DUAL-POLARIZED HIGH-EFFICIENCY SPLINE-PROFILE SQUARE HORNS FOR SATELLITE ARRAY APPLICATIONS

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ABSTRACT

We investigate the design of high-efficiency dual-polarized rectangular horns by optimizing the profile and length of the horn. The geometry of the horn is represented using spline functions and the field using a mode matching method. A performance index is computed that maximizes gain and minimizes the reflection coefficient and peak cross-polarization level over a band of frequencies. A practical example that would be suitable for on-board satellite arrays is described that has an efficiency > 94% and cross-polar isolation > 25 dB for the frequency band 11.7 - 12.2 GHz.

INTRODUCTION

Arrays of rectangular or square horns are frequently used for on-board satellites as direct radiators or as feeds for reflectors to create shaped beams on the earth’s surface [1]. The rectangular or square cross-section geometries are suitable for stacking and the square cross-section is convenient for dual-polarization applications. In most applications a square horn is used to provide two planes of symmetry and ease of feeding. In practice, compared to a circular horn of about the same size, a rectangular horn has higher cross-polarization which is undesirable in dual-polarization applications. Recently, we described an approach for achieving a high efficiency with a rectangular horn [2]. Whilst excellent results were obtained, cross-polarization was ignored in the design procedure. The purpose of the present work is to describe the extension to dual-polarization and to compare the results obtained with the single polarization case. We will illustrate the method with results of a practical case of an on-board satellite application.

In the intended application, an array was required to cover the 10.70 - 12.70 GHz frequency band with as high an aperture efficiency as possible; a target of 92% would be highly desirable. A horn design could be provided for the full band or it could be split into two smaller 1 GHz sub-bands (10.70 - 11.70 GHz and 11.70 - 12.70 GHz) or four 500 MHz sub-bands (10.70 - 11.20 GHz, 11.20 - 11.70 GHz, 11.70 - 12.20 GHz, 12.20 - 12.70 GHz). In each sub-band, a different horn design could be used. One of the firm requirements for this application is that the aperture size is limited to 30.5mm square, the input size is to be 22.86mm square (to match an existing square-input orthomode transducer) and the maximum length is 80 mm. As this is for a space application a more compact design would be preferrable.

What follows is a description of a short feasibility study to demonstrate that spline-profile square horns can be designed to have high aperture efficiency.

DESIGN OF SPLINE-PROFILE HIGH-EFFICIENCY SQUARE HORNS

The technique for designing and optimizing the performance of a profiled horn is described in [2-4]. Initially, the two orthogonal profiles are represented with cubic-splines. The coefficients of the spline functions are then optimized to minimize a performance index. The spline function requires only a few nodes to create the spline. Only seven nodes are used, but the input and output radii are fixed, so we are left with only five parameters to optimize per profile.

Several schemes for optimizing the profile are available [2-4] and the method chosen will depend on the application. The scheme adopted here is one where the aperture efficiency itself is maximized and a performance index containing input reflection coefficient and maximum cross-polarization are minimized across the frequency band against target levels. Weights are applied to emphasize efficiency, reflection coefficient or cross-polarization or to provide roughly equal emphasis. A mode-matching method is used to analyse the horn [4] at each frequency and a standard optimization method is used to minimize the performance index.

In the following, to demonstrate the concept of high-efficiency, dual-polarized, spline-profile square horns, greater weighting is given to aperture efficiency and with the input reflection coefficient target and maximum cross-polarization target both set at moderate targets of -20 dB. We have used a least p-th index and a Fletcher's quasi-Newton search method to minimize the performance index [2].

RESULTS

We developed two horn designs and compared the results. One design covers the sub-band 11.70 - 12.20 GHz frequency band (as in [2]) and the other one for comparison covers the full 10.70 - 12.70 GHz band required by the application.

