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An Array of Tilted Dipoles Loaded with Artificial Dielectrics with an Asymmetric Pattern

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***Abstract*—We present the design of an array of tilted dipoles loaded with artificial dielectrics, to achieve asymmetric radiation patterns. First, a simplified array element consisting of skewed stacked dipoles in the presence of a backing reflector is studied, by means of a dedicated spectral periodic method of moments (MoM). The analysis of the stacked dipoles provides guidelines to design arrays with certain radiation characteristics, by varying the tilt angle and the inter-element spacing. Based on the findings of numerical analysis, we then propose a tilted dipole element design with artificial dielectric loading to implement the pattern asymmetry. The design includes the feeding structure and the balun transition to a 50-Ohm coaxial line.**

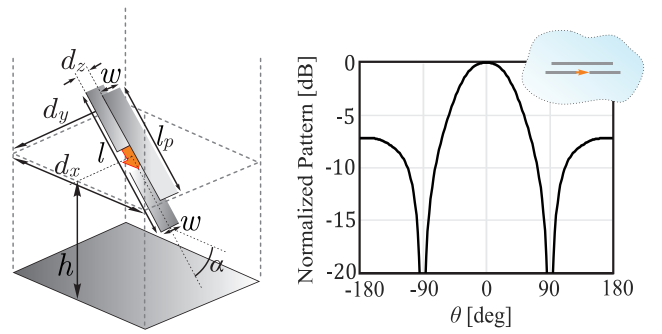
***Index Terms*—Antenna array, low-profile, method of moments, pattern shaping.**

I. Introduction

Low profile array antennas with very large (close to hemi-spherical) field of view are of great interest for applications such as aircraft-to-satellite communications. To reduce the scan loss typical of planar antennas arrays, conformal arrays [1] or multi-panel configurations [2] have been proposed. However, these solutions are bulky and increase the volume occupation of the antenna system. To obtain a wide field of view while maintaining a low antenna profile, hybrid scanning mechanisms have been implemented. These solutions consist of arrays that scan from broadside to a positive, as high as possible, angle, and achieve full coverage by mechanical rotation along the azimuth [3], [4].

An array of stacked patches was presented in [3] to support digital video broadcast, scanning electronically in elevation from 20° to 70°, and mechanically in azimuth through rotation. Nevertheless, as the element spacing is higher than half wavelength, grating lobes appear in the visible region, resulting in $-5.8\,\mathrm{dB}$ side lobe level. In [4], an effort to reduce the amount of power radiated to undesired directions was made. However, the improvement in terms of pattern selectivity is achieved at the expenses of a more complex feeding architecture.

Although skewed antenna elements have been used in [3], [4], the properties of these type of antenna arrays in terms of radiation characteristics have not been studied in detail. In [5], we presented a spectral method of moments for arrays of dipoles and stacked dipoles in free space and in the presence of a backing reflector. Here, we report the main results of



(a) (b)

Fig. 1. (a) Stacked dipole unit cell with its parametric dimensions and (b) normalized pattern of the isolated non-tilted stacked dipole radiating in free space.

the MoM for a simplified stacked dipole element, to provide some design guidelines on how to shape the radiation pattern varying the inter-element distance and the inclination angle of the elements.

Based on the findings of the numerical analysis, a realistic unit cell design is then proposed, consisting of a tilted dipole loaded with artificial dielectric layers (ADLs) to enhance the front-to-back ratio. The feeding structure is also designed to implement the transition from the differential input at the dipole terminals to the single ended coaxial line feeding the array element. The simulated results in term of impedance and radiation patterns are presented for a one-dimensional infinite array. The resulting active element pattern exhibits strong asymmetry characteristics, effectively implementing an angular filter.

