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Performances of Magneto-Electric Dipoles in an Antennas Array with a Reduced Beam Forming Network

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Abstract — In this paper, we propose an architecture of array based on parasitic element antennas with multiple excitations. The objective is to improve the directivity of these antenna arrays using Magneto-Electric Dipoles (MED). In this contribution, we consider a 49 (7 X 7) element array with only 8% of the elements directly fed. The others are fed by couplings and they are loaded on reactive values (ideally). The proposed radiating element is compared to a stacked patch design in the same reduced feed network configuration. A maximum directivity of 20 dBi is obtained, allowing several reconfigurable antenna scenarios based on such as design.

Keywords — antenna array, parasitic element antenna, reconfigurable antenna, magneto-electric dipole.

I. INTRODUCTION

Electronic beam steering or beam forming capabilities are very attractive for many applications such as satellite communications, wireless networks and automotive radars. In this context, phased-arrays antennas [1] are considered as good candidates due to their attractive features in terms of performances, several degrees of freedom and complex beamforming possibilities. Nevertheless, in some cases they suffer from very complex and expensive feed network. Because of their cost, they are often limited to spatial missions or military applications. To overcome these limitations, a hybrid antenna array is proposed in [2] derived from the original one from Harrington [3] and is depicted in Fig. 1. This solution is considered as a crossover between lacunar arrays and parasitic element antennas. A reduced number of elements are fed directly with RF chains, in order to spread the couplings on the lattice surface. These couplings are used to feed radiating elements (parasitic ones) not connected to the feed distribution network. Each of them is connected to a reflection-type phase shifter (RTPS) in order to manage their contribution to the radiated electromagnetic field. They are considered as degrees of freedom to optimize the overall performance of the system. The obtained directivity is only decreased by 1.2 dB whereas only 15% of the elements are directly excited in the lattice, in the ideal case of no insertion losses for RTPS.

From the classical antenna array theory [4], the amount of directivity is generally related to several factors such as the directivity of the radiating elements, the number of elements

and the level of coupled energy into adjacent parasitic elements when dealing with parasitic arrays. However, when a classical wideband stacked patch antenna is used as radiating element, the coupled energy in the **E** Plane and **H** Plane are not equal. Hence, the need to use radiating elements which can achieve homogenous coupling between **E** and **H** plane is an important improvement to enhance overall performances.

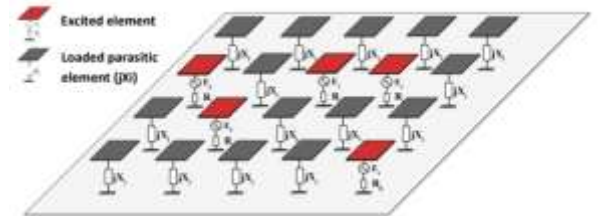


Fig. 1. Principle of hybrid array

A detailed state of art shows that “Magneto Electric” dipole antennas proposed in [5] are promising solutions with excellent radiation characteristics and wide impedance matching. These antennas are based on the concept of the Huygens source [5] with very interesting characteristics such as identical radiation pattern and very low back lobe radiation, both in the **E** and **H** planes.

In this paper, we present a reduced BFN parasitic array using magneto-electric elements to improve the antenna directivity. The paper is organized as follows. The magneto-electric dipole is presented in Section II. Here, its principal operation and performances are presented. The magneto-electric dipole is then used to form 7 X 7 reduced BFN array to achieve a reconfigurable radiation beam. The structure of the array and its operation principle is presented in Section III. The array has been simulated and directional radiation beams were synthesized. The obtained results are presented in Section IV. Concluding remarks are presented in Section V.

II. MAGNETO-ELECTRIC DIPOLE

A. Antenna element description

The Magneto-Electric dipole (MED) antenna used in this paper was developed in [5] and presented in Fig. 2. The

Antenna consists on combining an electric dipole antenna with a magnetic dipole antenna. The electric dipole is made from two planar rectangular metal sheets; while the magnetic dipole is made from a wideband short-circuited patch. The short-circuited patch is placed vertically and is connected to the planar electric dipole. To excite the antenna, an Γ -shaped probe feed is employed. This feed consists of three portions, which is made by folding a straight metallic strip of rectangular cross-section into a Γ -shape. The antenna dimensions are presented in Table 1.

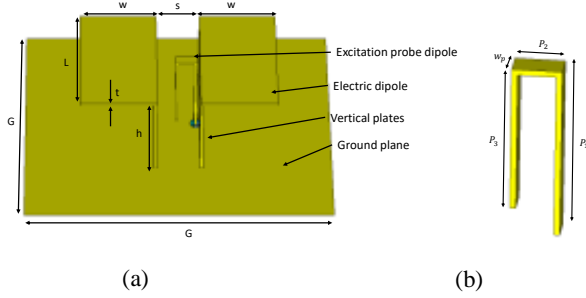


Fig. 2. (a) Magneto-electric antenna (b) Excitation probe.

