

Application of EBG Structures at Sub-Array Level

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Abstract - Low efficiency and pattern degradation are specific problems encountered in phased-array designs based on integrated technology, as for example used in low-profile radar applications. These problems are largely due to the excitation of surface waves (SW). It was demonstrated in earlier work that Electromagnetic Band Gap (EBG) technology can decrease or even eliminate SWs. However, for the most effective application, the EBG should preferably fully enclose the individual elements that compose the array. This inherently creates a problem of spacing, in the sense that scanning becomes more limited or virtually impossible. A solution to the problem could be found in the application of the EBG at sub-array level. In this contribution we investigate the effect of this concept in terms of directivity, radiation-pattern purity and scattering parameters. Commercial software was used to study various sub-array concepts with the application of EBGs to limit SWs. Two hardware demonstrator array panels were produced and experimentally tested for validation purposes.

I. INTRODUCTION

Low-profile phased array antenna designs for radar applications based on printed technology suffer from specific problems, e.g., low efficiency, pattern degradation. These problems are mainly caused by the excitation of SWs. In earlier work [1-2] it has been shown that EBG-technology can decrease or even eliminate these problems. At TNO a planar circularly symmetric EBG solution has been developed [3-5] for the suppression of SWs. For a certain frequency band of operation, the array benefits from EBG structures thanks to:

- Reduction of mutual coupling between array elements,
- Improvement of pattern purity and efficiency.

For the EBG to be functional it will need a relative large area around its source to sufficiently block the SWs. Application of EBGs in an array at element level will limit the maximal achievable scanning angle. When however EBGs are applied at sub-array level, this maximal achievable scanning angle can be enlarged. The advantage in terms of radiation-pattern purity would still be granted as well as the isolation, provided that the isolation requirements are set at sub-array level. In this contribution we have investigate the advantage of such a concept in terms of directivity and scattering parameters.

For reasons of low-profile, good bandwidth characteristics and exclusion of spurious radiation of the feeding network from the antenna element's radiation, we

have chosen for slot coupling a dipole (see Figure 1). The antenna configuration, as used in [3-5], is such that a 10dB front-to-back ratio is guaranteed (see also Figure 3), the used substrate material permittivity is 9.8.

Due to the nature of the used radiating element and feeding structure the predominant contribution of the first order surface wave (TM_0) is in the direction of the dipole (Figure 2). Therefore we have chosen for selective placement of the EBG structures in exactly that direction. Because of this a more compact array grid is allowed in the other direction. In addition we have also used straight EBG structures instead of circular segments partially surrounding the outer elements of the sub-array, as used in [4-5]. The so-called PCS-EBG would be optimal as explained in [4], but the advantage of straight EBG stro-

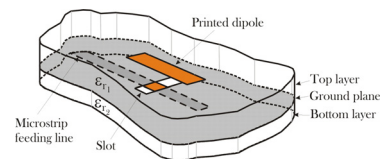


Figure 1: Perspective view of the radiating element used in this work. The construction is a ground plane in between two dielectric layers. The printed dipole on the top layer is fed through a slot in the ground plane with a microstrip line etched on the bottom substrate.

kes is that two adjacent sub-arrays can be isolated from each other using the same straight EBG structure. This would not have been possible in case of a curved EBG. In that case the sub-arrays will be placed too far apart in the overall array and therefore induce grating lobes.

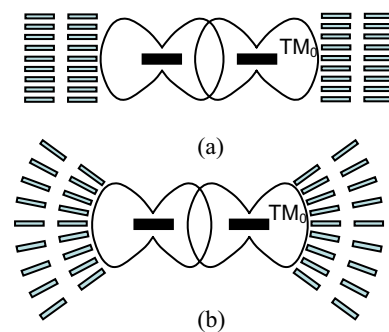


Figure 2: Sub-array of two dipoles (black) flanked on both sides by a straight EBG structures (a), and the same sub-array flanked on both sides by a circular segment EBG structure (b). The 4 cones in (a) and (b) show the angular dependence of the TM_0 -SW power, maximum power is in the collinear direction.

Obviously, the EBG structures required to increase the array's efficiency replace active radiating elements of the full array. These structures enable the re-radiation of the SW-power that would otherwise be confined to the substrate. Figure 3 shows the distribution of power in case of a grounded slab ($\epsilon_r=9.8$) as a function of its electric thickness. When the radiated power is maximal the power launched into the first order SW is relatively high. To avoid a heavily excited SW (P_{TM_0}) the used slab needs to be quite thin, at the cost of bandwidth. When we are able to eliminate the SW using an EBG, the slab thickness can be increased to the level of maximum radiated power (P_{rad}). At a slab thickness of $\lambda_g/4$ the structure will render much more efficient. It is important to investigate to what extent the EBGs will use this SW-power to increase the directivity and array bandwidth. Comparison of an EBG enhanced array with a full array should provide this information.

