A design of wideband high-power 3-dB quadrature coupler using defected ground structure for status data transmitting system

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ABSTRACT

The paper presents a wideband 3-dB quadrature coupler designed for operation at 2 GHz. The presented coupler is based on a broadside-coupled suspended structure in combination with a proposed defected ground structure (DGS) allowing for high power, wide-band and improved harmonic suppression performance. The experimental results show 0.2 dB of insertion loss, return loss of better than 18 dB and isolation of better than 25 dB in the frequency range from 1.74 to 2.67 GHz. The proposed coupler is able to be integrated in the status data transmitting system, which is suitable for vessel monitoring. The fundamental characteristics of the implemented coupler have been measured and verified.

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1. INTRODUCTION

High power, wide bandwidth, low-loss combiners or dividers with an average power handling capability of hundreds of Watts are used generally for combining high power amplifiers. The functionality of the coupler is to combine two input signals which have equivalent power levels and with a 90 degree relative phase difference. It can also separate an incoming signal into two output signals with similar amplitudes and a phase difference of 90 degrees.

Various methods are proposed to improve the performance of couplers [1-9]. Most of them are applied to low power systems. Typically, A 3-dB quadrature coupler which is suitable for printed circuit board implementation presented in [1]. It shows that the coupler can reduce the drawbacks of conventional thin-film microstrip line Lange coupler with the advantages of coplanar waveguide coupled line structures. Another 3-dB quadrature coupler using broadside-coupled coplanar waveguides [2] illustrates that the coupler with a broadside-coupled structure can easily be designed on a single-layer substrate printed circuit board, without using multi-layer substrates. However, such low-power couplers cannot be used directly for high power applications, because of the field breakdown effect [10] and thermals issues with the coupler.

Defected Ground Structures (DGS) have been proposed for microwave applications such as filters [11-15], amplifier [16], and wireless power transfer [17]. In this paper, we propose a new coupler design for high power applications, adopting a broadside-coupled suspended structure (BSS) and a defected ground structure (DGS) to improve bandwidth, reduce insertion loss and offer a truly high power solution. The proposed coupler is able to be integrated in the status data transmitting system, which is suitable for vessel monitoring [18-19]. The paper is organized as follow. Section 2 introduces the design considerations of the proposed coupler. The experimental results are provided in section 3 and discussed in the last section.

2. THEORY AND DESIGN

The presented power combiner is based on a broadside-coupled air suspended strip-line (BSS), realizing a tightly coupled structure. A 3-D drawing of the combiner is shown in Figure 1. The BSS structure is characterized by two transmission lines in which $Z_{0,e}$ and $Z_{0,o}$ are respectively the even and odd characteristic impedances. Expressions for the mode characteristic impedances, coupling ratio (C) and characteristic impedance (Z_0) are given as following [20, 21]:

$$Z_{0,e} = Z_0\sqrt{\frac{1+C}{1-C}} \quad (1)$$

$$Z_{0,o} = Z_0\sqrt{\frac{1-C}{1+C}} \quad (2)$$

$$Z_0 = \sqrt{Z_{0,e} \times Z_{0,o}} \quad (3)$$

The dimensions of the structure are determined for a given dielectric substrate and substrate thickness following [20, 22] :

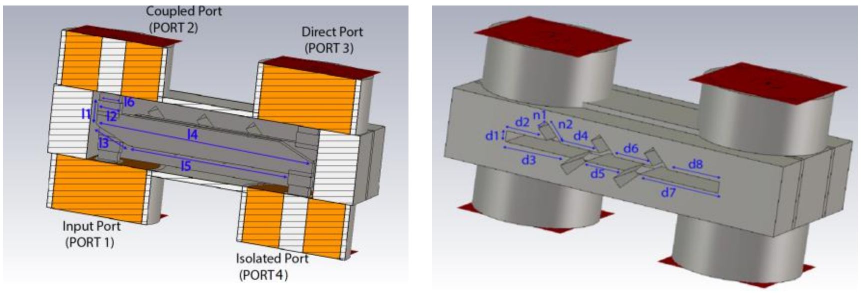
$$\frac{W}{b} = \frac{1}{\pi}\left[ln\frac{1+M}{1-M} - \frac{S}{b}ln\frac{1+\frac{M}{k}}{1-\frac{M}{k}}\right] \quad (4)$$

$$\frac{S}{b} = 0.0017 Z_o\sqrt{\epsilon_r}\left(\frac{1-C}{1+C}\right)^{1/2} ln\frac{1+k}{1-k} \quad (5)$$

Where,

$$M = \left[\left(k\frac{b}{S} - 1\right) / \left(\frac{1}{k}\frac{b}{S} - 1\right)\right]^{1/2}$$

$$N = \frac{60\pi}{Z_0\sqrt{\epsilon_r}}\left(\frac{1-C}{1+C}\right)^{1/2}$$



(a) (b)

