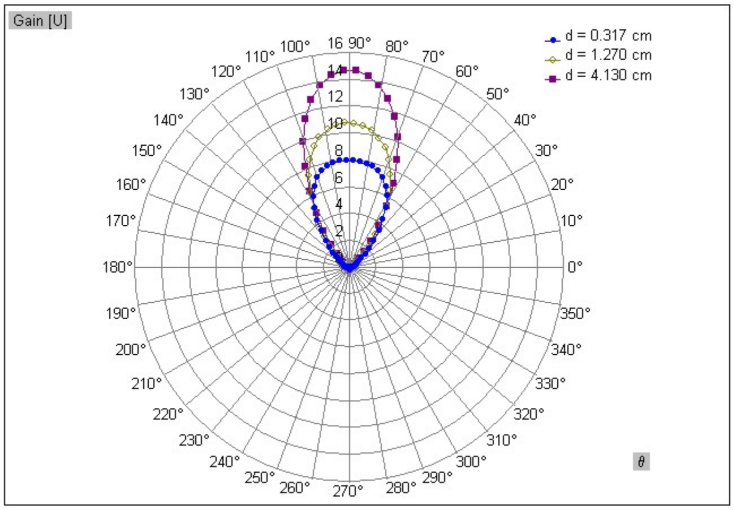


Figure 3. Effect of the conductor diameter on the realized gain of the helical antenna at 400 MHz (WIPL-D calculations)

We compare and contrast our findings with that of Tice and Kraus [2], in Table 1.

TABLE 1. Comparison of our findings with that of Tice and Krauss [2]

Performance Parameter	**Conclusions from [2]**	**Our findings**
Half-power beam width	varies only a few percent	same as [2]
Ratio of maximum main lobe to maximum side lobe	varies only 8 %	did not investigate
Axial ratio	varies only ± 4%	did not investigate
Terminal impedance	nearly resistive, no reactance mentioned resistance varies ± 25%	Resistive variation is about ± 50% however, we do see a reactive component shown in Figure 3
Phase velocity	unaffected by conductor size	did not investigate
Realized Gain	**No mention is made**	**Significant Effect** Numerical Realized Gains 8, 10.8 and 14.6 Realized Gain (in dB) 9.03,10.33,11.64 Fatter wire has higher gain

From Figure 3 above, it is evident that there is a significant improvement in the realized gain of the antenna as one increases the conductor diameter. This can also be correlated to the fact that the terminal resistance is going down with the conductor size. As the terminal resistance goes down (from about 150 to 100 to 50 Ohms, which is a variation of $\pm$ 25 %), the current on the antenna goes up and hence more radiation. Since Tice and Kraus [2] also found almost exactly the same the resistance variation, it is curious why they did not look at or comment about the antenna gain. Their results are based on measurements and our results described above are purely based on numerical computations.

Furthermore, some measurements [3] validate the increased realized gain with increased conductor radius. Using a 1 GHz helical antenna, 1/2" tubing produced 35% higher output than 1/4" tubing. No further improvement was seen with ~ 1" tubing. It is entirely possible that there is an optimal conductor radius that matches the source impedance to the antenna impedance..

2. A Second Example

Let us consider the helical antenna designed for the frequency band of 790 to 1500 MHz with a center frequency of 1145 MHz. The free-space wavelength ranges from 20 cm to 37.97 cm, with the central wavelength of 26.2 cm. The antenna parameters are listed in Table 2.

TABLE 2. A second example of helical antenna with varying minor diameter

Parameter	Values
Frequency Band MHz	790 MHz -1500 MHz
Center Frequency f	1145 MHz
Center Wavelength λ	26.200 cm
Number of Turns N	4
Major Diameter D	8.128 cm (used in WIPL-D)
Circumference C	25.53462 cm
Minor Diameter (2 r)	0.75"= 19.05 mm
Minor Radius r	0.375" = 9.525 mm
Spacing Between Turns S	5.8928 cm
Length of Each Turn L1=sqrt(C^2+S^2)	26 cm
Pitch Angle alpha	13 deg
length of the Helix = N S = 4 S	23.57 cm
Ground Plane Shape	FLAT CIRCULAR
Ground Plane Diameter D_g	2.5 λ = 65.5 cm

We have studied the effect of the helical antenna of Table 2 for a range of minor diameters. The calculated transfer function is shown in plotted in Figure 4 as a function of frequency. These calculations are for an antenna of 10 turns (Table 3). This was before we decided to reduce the number of turns.