Table 1. Antenna Dimensions.

| Parameters | G | L | W | H | S |
|-----------------|-----|-------|-------|-------|-------|
| Dimensions (mm) | 120 | 60 | 30 | 31 | 17 |
| Parameters | t | P_1 | P_2 | P_3 | W_p |
| Dimensions (mm) | 1 | 30 | 8.5 | 26.5 | 2.91 |

B. Operation Principle

In this section, the operating principle of the magneto-electric dipole is discussed. This basic design of the magneto-electric dipole is composed of a vertically oriented quarter-wave shorted patch antenna and a planar electric dipole, which is equivalent to a combination of a magnetic dipole and an electric dipole to form a radiating element.

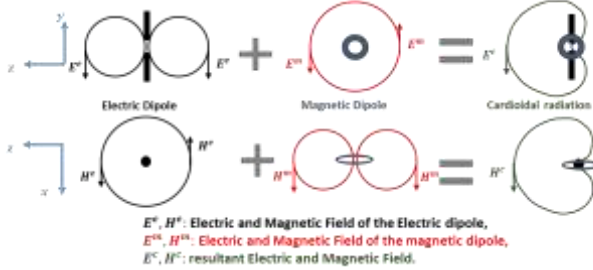


Fig. 3. (a) Radiation pattern of the combination of an electric dipole and a magnetic dipole.

The radiation pattern due to the combination of an electric dipole and a magnetic dipole is shown in Fig. 3. Two radiating sources are placed perpendicularly to each other to radiate in a complementary manner. Black and red lines describe the field patterns of the electric and the magnetic dipoles, respectively. The electric dipole radiates uniformly in the \mathbf{H} plane, whereas the magnetic dipole radiates bi-directionally in the \mathbf{H} plane. In the \mathbf{E} plane, the electric dipole radiates bidirectionally, whereas the magnetic dipole radiates uniformly in the \mathbf{E} plane. When the electric and magnetic dipoles are excited simultaneously with

proper amplitudes and phases, a circularly symmetric cardioid-shaped radiation pattern with very low back lobe radiation, both in the \mathbf{E} and \mathbf{H} planes, can be achieved. The Huygens source's concept of a magneto electric type antenna was demonstrated in [6] using spherical wave expansion analysis; the antenna presents the same behavior as a generalized Huygens source with identical contribution of transverse electric (TE) and transverse magnetic (TM) modes over a wide bandwidth.

C. Operation Principle

The simulated VSWR and realized gain at $(\theta=0^\circ, \phi=0^\circ)$ of the Magneto-electric dipole antenna is depicted in Fig. 4. The antenna operates from 1.79 to 2.57 GHz with a bandwidth of 36% ($\text{VSWR} < 2$). The broadside gain at $(\theta=0^\circ)$ is 7.65 ± 0.15 dBi over the operation band. These results show a stable radiation pattern over the operation bandwidth.

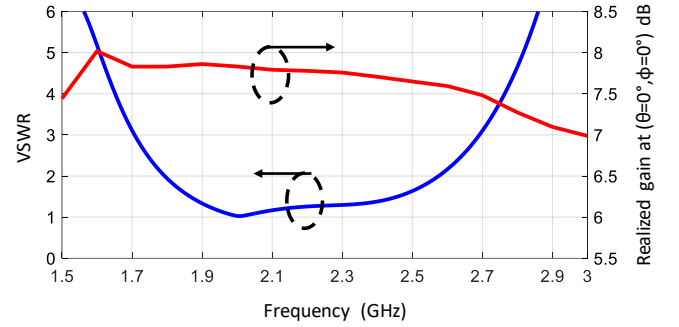


Fig. 4. VSWR and Realized gain at $(\theta=0^\circ, \phi=0^\circ)$ versus frequency.

III. RADIATION PANEL

This section describes the design and analysis of the radiating panel of 49 (7-by-7) radiating elements. The design of the proposed antenna is shown in Fig. 5. The radiation panel is composed of 49 Magneto-electric dipoles with a half wavelength (at 1.9 GHz) spacing to maintain a high level of mutual couplings.

