Progress in the Design and Realization of an Electrically Small Huygens Source

Steven R. Best

The MITRE Corporation, 202 Burlington Road, Bedford, MA USA
Email: sbest@mitre.org

ABSTRACT: In this paper, we describe our progress to date in the design and realization of an electrically small Huygens source. We begin discussing work by Yaghjian that predicts the maximum directivity achievable with single and dual Huygens sources. Here, we attempt to realize the Huygens source utilizing electrically small electric and magnetic dipoles. Using straight-wire dipole and circular-loop elements, we demonstrate that the directivities predicted by Yaghjian can be achieved with the single and dual Huygens sources. Next, we attempt to realize the Huygens source using recently described, more practical electrically small electric and magnetic dipoles. In free space, these antennas are impedance matched to 50 Ohms and exhibit a quality factor (Q) that approaches the lower bound (the Chu limit). When used in the realization of a Huygens source, these antennas no longer exhibit matched impedances nor low *Q's*. The limitations that arise in realizing the Huygens source are discussed.

INTRODUCTION

There has been significant work in the design of electrically small antennas that are optimized to achieve low *VSWR*, high efficiency, and a Q that approaches the lower bound [1] – [5]. Work in this area primarily focuses on achieving low Q, since in theory; any electrically small antenna can be matched to achieve a low *VSWR*. The majority of work in this area has focused on the design of electrically small electric (TM mode) dipoles, since they are generally easier to realize in practice. In recent publications [3] and [5], several approaches to designing low Q, electrically small magnetic dipoles (TE Mode) have been described. Designs from these previous publications are used here in our attempt to realize the Huygens source.

In [6], Yaghjian presented a detailed theoretical work on the directivity that can be achieved with crossed electric and magnetic dipoles, or a Huygens source. It was shown that a single Huygens source can achieve a directivity of 4.8 dB, while a dual Huygens source can achieve a directivity of 9 dB. Since the Huygens source utilizes two dipole elements (electric and magnetic), we must also note that superdirectivity can also be achieved with two electric or two magnetic dipoles [6]. In our previous work on super-directive arrays [7] – [8], we described 2-element arrays that exhibit directivities approaching theoretical limits. Two closely spaced electrically small electric dipoles can achieve a directivity of approximately 7.2 dB, which is greater than that of the Huygens source.

THE ELECTRICALLY SMALL SPHERICAL ELECTRIC AND MAGNETIC DIPOLES

To realize a Huygens source here, we utilize crossed electric and magnetic dipoles. In the final implementation of a Huygens source, we use electrically small, multi-arm folded spherical helix electric and magnetic dipoles. The spherical helix magnetic dipole used here was designed by Kim [5]. Both of these antennas are designed to operate at 300 MHz, exhibit a 50 Ohm radiation resistance, high efficiency and Q that approaches the lower bound. These antennas are depicted in Fig. 1. The spherical electric dipole has an overall height of 8.36 cm, while the spherical magnetic dipole has an overall height of 8.8 cm.

DIRECTIVITY OF DIPOLE-LOOP HUYGENS SOURCES

To first validate the theoretical work presented by Yaghjian, we first implement the single and dual Huygens sources using an electrically small straight-wire dipole (electric dipole) and an electrically small circular-loop (magnetic dipole) as shown in Fig. 2. The straight-wire dipole and circular-loop have an overall length and diameter of 10 cm, respectively. In their Huygens source configurations, these antennas are fed and phased to operate at 300 MHz. These antennas were modelled using the Numerical Electromagnetics Code (NEC4). The single Huygens source [Fig. 2(a)]

978-1-4244-4885-2/10/$25.00 ©2010 IEEE

exhibits a directivity of 5.05 dB and the dual Huygens source [Fig. 2 (b)] exhibits a directivity of 8.79 dB, both consistent with the work presented by Yaghjian. Directivity patterns for these Huygens sources are presented in Fig. 3.