TABLE 3. Parameters of an initial 10-turn antenna

Parameter	**Antenna (L-3)**
Axial length L	69.30 cm for 10 turns
Diameter D	9.55 cm
Circumference: $C = \pi D$	27.72 cm
Spacing (pitch) S	6.93 cm
Pitch angle α	13°
Length of 1 turn LT	30.79 cm
Number of turns N	10
Wire radius r	*3.2 mm or (1/4)" diameter*
Ground plane	Infinite (in the model) Finite (in the Experiments)

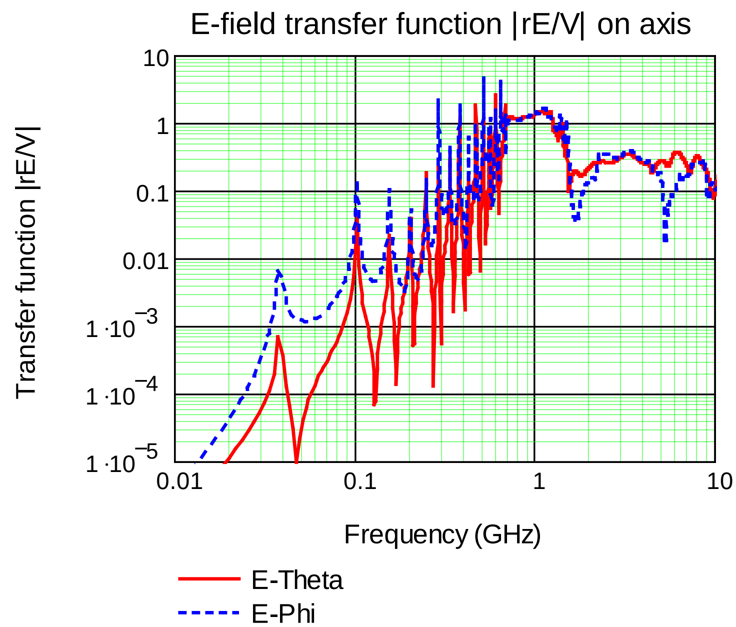


Figure 4. Calculated transfer function as a function of frequency

Extensive antenna current and off axis fields were calculated. Measurements of this 10-turn helix were made with a transient excitation from a PBG-1 pulser.

Temporal Field at 3.69 m corresponding to Shot 11 [of Dr. Jerrold Levine's Measurement] and computed values are shown in Figure 5.

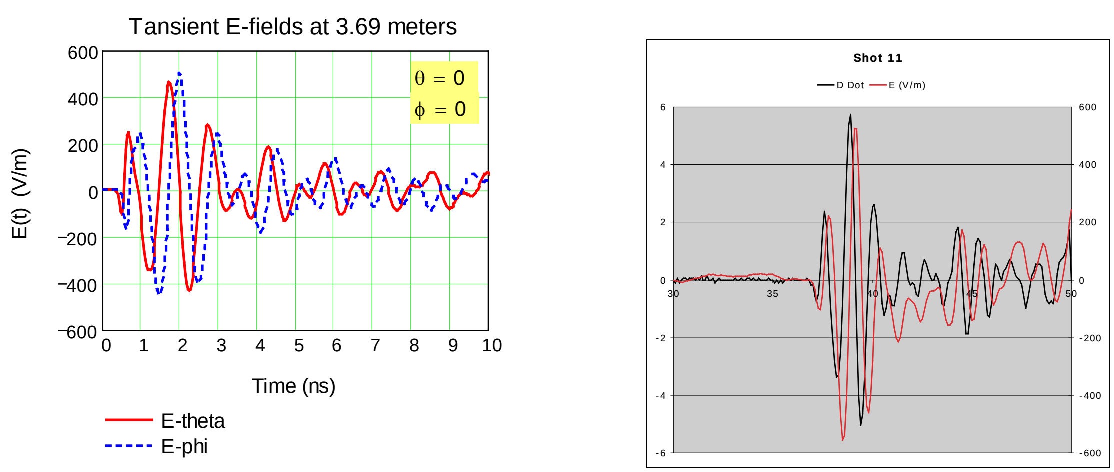


Figure 5. Comparison of calculated and measured transient field at a distance of 3.69m

Spectral field at 3.69 m corresponding to Shot 11 [of Dr. Jerrold Levine's measurement] and computed values are shown in Figures 6 and 7.

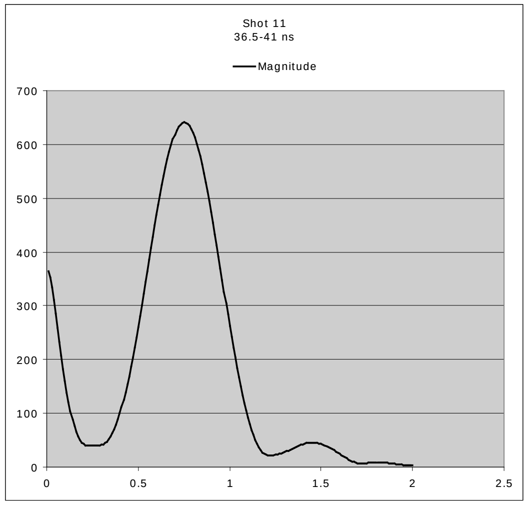


Figure 6. Measured spectral field at a distance of 3.69m; [620 (V/m)/GHz]