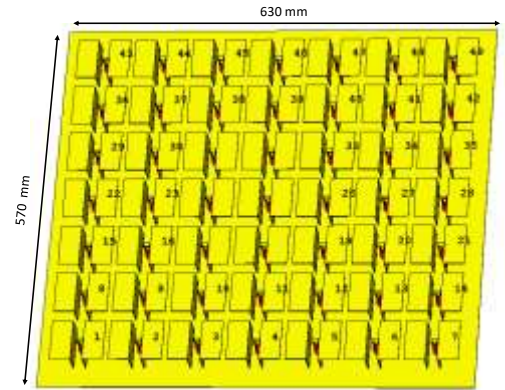


Fig. 5. Geometry of Magneto-Electric dipoles array with 7 X 7 Elements.

A. Characteristics of the 7 X 7 Array Elements

Before using the lattice as a reduced BFN array, the main characteristics of the panel are studied. The simulated S

parameters when central (red curve) and edge (blue curve) elements are excited are shown in Fig. 6. The proposed antenna offers a 36% bandwidth from 1.8 to 2.59 GHz. The mutual couplings between the cells are shown in Fig. 7. The couplings between two adjacent cells are above -16 dB on a wide bandwidth in both **E** plane and **H** plane. For example, at 1.9 GHz the coupling is -12 dB and -15 dB in both **E** plane and **H** plane, respectively.

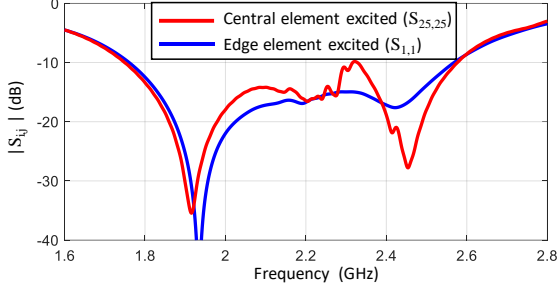
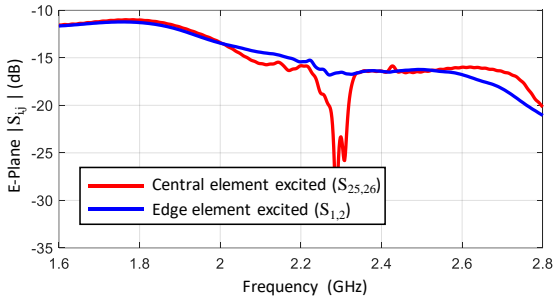
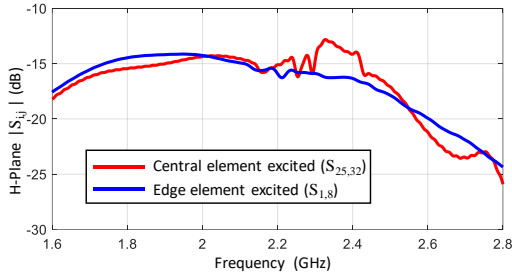


Fig. 6. Simulated reflection coefficient of the proposed design.



(a)



(b)

Fig. 7. Mutual coupling between two adjacent cells in the (a) E Plane and (b) H plane.

IV. REDUCED BFN ARRAY PERFORMANCES

The proposed antenna has a behaviour strongly defined by mutual couplings. A synthesis process based on [7] is used to define the phase shifts required for each RTPS, provided a set of objectives in terms of gain and directions, and constraints on the active VSWR. The number and locations of excited elements is defined by the user. We have synthesized the array configuration based on the 7 X 7 Magneto-Electric dipole lattice. The radiation objective has been set to tilt in the direction $\{\theta_0=30^\circ, \phi_0=30^\circ\}$. In this configuration, a constraint

on the antenna active matching has been set below -10 dB from 1.8 to 2.2 GHz. The hybrid array configuration is shown in Fig. 8. It is composed of 4 excited elements among 49, other ones are considered as parasitic with RTPS. Red squares correspond to excited elements and grey squares to those excited by mutual couplings.

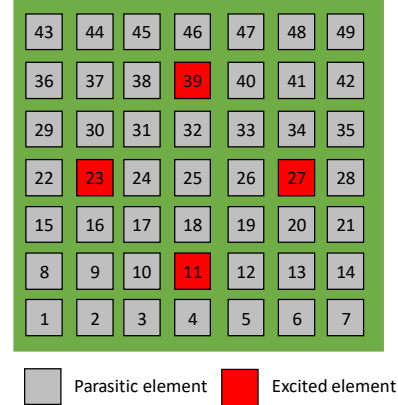


Fig. 8. Hybrid antenna array 7 X 7 with only 4 elements excited.

A. Synthesis results

The resulting radiation pattern and reflection coefficients for all the RF excited ports are given on Fig. 9 and Fig. 10, respectively. The obtained directivity is 18.3 dBi and all the excited ports are matched over the desired frequency bandwidth. According to Fig. 11, couplings are well spread and we note that almost all ports contribute to the radiation.

