Study of the Effects of the Back Cavity on a Broadband Sinuous Antenna and an Optimized Loaded Back Cavity

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Abstract **─** Sinuous antennas, like spiral antennas, have wideband characteristics, such as constant beam width and low axial ratio over a broad range of frequencies, and thus they are suitable for communicating in transmitting and receiving over bands of frequencies that may encompass multiple channels. In the presence of the back cavity, the performance of the sinuous antenna is affected. The purpose of this paper is to study the affects of the back cavity, and use these findings to build an optimized lossy cavity to improve the performance of the sinuous antenna. The performance of the antenna with and without the back cavity is compared to the antenna with the optimized loaded cavity.

Index Terms **─** Sinuous antenna, spiral antenna.

I. INTRODUCTION

Broadband antennas have many applications in airborne and communication systems [1,2]. Sinuous antennas, being broadband with constant beam width, low axial ratio, constant input impedance level and compact size, are good candidates in modern communication systems. Sinuous antennas, first conceived by DuHamel [3], perform like spiral antennas, but unlike spiral antennas, sinuous antennas are dual circular polarized. These antennas are usually cavity backed for unidirectional radiation [4], but the reflections from the cavity might degrade the performance of the antenna. The purpose of this study is to compare the performance of the unidirectional broadband (2 GHz- 18 GHz) unloaded cavity backed sinuous antenna with the performance of bi-directional sinuous antenna without the back cavity, and use these results to design an optimized lossy back cavity. Most often, the cavity used is a lossy cavity to absorb the back radiation, but that degrades the efficiency of the antenna by 50 percent. Recently much research is done on metamaterials for the use in the cavity for increasing the efficiency of the antenna while not degrading its performance.

Four arm, constant growth, sinuous antenna is used in this study. Like spiral antennas, different types of sinuous antennas can be formed by varying the growth rate (constant growth vs. logarithmic growth), sweep angle and number of arms. Each of these types has some benefits over the other. For example, the type of sinuous antenna under consideration is self-complimentary, and thus has a constant input impedance level throughout the band [5]. Shown in Fig. 1 are two sinuous antennas, one with a faster rate of growth than the other [5]. Each arm of the sinuous antenna is formed by rotating the curve formed by using the equation:

$$\phi(r) = (-1)^p \alpha_p \sin\left[\frac{\pi \ln(r / R_p)}{\ln(\tau_p)}\right],$$

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where r is the distance from origin, r_p is the radius of the pth sector, τ_p is the radius growth rate (usually less than 1) and α_F is the sweep angle.

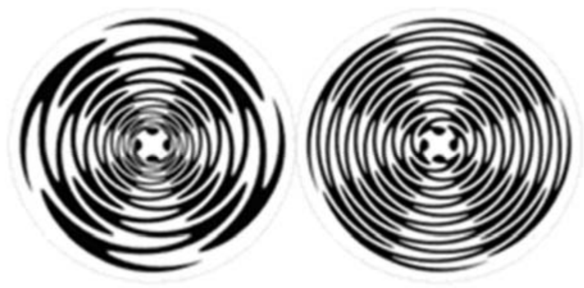

Fig. 1. Typical four-arm sinuous antennas with different growth rates

The bandwidth of the sinuous antenna is limited by its physical size. Lower frequencies radiate from the outer turns of the antenna, while the higher frequencies radiate from the inner turns. The lowest frequency of operation is approximately where the length of the outermost turn is half a wavelength, and the highest frequency of operation is approximately where the length of the innermost turn is half a wavelength.

II. METHODOLOGY

A 13 turn sinuous antenna, with and without a back cavity is simulated using FEKO [6], which employs the method of moments (MoM). Shown in Fig. 2 is the meshed model of the sinuous antenna with and without a back cavity under consideration. Each arm of the antenna has 13 turns, and each turn is swept 180 degrees. The outer radius of the antenna is chosen as 1 inch, to accommodate the lowest frequency of 2 GHz, and the inner radius of the antenna is chosen as 0.075 inches to accommodate the highest frequency of 18 GHz. The back cavity depth is chosen to be 0.9 inches, which is roughly one wave length at the center of the band of interest. Figure 3 shows a comparison of the simulated input impedance of the sinuous antenna, with and without the back cavity from 2 GHz to 18 GHz. Figure 4 shows the simulated return loss comparison of the sinuous antenna, with and without the back cavity, when feeding with a balun of constant 188 ohm impedance.

