Analysis of the Performance of Multi-Beam Reflector Antennas Using EBG Super-Strates to Realize Equivalent Overlapping Feed Configurations

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Abstract- This paper deals with the analysis and the Design of Electronic Bandgap, EBG, super-strates to improve the aperture efficiency of the elements in an array of small waveguide feeds located in the focal plane of a reflector antenna. A dedicated software capable of analyzing these arrays in a full wave manner has been developed and interfaced with a Physical Optics tool in order to characterize the increase of the performance of the entire system. The preliminary results are encouraging as at least 1 dB improvement in the edge of coverage gain is achieved, over a significant bandwidth (8%), for an array of 9 elements when only the central element is fed.

1-Introduction

There is an increasing demand for multibeam capability in present and next generation satellite communication systems, in particular at Ka-band, 20/30 GHz. Two main techniques are used to obtain high beam crossover gain; one is to use a single feed per beam and interleaved beams, with multiple feed clusters and reflectors, another is to use overlapping feed subarrays. The drawback with the first method is the large mass and volume, and with the second the complex feed network.

A simpler concept, and most attractive from an implementation point of view, is to use one feed per beam and a single reflector system. This concept suffers, however, from low gain in the crossover points between the beams. In determining the feed size, there is a conflict between beam separation and spillover loss, and the aperture efficiency is determining the achievable crossover gain. More directive elements can be realized by introducing a set of EBG super-strates that improve the radiating efficiency of each element and simulate larger aperture horns than would physically fit in the array. The concept is similar to that originally proposed by G. V. Trentini 1956 [1]. A point source generates an ensemble of waves that impinge on a screen that is partially reflective and partially transmitting. The reflected rays propagate laterally and then are redirected toward the partially reflecting screen, so that overall they generate a unique leaky wave that mostly radiates in the broad side direction. More recently [2] by using this concept it has been proven that it is possible to design antennas greatly reduced in volume and mass yet offering potentially similar performance to horn antennas designed with more standard technology.

As is the case with most leaky wave configurations also this one is characterized by narrow frequency bandwidths. Original contributions to this type of leaky wave radiation were produced by Jackson and Oliner, and in particular [3] appears to be one of the most significant. More authors have taken the same concept and applied it to the characterization of EBG type of structures. One of the most successful has been the group of Prof. Jecko [4]. However in most existing design a narrow band has been accepted. For a Ka band telecommunication application, a relative narrow frequency band (1 to 3%)

can be sufficient in absolute terms. But from a proper engineering point of view a reasonable margin should be included to allow for manufacturing tolerances, temperature effects etc. Prof. Mittra, [5] suggested that a larger bandwidth could be achieved by severely reducing the directivity by truncating the superstructure. Overall it appears that one of the most tricky aspects of the designs of these structures is the trade off between the desired directivity enhancement, the coupling between the elements and the frequency range over which the structure is supposed to work.

3- Evaluation of EBG WG Feed Array

In this paper the focus is placed in the design and the analysis of a specific geometry that is represented in fig. 1. A multibeam feed array will most likely form a hexagonal lattice, but the concept is evaluated in a rectangular array at Ku band.

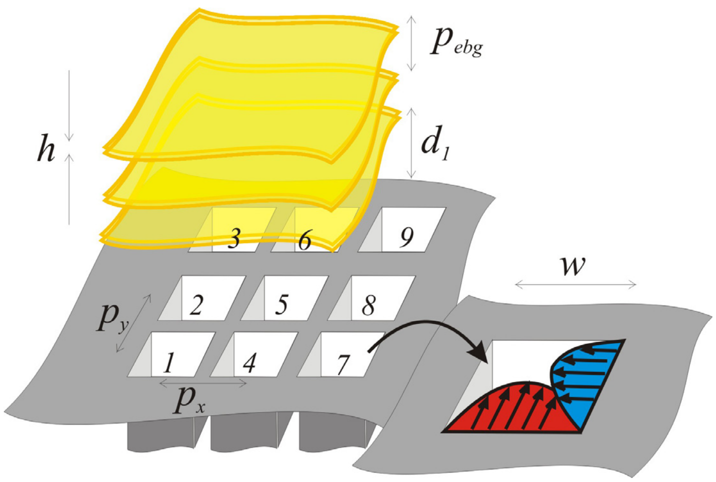

Fig. 1 Investigated geometry.

The geometry consists of 9 square waveguides (with each side indicated by *w*) that open in a common metallic plane that is infinitely extended in *x-y* and is located at *z=0*. The apertures are arrayed in a rectangular grid, p_x, p_y. At a distance d_1 there is a super structure composed by an array of parallel dielectric layers. Each of the layers has thickness *h,* dielectric constant ε_r while their periodical displacement is p_{ebg}. The waveguides are numbered progressively in order to address each one of them separately when necessary.

<u>*Analysis Tools*</u>

A MoM code [6] has been developed capable of analyzing finite wave guide array structures loaded by an arbitrary number of dielectric stratifications. Note that the code is not a design tool yet. The design is still performed resorting to trial and error. Four EBG configurations have been selected as test cases in order to obtain a preliminary proof of concept of the potential of the EBG super-strate configurations. In particular, the task was to benchmark the performance of the feed structures in the presence of the four EBG configurations with respect to a fifth case, representing the array in free space. The analysis of the feed structure, was performed using the TNO waveguide array code, while the interaction with the reflectors was performed using a separate code from Saab Ericsson space.