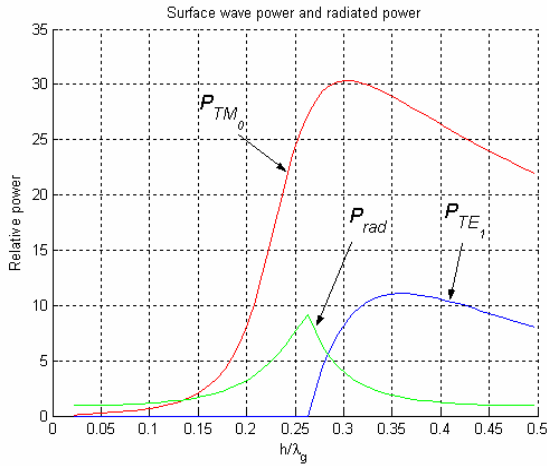


Figure 3: Plots of the power confined to the dielectric slab and the power radiated into free space. The structure is excited via an elementary magnetic dipole which is positioned on the ground plane supporting a dielectric slab of $\epsilon_r=9.8$. The power is plotted as a function of the height in terms of the wavelength in the dielectric (λ_g) and is relative to the power radiated by an elementary magnetic dipole into a free space hemisphere [4].

For the test arrays used in this research activity we had however for budgetary and time related constraints to resort to readily available materials. For this reason we have chosen to use standard RO4003 ($\epsilon_r=3.4$) material to base our designs on. The power curves with respect to this material with lower dielectric constant are given in Figure 4. Clearly the ratio between the power confined to the dielectric slab and the power radiated into free space is less pronounced in comparison to the case of Figure 3.

To focus entirely on the behaviour of the array, we fixed the geometry of the radiating element, i.e., a microstrip line excited, slot-coupled dipole (Figure 1). This element was optimised for impedance bandwidth at X-band before introducing the EBG structures. The length and the width of the dipole are respectively given as 8 mm and 0.5 mm.

II. EBG AT SUB-ARRAY LEVEL

To enable larger scanning angles but also larger bandwidth of the array we chose to apply the EBGs at sub-array level rather than at element level for the reasons stated in Section I. To show the added value, in particular in terms of directivity, of enhancing an array with the proposed EBG structures, two array configurations needed to be designed.

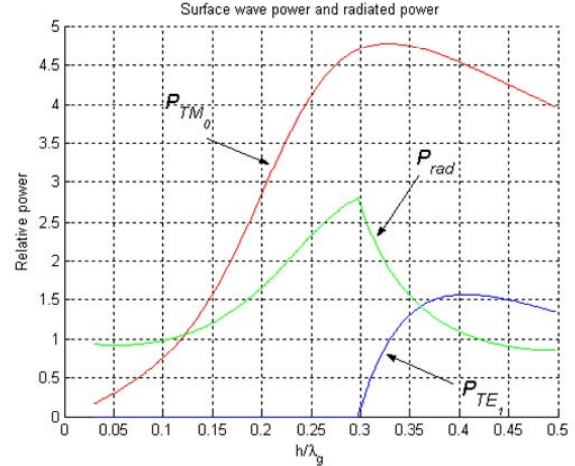


Figure 4: Plots of the same nature as Figure 3, the ground plane now supporting a dielectric slab of $\epsilon_r=3.4$.

These designs are based on RO4003 ($\epsilon_r=3.4$) which is a commercially and readily available material. An extensive set of simulations were performed to find the optimum designs of the arrays. The placement of the EBGs relative to the dipole is important and needs to satisfy a certain distance from the dipole to ensure a good impedance match. This distance needs to be half of the SW-wavelength ($\lambda_{TM_0}/2$ [4-5]) and thus determines the applied lattice of the array. The optimum position of the EBG strokes relative to the active elements was determined with respect to the scattering parameters. As a first step, the positions of the first and second stroke were determined with an in house developed software tool. This tool determines the dispersion characteristics of a grounded slab loaded with a 2D EBG (PCS-EBG [4-5]) structure.

