ANALYSIS AND DESIGN OF FLANGE-INTEGRATED RECTANGULAR-TO-CIRCULAR WAVEGUIDE TRANSFORMERS FOR SPLASHPLATE ANTENNA FEEDS

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A new design concept for compact rectangular-to-circular waveguide transformer is presented. It allows the integration of the transformer in the flange of a circular waveguide splashplate feed. Instead of using a conventional taper, short and abruptly stepped rectangular and circular transformer sections are utilized. Two different designs are presented which achieve 30dB-return-loss bandwidths of 12 and 19 percent. The corresponding component lengths are only 0.71 and 1.1 guided wavelengths, respectively, at the center frequency of the rectangular input waveguide. The design methodology is validated by excellent agreement between theoretical predictions, HFSS analyses and measurements.

I. INTRODUCTION

Splashplate feeds, e.g. [1], are increasingly used for high performance parabolic antennas. The feed is directly interfaced in the focus of the antenna by a straight circular waveguide through the antenna vertex which simultaneously acts as feed support. At the far side of the waveguide, the need of a circular-to-rectangular waveguide transition is obvious to overcome proper interfacing with standard rectangular waveguide types commonly used for commercial transceiver equipment. The direct integration of a suitable transition design within the vertex feed support flange facilitates compactness, handling and, therefore, low overall feed system cost. As shown in Fig.1, such a concept requires design capabilities for short and compact transformers as well as the incorporation of milling radii in the cross section of the flange to account for an easy manufacturing process.

Tapered rectangular-to-circular waveguide transformers are commercially available but are too long for this application. The same holds for any other known transformers involving stepped tapers of one sort or another, e.g. [2], [3]. The shortest design consists of a direct connection between the rectangular and circular guides using an iris in the plane of transition, e.g. [4]. However, this approach, although suitable in filter applications [5], results in a performance which often fails to provide enough bandwidth for a practical dielectric antenna feed.

Therefore, this paper introduces a new and compact circular-to-rectangular waveguide trans-former concept which is based on short and abruptly stepped rectangular and circular waveguide sections. It will be demonstrated that bandwidths in the order of 12 and 19 percent can be achieved with a transformer length of approximately one guided wavelength and that the design can be integrated in the flange of a splashplate feed (c.f. Fig. 1).

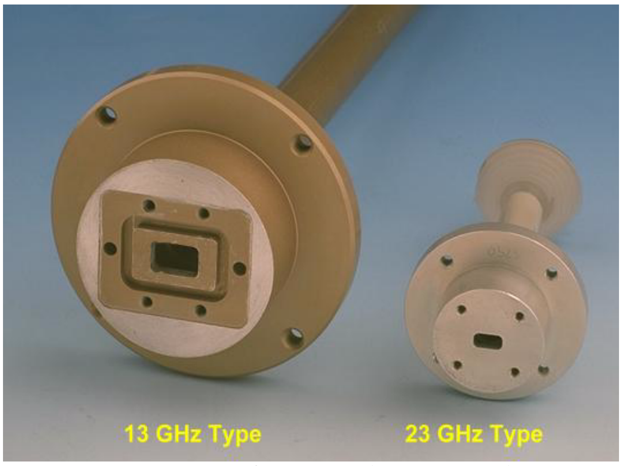

Fig. 1 *Integration of rectangular-to-circular waveguide transformer in splashplate feeds for 13 GHz and 23 GHz.*

II. THEORY

The basic rectangular-to-circular waveguide transformer considered for this application is shown in Fig. 2. The interconnecting waveguides are considered to provide sole fundamental mode propagation in the operating frequency band, which is restricted by the TE_{20} mode in rectangular, and by the TM_{01} mode in circular waveguide. Note that although these modes are not directly excited by the strucure of Fig. 2, they are present in other parts of the system and, therefore, limit the maximum theoretically achievable bandwidth to 67 and 27 percent, respectively.

The basic transformer in Fig. 2 comprises an on-axis connection of one rectangular and one circular waveguide section. The second circular section is introduced for further return-loss improvement. To accommodate an easy manufacturing process by machining from the flange faces only (c.f. Fig1), the height of the rectangular waveguide section is kept at the same value as the interfacing waveguide.