Figure 1. (a) The 3D drawing of the presented quadrature coupler at 2 GHz, (b) The proposed DGS structure introduces the tree-shaped ground slot patterning in the 3D model

for $N \leq 1$

$$k = \left[1 - \left(\frac{0.5exp(\pi N)-1}{0.5exp(\pi N)+1}\right)^4\right]^{1/2}$$

for $N \geq 1$

$$k = \left(\frac{0.5exp(\pi N)-1}{0.5exp(\pi N)+1}\right)^2$$

For a given coupling ratio with air as dielectric substrate ($\epsilon_r = 1$), the ratios S/b and W/b can be computed following the formulas (4) and (5) in which S, b, and W are defined in Figure 2. For the 3-dB coupler design, the initial dimensions are obtained as follows: W = 6.9 mm, b = 6.35 mm, S = 1.4 mm, t = 0 mm. Due to Ohmic loss characteristics at a high-power level, the thickness of strip conductors is increased to 1.5 mm, thus allowing an improved average power handling capability. Though, the high thickness of the strip conductors takes adverse effect on the accuracy of the formulas (4) and (5). The thickness correction is numerically calculated by using the computer-aided design software CST. The numerical results of the structural dimensions of the coupler are given as follows: W =5.4mm, b=10.8mm, S=0.8mm for the 1.5mm of strip conductor thickness. The proposed tree-shaped defected ground structure (DGS) in association with a bevel at the corner edge of each strip conductors allows improving the bandwidth as well as the harmonic rejection (see Figure 1a and Figure 1b). A trade-off between bandwidth and average power handling capability must be taken into consideration using beveling techniques. This reduces the high strength of the electric field at the beveled edges (Figure 3). The tree-shaped structure is symmetrically placed at the top and bottom of the ground plane (Figure 1b).

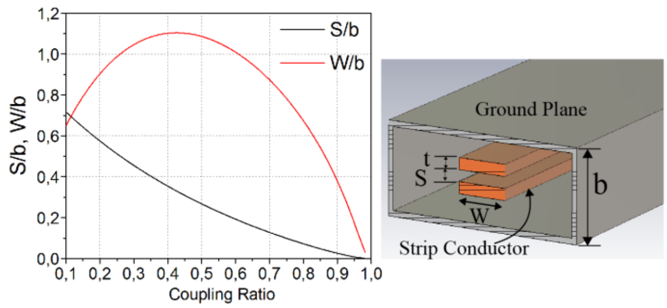


Figure 2. Variations of S/b and W/b as a function of coupling ratio with air substrate (left); Geometry of broadside-coupled suspended strip-line (right) in which S is the space between strip conductors, t is the thickness of conductors, W is the width of strip conductors, and b is the ground spacing

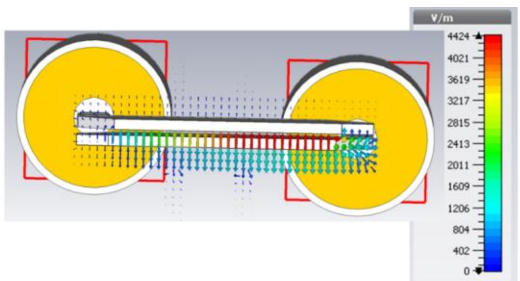
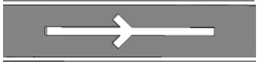
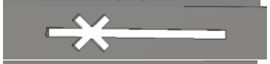
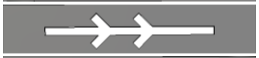


Figure 3. The electric field lines pattern (cross-view). The simulation is performed using a signal of 1 W fed into the output

The design of a conventional hybrid coupler based on the calculated dimensions is adapted considering the bevel technique, as to extend the bandwidth, which is normally from 400 MHz to 600 MHz for other combiners. We propose further optimization of the design using the new DGS structure, without any changes in the coupling structure realized previously.

Table 1. Typical defected ground structures

Case	DGS structure	Bandwidth (MHz)	Case	DGS structure	Bandwidth (MHz)
1		715	5		875
2		867	6		720
3		890	7		843
4		834	8		930

The optimization of the DGS structure is implemented following a set of requirements, i.e. bandwidth, S parameters, power handling capability (RF breakdown), etc. Table 1 illustrates some typical Defected Ground Structures with corresponding simulated bandwidths. In our design, the tree-shaped structure is optimally designed with 5 branches using the CST simulation software. For the presented coupler design, the final simulation parameters are: l1 = 4.35 mm; l2 = 4.5 mm; the bevel length l3 = 7.39 mm, for the initial design the bevel length is 0 mm; the length of the strip conductor is a quarter-wavelength at 2 GHz; l4 = 42 mm; l5 = 30.5 mm; l6 = 4 mm, in which l2 and l6 are step matching sections at ports; the spacing grounds b = 10.8 mm; the spacing between strip-lines S = 0.8 mm; d1 = 2mm; d2 =7.5mm; d3 =12.5mm; d4 =7.17mm; d5 =7.17mm; d6 = 7.17 mm; d7 =14.5 mm; d8 = 9.5 mm; n1 =2 mm; n2 =4.5 mm. The strip-line and the housing are made of copper. The overall dimension of the coupler is 30 mm x 65 mm x 38 mm (WxLxh). The electric field pattern of the combiner is described in Figure 3 for 1 W output power. For 1 kW signal, this translates into **0.126 MV**/m of the maximum E-field, which is lower than the threshold breakdown electric field of the dry air [10]. The simulated results are demonstrated in Figure 4 for both cases: with and without the DGS structure. It is clear that using DGS in the coupler design has remarkable advantages in term of bandwidth and return loss improvement.