The major performance issues with these implementations of the single and dual Huygens are the high *VSWR*, low efficiency and high Q associated with these coupled electrically small elements. While these Huygens source implementations validate the directivities that can be achieved using crossed electric and magnetic dipoles, they are not practical to implement.

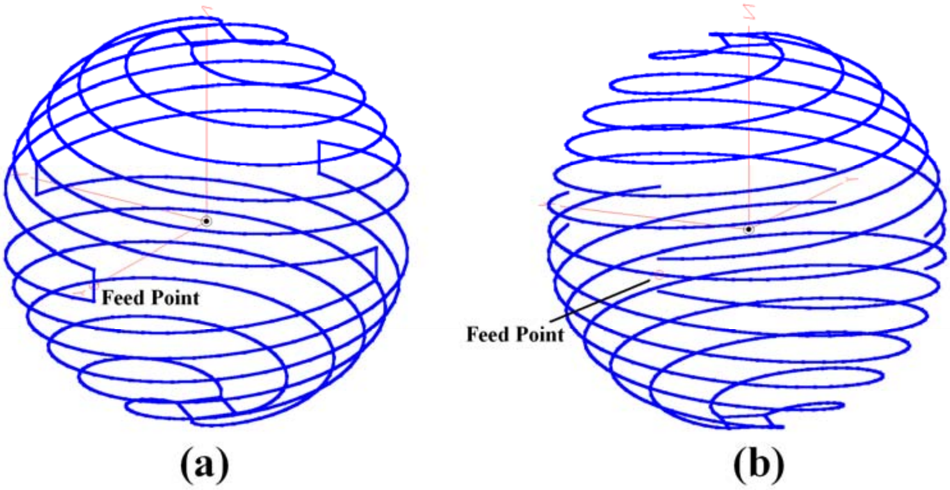

Fig. 1 (a) The electrically electric (TM Mode) dipole [1]-[2]. (b) The electrically small magnetic (TE Mode) dipole, Kim [5].

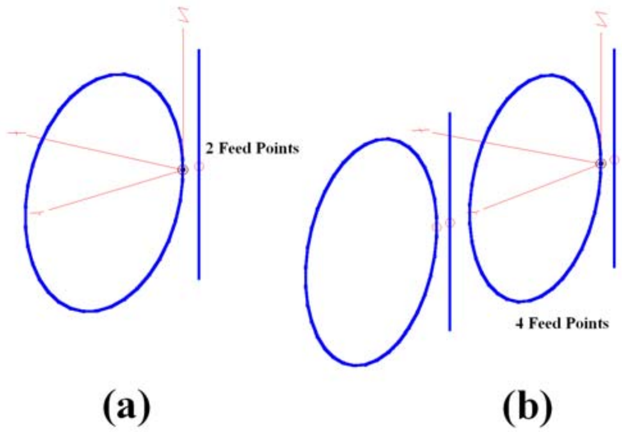

Fig. 2 (a) The single Huygens source realized using a dipole-loop pair. (b) The dual Huygens source realized using a dual dipole-loop pair.

HUYGENS SOURCE REALIZED USING THE SPHERICAL ELECTRIC AND MAGNETIC DIPOLES

In our attempt to realize a more practical Huygens source, we presumed that substantially better impedance and Q performance could be achieved through the use of electrically small electric and magnetic dipoles that exhibit low *VSWR* and low Q in free space. The choice of elements used in this approach was the electric and magnetic dipoles depicted in Fig. 1. The Huygens source implementation with these elements is depicted in Fig. 4. The magnetic dipole is slightly larger than the electric dipole, so that in free space both operated at 300 MHz with low *VSWR* and low Q. The overall diameter of this Huygens source is approximately 18.1 cm, resulting a value of ka = 1.138. While the individual elements are electrically small, the combination to create a Huygens source is not.