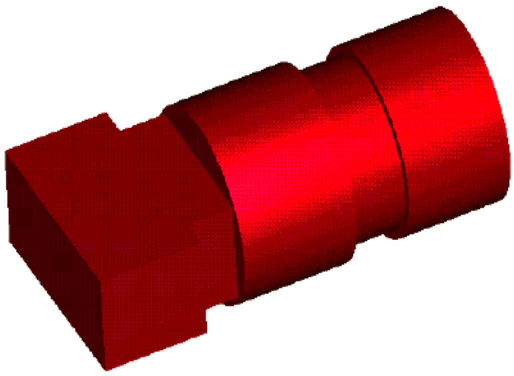

Fig. 2 *Compact rectangular-to-circular waveguide transformer with two transformer sections and a circular matching section.*

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Initial Design:

Although the relationships of the fundamental mode cut-off frequencies in rectangular and circular waveguides usually vary for different designs, the following initial dimensions have been extensively tested and will commonly yield a return loss of better than 20 dB.

Rectangular section:

$$d = 0.59c/f_m;\ l=0.1\lambda_g \qquad (1)$$

1st circular section:

$$d = 0.75c/f_m;\ l=0.3\lambda_g \qquad (2)$$

2nd circular section:

$$d = 0.65c/f_m;\ l=0.1\lambda_g \qquad (3)$$

where a is the width of the rectangular waveguide, d the diameter of the circular waveguide; c is the speed of light and λ_g the respective guided wavelength at midband frequency f_m. The design is finalized in a succeeding optimization which, due to the excellent initial values given above, will rapidly converge to a return loss better than 30 dB over an operating bandwidth of typically 12 percent. The extension of this core structure by only a single additional transformer section at the circular or rectangular interface will enhance the achievable bandwidth to 19 percent.

Optimization:

The fine optimization is carried out using the Mode-Matching Technique (MMT), e.g. [5], as analysis tool combined with a MiniMax-based optimization strategy, e.g. [6]. The cost function to be minimized is given by

$$F_{cost} = \sum_i [RL_{goal}/RL(f_i)]^2 \qquad (4)$$

where RL_{goal} is the desired return loss and $RL(f_i)$ is the actual return loss at frequency f_i.

Analysis:

Since the optimization routine varies section lengths and cross sections simultaneously, five different combinations of discontinuities need to be distinguished in the MMT analysis: First, the on-axis rectangular-to-rectangular and, second, circular-to-circular waveguide discontinuities are calculated following standard procedures as given, e.g., in [5]. Third, the large-rectangular-to-small-circular discontinuity is explicitly solved in [7]. Fourth, a series expansion according to [8] is employed for the large-circular-to-small-rectangular discontinuity. For the case of overlapping rectangular-circular discontinuities, fifth, an intermediate region encompassing both cross sections is used, e.g. [5]. The design is deemed to be accomplished once every single term in (4) is less than unity.

III. RESULTS

Using the procedure outlined in the previous section, a rectangular-to-circular waveguide transformer according to Fig. 2 was designed for a WR137 input guide and an output guide of 28.9 mm in diameter. Fig. 3 shows the performance calculated by the MMT and its validation by the commercial finite-element package HFSS. The 30-dB return-loss bandwidth is 12 percent, and the component has a lengh of 0.71 guided wavelengths with respect to the input WR137 guide. Notice the two return-loss poles due to the two transformer sections (cf. legend to Fig. 2).

In order to increase the bandwidth of this design, an additional rectangular transformer section is added. This comes, of course, at the expense of larger component size. The transformer length is now 1.1 guided wavelengths with respect to the input WR137 guide. However, the bandwidth is increased to 19 percent due to the appearance of a third return-loss pole. Fig. 4 shows the performance of the final design as computed by the MMT and HFSS. Again, excellent agreement between the results of both methods is obtained.

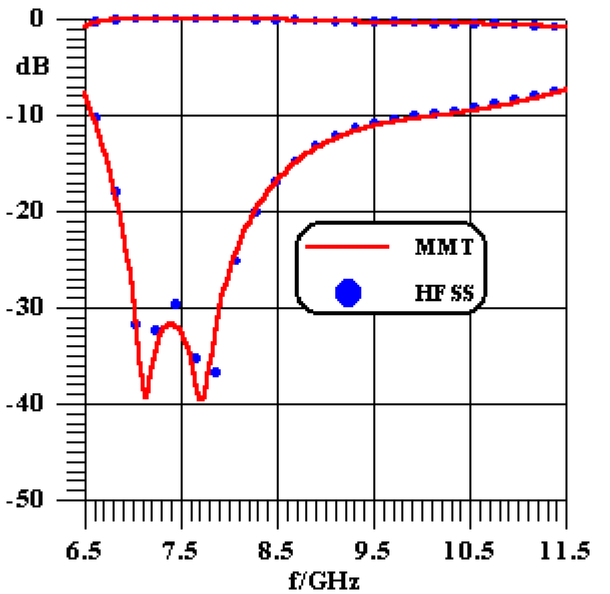

Fig. 3 *Performance of rectangular-to-circular waveguide transformer according to Fig. 2 and comparison with HFSS.*