From Fig. 3, it is evident that the back cavity made the impedance level not flat, compared to the case of not having the back cavity. A reason for this may be the difficulty in matching the sinuous antenna with the back cavity. This is evident from Fig. 4. Without the back cavity, the return loss of the antenna is better than 10 dB through out the band, but due to the reflections from the back cavity, the reflected power back into the input port increases, thus making the return loss worse.

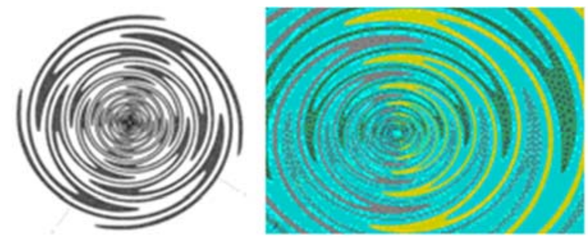

Fig. 2. Meshed FEKO model of the four-arm sinuous antenna, with and without back cavity; input is applied between two opposite arms

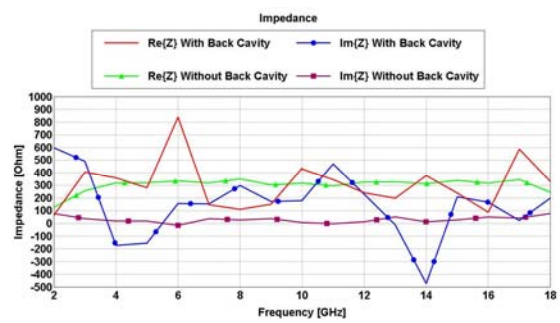

Fig. 3. Input impedance comparison of the sinuous antenna, with and without back cavity

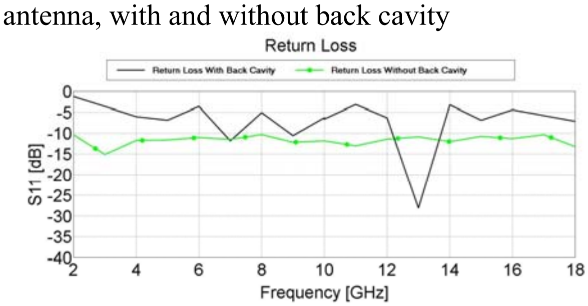

Fig. 4. S_{11} comparison of the sinuous antenna, with and without back cavity, using a 188 Ohm reference impedance.

The four-arm sinuous antenna exhibits good axial ratio performance. Figure 5 shows the simulated boresight axial ratio comparison of the sinuous antenna with and without back cavity. The axial ratio at different angles over a broad frequency band of 2-18 GHz is shown in Figs. 6(a) and 6(b) for the antenna with and without the back cavity.

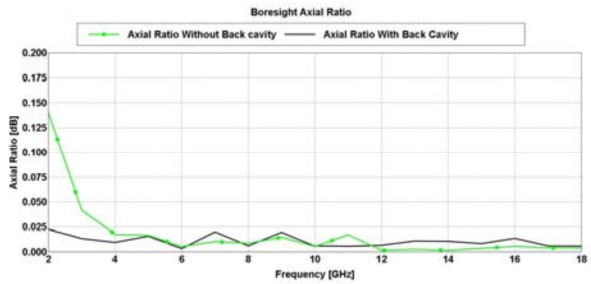

Fig. 5. Axial ratio comparison of the sinuous antenna, with and without back cavity.

From Fig 5, we see that the boresight axial ratio is not effected by the addition of the back cavity, but from Fig 6, it is evident that the off axis axial ratio is greatly effected. The reflections from the cavity, depending on the frequency, may not add in phase with the front radiated power, thus causes degradation of the off axis axial ratio of the antenna.

The comparison of the radiation pattern is shown in Fig 7(a) and 7(b). The radiation patterns of the sinuous antenna are plotted with and without the back cavity over the frequency band of 2 GHz to 18 GHz.

From Fig. 7, it can be seen that the 3 dB beam width is not constant when a back cavity is added, compared with the absence of the back cavity. The reflections from the back cavity, when added in-phase, with the front radiation gives higher gain than the bi-directional antenna, but when the reflections are out of phase compared to the front radiation, we see degradation in the gain. The reflections add in-phase when the depth of cavity is an even multiple of half wavelength at the operating frequency, which gives a total additional phase of multiples of full wavelengths (multiples of 360 degrees) thus adding in phase with the forward radiating wave. The reflections from the back cavity subtract from the forward wave when the depth of the cavity is an odd multiple of quarter wavelength at the operating frequency, which gives the reflected wave a total additional phase of multiples of 180 degrees, which is opposing to the phase of the forward travelling wave.

