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EBG SUPERSTRATES FOR DUAL POLARIZED SPARSE ARRAYS

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Abstract — A superstrate of an EBG material (or equivalently a Fabry-Perot cavity) is used to design array antennas with large distance between the radiating elements. This configuration provides some advantages: i) a reduction of the number of array elements to achieve high directivity; ii) large space between contiguous elements decreases their coupling and permits an easy arrangement for complicated feeding network (as needed for dual polarization), also on the same plane of the radiating elements. These possibilities are clearly shown in a few examples treated here and in the design of dual polarized antennas with two interleaved arrays. Furthermore, we indicate that in these designs there are optimum distances between elements that either maximize the directivity or minimize the side lobe level. It is also shown that due to the fact that the radiating elements have larger-than-usual mutual distances it is easy to achieve -40dB of isolation between the two excitation ports, for the two polarizations.

INTRODUCTION

Recently some arrangement was proposed for antennas radiating under an electromagnetic band-gap (EBG) superstrate [1]-[4]. This configuration allows to enhance the radiating element directivity. The effect can be explained resorting to a spectral wavenumber filtering effect of the superstrate for the rays outcoming from the source at aspects out of the boresight. Such selective behavior is strictly connected to the frequency filtering effect of the EBG material, which is designed to be slightly out of the forbidden band at operating frequency. A sharp frequency transition between stop and pass frequency bands implies a very small transmitted bundle of rays around the boresight, i.e. a small lobe in the radiation pattern. A more complete interpretation of the increase directivity involves leaky waves that

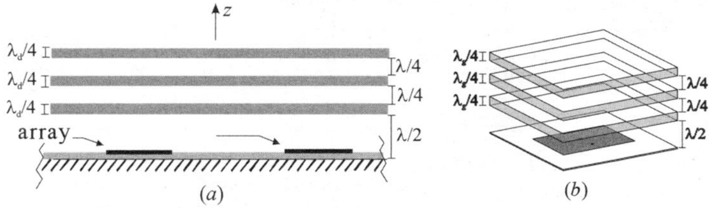

Fig. 1. (*a*) Lateral view of a sparse array in a Fabry-Perot cavity (also called EBG material slab) made of dielectric layers. (b) 3D geometry with a single antenna.

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are launched by the sources and that produce directive patterns [5][6]. The leaky waves are trapped between the ground plane and the above partially reflective surface. Although in line of principle the source directivity could be unlimitedly enhanced, a strong directivity results in a very small antenna bandwidth and a very critical design. This trade-off between directivity enhancement and bandwidth suggests to use EBG superstrate arranging sparse arrays of moderately enhanced directivity elements. Such configurations allow to preserve the needed operating bandwidth and achieve the requested directivity by using arrays of sources. Since each element in the EBG environment is individually quite directive a larger spacing between elements is permitted still avoiding grating lobes. The sparsification of the array element lattice results in a simpler structure with fewer elements, a simpler feeding network and a lower coupling between elements. Furthermore, since a large space is available between elements, an interlaced array can be arranged to achieve dual polarization or dual band facilities. In this paper we investigate the abovementioned issues showing by some examples how the use of an EBG superstrate allows to decimate the radiators in a standard spaced array without degrading pattern characteristics, especially focusing on coupling effects.

INCREASE OF DIRECTIVITY FOR ARRAYS WITH EBG SUPERSTRATE

The EBG superstrate has the scope of increasing the directivity of a single antenna located underneath. The geometry is shown in Fig. 1 with the thickness of the various dielectric layers. The space right above the antennas is $\lambda/2$ to form a resonant cavity. The increase of directivity is shown in Fig.2 for a patch antenna feed by a coaxial line. The superstrate consists of n layers of dielectric material with relative permittivity $\varepsilon_r = 2.5$; each layer is a quarter of a wavelength (in that dielectric material $\lambda_d = 15.8\text{mm}$) thick and the spacing between them is a quarter of a wavelength in free-space ($\lambda = 21.4\text{mm}$) at the operating frequency $f = 14\text{GHz}$. The radiating element is a 6.2mm×10mm metallic patch, located half wavelength under the lower layer and suspended on $h = 1.52\text{mm}$ thick substrate with $\varepsilon_r = 3$. In Fig.2 the radiation patterns on the E-plane at operating frequency is shown for an increasing number of superstrate layers. The maximum remains at broadside and the lobe narrows by increasing the number of layers. Since we cannot obtain high directivity and large bandwidth at the same time with these simple geometries, we could use a limited number of layers (say two) to keep a reasonably large bandwidth, and increase the number of radiating elements to increase the directivity.

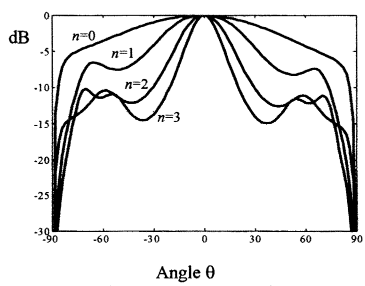

Fig. 2. Directivity enhancement of a patch antenna for different number of layers of the EBG material. Only the E-plane is shown.

