4E2-2

Proceedings of ISAP2007, Niigata, Japan

Transmission Line Model of a Hertzian Dipole Antenna with FSS Superstrates and AMC Ground Plane to Extract Its Far-field Radiation Properties

Alireza Foroozesh and Lotfollah Shafai
Department of Electrical Engineering, University of Manitoba, Canada
alireza@ee.umanitoba.ca, shafai@ee.umanitoba.ca

1. Introduction

Highly reflective surfaces as antenna superstrates have applications in the gain enhancement [1]. These surfaces can be realized by different means using high permittivity or high permeability materials, or highly reflective frequency selective surfaces (FSSs) [1-6]. On the other hand, one can make these high-gain antenna designs low-profile, using artificial ground planes [5-6]. A full wave analysis of actual antennas, which will have truncated FSS superstrates and artificial magnetic conductor (AMC) ground plane will be time-consuming and will need a large amount of computer memory due to the metallic patches or different dielectric layers. The transmission line equivalent network (TEN) models have been successfully employed to extract far-field radiation properties of Hertzian dipoles over conventional ground planes (PEC) with superstrates [2-4]. It was proposed in [6] that TEN models can also be used in designing antennas with artificial ground planes. However, only full-wave analysis of a few antennas having ideal (lossless, angular- and polarization-independent) reactive impedance surfaces and a truncated FSS superstrate was reported. In this paper, TEN models are used to obtain radiation properties of a Hertzian dipole with angular-dependent FSS superstrates and AMC ground planes. The results are compared with selected ideal cases.

2. Theory and Formulation

The configuration of the original problem is shown in Fig. 1(a). This problem is simplified using TEN model as shown in Fig. 1(b), which is the general form of the model proposed in [6, Fig. 1]. It is also similar to the one shown in [3, Fig. 2], except that the susceptances which model FSS superstrates are included. The formulations are the same as [3, eq. (2)] and can be written as follows.

$$\begin{cases} \begin{bmatrix} V_s - I_N R_s \\ I_N \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} I_o Z_L \\ I_o \end{bmatrix} \\ \begin{bmatrix} V_x \\ I_x \end{bmatrix} = \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} \begin{bmatrix} I_o Z_L \\ I_o \end{bmatrix} \end{cases} \Rightarrow \begin{cases} V_x = \dfrac{V_S (A' Z_L + B')}{C Z_L R_S + D R_S + A Z_L + B} \\ I_x = \dfrac{V_S (C' Z_L + D')}{C Z_L R_S + D R_S + A Z_L + B} \end{cases} , \quad (1)$$

where A, B, C and D are the elements of the ABCD matrix of the entire cascaded transmission lines and susceptances, while A', B', C' and D' are the elements of the ABCD matrix of the portion below the Hertzian dipole. Details can be found in [3]. One should note that Z_L and Y_B's are frequency, angular and polarization dependent in general, unless otherwise indicated. For the x-directed Hertzian dipole placed in origin, the radiation patterns are obtained using [3, eq. (4)]:

$$E^{TE} = E_\phi = -V_x \sin(\phi)\,;\; E^{TM} = E_\theta = V_x \cos(\phi)\,. \quad (2)$$

ISBN: 978-4-88552-223-9 C3055©IEICE

3. FSSs and AMCs Design and Characterization

A Hertzian dipole embedded in between an air layer, over an AMC ground plane and covered by an FSS superstrate is shown in Fig. 2(a). Two different unit cells of the free-standing FSSs are shown in Fig. 2(b). Also, two different unit cells of AMCs which synthesize the artificial ground planes are depicted in Fig. 2(c). In order for the FSS superstrates to make the antennas high gain, their reflection coefficient magnitudes should be close to unity [1]. Reflection properties of the designed FSSs and AMCs, are plotted in Fig. 3, vs. elevation angles and for both TE and TM polarizations at the operating frequency. Note that the reflection phase is zero for the normal incidences in AMC cases. These results are obtained using MoM-CAD (Ansoft Designer). The Y_B's and Z_L's corresponding diagrams to FSS superstrates and AMC ground planes are shown in Fig. 4.

4. Far-field Radiation Properties

Antenna directivities versus air-gap height (l) are shown in Fig. 5(a), for different combinations of the aforementioned FSSs and AMCs. Directivities vs. air-gap height for an ideal PMC and lossless but angular-dependent AMC are shown in Fig. 5(b), as well. In the latter case, the reflection phase of the AMC_1 is kept while its reflection magnitude is unity for all angles. The corresponding radiation patterns are shown in Figs. 6(a) and (b), respectively, for resonance conditions. Interestingly, the antennas with angular-dependent AMC ground planes offer more directivity rather than the antenna with ideal PMC ground plane. Since the antenna gain is highly dependent on the elevation angles, this is due to the angular dependency of the AMC ground planes which does not exist in ideal PMCs.

