Simulation of the radiation charateristics of 3D quasi self-complementary arrays

X. Dardenne and C. Craeye

Université catholique de Louvain, laboratoire TELE,
Place du Levant 2, B-1348 Louvain-la-Neuve, Belgium,
Email: dardenne@tele.ucl.ac.be, craeye@tele.ucl.ac.be,
Phone : +32 10 47 2543, +32 10 47 2311, Fax : +32 10 47 2089

Abstract

Self-complementary arrays potentially exhibit a very large bandwidth. However, their bidirectional radiation characteristic limits their range of applications, and the introduction of a ground plane below the array dramatically reduces the achievable bandwidth. We confirmed the latter point by applying infinite-array MoM simulations on planar bicone arrays. When the required instantaneous bandwidth is not very large, by just moving the ground plane, the array can be operated over a quite large total frequency band. Simulation results showed a total frequency band of one octave, made of 10% instanstaneous bands. Another approach consists of folding the plates to form TEM horn arrays. In that case, 3D MoM simulations showed that a total instantaneous bandwidth of 75% can be opened. In this case, moving the ground plane has little effect.

1 Introduction

As shown by Mushiake [1], self-complementary antennas exhibit a constant impedance equal to $\eta/2$, where η is the free-space impedance. Of course, to be exactly self-complementary, the antennas should be infinite. In fact, there exists a relationship between the volume occupied by an antenna and its lowest achievable Q [2]. For arrays, an elegant solution, proposed by McGrath and Baum [3], consists of ensuring that the array itself, rather than the array elements, has a self-complementary structure. This is, for instance, the case for arrays made of square plates connected at the corners, where they are also fed ("planar bicone" arrays).

Such arrays are compact and naturally exhibit a very wide bandwidth. However, these structures radiate on both sides of the plane, which makes them practically useless for most applications. The simplest way of avoiding back-side radiation probably consists of placing a ground plane. It has been shown in the literature that the presence of a ground plane may have a dramatic effect on the bandwidth of isolated elements. Based on this, it may be expected that a ground plane destroys the wideband behavior of self-complementary arrays. For the particular case of self-complementary arrays, this problem has received very little attention. It will be analyzed numerically in this paper, together with some potential solutions.

Another structure proposed by McGrath and Baum [3] consists of folding the plates, in order to obtain TEM horns. Since the power tends to be radiated in the direction of the horns, we may expect a smaller effect of the ground plane on the active impedance of the elements. This is done at the expense of more cumbersome elements, and the reduction to a single polarization.

The objective of this paper is to analyze numerically the planar bicone and TEM horn arrays in the presence of a ground plane. This is done with the help of a MoM code allowing three-dimensional elements, and involving the periodic Green's function. In Section 2, simulation results are shown for the periodic planar bicone array, with and without a ground plane. The effect of moving the ground plane is shown in Section 3. Section 4 deals with the effect of a ground plane on the TEM horn arrays, and conclusions are drawn in Section 5.

2 Self-complementary array and effect of the ground plane

The square antennas are fed at the corners, where they connect with the neighboring elements. In order to include efficiently the effects of the very strong couplings between the antennas, the array is supposed to be infinitely periodic (the effects of array truncation are omitted). We developed a MoM code to analyze this structure, using the Galerkin testing procedure. The basis functions consist of rootop vector functions defined on rectangular and triangular domains (RWG basis functions [4]). The feeds are implemented as delta-gaps sources. To be effective, this source representation required the use of a few more basis functions in the source region, which slightly degrades the self-complementarity of the structure. The free-space periodic Green's function in the on-plane case has been computed using a method described in [5], while the out-of-plane Green's function, has been computed using the formulation presented in [6].

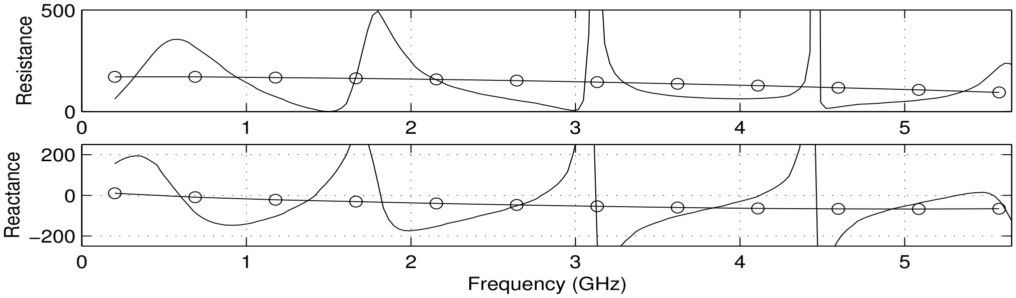

Figure 1: Impedance of a planar-bicone self-complementary array, without ground plane and with ground plane at d=10cm.