<u>*Benchmarking*</u>

The geometrical parameters defining the array were set to w=20 mm, p_x= p_y=22 mm. The super structure is defined by d_1 = 12.5 mm*,* h=4.42mm, ε_r =2 with the number of layers *n* and the period of the EBG as only parameters allowed to be changed. The parameter n can be 2 or 3 while the period p_{ebg} can assume the values 12.5mm or 6.25 mm corresponding to 0.5 λ_0 and 0.25 λ_0 at 12 GHz respectively. Note that most existing designs fix the periodicity to d_{ebg} =0.25 λ_0 at the central operating frequency for maximum directivity enhancement.

Thus five square waveguide feed cases have been analyzed, these are: 1) 2 layers with 0.5λ spacing; 2) 2 layers with 0.25λ spacing; 3) 3 layers with 0.5λ spacing 4) 3 layers with 0.25λ spacing, 5) Free space reference case.

The results for the feeds embedded in a 3 x 3 array are shown here. For each case, linear co- and cross-polarisation patterns, in the 0º and 90º directions are provided. The evaluation has been performed following the next steps:

1. An optimum axial position is calculated and adjusted for, so that the phase variation over the reflector is minimized.
2. A reflector geometry is selected with fixed diameter (0.5 m) and possibility to vary the F/D ratio, giving the maximum feed angle for which the radiation is hitting the reflector. The antenna far field patterns for circular polarisation are calculated by integrating the feed patterns over the reflector aperture.
3. Direction of adjacent beams is calculated from the feed separation, focal distance and Beam Deviation Factor, BDF..
4. Critical parameters, like EOC gain, beam roll-off, antenna efficiency and spillover loss are calculated.
5. The optimum F/D- ratio, in terms of EOC gain for each case is identified.

A compilation of the result is made in Table 1. The optimum F/D ratio is found for each case, and is for all cases 0.8, corresponding to approximately 35 deg angle to reflector edge. When not other wise stated the results shown in table 1 represent the worst ones between the investigated frequencies (11.5-12.5 GHz).

Case	**Geoc [dBi]a)**	**Roll-Off [dB]b)**	**Aeff [dB]c)**	**Spillover [dB]d)**	**ΔGeoc [dB]e)**	**G*eoc [dBi]f)**	**Comment**
1	31.2	3.0	-2.1	-1.9	0.45	31.5	
2	30.8	2.8	-2.4	-2.2	1.58	31.9	Large variation with frequency band
3	31.0	2.8	-2.3	-2.0	0.17	31.0	
4	29.5	2.7	-3.6	-3.4	2.50	31.3	Large variation over frequency band
5	30.3	2.9	-2.8	-2.7	0.61	30.6	In agreement with expected results

Table 1 *Optimum EOC gain, two-beam roll-off, antenna efficiency and feed angle to reflector edge, for the five cases defined above. The mentioned parameters are defined as: a) the EOC gain is defined as the gain in the point where two adjacent beams cross, b) Roll-Off is defined as the difference between the beam peak gain and the EOC gain, c) Antenna efficiency is defined as peak gain related to the maximum gain from the given aperture (for the frequency where Geoc is minimum), d) Spillover is the relative power hitting the reflector, e) ΔGeoc is the variation in EOC gain over the full frequency band, f) G*eoc is the minimum gain over the best half of the frequency band*

Finally in fig.2 the radiation patterns of the central waveguide in the 9 element feed array of fig.1 are shown for two of the investigated cases. In particular fig. 2a shows parametric curves presenting the corresponding free space configuration (case 5), and to the optimal case of table 1, (case 1). The half power beam width corresponding to case 1 is smaller, indicating a higher directivity but even more promising is the angular filtering effect of the super-layers, with steep roll offs of the field after 35 °. This second property is associated to the fact that more than one leaky is in propagation in structures characterized by distances between the dielectric layers in the order of 0.5 λ_0 .

a) b)

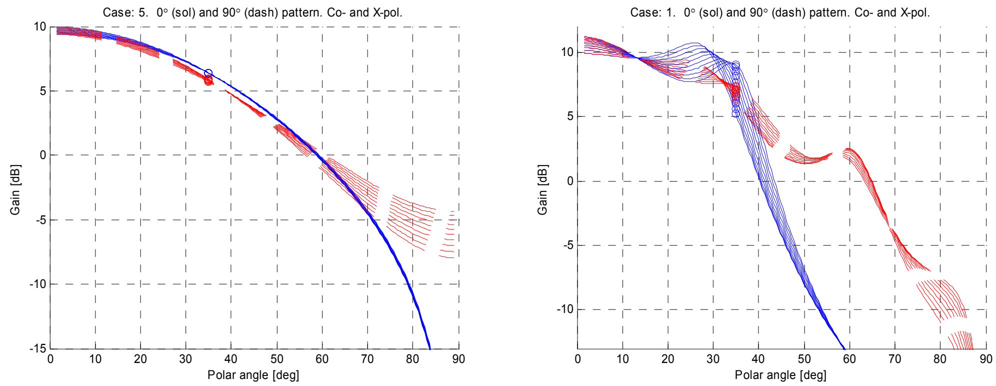

Fig.2 Amplitude of field radiated by the central feed in two configurations: a) case 5; b) case 1

4- Conclusions

A multiple beam reflector configuration in a Ka-Ku band telecommunication system is selected as an application scenario to determine potential improvements by using EBG technology. Qualitative considerations and preliminary numerical simulations seem to indicate that at least 1 dB improvement is obtained in edge of coverage beam amplitude over a bandwidth which is sufficiently large for the selected application. As will be shown during the oral presentation, a degradation of performances in terms of impedance matching and mutual coupling between apertures occurs as a consequence of the presence of the EBG super-layers. Nevertheless, even without specific ad hoc design, matching better than -15 dB and mutual coupling in the order of -20 dB are maintained. A design goal could be to achieve 2 dB of gain increase by optimizing the super-layer structure taking into account the location of the higher order poles in the multilayer structure. Evolutions of the results of this investigation will be presented during the oral presentation

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