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IMPORTANT INFORMATIVE STATEMENTS

Contra-Directional 3dB 90º Hybrid Coupler in Ridge Waveguides Using Even and Odd TE Modes

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***Abstract*—A novel compact wide-band contra-directional single conductor ridge waveguide coupler is presented. It exhibits 50% fractional bandwidth with equal power split between the through and coupled ports while occupying a very compact volume. The design can be exploited in versatile applications, such as beam forming, or high-power combiners. The methodology to design the coupler is presented. It starts with designing the coupling section in a modified double ridge waveguide that supports two independent propagating TE modes. Proper choice of the cross section allows the designer to achieve the required impedance levels for tight coupling values, not common for standard waveguide contra-directional couplers. An S-band proof of concept prototype was synthesized, simulated, fabricated and tested demonstrating excellent measured results without any tuning.**

***Keywords*— Ridge waveguide, backward coupling, beam forming, power amplifiers.**

I. INTRODUCTION

Directional couplers find versatile uses in many microwave systems, whether in signal sampling, beam forming or in power combining [1, 2]. TEM based contra-directional operation, in particular, offers wide bandwidth and compactness. Traditionally, this type of couplers have been mainly realized in multi-conductor transmission media, limiting it to technologies such as strip-line, re-entrant coaxial lines or simple microstrip lines. The reason for using these structures is that the coupler's principle of operation relies on the existence of two propagating modes: TEM modes in strip-lines and re-entrant coaxial lines or quasi-TEM modes in microstrip lines. However, this constitutes some limitations due to the inherent characteristics of these structures, in terms of power handling in the case of planar microstrip realization, and difficult manufacturing and assembly processes in strip-line and re-entrant coaxial line realization.

Classical four port ridge waveguide coupler realizations have been limited to co-directional couplers such as cross-guide and broad wall [3], multi-hole [4] which are often used for loose coupling applications or branch-line configuration for tight coupling designs [5]. More recent realizations include Riblet type couplers [6], and 3λ/4 coupler in ridge-gap technology [7].

This paper presents a novel ridge waveguide contra-directional coupler realization (see Fig. 1-a). The basic idea in this design is to utilize the unique characteristics of the double ridge waveguide cross-section to engineer the coexistence of two propagating modes. The two modes play the role of the even and odd modes used to describe TEM-based couplers [1], although with distinct differences. In this case, the modes are TE with different (non-zero) cutoff frequencies, and, with characteristic impedances that vary with frequency.

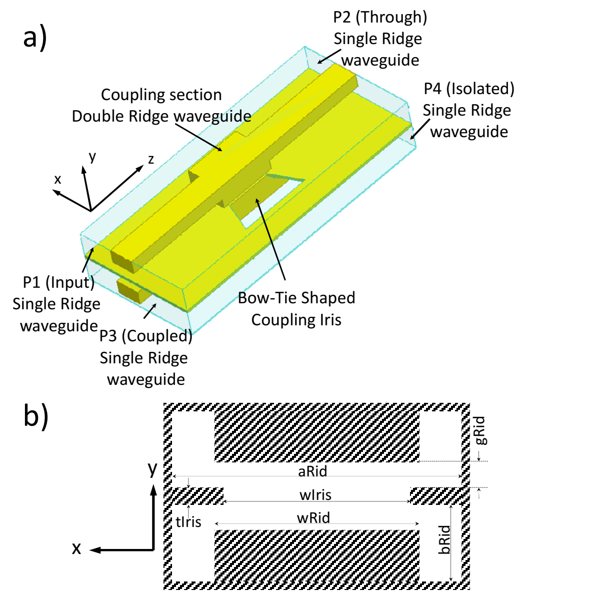

Fig. 1. Proposed ridge waveguide contra-directional coupler. a) 3D model showing the top and bottom ridge waveguides and the coupling Iris b) Modified double ridge waveguide xy-cross section at the middle of the structure.