Based on the technique described in [2], we were able to quickly optimize two horn-geometries to cover the required bands. One of the advantages of spline-profile square horns is that the two orthogonal profiles are identical and, compared to [2], where 10 independent parameters were used, only five parameters are required to be optimized in this case. The geometry of the optimized 11.70 - 12.20 GHz design (Horn No. 1) is shown in Fig. 1 while Fig. 2 shows the optimized 10.70 - 12.70 GHz design (Horn No. 2). In both cases, a 2 mm-wide aperture-flange is assumed to surround the aperture. Particularly noteworthy is that both horn designs are significantly shorter than the 80mm maximum; for example Horn No. 2 is only 55mm in length.

The radiation patterns of both horns over the respective bands are shown in Fig. 3 while a summary of the aperture efficiency is shown in Fig. 4. It can be seen from Fig. 4 that the target of 92% aperture efficiency is almost met by Horn No. 2 for the wide-band application. Also shown in Fig. 4 is the efficiency of a horn with single polarization optimized to have a WR75 input waveguide and have the same aperture size and length as the optimized dual-polarized Horn No. 2. The efficiency for the dual-polarization design is usually less than the single polarized design, as is the case here, as the optimization of both walls of the single-polarization horn allows the optimizer to push the aperture efficiency higher.

While the mode-matching technique has been used to analyze the performance of the horns [2], to ensure that the return-loss does not have frequency spikes in the reflection coefficient response, both horns were also analyzed using CST Microwave Studio [5] to calculate the wide-band frequency response. Agreement is excellent between the two approaches. As an example, the three-dimensional geometry of the 10.70 - 12.70 GHz horn is shown in Fig. 5 while the theoretical return loss is shown in Fig. 6. Note that the CST Microwave Studio takes into account the external body of the horn as well, while the mode-matching technique only takes into account a finite-flange at the aperture.

CONCLUSIONS

We have demonstrated that spline-profile, dual-polarized square horns can be designed to have high aperture efficiency. Preliminary results show that it is possible to reach aperture efficiencies of about 92% over a 10.70 - 12.70 GHz band for a horn with a 30.5 mm-square aperture and a length of only 55 mm.

REFERENCES

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[4] T.S. Bird & A.W. Love, "Horn antennas", in J. Volakis, "Antenna Engineering Handbook", McGraw-Hill, 4th ed., 2007, Chap. 14.
[5] http://www.cst.com