The Huygens source was modelled using NEC with both fixed current and voltage sources at each feed. Using fixed current sources, the maximum directivity achieved was 4.34 dB. The directivity pattern of this Huygens source is presented in Fig. 5. Similar results were achieved using fixed voltage sources. The current is the electric dipole was set at 1 A @ 0 degrees while the current in the magnetic dipole was set 1.2 A @ 3 degrees. Much like the Huygens source implemented using the straight-wire dipole and circular-loop, this Huygens source also exhibited poor impedance properties and high Q. The realization of this Huygens source is not practical at this time.

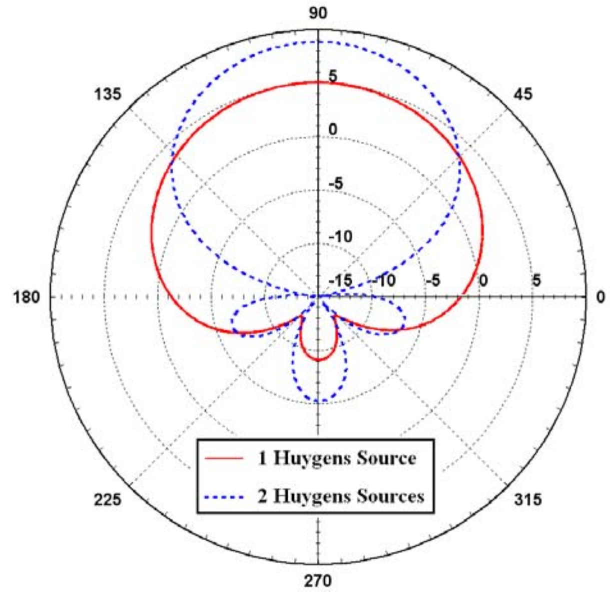

Fig. 3 Radiation patterns of the single and dual Huygens sources realized using dipole-loop pairs. The single Huygens source exhibits a directivity of 5.05 dB. The dual Huygens source exhibits a directivity of 8.79 dB.

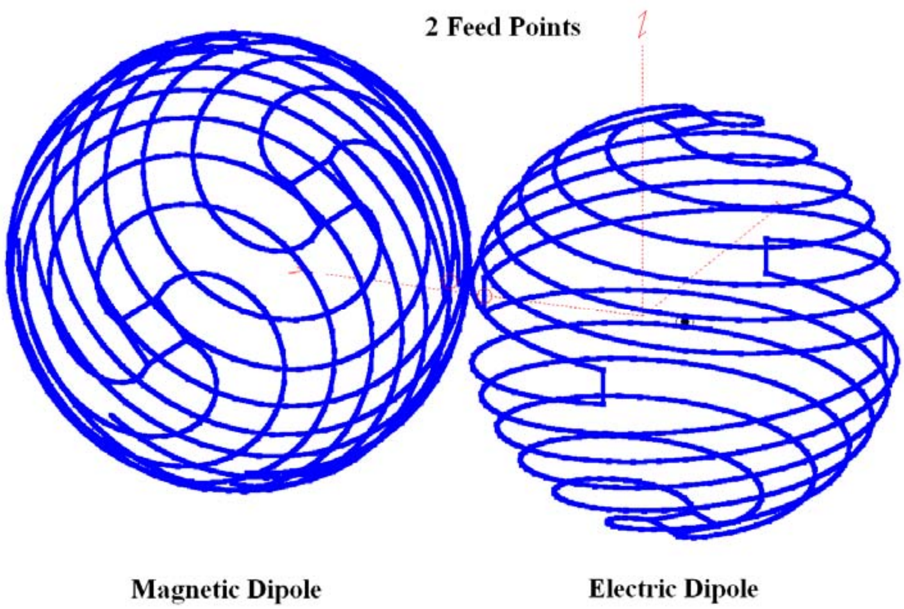

Fig. 4 Realization of the single Huygens source using the electrically small spherical electric and magnetic dipoles.

