Results for a Simple Compact Narrow-Wall Directional Coupler

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***Abstract*—Results are presented for a compact narrow-wall directional coupler which is suited for use in low-profile beamforming networks. This geometry, based on the Riblet short-slot coupler, makes use of continuous coupling between adjacent waveguides through a common full-height slot in the narrow wall. From the point-of-view of design and manufacturing this coupler geometry is attractive since it does not require capacitive loading. This comes at the expense of bandwidth: measured results show that over a 6.5% bandwidth ±0.125-dB power equality, 30 dB isolation and 1.07 VSWR is achieved for a coupler of length 1.25λ_g. Although this is less than the 15% achieved for capacitively-loaded couplers it is sufficient for many applications and the simplicity of the geometry makes it an attractive option in narrowband designs.**

***Index Terms*—Beamforming network, directional coupler, mode matching, Riblet coupler.**

I. Introduction

Directional waveguide couplers are widely used in microwave components and networks. Numerous publications have appeared on this subject of which an excellent overview is given in [1]. In many applications co-directional narrow-wall couplers are required due to specific space restrictions. Narrow-wall couplers are classified by the way in which coupling is achieved. Examples are single aperture coupling [2], multi-aperture coupling [3]–[5], and continuous aperture coupling [6]. The compact Riblet short-slot coupler [6] with close to equal power splitting, high isolation, low VSWR, and accurate 90° phasing over 15% bandwidth is an example of the continuous aperture coupling type. This coupler represented a major contribution to the field and has been widely adopted by industry [1]. For this coupler, it was found that in practice a capacitive tuning screw or dome must be carefully inserted in the coupling region in order to provide the desired performance [7]. There are situations in practice however, where not having to use a capacitive dome presents definite advantages, in spite of the slightly inferior (but sufficient) RF performance of the resulting hybrid. These advantages include a much simplified design procedure and an inexpensive manufacturing process. This paper presents results for such a simplified geometry and compares the bandwidth performance with that of a commercially-available capacitively-loaded coupler.

II. Design Considerations

A schematic representation of the geometry of this coupler is shown in Fig. 1. This figure shows a full-height slot in the common narrow-wall between two adjacent rectangular waveguides. H-plane steps are employed to achieve impedance match. The number of steps employed determines the bandwidth performance of the coupler; with more steps it is possible to improve on the bandwidth performance at the expense of size. The input-, coupled-, output- and isolated ports, and the associated port numbering convention, is shown in this figure.

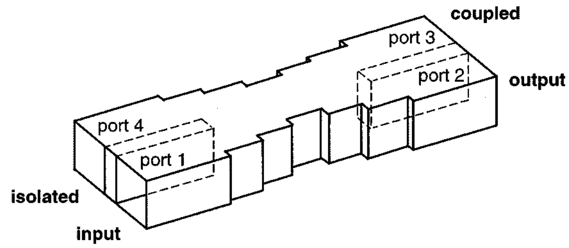

Fig. 1. Schematic representation of the proposed coupler geometry.

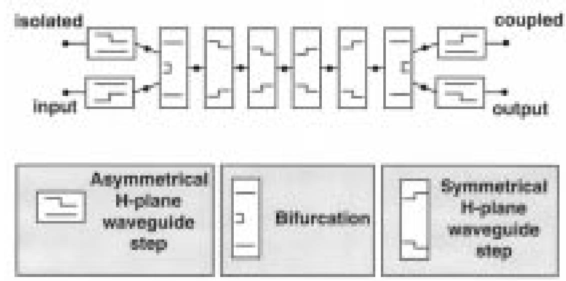

Fig. 2. Schematic representation of the mode-matching model of the coupler. Nodes are shown as dots $(\cdot)$ and the input and output ports are identified. The building blocks of the model are discontinuities for which mode-matching models are readily available: H-plane waveguide steps and bifurcations.

The full-wave mode-matching method is used in the design and Fig. 2 presents a schematic representation of the model consisting of a series of interconnected H-plane waveguide steps and bifurcations. The effort required in the construction of the model is minimal and since mode-matching is highly efficient in the analysis of these waveguide discontinuities, execution time is such that optimization of the variable dimensions $L_1, L_2, L_3, L_{\rm gap}, W_1, W_2$, and W_3, shown in Fig. 3 can easily be performed. For capacitively-loaded couplers, on the other hand, the need for a dome complicates both the construction of the model and also considerably increases the execution time for analysis—let alone optimization. This increase in execution time is also evident in cases where finite element-based analyzes such as HFSS are employed since many elements would be needed to accurately model the dome or tuning screw. Therefore, the proposed coupler geometry

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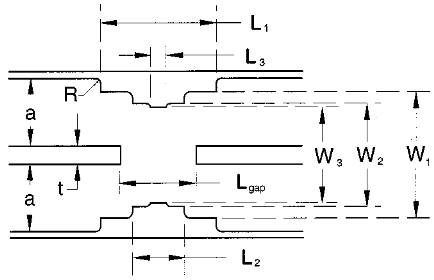

Fig. 3. H-plane cross-sectional view of a three-step coupler.