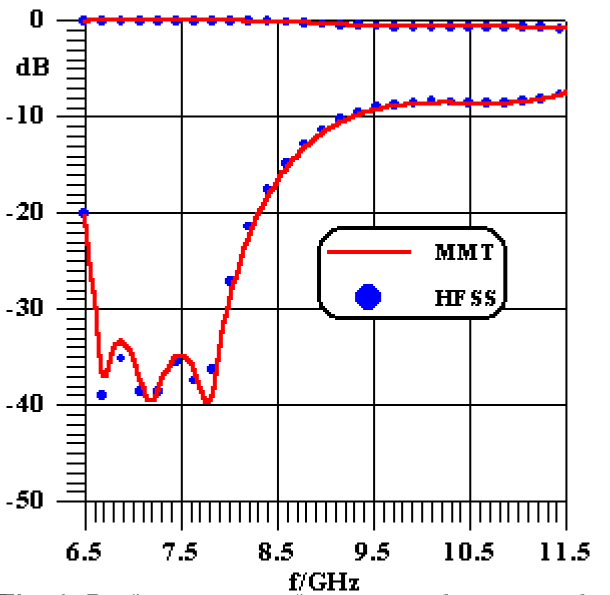

Fig. 4 *Performance of rectangular-to-circular waveguide transformer with an additional rectangular waveguide section and comparison with HFSS.*

Following these investigations and design procedures, several components for center frequencies between 6 and 38 GHz have been designed and fabricated. At the example of the component with an additional section in the 7GHz band, a direct comparison between computed results and measurements is shown in Fig. 5. To account for an easy manufacturing process and to facilitate the integration into the flange of the antenna feed, milling radii have been considered in the cross section of the rectangular transformer step (c.f. Fig. 1). Hence, the final optimization of this transformer has been performed with a CAD tool based on the boundary contour mode matching method (BCMM) [9]. The structure has been realized from one piece with CNC milling techniques by machining from the waveguide faces at both sides. Computed and measured results coincide accurately up to 35 dB return loss, demonstrating a 19 percent bandwidth with more than 30 dB (c.f. Fig. 5). (As is well known, agreement at return loss levels beyond 35dB is hardly achieved, due to slight manufacturing inaccuracies and sensitivity limits of standard test equipment.) The measured insertion loss is much smaller than 0.1 dB.

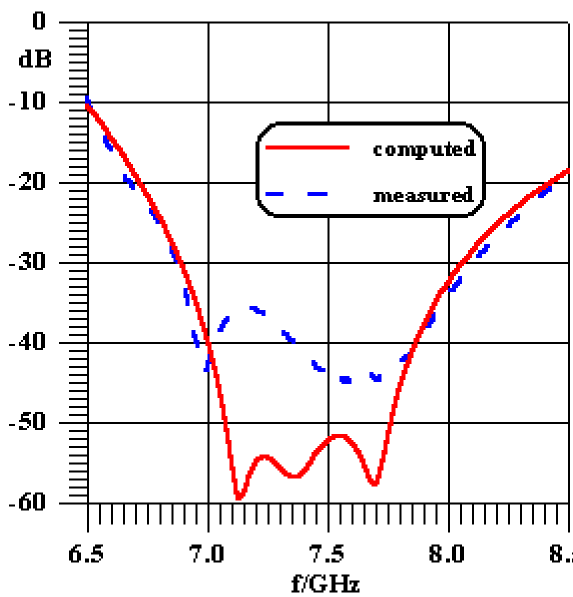

Fig. 5 *Comparison between computations and measurements for a rectangular-to-circular-waveguide transformer (WR134 to 28.9mm diameter guide)*

IV. CONCLUSION

The new and compact rectangular-to-circular waveguide transformers presented in this paper offer an attractive solution for integration in dielectric antenna splashplate feeds. Bandwidths in the order of 12 or 19 percent are achievable. The design process involving initial design and optimization is straightforward. Two examples in the WR137 waveguide band, measurements as well as component integration at 13 and 23 GHz demonstrate that this is a viable option for waveguide based dielectricantenna feeds.

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