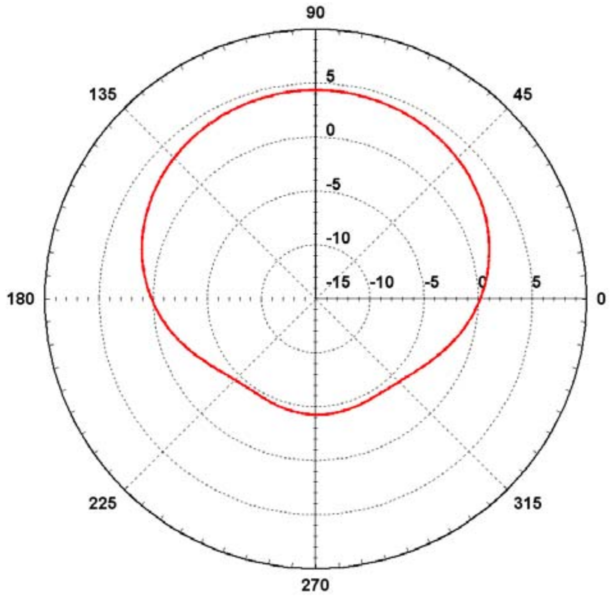

Fig. 5 Directivity of the Huygens source realized using the electrically small spherical electrical and magnetic dipoles. The directivity of the Huygens source is 4.34 dB.

DISCUSSION AND FUTURE EFFORTS

At this point, the realization of a practical Huygens source using crossed electric and magnetic dipoles was not successful. While it was demonstrated that the directivities predicted by Yaghjian can be achieved, the electric and dipole elements exhibit poor impedance properties and high Q when coupled in a Huygens source configuration. Additionally, less directivity is achieved compared to the straight-wire dipole and circular-loop implementation of the Huygens source. This is believed to be a result of the fact that the current distributions and the coupled near fields of these antennas are distributed over a larger volume.

The other theoretical and practical issue to recognize is that higher directivity can be achieved using two electric dipoles, which are generally easier to realize in practice. Future efforts are focusing on the merits of trying to optimize the Huygens source configuration from an impedance and Q perspective.

REFERENCES

[1] S. R. Best, "The Radiation Properties of Electrically Small Folded Spherical Helix Antennas," *IEEE Trans. Antennas Propagat.*, Vol. 52, No. 4, pp. 953-960, Apr 2004.

[2] S. R. Best, "Low Q Electrically Small Linear and Elliptical Polarized Spherical Dipole Antennas," *IEEE Trans. Antennas Propagat.*, Vol. 53, No. 3, pp. 1047-1053, Mar 2005.

[3] S. R. Best, "A Low Q Electrically Small Magnetic (TE Mode) Dipole," *AWPL*, vol. 8, pp. 572-575, 2009.

[4] J. J. Adams and J. T. Bernhard, "Tuning Method for a New Electrically Small Antenna with Low Q," *AWPL*, vol. 8, pp. 303-306, 2009.

[5] O. S. Kim, "Low-Q Electrically Small Spherical Magnetic Dipole Antennas", *IEEE Trans. Antennas Propagat.*, Accepted for Publication.

[6] A. D. Yaghjian, "Increasing the Supergain of Electrically Small Antennas using Metamaterials," *European Conf. Antennas Propagat., (EuCap)*, pp. 856-860, 2009.

[7] E. E. Altshuler, T. H. O'Donnell, A. D. Yaghjian, and S. R. Best, "A Monopole Superdirective Array," *IEEE Trans. Antennas Propagat.*, Vol. 53, No. 8, pp. 2653-2661, Aug 2005.

[8] S. R. Best, E. E. Altshuler, A. D. Yaghjian, J. M. McGinthy, and T. H. O'Donnell, *AWPL*, vol. 7, pp. 302-305, 2008.