Efficient, Wide Band, Scanning Phased Array Demonstrator Using Planar Circularly Symmetric EBGs.

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Abstract- This paper shows how the design of integrated arrays can significantly benefit from Planar Circularly Symmetric (PCS) EBGs. Using this technology a phased array that scans up to 40° in one dimension and characterized by relatively large bandwidth (BW ≈ 15%) is designed, manufactured and measured. The specific advantages tied to the use of PCS-EBGs are twofold. On one side, the losses associated to surface waves are significantly reduced. On the other side, each element of the array has a larger effective area that leads to a higher gain for the complete arrays when compared with a standard technology. Further side benefits are the very low cross-polarization levels and the excellent front to back ratio considering that the antenna is low profile and does not include a backing reflector. Since the PCS-EBG technology is completely planar, it is suited for applications that require low cost integrated solutions such Synthetic Aperture Radar (SAR) front ends, wireless LAN, etc.
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1-Introduction

The purpose of this work is to present a hardware demonstrator of a low cost, low profile and high gain array suited to be integrated with the Transmit/Receive (T/R) modules on the same printed circuit boards that contain the antenna array elements. These latter elements are resonant dipoles printed on the opposite side of the metallic plane that constitutes the ground for the micro-strip feeding lines and the T/R modules. The electromagnetic coupling between the two half spaces defined by the ground plane is achieved via resonant slots. The antenna and the T/R modules can be made completely planar. There are two significant advantages in using completely planar technology. The first is that it is rather inexpensive since the manufacturing steps are reduced with respect to other designs that require cavity backing or vertical metallic connections to transfer the signal vertically from the lower feeding planes to the antennas. The second is that spurious radiation from the vertical connections can affect the level of cross polarization as explained in [1]. Focusing the attention on these purely planar structures, a useful approach is to use dense dielectric slabs in order to maximize the front to back ratio. Alternative solutions using non dense dielectrics in the radiating half spaces necessitate the introduction of a backing reflector that potentially supports parallel plate waveguide modes. This type of solution would simply shift the design difficulties from the antenna layer to the feeding layer. As a drawback, thick dielectric layers of high permittivity support surface wave propagation, whose control is now the key design difficulty.

Typical requirements for SAR applications involve bandwidths (BW) larger than 10% and scanning until 40 degrees in the longitudinal plane. For these applications the advantages associated to the planarity of the structures can be achieved, without sacrificing the performances due to surface wave losses, using planar circularly symmetric Electromagnetic Band Gap substrates (PCS-EBG). In fact, PCS-EBGs are used to reduce the power launched in surface waves by each one of the antennas composing the array and to enlarge the effective area of each these radiating elements.

The example of such planar array with PCS-EBG discussed in this paper is shown in Fig. 1.

Fig. 1 *1D scanning array composed of 8 elements with PCS-EBGs. Also some details of the feeding network are visible.*

Most of the pioneering works on the use of EBG for phased arrays typically covered infinite array simulations [2] and theoretical demonstrations of the possibility to reduce mutual coupling [3] between adjacent elements. When, as in [4], real phased arrays where manufactured and measured, the useful bandwidth observed were in the order of 2.5\% only. With this work an EBG based array with BW up to 15% is demonstrated via hardware and measurements.

2-Array Demonstrator

The analysis and design of single antennas surrounded by a PCS-EBG structure have been the object of two consecutive papers, [5] [6]. In [6], choosing as an example a slot antenna, in order to simplify the analysis without a significant loss of generality, a simplified quasi analytical model was presented that allows to characterize the interaction between the central antenna and the surrounding EBG. The most striking result of such model was that the optimal radiation bandwidth (defined as the range of frequency over the antenna radiates with high efficiency) for printed antennas on grounded dense dielectric slabs and surrounded by EBGs was achieved when:

1) the height of the dielectric slab at the central frequency is in the order of 0.18 λ_d with λ_d the wavelength in the dielectric
2) the equivalent cavity defined by the PCS-EBG, has a radius approximately equal to half of the TM0 surface wave.

Even though these conclusions were demonstrated for slot antennas only, they can be extended to other central resonant antennas, that are still slot coupled, i.e. dipoles or patches. The same PCS-EBG concept is used here for 1D scanning arrays. The key design attention is to use linearly polarized antenna elements arrayed in such a way that their interaction via surface waves is reduced. A slot coupled dipole launches TM waves that are dominant on the E-plane cut of the slab. For this reason one can use PCS-EBGs radially oriented to reduce the TM waves only in an angular sector, see inset of Fig. 1.

An X band demonstrator composed of eight slot coupled dipoles arrayed in the H plane, Fig. 1, was designed and then manufactured. The array is printed on dense dielectric material. Thanks to the sector configuration, we can place the elements at a distance that corresponds to a maximum scanning without grating lobes of 52° at 12GHz. All antennas are fed via 50 micro-strip lines connected to coaxial cables after equivalent electric paths.

3-Measured Performances

S-parameters, reflection coefficients and radiation patterns have been measured and compared with calculated data, showing excellent agreement.