By properly choosing the parameters of a modified double ridge waveguide cross-section (see Fig. 1-b), two independent propagating modes can be made to coexist within the frequency band of interest in the coupling region between the single ridge waveguide ports. The design methodology will be explained in the following sections, elucidated with an S-band 3-dB coupler centered at 2.25 GHz, where the compactness of ridge waveguide is especially advantageous.

II. COUPLER DESIGN

A. Ideal Circuit Model

The ideal circuit model of the contra-directional coupler is the widely known classical coupled line model. The model is based on the well-known even and odd impedances, and their relation to the coupling factor. While approximate closed form expressions for the characteristic wave impedance of the odd-mode case (electric wall symmetry) of a double ridge waveguide [8] can be used, no such expressions exist for the even-mode case (magnetic wall symmetry) that is needed in this design. In fact, the double ridge waveguide in Fig. 1-b has a

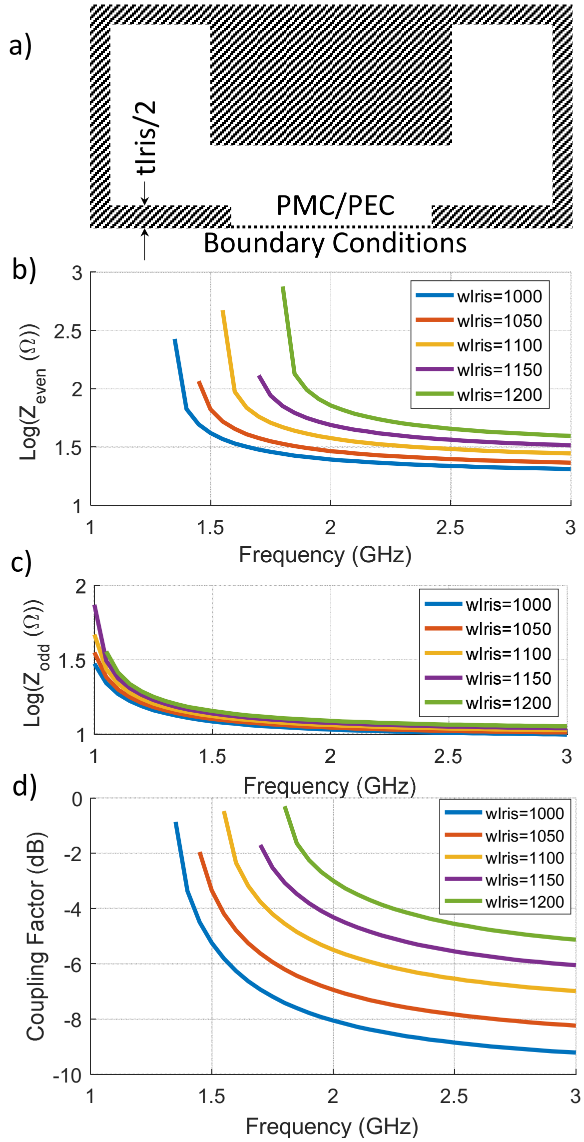

Fig. 2. a) Cross section of the double ridge waveguide coupling section cut along the symmetry plane. Variation of even (b) and odd (c) mode impedance, and coupling factor (d) with frequency for different iris widths. Dimensions according to Fig. 1-b: aRid=2200 mil, bRid=450 mil, wRid=1325 mil, gRid=23 mil, tIris=50 mil. The terminating single ridge waveguide has aRid=2200 mil, bRid=450 mil, wRid=1100 mil, and gRid=100 mil.

non-conventional shape due to the metallic side protrusions. The cross section is formed in the middle of the structure due to the existence of the large coupling Iris. Numerical techniques must be used to solve for the even-mode and odd-mode characteristic impedances for the used cross-section. Fig. 2-a shows the modified double waveguide cross section cut along the horizontal symmetry plane.