II. Theoretical Guidelines for Skewed Stacked dipoles with Backing Reflector

For the theoretical analysis we consider the unit cell in Fig. 1(a) consisting of a stacked dipole in the presence of a backing reflector. The passive metal strip enhances the radiated power in one direction, increasing the front-to-back ratio of the element. As we highlighted in [5], in order to achieve certain pattern asymmetry with such an element, three conditions must occur: the array element must have a high front-to-back ratio, the array spacing has to be higher than half wavelength and

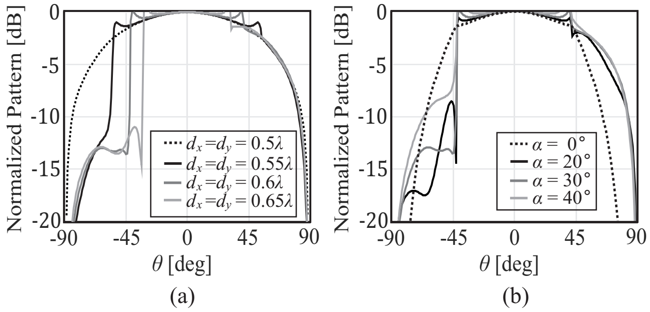


Fig. 2. Normalized active element pattern for an infinite array of stacked dipoles (a) with a tilted 30° varying the spacing between elements d_x and d_y and (b) with a periodicity of $d_x = d_y = 0.6\lambda_0$ varying the inclination angle of the elements α.

the elements must be tilted by an angle $\alpha \neq 0$. The high front-to-back ratio is needed because, if the element radiates the same power above and below, the power reflected by the backing reflector will be the same as the power radiated above by the dipole but in the specular direction, resulting in a symmetric pattern. Moreover, even if the element is tilted, but the periodicity is equal or smaller than half wavelength, the symmetry properties known from Floquet theory [6] will apply, resulting in a completely symmetric radiation.

The dimensions of the element are chosen as $l = 0.5\lambda_0$, $l_p = 0.4\lambda_0$, $d_z = 0.07\lambda_0$, the width $w = 0.12\lambda_0$, the length of the feeding port $\delta = 0.1\lambda_0$, where λ_0 is the wavelength at 10 GHz. The parameters are set to provide high front-to-back ratio, as shown in Fig. 1(b), which reports the radiation pattern of the isolated stacked dipole radiating in free space.

The active element pattern for an infinite array of stacked dipoles with the chosen geometrical parameters is shown in Fig. 2(a), varying the inter-element distance between element and setting the tilt angle as $\alpha = 30°$. It can be appreciated that the gain drop is strongly dependent from the inter-element spacing and corresponds to the angle at which grating lobes appear in the visible region:

$$\theta_{GL} = \sin^{-1}\left(\frac{\lambda}{d_x} - 1\right). \quad (1)$$

Figure 2(b) shows a similar plot where the inclination angle of the elements is varied and the period of the array is fixed to $d_x = d_y = 0.6\lambda_0$. It can be noted that the variation of the inclination angle shapes the gain levels on the suppressed angular region. Therefore, combining the periodicity and the tilt angle, stacked dipoles arrays can effectively realize angular filtering.

III. Design of a Linear Infinite Array

Based on the theoretical analysis of the previous section a design of a linear array is being carried out. The element chosen consists of a dipoles loaded with three layers of artificial dielectric printed on a vertical circuit board (PCB), as shown in Fig. 3. The dimensions of the element are $l_a = 0.44\lambda_0$, $w = 0.05\lambda_0$, $\delta = 0.01\lambda_0$, $l_{ADL} = 0.22\lambda_0$, $w_{ADL} = 0.033\lambda_0$ and $t_{1,ADL} = t_{2,ADL} = 0.01\lambda_0$, where λ_0 is the wavelength at 10 GHz. The dielectric used is Rogers RO4530 TM with $\varepsilon_r = 3.66$ and thickness 101μm.