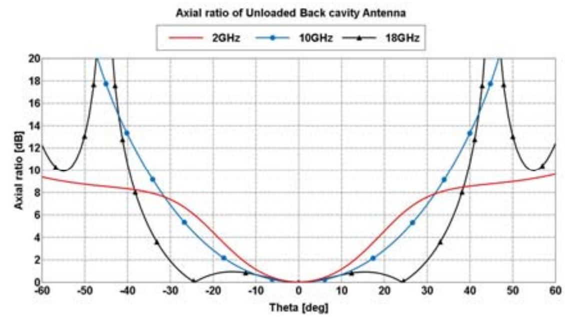

Fig. 6(a). Axial ratio of the sinuous antenna with the back cavity.

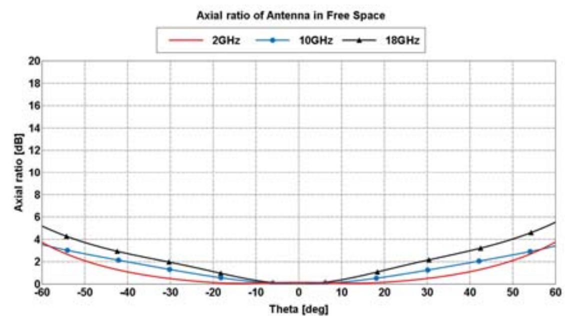

Fig. 6(b). Axial ratio of the sinuous antenna without the back cavity.

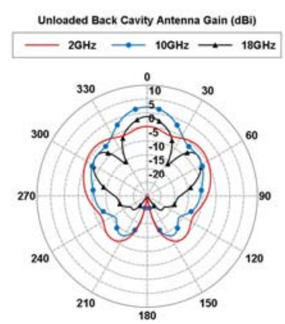

Fig. 7(a). Gain pattern of the sinuous antenna with the back cavity.

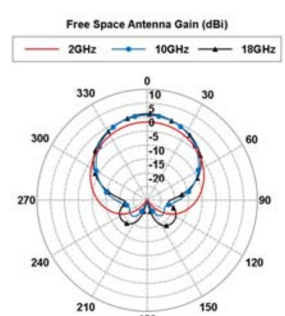

Fig. 7(b). Gain pattern of the sinuous antenna without the back cavity.

III. LOADING CAVITY

As illustrated, in the presence of the back cavity, the reflections from the cavity, depending on the frequency, might not add in phase with the front radiated energy, thus degrading the performance of the antenna. One way to stop this from happening is to absorb the back radiated power [9] by loading the back cavity with absorbers as shown in Fig. 8. The cavity is loaded with three different absorbers with different thicknesses. The optimization is carried by keeping the total cavity depth fixed at 0.9 inches, while optimizing the thicknesses and electrical properties of the absorbers using FEKO [6] to achieve a goal of axial ratio better than 0.2 dB at the boresight and a gain better than 3 dB, while maintaining an off-axis axial ratio less than 2 dB in the 30 degree scan on the either side of the boresight. The results from the optimization show the top layer, closer to the antenna, is 0.29 inches thick with relative permittivity of 1.4 and loss tangent of 0.225. The middle layer is 0.155 inches thick with relative permittivity of 1.59 and loss tangent of 0.62. The bottom layer, closer to the back short, is 0.3 inches thick with relative permittivity of 2.66 and loss tangent of 1.6. The optimization was performed on a quad core machine and it required 8.2 GBytes of memory and 44.8 hours of optimization. The FEKO recommended mesh size of λ/12 at 18 GHz was chosen during meshing. The three layer absorbers can be custom ordered from Emerson & Cuming [7] from the eccostock and eccosorb series absorbers. The fabrication of the optimized antenna would not be hard, as the dimensions of the antenna are easily realizable and the absorbers can be obtained. The performance of the optimized antenna is verified by comparing the FEKO results (method of moments) with the results from HFSS (finite element method) [8]. The HFSS simulation required 4.7 GBytes of memory and 18 hours of run time. Figures 9 and 10 show the gain pattern and off-axis axial ratio, respectively, of the optimized loaded back cavity model. Figures 11 and 12 show the respective boresight axial ratio and boresight gain comparison of the optimized antenna. Figures 13 through 15 show the gain pattern comparison of the optimized antenna at 2 GHz, 10 GHz, and 18 GHz, respectively. While Figs. 16 through 18 shows the axial ratio pattern comparison of the optimized antenna at 2 GHz, 10 GHz, and 18 GHz, respectively.