5. Conclusions

The TEN model was extended to the antennas with FSS superstrates and ground planes with arbitrary impedance surfaces. The special case of AMC ground planes was studied. It was shown that the angular dependency of FSS superstrates and AMC ground planes may have beneficial effects on the antenna radiation properties.

References

[1] G. V. Trentini, “Partially reflecting arrays,” *IRE Trans. on Antennas and Propagat.*, pp. 666-671, Oct. 1956.

[2] D.R. Jackson and N. G. Alexopoulos, “Gain enhancement methods for printed circuit antennas,” *IEEE Trans. on Antennas and Propagat.*, vol. 33, pp. 976-987. Sep. 1985.

[3] X. H. Wu , A. A. Kishk and A. W. Glisson, “A transmission line method to compute far-field radiation by arbitrarily directed Hertzian dipoles in a 1-D EBG structure,” *Proc. IEEE AP-S Int'l Symp.*, Albuquerque, NM, July 10-15, 2006, pp. 2997-3000.

[4] T. Zhao, D. R. Jackson, J. T. Williams and A. A. Oliner, “General formulas for 2-D leaky-wave antennas,” *IEEE Trans. on Antennas and Propagat.*, vol. 53, pp. 3525-3533, Nov. 2005.

[5] A. Feresidis, G. Goussetis, S. Wang and J. C. Vardaxoglou, “Artificial magnetic conductor surfaces and their application to low-profile high-gain planar antennas,” *IEEE Trans. on Antennas and Propagat.*, vol. 53, pp. 209-215, Jan. 2005.

[6] A. Foroozesh and L. Shafai, “2-D truncated periodic leaky-wave antennas with reactive impedance surface ground planes,” *Proc. IEEE AP-S Int'l Symp.*, Albuquerque, NM, July 10-15, 2006, pp. 15-18.

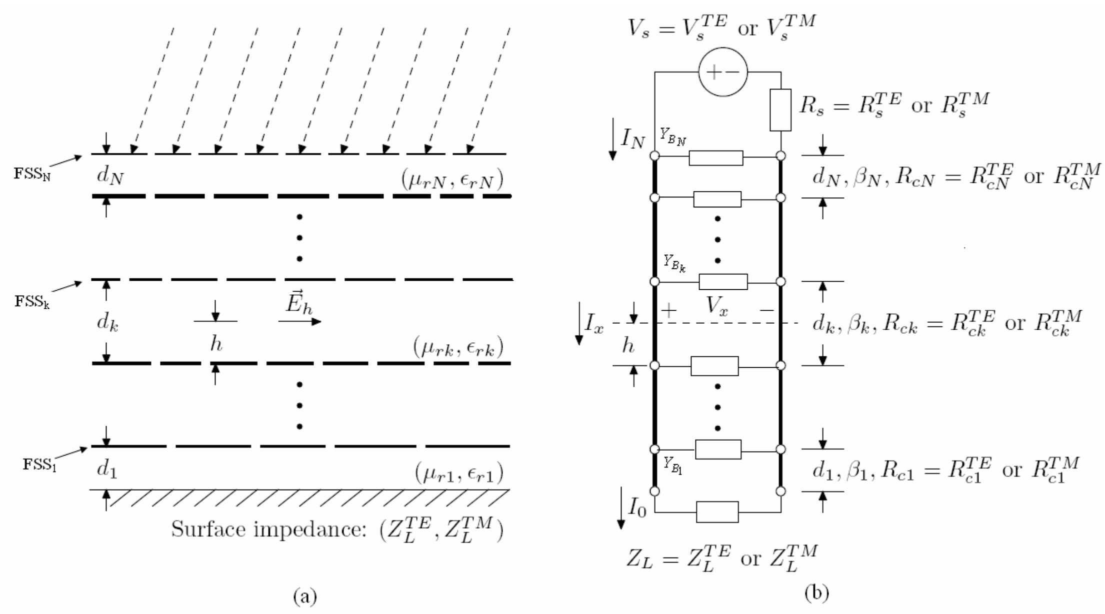


Fig. 1. (a) A Hertzian dipole embedded between FSS layers. (b) TEN model of the structure.