3. RESULTS AND DISCUSSION

The fabricated coupler is designed at the center operating frequency of 2 GHz as shown in Figure 5. We use the PNA-N5221A vector network analyzer (VNA) to measure the S-parameters of the combiner. The simulated and measured results are in good agreement as shown in Figure 6. The bandwidth is measured up to 930 MHz. The insertion loss is measured on the order of −3.02±0.2 dB. The maximum return loss at port 1 and 3 are measured approximately 40 dB, while on the order of 30 dB at port 2 and 4 due to a slight mismatch between the conductor of the coaxial connector and the transmission lines. It results from the manual assembly.

The phase shift between ports is illustrated in Figure 7. The phase shift between two Output ports of coupler is 90±1 degree. There is a high agreement between the simulation result and the measurement result.

Our results are compared with the recent published work in Table 2. It can be seen that the power handling capacibility can reach to 1 kW by using copper busbar for transmission line. The bandwidth and return loss can be improved by using DGS. Thus, our coupler can be used in the status data transmitting system as presented in [18, 19].

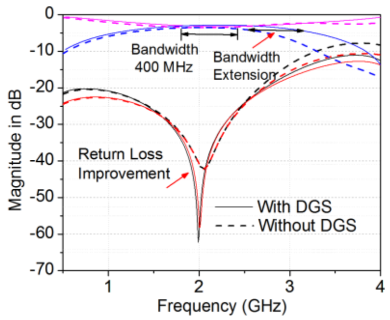


Figure 4. The simulated results of the coupler as function of frequency with and without DGS

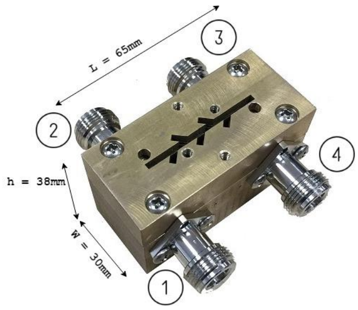


Figure 5. The proposed DGS-coupler is shown

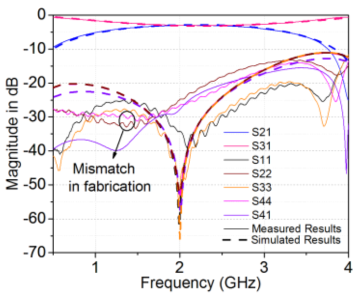


Figure 6. A comparison of the simulated and measured results of the coupler is shown

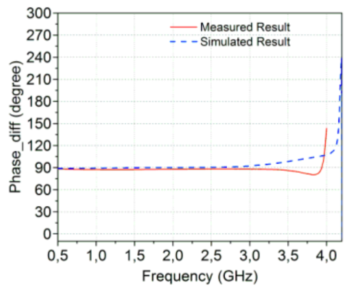


Figure 7. Phase shift among ports

Table 2. The comparison between our research and previous published researchs

References	Frequency (MHz)	Bandwidth (MHz)	Power Handling Capability (W)	Insertion Loss (dB)	Isolation Loss (dB)	Return Loss (dB)	Manufacture Material
[1]	1800÷2800	1000	-	3÷0.1	Better than 20	Better than 20	Printed Circuit Board (PCB)
[2]	2100÷2700	600	-	3.2÷0.1	Better than 19	Better than 19	PCB
[23]	1770÷2200	570	-	3÷0.5	Better than 20	Better than 20	PCB
[24]	2000÷2800	800	-	3÷1	Betterthan 14	Better than 15	PCB
[This work]	1740÷2670	930	**Up to 1 kW**	3.02÷0.2	Better than 25	Better than 18	**Copper BusBar**

4. CONCLUSION

We analyzed and successfully designed a 3-dB coupler using a newly proposed DGS structure. Our coupler has a bandwidth of 930 MHz. The insertion loss, return loss, and isolation loss of this coupler are 3.02 ÷ 0.2, 18 dB and 25 dB respectively. The power handling capability of the design can further be improved by choosing the higher thickness of the strip-conductors and the proper connectors, i.e. 7/16 type. The design methodology can be applied to any frequency range of interest up to 3 GHz, and it could be adapted for other combining structures such as e.g. the Wilkinson and Gysel types, as to expand their nominal bandwidths. The results prove that our coupler can be used in the status data transmitting system.

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