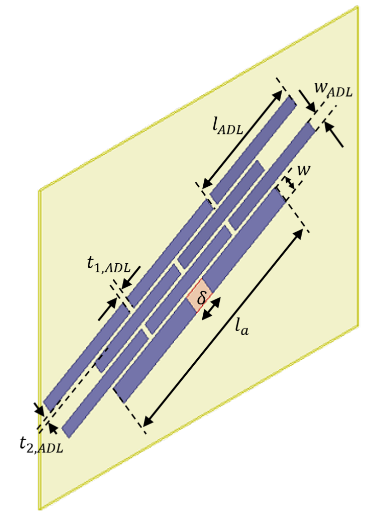


Fig. 3. Array element consisting of a dipole printed on a vertical PCB loaded with layers of artificial dielectric.

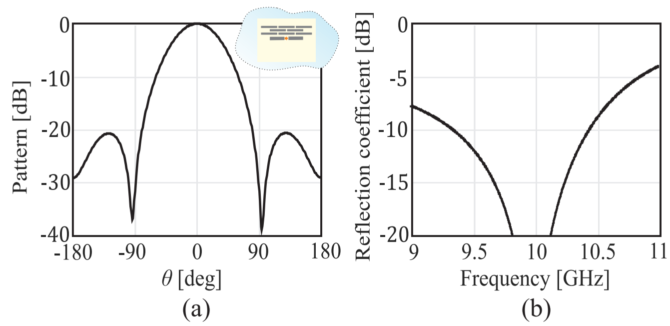


Fig. 4. (a) E-plane isolated element pattern and (b) the reflection coefficient of the structure depicted in Fig. 3

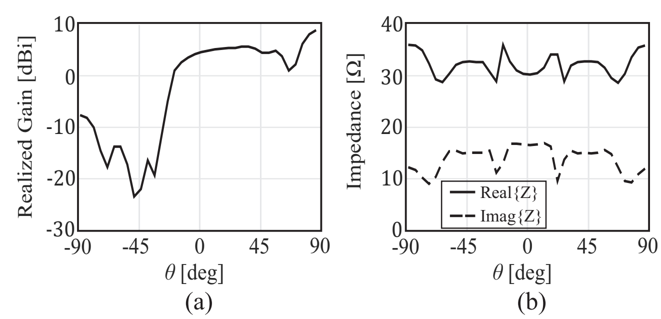


Fig. 5. (a) E-plane active element pattern and (b) the imput impedance of the structure depicted in Fig. 3

The choice of the element was made to yield high front-to-back ratio: Figure 4(a) shows the pattern of the isolated element in free space element, achieving a front-to-back ratio of about 20 dB. Figure 4(b) depicts the reflection coefficient of the isolated element, normalized to an impedance of 30 Ω.