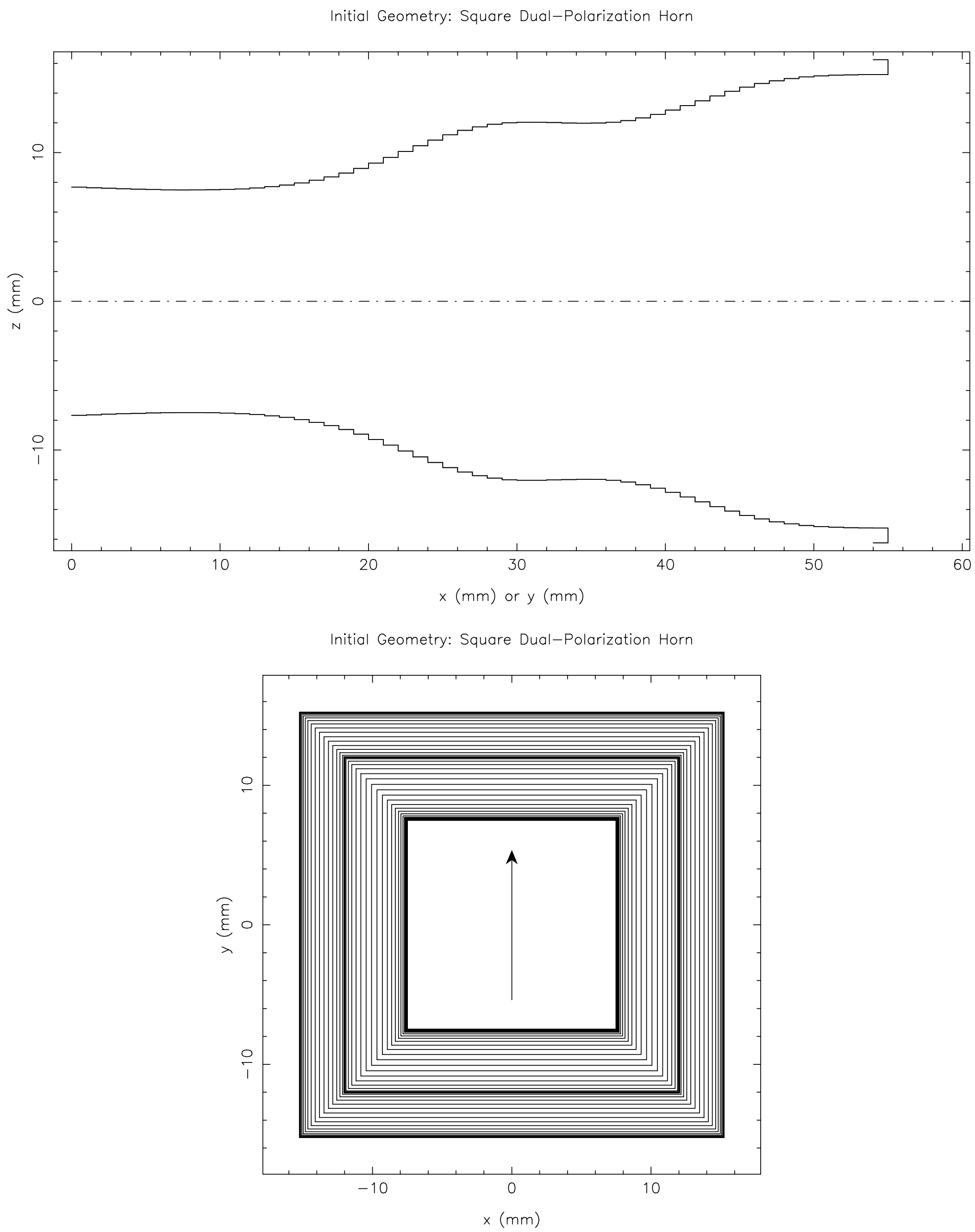

Figure 1: Geometry of the 11.70 - 12.20 GHz design (Horn No. 1).