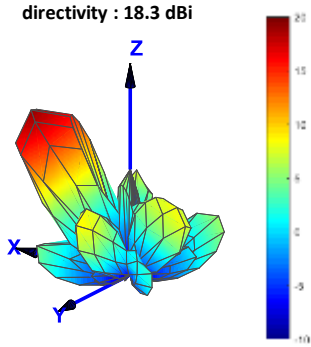


Fig. 9. Radiation pattern for an objective beam steering in the direction $\{\theta_0=30^\circ, \phi_0=30^\circ\}$.

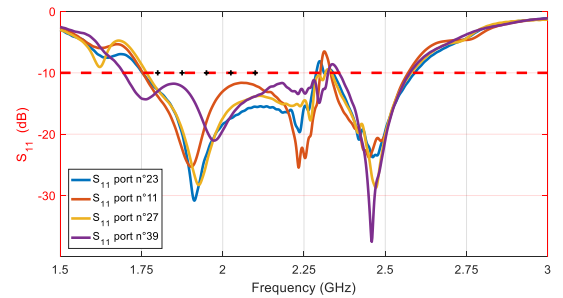


Fig. 10. Active reflection coefficient for excited ports 11, 23, 27 and 39.

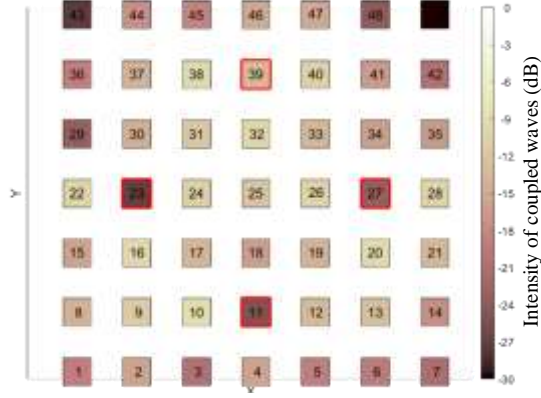


Fig. 11. Cartography of the intensity of coupled waves.

A. Synthesis results for different beam steering and comparison to a patch unit cell

The synthesized directivity for different radiation pattern direction objectives: $\{0^\circ < \theta_0 < 60^\circ \text{ with } \Delta\theta = 10^\circ\}$ and $\{0^\circ < \phi_0 < 90^\circ \text{ with } \Delta\phi = 10^\circ\}$ of the reduced BFN array with MED and classical patch antenna [4] are presented in Fig. 12a and Fig. 12b respectively. For a fair comparison, the optimization was made on a bandwidth of 15% for both arrays (because a clear advantage of MED is the frequency band behaviour). The directivity using magneto-electric dipole is typically 2 dBi higher than the classical stacked patch antenna. This is explained by the presence of higher coupling in both **E** and **H** planes and higher gain of the unit cell compared to the patch array antenna. The maximum attainable directivity is in the broadside direction ($\theta=0^\circ$) and is equal to 20 dBi.

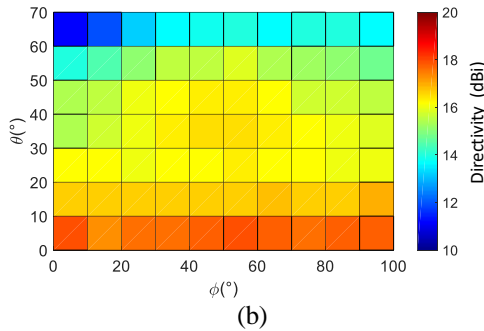
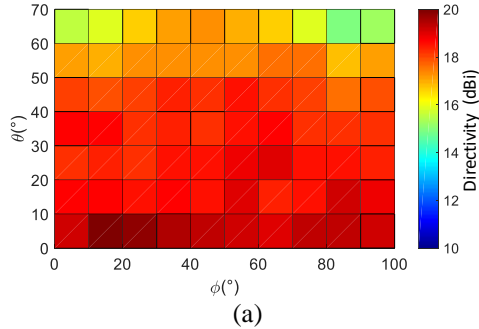


Fig. 12. Directivity as function of the beam steering direction for the reduced BFN antenna: (a) MED antenna, (b) patch antenna.

V. CONCLUSION

In this paper, an interesting concept of array with parasitic element antennas and multi-excitation has been proposed and its performances have been estimated. The proposed antenna array is composed of 49 Magneto-electrical dipoles. Due to their Huygens' source principle, magneto-electric antennas have almost equal and stable **E** and **H** plane radiation over wideband operation frequency compared to classical patch antennas. The maximum obtained directivity is 20.6 dBi compared to 17.5 dBi in the same reduced BFN array with microstrip patches. Future works to realize a demonstrator are currently being led.

ACKNOWLEDGMENT

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