We investigate the simulated performance of a linear infinite

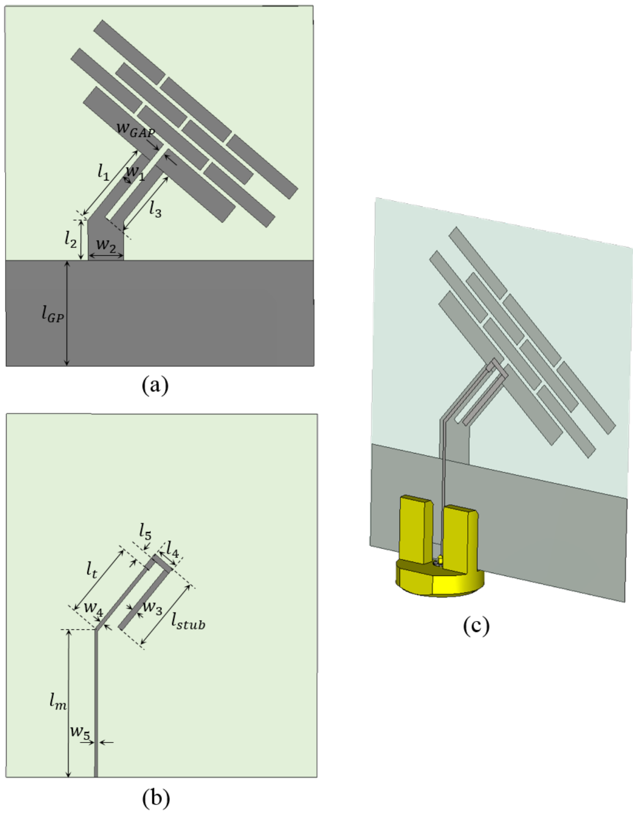


Fig. 6. (a) Front, (b) back and (c) 3D view with an SMA connector of the unit cell design consisting of the dipole loaded with layer of artificial dielectric, a feeding line with quarter wavelength transformer and a vertical ground plane.

TABLE I
GEOMETRICAL PARAMETERS OF THE DESIGNED FEEDING LINE (IN mm)

l_1	l_2	l_3	l_{GP}	l_{stub}	l_4	l_5
6.2	2.82	5.18	7.5	5.65	1.54	0.75

l_t	l_m	w_1	w_2	w_{GAP}	w_3	w_4	w_5
5.7	10.38	0.8	2.61	0.45	0.4	0.25	0.2

array with the proposed element, including an infinite backing reflector at a distance of $0.25\lambda_0$, and with spacing $d_x = 0.75\lambda_0$ and a tilt of the elements of $40°$. Figure 5(a) shows the E-plane active element pattern where a clear drop in gain is obtained from $\theta = -90°$ to $\theta = -20°$, as expected from Eq. 1. Figure 5(b) shows the real and imaginary part of the active input impedance of the array while varying the scanning angle θ, with the impedance at broadside being $30+16j\ \Omega$. A feeding line with a microstrip and a Marchand balun to avoid the propagation of the common mode is included (see Fig. 6). The dimensions of the feeding line are given in Table I. A quarter wavelength transformer with length l_t is included to match the impedance of the dipole with the 50 Ω of the coaxial connector.

An infinite linear array with the structure shown in Fig. 6(c), including also a SMA connector, is considered. Figure 7(a) shows the simulated radiation pattern and Fig. 7(b) depicts the input impedance of the entire structure with the feed network

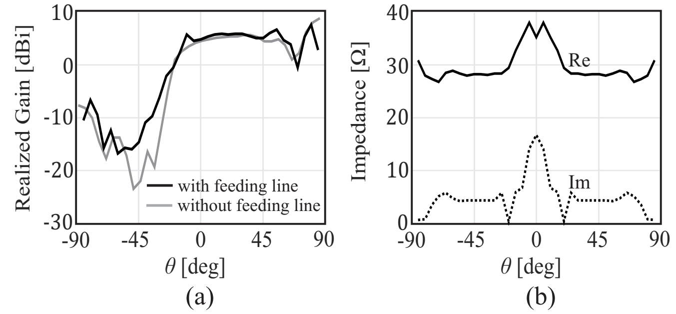


Fig. 7. (a) E-plane active element pattern and (b) input impedance of a linear infinite array of dipoles loaded with layers of artificial dielectric and the feeding line including the connector.

compared with the one with an ideal feed (Fig. 3). It can be noticed that the radiation patterns are very similar after including the feeding line.

IV. CONCLUSIONS

In this work we presented an array design to achieve asymmetric radiation pattern, characterized by low gain in a given angular region and high gain in a desired scan range. We started with the analysis of a simplified array element consisting of a stacked dipole in the presence of the backing reflector and tilted with respect to the array plane. The analysis of this element, based on a spectral periodic method of moments provided guidelines on how to choose the tilt angle and the element spacings to achieve a desired pattern. Such design rules were used to design of an infinite linear array of dipoles loaded with three layer of artificial dielectric to improve the front-to-back ratio. The tilt of the element and the inter-element distance were chosen to be $40°$ and $d_x = 0.75\lambda_0$, respectively. The simulations showed a gain reduction in the angular region between $-90° < \theta < -20°$. At the time of the conference, a finite linear array design and experimental validation will be presented.

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