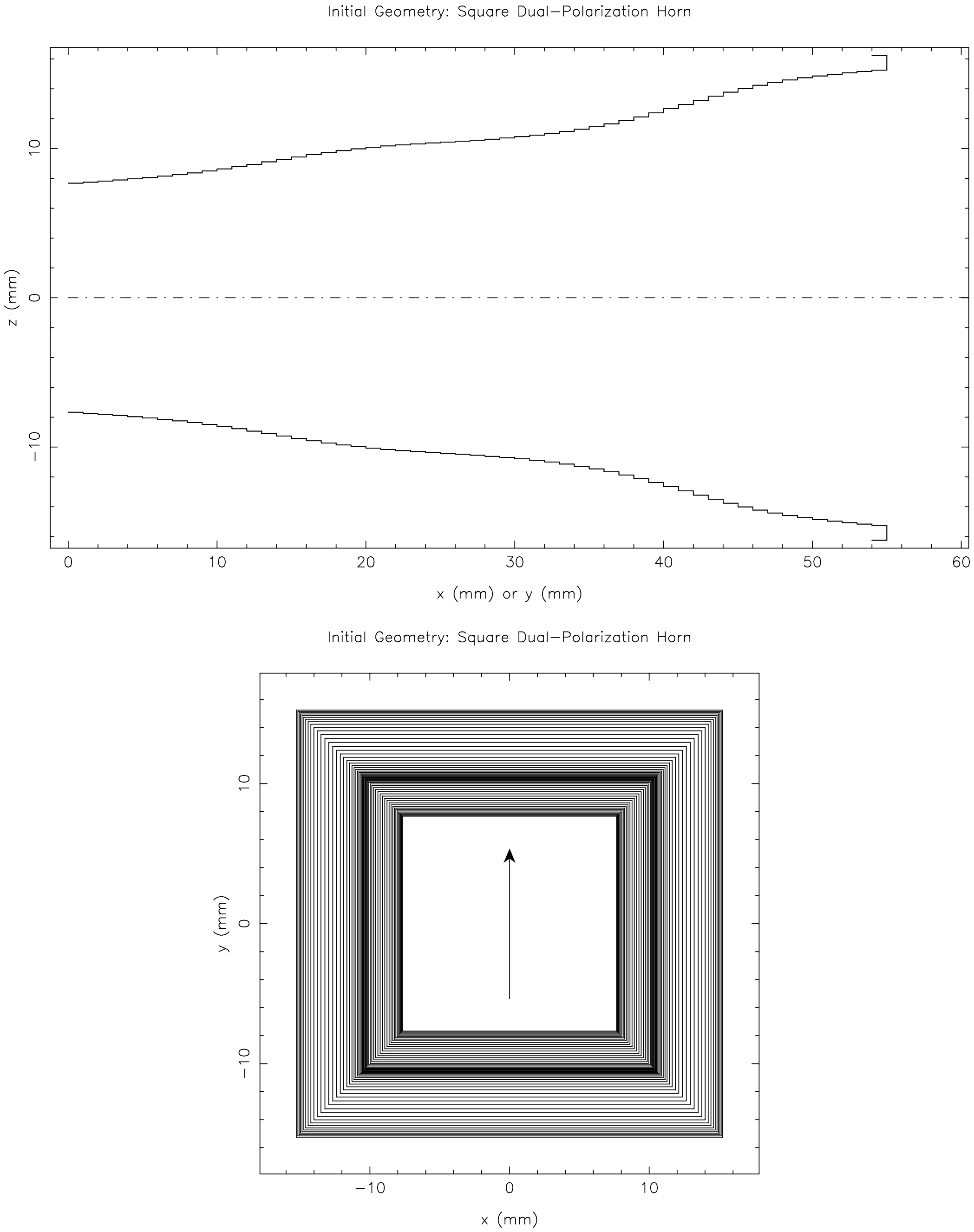

Figure 2: Geometry of the 10.70 - 12.70 GHz design (Horn No. 2).