By applying Perfect Magnetic Conductor (PMC) or Perfect Electric Conductor (PEC) boundary conditions at the symmetry plane and solving their associated two-dimensional electromagnetic eigenvalue problems, the even mode and odd modes can be characterized. The characteristic wave impedances as well as the coupling factor can be then readily calculated. Fig. 2-b, -c, -d show the calculated values of these parameters for variations of the cross section.

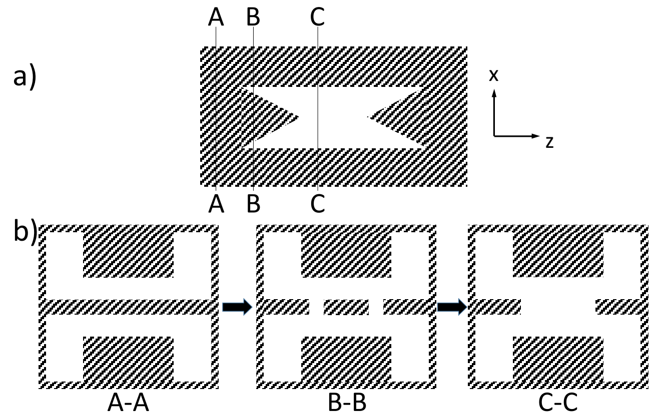

Fig. 3. Shaping of the coupling iris placed in between the two main single ridge waveguides. a) Bow-tie coupling iris. b) Different ridge waveguide cross sections (xy-planes) at different planes along the coupling iris (different planes for constant z).

Initial choice of the coupling iris width is based directly on the obtained design curves. The initial length of the coupling section is chosen to be approximately $\lambda_g/4$ at the center frequency of the coupler. The single ridge waveguide terminating ports are chosen such that their characteristic wave impedance $Z_0 = \sqrt{Z_{even} \times Z_{odd}}$. The effects of non-zero different cutoff frequencies for these modes are evident, in particular for the even impedance case. Careful design of the large coupling window is needed to account for such variation.

B. *Shaping of the Coupling Iris*

A problem frequently encountered in contra-directional couplers is the degraded return loss and isolation across the wide bandwidth. This is partly due to the frequency dependent effects of the geometrical discontinuity between the terminating ports and the coupling region. Another reason is the differences between propagation velocities of the used modes if they are not purely TEM. Special care must be taken to reduce such degradation. This can be partially done for some cases with the help of tuning screws [1].

In the presented design, shaping of the coupling window in a form different from the regularly used circular or rectangular irises is needed. A bow-tie shape provides a gradual geometrical change where the cross section basically morphs smoothly from two separate single ridge waveguides to a modified double ridge waveguide in the coupling region as shown in Fig. 3

C. *Coupler Synthesis*

The initial dimensions of the coupling section are synthesized using the design curves in Fig. 2. These preliminary dimensions are then used as the starting point for a full-wave optimization process where the dimensional parameters are optimized to obtain the required power split, return loss as well as isolation levels across the frequency band of interest.

To improve the performance, the input ridge waveguides are also tapered into the double ridge waveguide section. The simulated full-wave response using ridge waveguide ports is shown in Fig. 4.

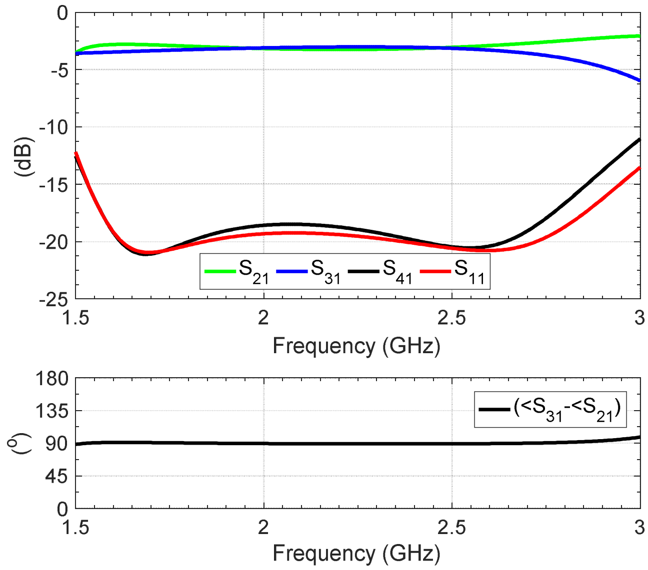

Fig. 4. Simulated results of the ridge waveguide contra-directional coupler using single ridge waveguide ports.