Finally, the dimensioning of the EBG structures and the fine tuning was done with Ansoft Designer. The insets of Figure 5 show the sub-array configuration, in which the third dipole element is used to probe the propagating SW. The sub-arrays used in Figure 5 will be referred to as isolated sub-arrays in the remainder of this paper. Besides the dimensioning and the fine tuning, we considered also possible feeding structures for the active elements and we investigated proximity effects (placement of the EBG close to the dipoles).

III. HARDWARE DEMONSTRATOR

For the validation of the simulation results, two hardware demonstrator array panels were manufactured, based on

RO4003 material. One panel consists of a fully driven array of 3 x 6 active dipole radiators, see Figure 6a. The (enhanced) panel shown in (b), contrary to the full array, has sub-arrays of two dipoles replaced with EBG structures. Both panels are of the same dimensions and lattice. Of both array panels the scattering parameters and radiation pattern were measured.

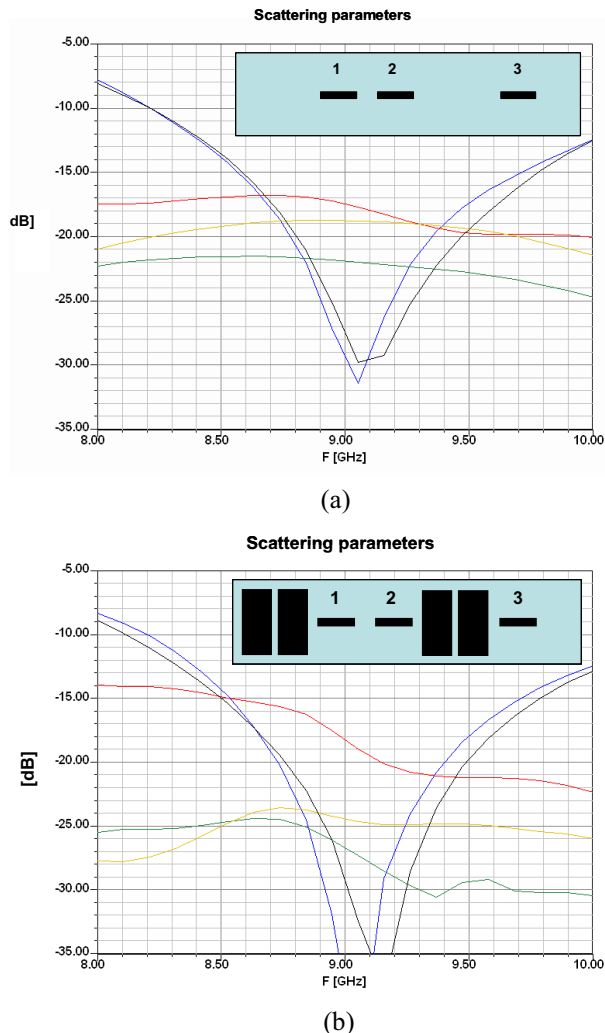


Figure 5: Calculated self and mutual coupling in case of an isolated sub-array of two dipoles. In plot (a) the scattering parameters are shown in absence of the EBG strokes. The scattering parameters when the sub-array is flanked by EBG strokes (see inset) is shown in (b). Blue $S_{1,1}$, black $S_{3,3}$, red $S_{1,2}$, yellow $S_{2,3}$, green $S_{1,3}$. Note that dipole 3 is used to probe the power at a fixed position relative to the sub-array. The EBGs in (b) are shown as solid block for ease, in reality they are as shown in Figure 2a.

The measured E-plane pattern for broadside radiation for both the full array panel and the EBG array panel are shown in Figure 7. For the measurement of both patterns the same external beam-forming network (BFN) was used. In case of the EBG array, this means that only 8 elements were connected instead of 18 for the full panel. The remaining ports of the BFN were closed with matched loads and hence 56% ($10/18 \times 100\%$) of the input power was therefore absorbed by these loads.