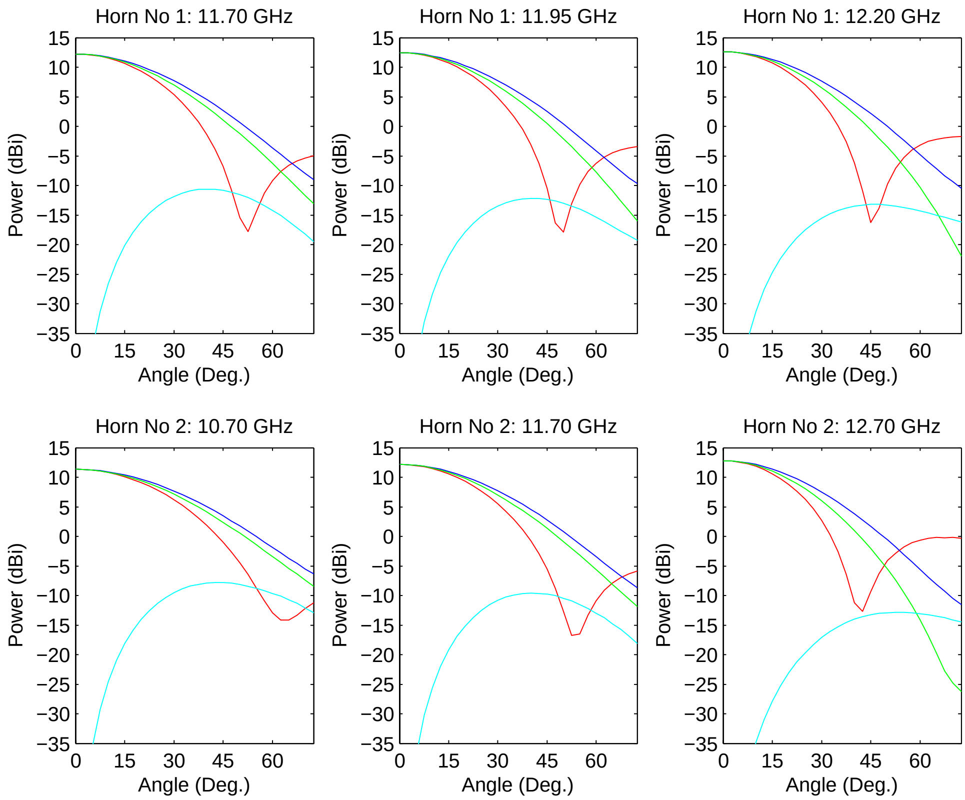

Figure 3: Radiation patterns of (a) 10.70 - 12.70 GHz and (b) 10.70 - 12.70 GHz horns. Red: E-plane, Blue: H-plane, Green: 45°-plane, Co-polar, Cyan: 45°-plane, X-polar.

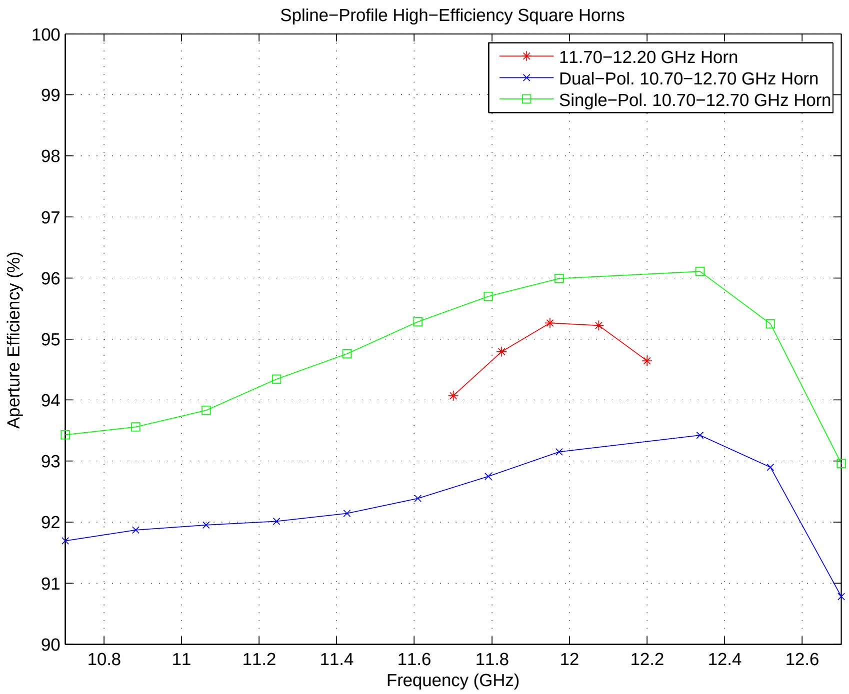

Figure 4: Aperture efficiency of the dual-polarized 11.70 - 12.20 GHz and 10.70 - 12.70 GHz horns and the single-polarized 10.70 - 12.70 GHz horn.

