Radiation Modes Investigation of Huygens Source Type Antenna Using Spherical Wave Expansion

Abdul Sattar Kadddour[1], Serge Bories[1], Antonio Clemente[1], Anthony Bellion[2] and Christophe Delaveaud[1]
[1]CEA, LETI, MINATEC Campus, Univ. Grenoble-Alpes, 38054 Grenoble, France
[2]CNES, 18 Avenue Edouard Belin 31401, Toulouse, France

***Abstract* - Spherical wave expansion (SWE) is usually used in numerous applications or analysis such as antenna measurement and physical limitations of electrically small antennas. In this paper, spherical wave expansion is used as tool to analyze the far-field radiation properties of a low profile dual-polarized wideband magneto-electric dipole antenna. The analysis demonstrates that the proposed magneto-electric antenna presents the same behavior as a generalized Huygens source with identical contribution of transverse electric (*TE*) and transverse magnetic (*TM*) modes on a wide bandwidth.**

***Index Terms* — spherical wave expansion, Huygens source, dual-polarized antenna, wideband antenna, magneto-electric dipole.**

1. Introduction

Spherical wave expansion (SWE) is typically used in antenna measurements in order to calculate the radiated far-field from the near-field measured on a spherical surface [1]. Chu [2] and Harrington [3] used SWE to describe and analyze the physical limitations (e.g. quality factor, bandwidth, and directivity) of electrically small antennas. Recently, SWE was used to analyze the radiated far-field [4] and to optimize the directivity of electrically small antennas [5].

In this paper, the SWE has been used to analyze the far-field radiation properties of a low profile dual-polarized wideband antenna based on the Huygens source concept.

2. Theory and background

The electric field $\vec{E}$ at large distance ($r \to \infty$) outside the antenna enclosing sphere can be represented as a weighted sum of the far-field spherical wave pattern functions $k_{smn}(\theta, \phi)$ defined in [1]

$$\vec{E}(\theta, \phi) = k\sqrt{\eta} \sum_{s=1}^{2} \sum_{n=1}^{N} \sum_{m=-n}^{n} Q_{smn} K_{smn}(\theta, \phi) \qquad (1)$$

where k is the wave number and η is the free-space wave impedance. N is the maximum degree (n) of SWE, m the order, and the index s is equal to 1 or 2 for *TE* and *TM* modes, respectively. Q_{1mn} and Q_{2mn} indicate the spherical wave coefficients related to the outward propagating TE_{mn} and TM_{mn} modes, respectively. From (1), the total power radiated by the sources enclosed in the minimum sphere P_{rad} can be easily calculated as

$$P_{rad} = \frac{1}{2} \sum_{s=1}^{2} \sum_{n=1}^{N} \sum_{m=-n}^{n} |Q_{smn}|^2 \qquad (2)$$

The far-field pattern $\vec{f}(\theta, \phi)$ of a generalized Huygens source composed of crossed *z*-oriented electric and *x*-oriented magnetic dipoles is given by

$$\vec{f}(\theta, \phi) = (\sin\theta + \sin\phi)\hat{\theta} + \cos\theta\cos\phi\,\hat{\phi} \qquad (3)$$

For this elementary antenna, N is equal to 1 and its directivity is equal to 3 (4.76 dBi) [1]. The radiation pattern and the distribution of the radiated power on both *TE* and *TM* modes computed as a function of the degree (n) of the SWE are showed in Fig. 1. The power has been computed by the sum of the order m when n is fixed. From the figure, it is possible to observe that the power radiated by a theoretical Huygens source is homogenously distributed on the TE_1 and TM_1 modes.

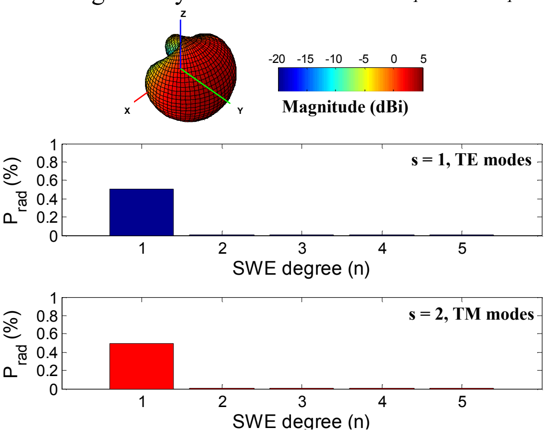

Fig 1. Generalized Huygens source radiation pattern and SWE power distribution as a function of the order n.