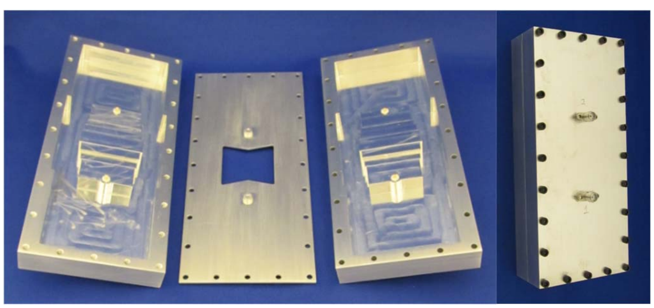

Fig. 5. Manufactured Prototype in two halves and an insert.

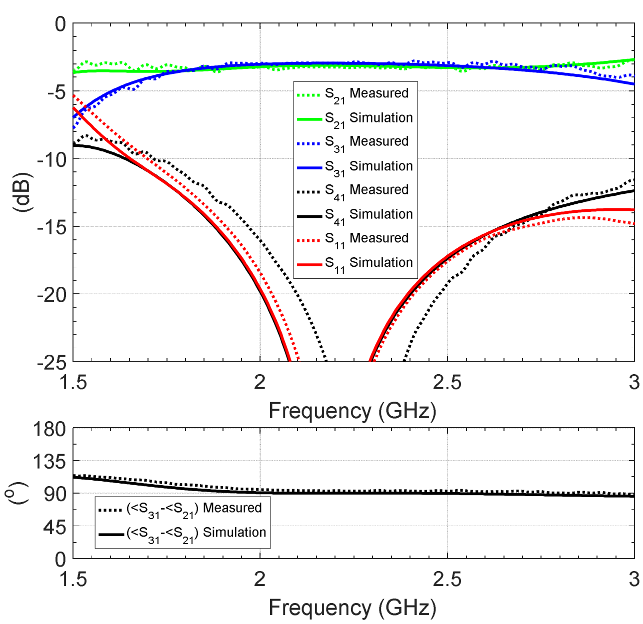

Fig. 6. Measured and simulated results of the ridge waveguide contra-directional coupler with SMA ports.

It shows very wide band power split performance with good return loss and isolation levels.

III. Experimental Results

In order to measure the performance of the coupler, a wide-band single ridge waveguide to SMA transition was designed and integrated at the four ports into the coupler hardware assembly. The design was fabricated out of aluminum by CNC milling. The coupler was assembled and tested. No tuning was required. Fig. 5 shows the fabricated hardware and Fig. 6 shows the measured results. The measured results agree well with the simulations including the transitions. With transitions integrated into the prototype, the full volume occupied is 30 mm × 58 mm × 155 mm. This can be further reduced if integrated waveguide interconnects are used instead of transitions to SMA. The actual ridge waveguide coupler without the transitions occupies merely 30 mm × 58 mm × 29.2 mm, which is a very compact design for an S-band waveguide coupler.

IV. Conclusion

A novel, wide-band, compact ridge waveguide contra-directional coupler is presented. Its principle of operation is based on utilizing two independent TE modes, similar to the classic even and odd TEM modes of multi-conductor coupled line couplers. The design provides tight 3 dB coupling over a 50% fractional bandwidth and occupies a very compact size. Designs based on the presented idea and methodology can find possible utilization in a variety of applications including high power sensing, beam forming and in particular in high power, wide band combining applications. A proof of concept prototype was synthesized, simulated, fabricated and tested.

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