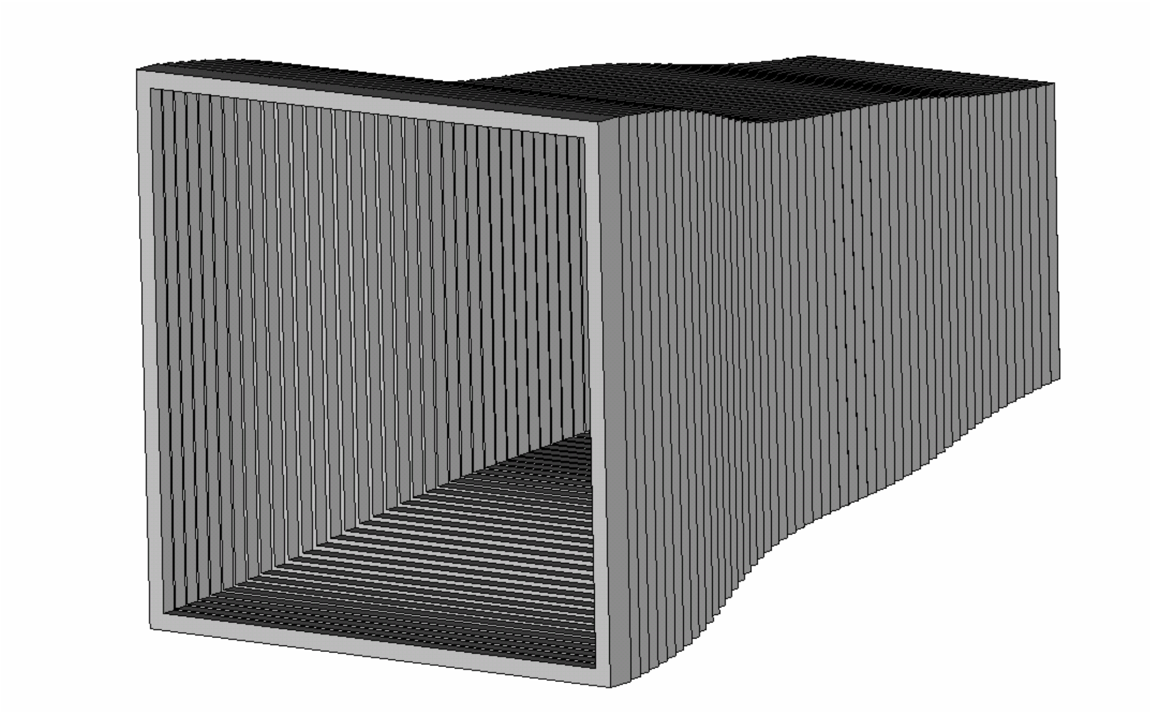

Figure 5: Three-dimensional view of the 10.70-12.75 GHz horn.

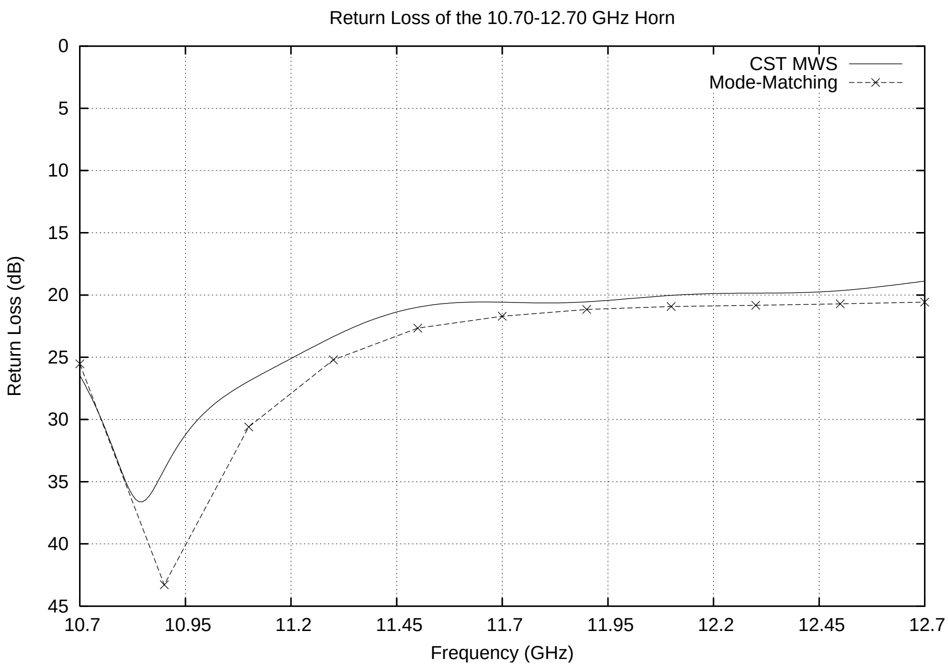

Figure 6: Return loss of Horn No. 2.