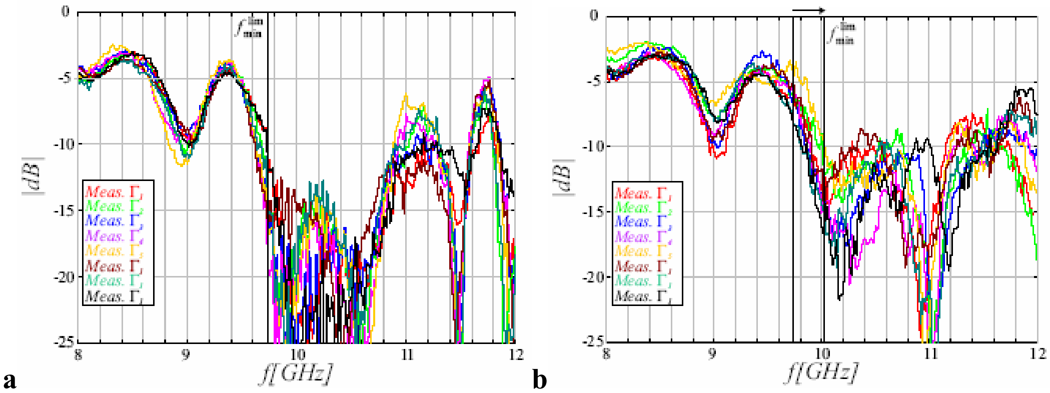

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Fig. 2. Measured active reflection coefficients at two different phase shifting conditions associated to scanning broadside and toward 40 degrees at 11GHz.

The measured and calculated active reflection coefficients of all the array elements are plotted in Fig. 2 as functions of the frequency (from 8 to 12GHz). The reflection coefficients are calculated as the ratio between the amplitude of the reflected and the incident waves measured using directional couplers directly before the coaxial to micro-strip connections, see Fig. 1. The measurements in the two different graphs correspond to two different phase shifting conditions, associated to scanning towards broadside and 40 degrees at 11GHz, respectively.

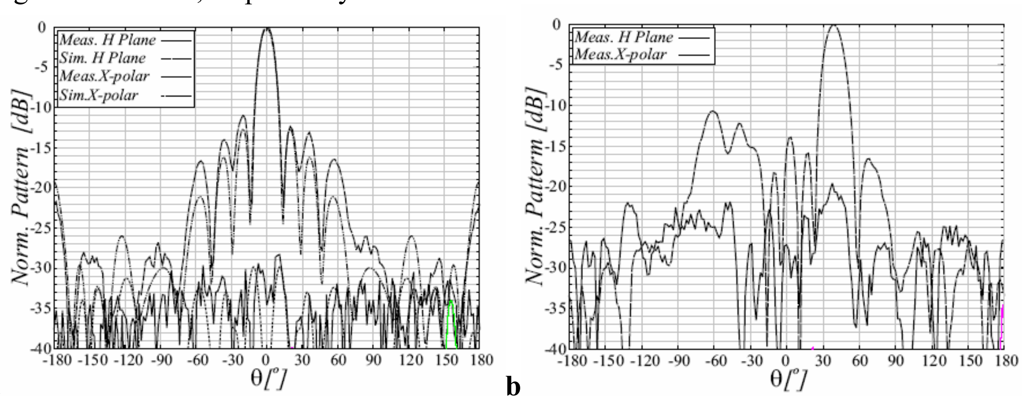

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Fig.3. Measured co-polar and cross-polar normalized radiation patterns for the array beam pointing at broadside and at 40° in the H-plane.

The radiation patterns from the array have been measured at the central frequency of 11GHz. The H plane, with the co and cross polarized radiation patterns, is shown in Fig. 3a for the case of broadside radiation. The patterns are normalized to their maximum value and the comparison with the results predicted by CST simulations show good agreement. The cross-polarized patterns are always 30dB below the co-polar radiation maximum. The H-pattern is shown in Fig. 3b when the array is phased to radiate toward 40°. In this case, simulations via CST of the full 8 elements structure could not be performed because the structure is too large in terms of the wavelength and symmetry conditions could not be used as in the broadside case. The beam is very clean and the only noticeable aspect is that the cross polarization pattern is also maximum in correspondence of 40° (at -20 dB level). This seems to be due to residual surface wave diffraction contributions that for this scanning angle contribute directly in the cross-polarized pattern.

4- Conclusions

An array prototype has been designed, manufactured and measured. The results demonstrate that PCS-EBG technology can be used to enhance the efficiency, bandwidth, directivity and polarization purity of very low cost and low profile one dimensional scanning arrays. The bandwidth over which a single layer and completely planar array can be scanned until 40 degrees without significant losses of efficiencies is extended to about 15%. Prior to the introduction of Planar Circularly Symmetric Electromagnetic Band Gap technology losses arising from the radiation into the feeding half space or from the excitation of surface waves in the dielectric would render the maximum useful BW achievable with comparable technology 4%. More measured data will be presented during the oral presentation.

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