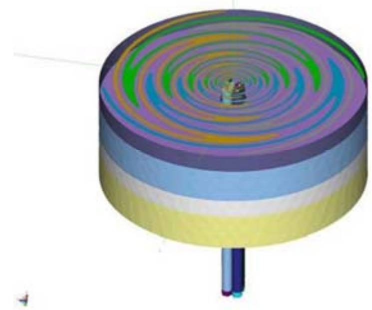

Fig. 8. Emerson and Cumming ECCOSORB AN absorbers loaded in back cavity.

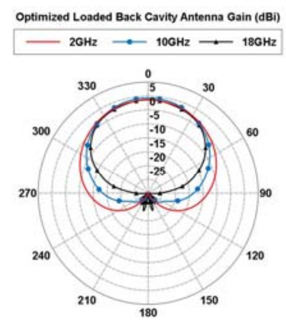

Fig. 9. Gain pattern of the optimized sinuous antenna.

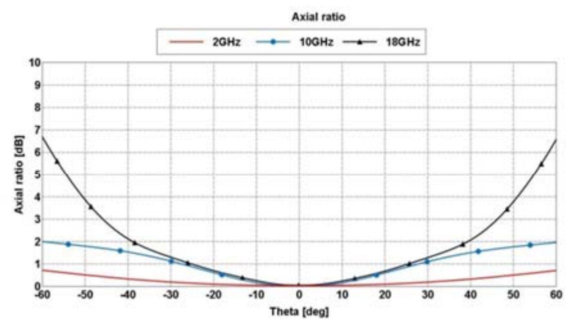

Fig. 10. Off-axis axial ratio of the optimized sinuous antenna.

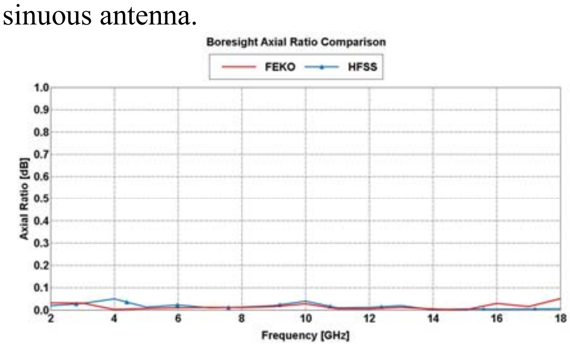

Fig. 11. Boresight axial ratio comparison of the optimized sinuous antenna.

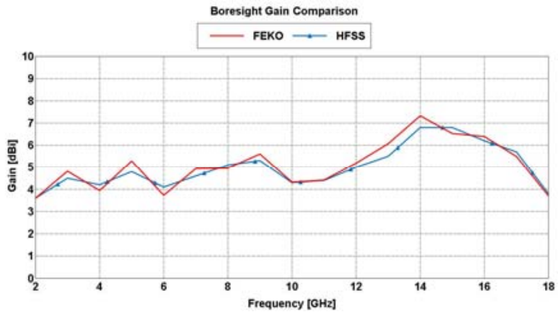

Fig. 12. Boresight gain comparison of the optimized sinuous antenna.

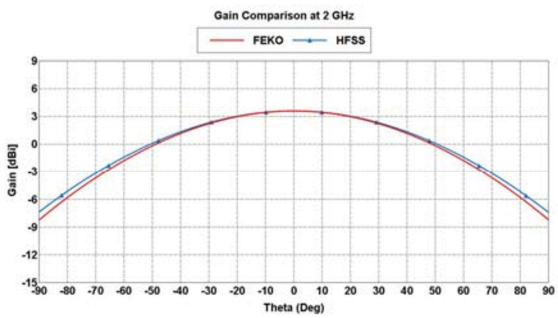

Fig. 13. Gain comparison of the optimized sinuous antenna at 2 GHz.

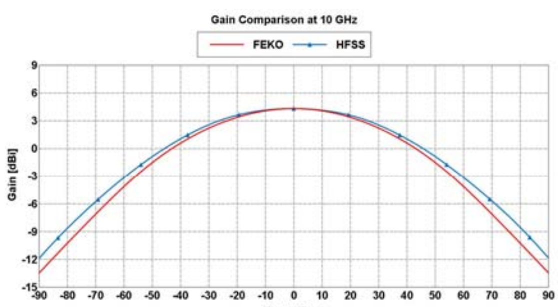

Fig. 14. Gain comparison of the optimized sinuous antenna at 10 GHz.