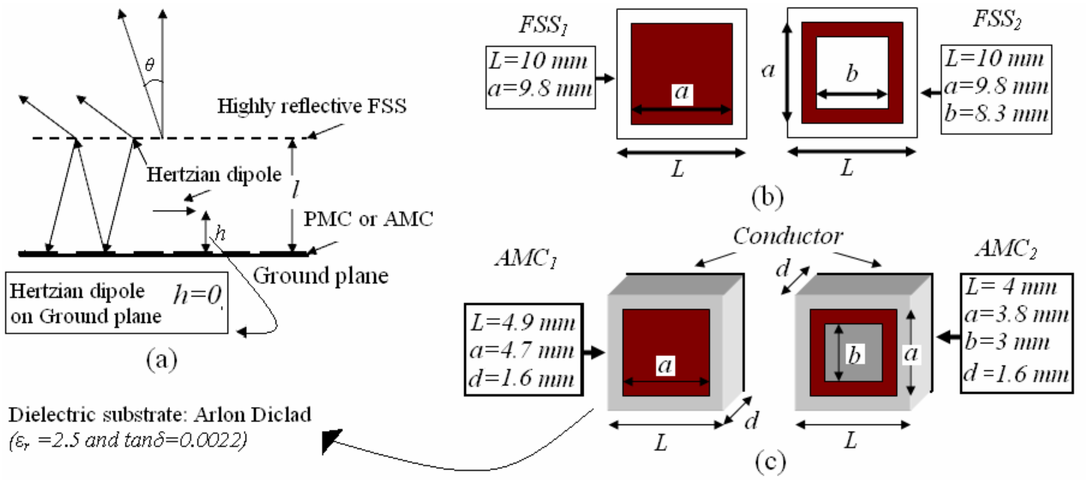


Fig. 2. (a) Geometry of the antenna. Properties of the unit cells (b) FSS and (c) AMC.

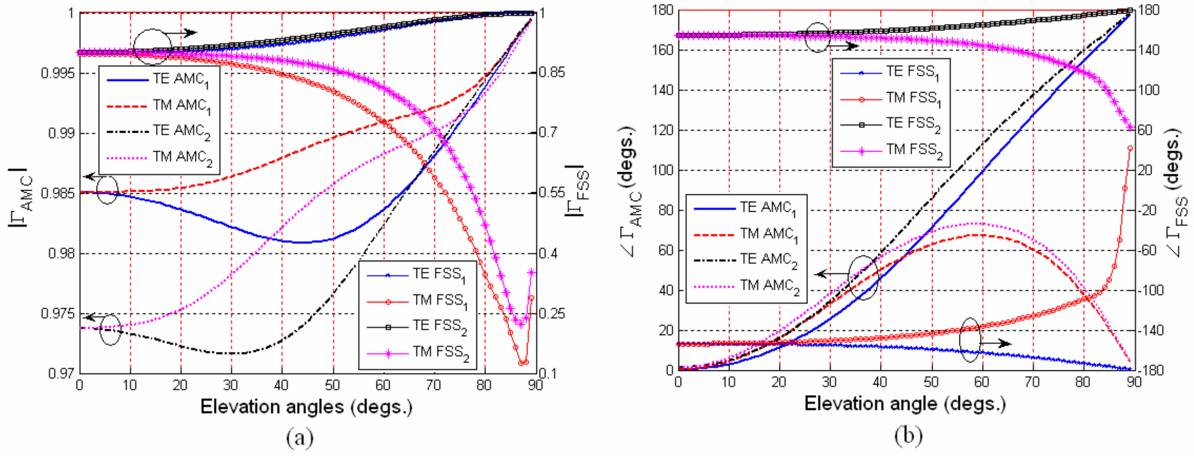
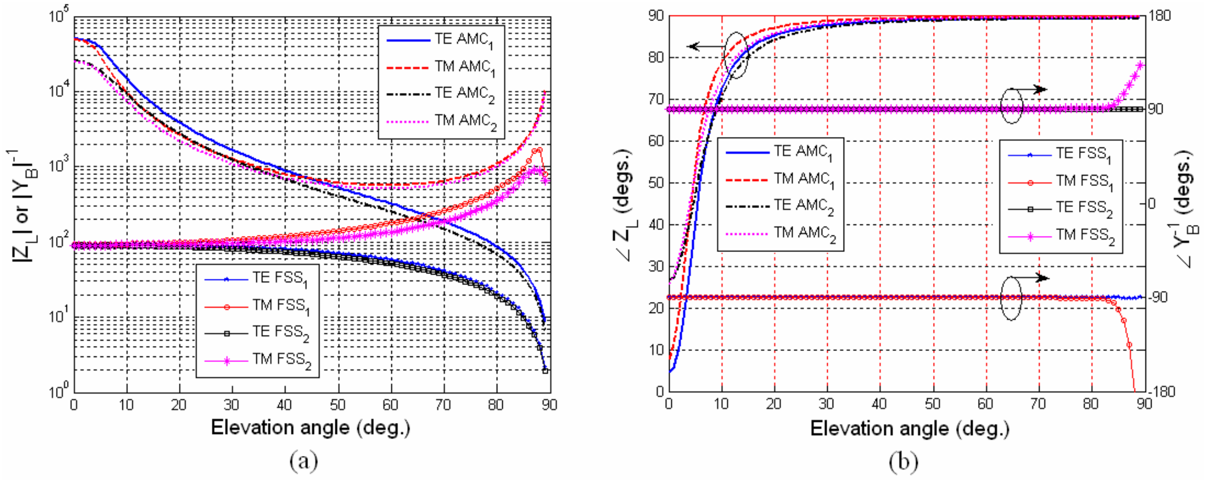