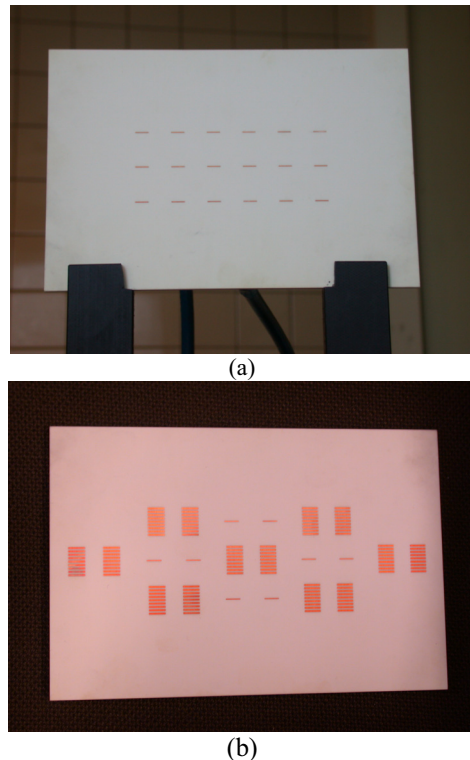


Figure 6: Photographs of the hardware demonstrator array panels. The fully driven dipole array (a) consists of in total 18 dipole radiators. The EBG-enhanced array is shown in (b), it consists of less than half of the active dipole radiators present on the fully driven array. Both arrays are physically of the same dimensions and exhibit the same lattice for the active elements.

Consequently, a power drop of 3.5 dB is created in the radiated power of the enhanced array with respect to the full array.

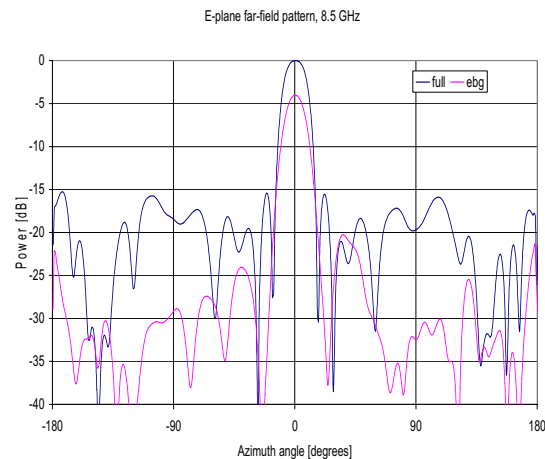


Figure 7: Measured broadside radiation pattern for both the full array and enhanced array panel.

IV. ANALYSIS RESULTS

Simulations showed that the applied EBG structure can effectively enhance the directivity of the array as was also measured (see Figure 7). For the enhanced panel, the same directivity is obtained for broadside radiation with fewer elements as for the full panel. The sub-array's

directivity improves as a result of an increased effective radiating aperture due to the presence of the EBG structure. The impedance bandwidth and matching quality are not significantly changed with respect to those of a sub-array without EBG structures (see Figure 5a and b). It is however shown that the isolation between elements separated by EBGs increases with an average of 7 dB over the functional band of the EBG (again Figure 5a and b).

Due to spacing restrictions, the EBG structures are not completely surrounding the sub-arrays. It was found that comparison of the isolated sub-array results with those after placing the sub-array in an array environment showed reduced performances. This reduction is due to the physical nature in the spreading of the TM_0 -SW in combination with the EBG not completely surrounding the sub-arrays. Via alternative paths, the SW may still reach elements in the array that would be sufficiently isolated in case of a 'complete' EBG. Consequently, both bandwidth and isolation quality are limited. This effect is even stronger when the array is scanned at angles off broadside. The mentioned effect gives argument that for effective blockage of SWs, the usage of EBGs should be such that the sub-arrays are completely enclosed. Therefore to achieve this and maintain 2D scanning capabilities, the only applicable solution seems to be the use a material with higher dielectric constant ($\epsilon_r=20$). At the present time, the effects of applying for that purpose a material with higher dielectric constant, is under investigation.

V. CONCLUSION

In this work we have investigated the effects of applying EBGs at sub-array level. For this purpose two array panels were manufactured. One panel with and one panel without EBG structures present in the array. Both exhibit the same array lattice, but specific elements of the rectangular array are replaced by EBG structures in the enhanced panel. As a result, the number of dipoles is reduced to 8.

In particular it has been observed that in case of the enhanced panel, the same directivity is obtained for broadside radiation with fewer elements as in the case of the full panel. With the present implementation, about 1 dB of non-optimal matching loss of the EBG structures was introduced. With more effort to match the EBG better results can be achieved. The EBG structures do not grant similar satisfying behaviors when used to obtain the same directivity of a full array under scanning conditions. This is due to the fact that SWs can still propagate in between the EBGs.

Therefore this gives evidence to the necessity of increasing the suppression of SWs that propagate in the antenna substrate by further extending the EBG enclosure of the radiating elements. This can be done by using antenna substrates of higher dielectric constant. Currently a further investigation of this aspect is in progress and more details will be presented at the conference.

In general, it is found that the inclusion of EBG structures in a planar array has the potential to enhance its performance when the substrate density is relatively high ($\epsilon_r=20$). This creates the space needed for the EBGs to completely enclose the radiating elements.

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