Figure 1 shows the active input impedance without a ground plane (bullets). As expected, it is essentially flat over a very wide frequency band. The active input impedance in the presence of a ground plane located at d=10 cm from the array is represented by solid lines. The ground plane dramatically modifies the behavior of the impedance over the frequency band. It can be verified that, each time the distance between the array and the ground plane is a multiple of $\lambda/2$, the resistance drops to zero (destructive interference between the array and its image). This dramatic change raises the question of the usefulness of starting from a self-complementary configuration. However, a few simulations were performed with elements having non-complementary shapes and led to even worse changes. This suggests that the planar bicone array still is a good configuration to start with.

Figures 2 and 3, respectively, show the element patterns without and with a ground plane at d=2.5 cm. These patterns were computed as $(1 - |\Gamma_a|^2) \cos\theta$, where Γ_a is the active reflection coefficient. As we can see, the ground plane narrows the 3 dB beamwidth. It is about 120 degrees without the ground plane, and about 70 degrees with it.

3 Moving the ground plane

The presence of the ground plane reduces the fractional bandwidth to about 10%. But, as the ground plane is moved, the nulls in the reactance move (cf. Fig. 1), and the operational frequency band is shifted along the frequency axis. Figure 4 shows the standing wave ratio simulated for several ground plane positions between 1.5 cm and 5 cm from the array plane.

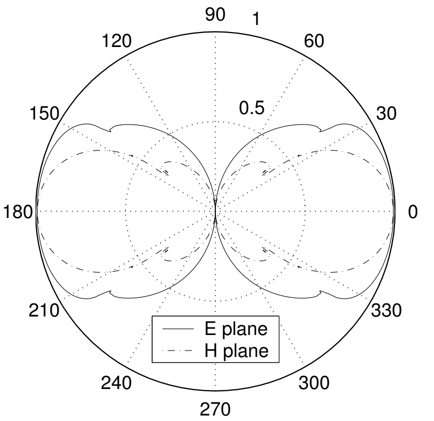

Figure 2: Radiation pattern without ground plane, f=3.75GHz.

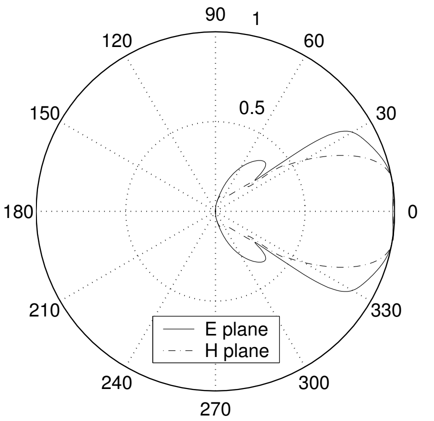

Figure 3: Radiation pattern with ground plane, f=3.75 GHz, d=2.5 cm.

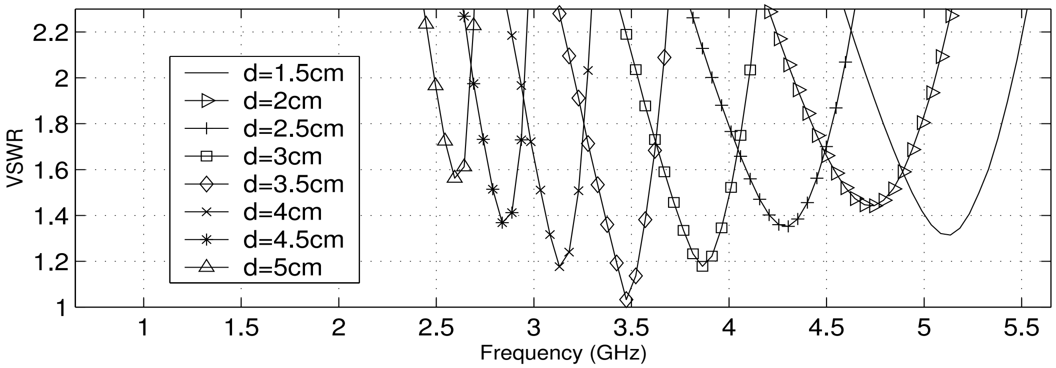

Figure 4: Simulated VSWR w.r.t. 50 Ω for planar bicone arrays for several ground plane distances.