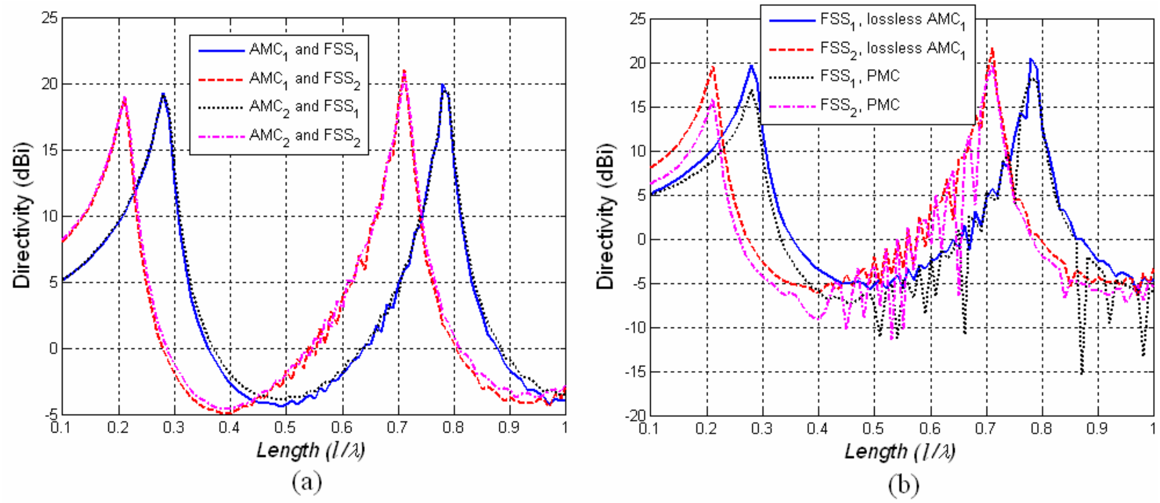
Fig. 3. Reflection properties of the designed FSSs and AMCs. (a) Magnitude and (b) phase.



(a)

(b)

Fig. 4. Impedances and susceptances corresponding to the aforementioned AMCs and FSSs, respectively. (a) Magnitude and (b) phase.



(a)

(b)

Fig. 5. Directivity vs. air-gap heights. (a) Actual AMC cases. (b) Ideal and lossless AMC cases.

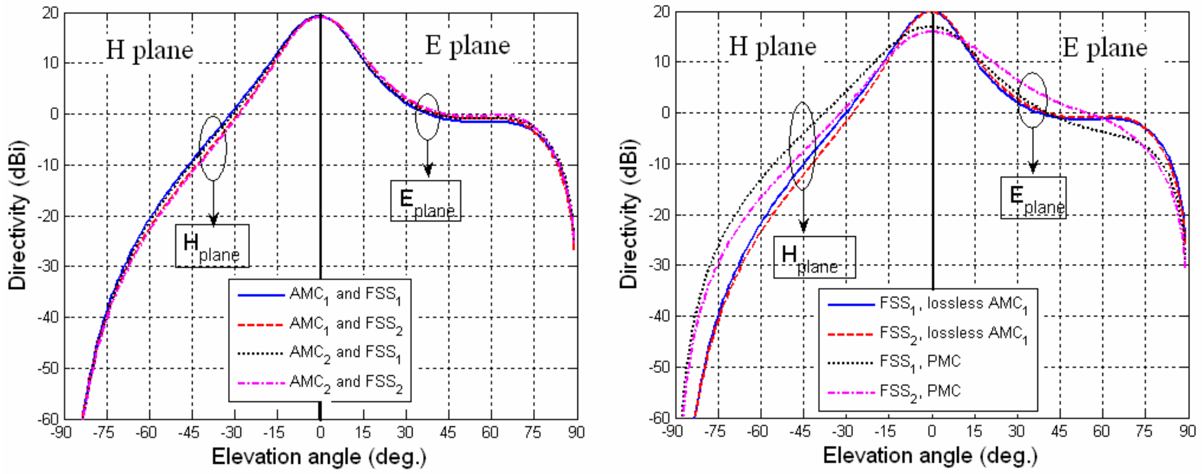


Fig. 6. Co-polar radiation patterns. (a) Antenna AMC cases. (b) Ideal and lossless AMC cases.