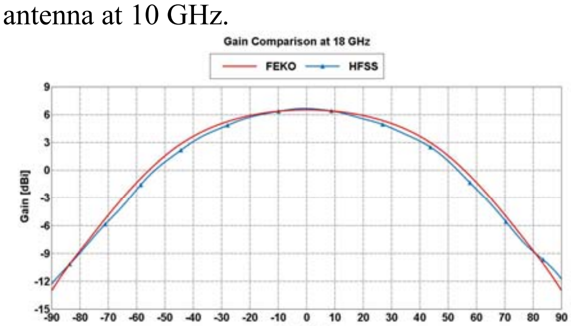

Fig. 15. Gain comparison of the optimized sinuous antenna at 18 GHz.

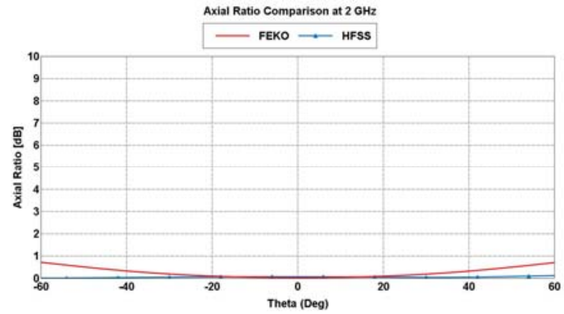

Fig. 16. Axial ratio comparison of the optimized sinuous antenna at 2 GHz.

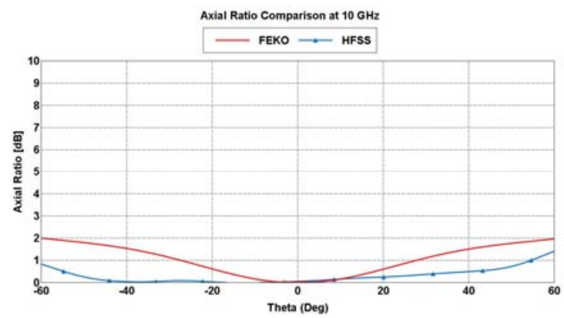

Fig. 17. Axial ratio comparison of the optimized sinuous antenna at 10 GHz.

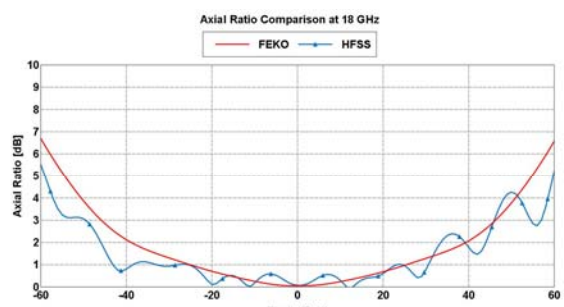

Fig. 18. Axial ratio comparison of the optimized sinuous antenna at 18 GHz.

Figures 9 through 18 shows that adding the absorbers in the back cavity has improved the performance of the antenna, compared to the unloaded cavity case, by absorbing the back radiated energy and thus preventing it to interfere with the forward radiated energy. The off-axis axial ratio of the antenna is greatly improved by loading the back cavity with three layers of absorbers. This paper shows that a broadband lossy cavity can be designed without degrading the performance of the antenna.

III. CONCLUSION

It is evident from this study that the back cavity affects the performance of the sinuous antenna. Due to the reflections from the back cavity, the input impedance of the antenna is not at a constant level, thus making it hard to match the antenna with a constant impedance source. It is also evident that the off-axis axial ratio and the gain pattern are adversely affected by the presence of the back cavity, due to the fact that the reflections from the back cavity may, or may not, add in-phase with the forward propagating wave depending on the frequency. We have also presented a way to improve the performance of the sinuous antenna by loading the back cavity with absorbers. The absorbers in the back cavity help absorb the back radiated energy and thus leaving the front radiating energy uninterrupted.

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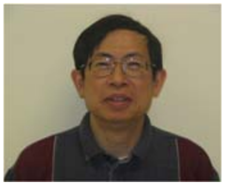

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Dr. Cheung has published many papers in the electromagnetic and optics areas. He is a member of IEEE and Tau Beta Pi. He had served as an industry advisory board member to the Electrical Engineering Department at University of Massachusetts, Lowell. He currently conducts a joint research program with the Department of Electrical and Computer Engineering at the Tufts University focusing on broadband cavity back spiral antennas.