The total frequency band over which the array can be operated now extends from approximately 2.5 GHz to 5.5 GHz. We should stress that, given that this does not correspond to an instantaneous bandwidth, this system cannot be used for transmitting or receiving very short pulses. However, such a configuration may be useful for some communication or astronomic systems, which should be able to shift their relatively narrow bandwidth within very broad limits.

4 TEM horn arrays

TEM horn arrays (Fig. 5) naturally radiate less power towards the back. Furthermore, McGrath and Baum [3] showed that a smaller horn's interior angle implies greater directivity and less back-radiation. In that case, we would expect the ground plane to have a smaller impact on the bandwidth. This is confirmed by the 3D MoM simulation results shown in Figure 6. We can see the VSWR obtained for TEM horn arrays with an interior angle of 60° and 120° and several ground plane distances. The position of the ground plane does not influence the position of the achievable bandwidth anymore. However, we notice the significantly wider achievable instantaneous frequency band. For an interior angle of 120° and a ground plane 1cm behind the array, the latter now extends from about 2.75GHz to 5.5 GHz. For an interior angle of 60°, the opened frequency band lies between 1.65GHz and 3.75 GHz. This structure, however, occupies a large volume.

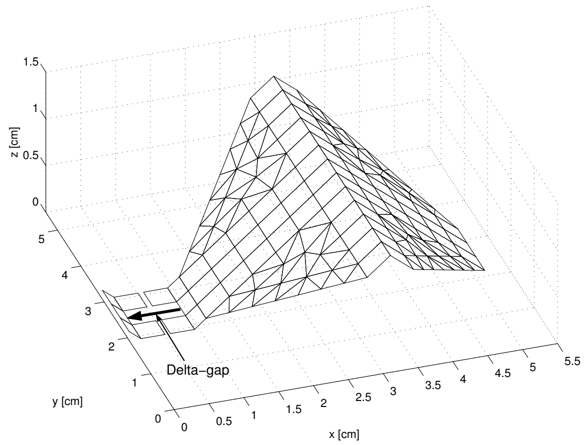

Figure 5: Mesh of the 5cm wide unit cell used in TEM horn arrays simulations

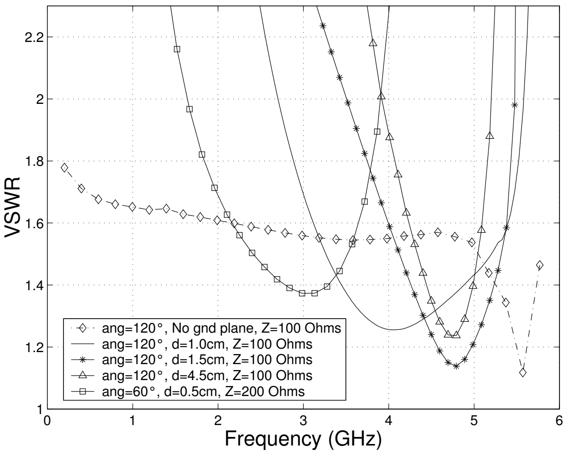

Figure 6: VSWR for TEM horn arrays with interior angle of 60° and 120°, for several ground plane distances.

5 Conclusion

Planar self-complementary arrays exhibit a very broadband characteristic but are not very useful because they radiate on both sides of the array plane. Introducing a ground plane solves this problem, but it dramatically reduces the array bandwidth and also introduces a smaller distorsion on the element pattern. With the help of MoM periodic-array simulations (which allow 3D elements), we verified that, when the whole bandwidth does not need to be covered instantaneously, a large fraction of the operational band can be recovered by moving the ground plane. Our simulation results provided a total band of one octave, while the instantaneous bandwith is of the order of 10%. The second approach consists of folding the plates, to obtain TEM horn arrays. In that case, simulations showed that we can recover a total instantaneous fractionnal bandwidth of about 65% to 75%, depending on the interior angle of the horns. The obtained frequency band cannot be shifted significantly by moving the ground plane.

References

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