3. Dual polarized Huygens source antenna

The proposed low profile antenna is based on the dual-polarized wideband magneto-electric dipole antenna presented in [6], the designed antenna is depicted in Fig 3 (dimensions in *mm*). The antenna consists of four horizontal plates operate together as two crossed electric dipoles. Each horizontal plate is shorted to the ground plane trough two vertical folded plates. Each adjacent vertically oriented plates and the ground between them act like a magnetic dipole. These elements form two crossed magneto-electric dipoles generating a dual polarization at ± 45°.

The antenna is fed by two "Γ" shaped probes orthogonally placed in the gaps between the vertical plates. The port 1 is the lower probe and the port 2 is the higher probe. The antenna is placed in the middle of a square cavity and prototyped using

3D printed technology. A more detailed description of the propose antenna is presented in [7].

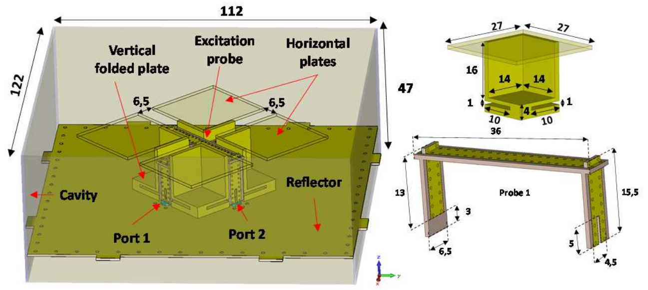

Fig 2. 3D view of the low profile dual polarized antenna.

The simulated and measured standing wave ratio (SWR) and gains computed at Port 1 and Port 2 are shown in the Fig.3. The antenna operate with a common bandwidth from 1.8 to 3.2 GHz 54.2% (SWR <2) with a gain of 7.4 dBi ±1.4 dBi.

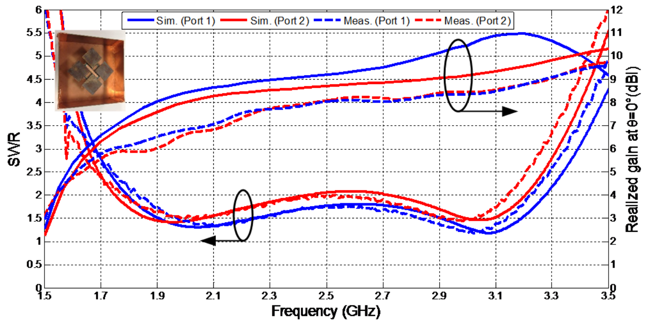

Fig. 3. Simulated and measured SWR and gains.

SWE was applied on the proposed antenna in order to analyze its radiation behavior. The relative powers radiated by *TM* and *TE* modes (of degree *n*) as a function of the frequency for Port 1 are showed in Fig. 4. From this figure, It can be seen that for a $P_{rad} > -10\ dB$ over the operation band the main contribution of *TM* and *TE* modes are for *n*=1 and *n*=2. Starting from 2.5 GHz the difference between radiated power of *TE* and *TM* modes is probably due of the antenna excitation. *TM* and *TE* modes are related to horizontal plates (electric dipoles) and vertical folded plates (magnetic dipoles) respectively. At higher frequencies, the antenna structures becomes electrically large witch explain the increase of the radiated power of higher (*n*=3 and *n*=4) *TE* and *TM* modes.