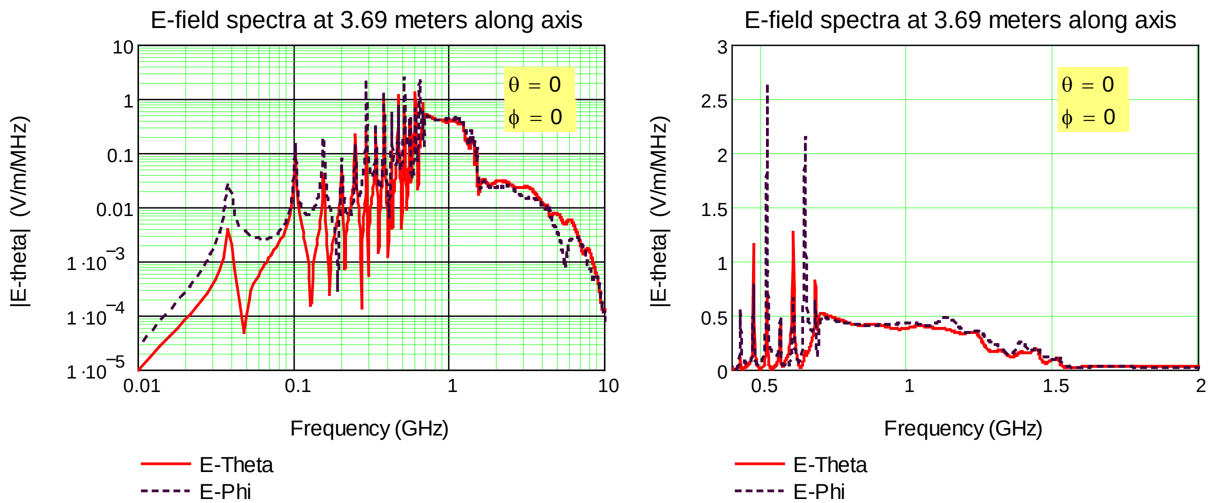


Figure 7. Calculated spectral field at a distance of 3.69m; [500 (V/m)/GHz]

Comparing the results of Figures 3 and 4, the calculated value is somewhat lower than the measured. One reason is that the calculations do not account for the voltage bump up (lower to higher impedance) at the input to the helix.

Next, we turn our attention to studying the effect of the minor radius of the 10-turn helix.
The radiation patterns for wire diameters of 2 mm, 6 mm, 10 mm and 20 mm are shown plotted in Figure 8.

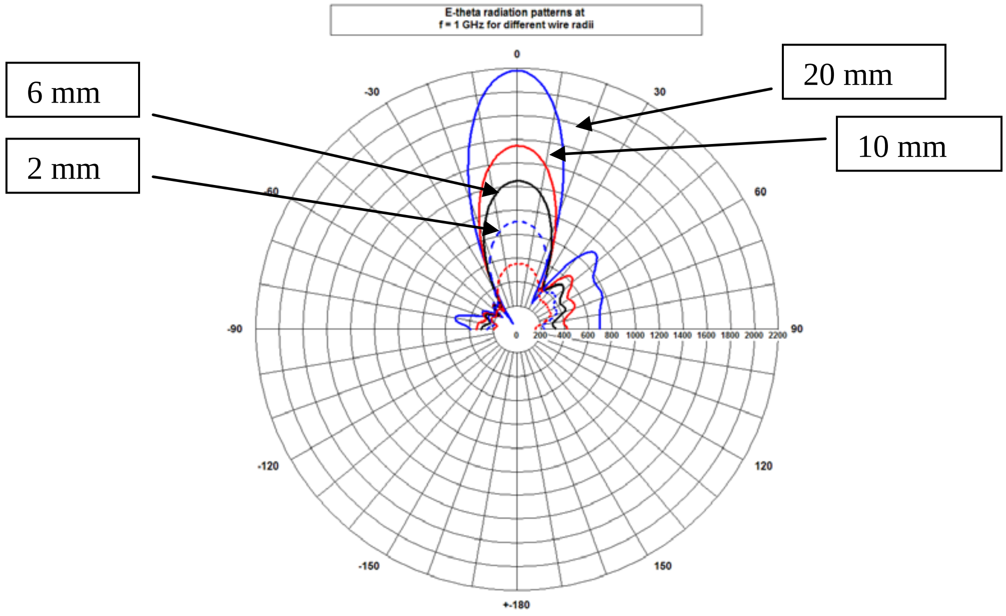


Figure 8. Radiation patterns at 1 GHz, for a range of minor diameters

Changing the wire diameter from 2mm to 20 mm (a factor of 10) → the radiation goes up by a factor of 2.5 indicating that fatter wire is better!

In the experiments changing the wire diameter from ¼” = 6.35 mm to ¾” = 19.05 mm, has resulted in enhanced radiation. At least there is qualitative agreement of this effect from the experiments, if not exact quantitative agreement. There were mechanical difficulties in going to higher diameters and we have chosen to use ¾” diameter for this helical antenna.

References

[1] J. D. Kraus and R. J. Marhefka, Antennas for all Applications, McGraw Hill Publication, 3rd edition.

[2] T. E. Tice and J. D. Kraus, "The Influence of Conductor Size on the Properties of Helical Beam Antennas," Proceedings of IRE, Volume 37, No. 11, November 1949.

[3] Dr. Jerrold Levine, L-3 Applied Technologies, Inc., San Leandro, CA, Private Communication, 2015.