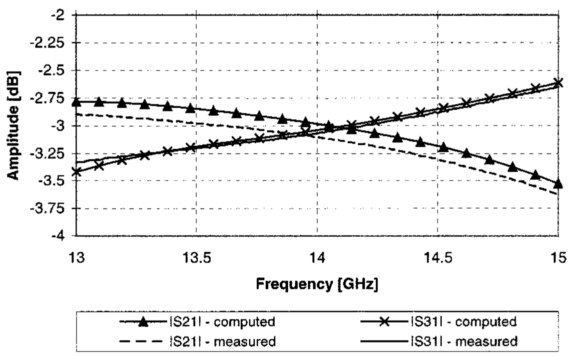

Fig. 4. Measured and computed $|S_{21}|$ and $|S_{31}|$ values of the proposed geometry.

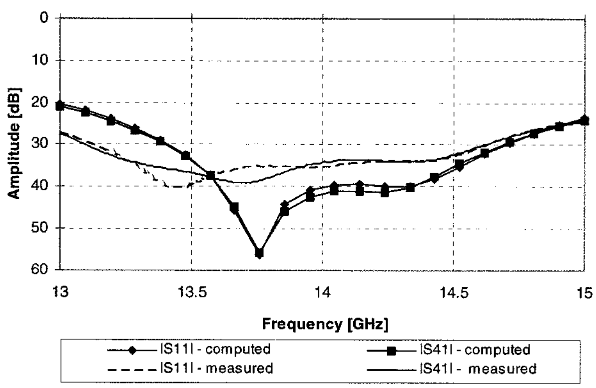

Fig. 5. Measured and computed return loss ($|S_{11}|$) and isolation ($|S_{41}|$) performance of the proposed geometry.

presents significant advantages over the capacitively-loaded couplers as regards ease of design.

III. Results

A three-step Ku-band design was performed for which Fig. 3 shows an H-plane cross-sectional view with $a = 0.75'', t = 0.2'', R = 0.040''$, $L_1 = 1.282'', L_2 = 0.572'', L_3 = 0.172''$, $L_{\text{gap}} = 0.838'', W_1 = 1.400'', W_2 = 1.142''$, and $W_3 = 1.060''$. At 14 GHz the coupler has a total length of $1.25\lambda_g$ which compares favorably with the commercially-available coupler in [8]. Fig. 4 presents a comparison between measured and computed $|S_{21}|$ and $|S_{31}|$ values for the proposed coupler. Computed results were obtained with Ansoft's HFSS assuming zero internal radii (R). Close comparison is found between measurements and predictions. $|S_{31}|$ is well predicted and $|S_{21}|$ predicted accurately to within 0.12 dB. The ± 0.125 dB power equality bandwidth is 6.5% compared to 15% achieved for the coupler presented in [8]. The return loss ($|S_{11}|$) and isolation ($|S_{41}|$) are in excess of 30 dB over a bandwidth of 10.6%, as illustrated in Fig. 5. Fig. 6 presents the measured and computed relative phases of S_{21} and S_{31}. As shown, the measured relative phase is within 0.3° of the required 90° across the entire frequency band of 13–15 GHz. This coupler succeeded in meeting the 5% bandwidth (± 0.2 dB power equality, 30 dB isolation and 1.07 VSWR) requirement for a practical beamforming application.

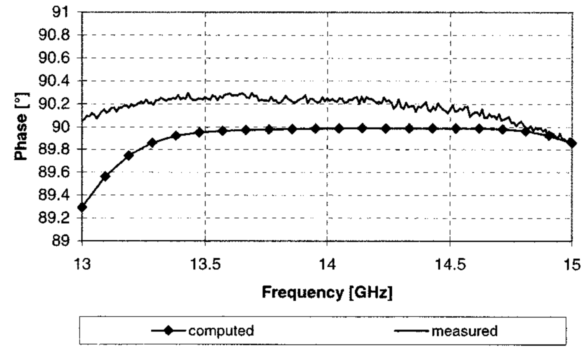

Fig. 6 Measured and computed relative phases of S_{21} and S_{31}. (Note that the vertical scale is 0.2° per division).

IV. Conclusions

Results were presented for a simple narrow-wall directional coupler which is based on the Riblet short-slot coupler. The advantage of this new coupler is that it does not require capacitive loading which considerably simplifies the design and manufacturing processes and hence reduces cost. This advantage comes at the expense of bandwidth: the measured ± 0.125 dB power equality, 30 dB isolation and 1.07 VSWR bandwidth is 6.5% compared to 15% for capacitively-loaded couplers. In practice however, the success of a design is judged both by its RF performance as well as by the cost and effort required in the design and manufacturing. Therefore this coupler presents an attractive alternative for narrowband applications.

References

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