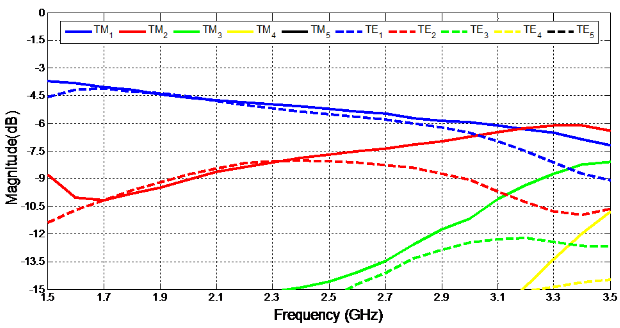

Fig 4. Extracted radiated power for *TM* and *TE* modes.

SWE shows that *TM* and *TE* modes have almost equal and stable radiation power in the operation frequency range; these results validate the concept of Huygens source and explain the reasons of stable radiation properties of magneto-electric antennas in term of gains and radiation patterns over the operation frequency band.

The 3D radiation pattern and the distribution of the radiated power on both *TE* and *TM* modes computed as a function of the degree (*n*) of the SWE at 2.5 GHz are showed in Fig. 5. This figure shows that the power radiated by the proposed antenna is distributed on the $TE_{n=1,2,3}$ and $TM_{n=1,2,3}$ modes. Higher modes (*n*=2 and *n*=3) are excited due to the presence of the reflector (ground plane). Radiation patterns of Port 2 has similar results as Port 1 due to the design symmetry.

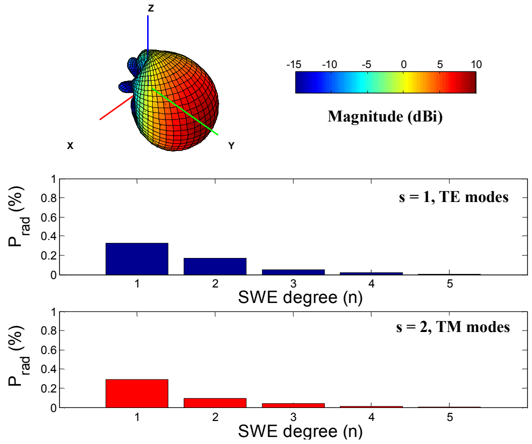

Fig 5. Radiation patterns and SWE power distribution as a function of the order n at 2.5 GHz.

4. Conclusion

In this paper, SWE tool has been used to analyze the far-field radiation pattern of the proposed low profile dual-polarized magneto-electric antenna in term of radiated power by *TE* and *TM* modes. These results showed that the proposed antenna is a multi-modal antenna and could be described as a set of multiple sources. The antenna radiates almost identical and stable *TE* and *TM* modes over the operation band from 1.8 to 3.2 GHz for a SWR<2. SWE proved that magneto-electric dipole antennas behave as a Huygens source.

Acknowledgment

The authors wish to thank the CNES, French space agency for partially funding this work.

References

[1] J. E. Hansen, *Spherical nearfield antenna measurements*, London, U.K.: Peter Peregrinus Ltd.,1988.

[2] L. J. Chu, "Physical limitations on omni-directional antennas," J. Appl. Phys., vol. 19, pp. 1163–1175, Dec. 1948.

[3] R. F. Harrington, "On the gain and beamwidth of directional antennas," *IEEE Trans. Antennas Propag.*, vol. 6, no. 3, pp. 219–225, Jul. 1958.

[4] K.Belmkaddem, L.Rudant and T. P. Vuong, "Electrically small antenna analysis using spherical wave expansion," *15th Intern. Symp. Antenna Techn. and Applied Electromagnetics* (ANTEM), Jul. 2012.

[5] A. Clemente, et al., "Design of a super directive four-element compact antenna array using spherical wave expansion," *IEEE Trans. Antennas Propag.*, vol. 63, no. 11, pp. 4715-4722, Nov. 2015.

[6] L. Mingjian and L. Kwai-Man, "Wideband magnetoelectric dipole antennas with dual polarization and circular polarization," *IEEE Antennas Propag. Magazine*, vol. 57, no. 1, pp. 110-119, Feb. 2015.

[7] A. S. Kaddour, et al., "Low profile dual Polarized antenna", *21st International Symposium on Antennas and Propagation* (ISAP), Oct. 2016, Okinawa, Japan, submitted.