Due to the fact that a single element with a superstrate with two layers (radiation pattern shown in Fig. 2) already presents an enhanced directivity of 14 dB, the array elements can be placed at distances even larger than a wavelength. This property is shown in Fig.3 where for f = 14 GHz the radiation patterns of a 4×4 sparse array (with EBG superstrate and spacings $1.5\lambda = 32.1\text{mm}$) is compared with an 8×8 array (with no EBG superstrate and halved spacings $0.75\lambda = 16.1\text{mm}$). Note that the main lobes of the two radiation patterns are identical in both the E- and H-planes. In the above results, in the EBG case we have simply doubled the interelement distance of a standard (without EBG) broadside array just to obtain the same main beam and directivity with ¼ of the elements. Indeed, that is not the optimal distance, in the sense that other distances may lead to higher gains. For example, in Fig. 4, we show the gain versus interelement distance, for three different frequencies centered around the operating frequency f = 14 GHz. At all frequencies the optimum is around $d = 1.8\lambda$; larger distances would result in a similar gain thus degrading the aperture efficiency.

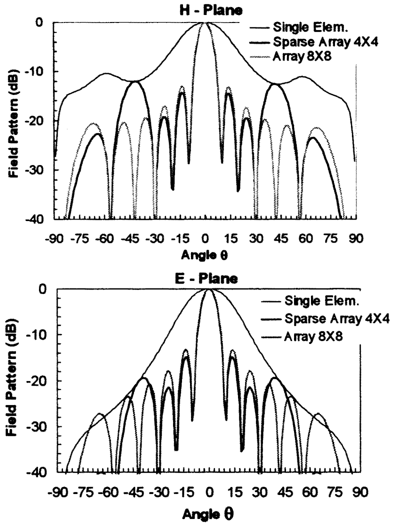

Fig.3. Sparse array of 4x4 patches under a three-layers EBG superstrate. Radiation Pattern on the H-plane and E-plane, at a frequency f = 14 GHz. The main lobe coincides with that of an array of 8x8 patches in free space.

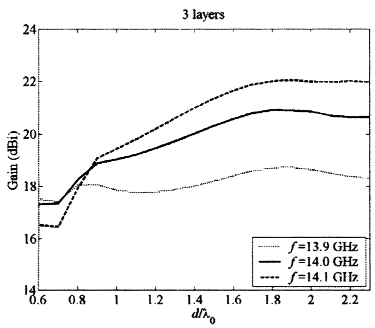

Fig.4. Gain versus element distances, for three different frequencies centered around the working frequency f = 14 GHz. Note that for the three frequencies the optimum is around $d=1.8\lambda$

DESIGN FOR A DUAL POLARIZED ANTENNA WITH EBG SUPETRATE

The layout of two interleaved 2×2 array antennas, for dual polarization applications, is shown in Fig. 5. The design includes the feeding networks on the same plane of the radiating elements. The EBG superstrate (not shown in the figure) consists of three dielectric layers as in Fig.1. The single patch length and width have been dimensioned to match the resonance frequency to $f = 14.4$ GHz. The feeding network is simply constituted by 140Ω microstrip lines that connect adjacent patches to 70Ω (larger) lines, that are, in turn, transformed to 100Ω (by λ/4 transformers) and connected to the 50Ω feeding port. This example demonstrates the possibility of using this interleaved solution to create dual polarized antennas with high isolation between the two ports as low as -40dB. For each 2x2 array, the distance between elements is 1.8λ, corresponding to the optimum radiation efficiency.

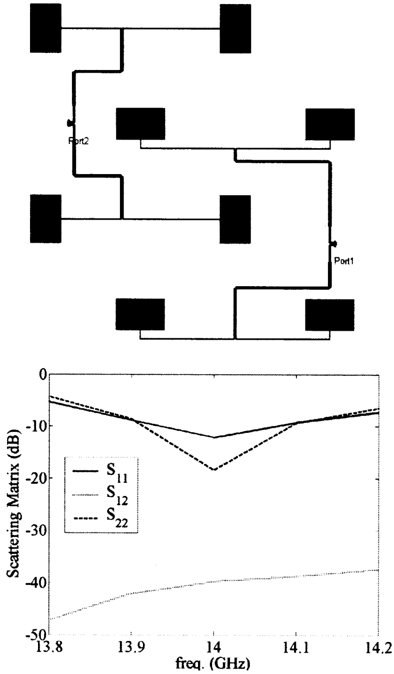

Fig.5 Layout of the two interleaved sparse array under the EBG superstrate (not shown here), and scattering parameters at the two feeding ports. Note the -40 dB isolation between ports.

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