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UWB Double Ridge Waveguide Coupler with Low Loss

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Abstract—A new ultra-wide band coupler obtained with two crossed double-ridge waveguides coupled through one aperture is proposed. The main features of the coupler include: operating frequency from 6 GHz to 18 GHz; coupling coefficient below -50 dB; return loss of all the ports under -15 dB; minimum directivity 15 dB; small size and low losses, which make it appropriate for high-power applications. The whole structure is simulated with CST and HFSS software, fabricated and measured. Excellent agreement between measured and simulated results was achieved.

Index Terms—directional couplers, double ridged waveguide, wide band couplers.

I. INTRODUCTION

directional coupler operating at the C, X, Ka and Ku H bands (6 GHz-18 GHz) is designed and fabricated to be used for satellite transponder applications, where it is required to sample high-power and ultra-wide band (UWB) signals. Its coupling coefficient is below -50 dB and this feature presents the advantage of eliminating the attenuator at the coupling port when sampling in high power applications. The design solution is based on the introduction of a tapered ridge to obtain wider frequency bandwidth. The traditional design of a microwave coupler was based on two waveguides that are coupled through small apertures so that the field could be considered uniform over the apertures. The number of apertures controls the amount of coupling. In the case of a single aperture, the bandwidth is about 5-7 %, which is not sufficient for making an UWB coupler. Augmenting the number of coupling apertures to improve the frequency bandwidth increases the mutual coupling, which is not desirable [?]. Various improvements have been made over the years [?]. To the best of our knowledge, there is not in the literature a directional coupler that meets all the features described above. The high-power requirement demands that waveguides be considered. In fact, microstrip technology cannot be used because it cannot handle high power levels, even though it satisfies the bandwidth requirements [?].

Other types of microwave couplers such as those based on ferrites cannot be considered because of their high losses. On the other hand, coaxial and waveguide directional couplers are the most common high-power solutions when bandwidth requirements are not critical. Hence, we start from a single hole coupler based on waveguide technology to handle high power and then we improve the design to achieve the UWB requirements.

II. DESIGN PROCEDURE

The proposed UWB double ridge waveguide coupler is shown in Fig ?? and it was designed to satisfy requirements including bandwidth, directivity, reduced size, power handling, losses and coupling coefficient [?]. The main features of our design are: (1) using a tapered ridge and (2) introducing a gap between the wall and the connector pin. Both these features improve the return loss and extend it over 3 octaves. The starting point of the design is the standard waveguide WRD650, which has the cutoff frequencies of the first two lowest order modes at 3.31 GHz and 18 GHz. An approximation of the dominant mode cutoff frequency is [?], [?]

$$f_c = \frac{3 \cdot 10^8}{2(a-s)} \left[1 + \frac{4}{\pi} \left(1 + 0.2\sqrt{\frac{b}{a-s}} \right) \left(\frac{b}{a-s} \right) \ln \csc \frac{\pi d}{2b} + \left(2.45 + 0.2\frac{s}{a} \right) \left(\frac{sb}{d(a-s)} \right) \right]^{-0.5}$$
(1)

where the symbols used are defined in Fig ??. The power handling capability of waveguides is related to the maximum power that can be transmitted without causing an electric arc inside the waveguides. One major limiting factor is the distance between metal edges inside waveguides. For double ridge waveguides this distance is shorter because it corresponds to the separation distance *d* between upper and lower ridges, shown in Fig ??. Accordingly, it is apparent that these waveguides. Fortunately, the ranges of levels of power handling capability are acceptable and still significantly higher than those achievable with other couplers such as microstrips. For the WRD650 waveguide, the average power handling is 1.5 KW and the peak power handling is about 3 KW [?].

The directivity of the cross waveguide depends on the location of the coupling aperture and is defined as [?]

$$D = -20 \log \frac{B_a}{A_a} \, \mathrm{dB},\tag{2}$$

where A_a and B_a are the transmission coefficients in the forward and backward directions, respectively, given by [?]

$$A_a = -\frac{Mh_x h_z k_c}{abs_a} - j \frac{P e_y^2 k^2}{2abs_a \beta},\tag{3}$$

$$B_a = -j \frac{P e_y^2 k^2}{2abs_a \beta}.$$
(4)

In the previous expressions, P and M are the electric and magnetic dipoles of the coupling aperture and depend on its shape. These quantities have been determined experimentally for various aperture shapes [?], [?]. Our design uses the cross shape because the coupling coefficients for the magnetic and

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Fig. 1: Geometry and parameters of the waveguide directional coupler (a) top view, (b) inside view, (c) one waveguide view, (d) side view (e) coupling hole view. The actual values of the dimensions are given in Table I.

electric fields can be adjusted independently [?]. Previous double ridge cross directional couplers use multiple holes to increase the bandwidth, which results into larger coupling coefficient and bulky structures [?], [?]. One goal of the proposed design is to avoid the presence of an attenuator, which is required when the coupler is used to measure RF power. In fact, when the output RF power is high, attenuators must be

TABLE I. PHYSICAL DIMENTIONS OF THE COUPLER

Parameter	L_1	L_2	L_3	L_4	L_5
Dimension (mm)	87.14	18.29	7.3	3.6	28.19
Parameter	Lo	<i>L</i> ₇	L_8	L	L_{10}
Dimension (mm)	4.4	14.86	2.81	3	6
Parameter	<i>L</i> ₁₁	<i>L</i> ₁₂	L ₁₃	L14	L15
Dimension (mm)	2.21	38	5.8	1.5	1
Parameter	L_{16}	L17	L_{18}	dg	
Dimension (mm)	5.5	3.6	8.15	2.5	



Fig. 2: Cross section of the proposed double ridge waveguide coupler.

used before RF power meters to protect them against damage. This goal is met by achieving a low value of the coupling coefficient below -50 dB by using only one coupling hole. The drawback of using only one hole is that the bandwidth is reduced, however the reduction in bandwidth is compensated for by introducing the tapering in the internal ridges. A similar approach was used for the different context of the transition from a waveguide to a coaxial cable in [?]. In addition, the advantages of using only one hole include (i) a shorter overall length of the coupler and (ii) lower losses. The expressions given in equations (??) and (??) depend on the TE modes in the trough region, which may be approximated as [?]

$$e_x = h_y = \frac{E_x}{E_0} = \frac{\eta k}{\beta} \frac{H_y}{E_0} = \cos \frac{k_c s}{2}$$
$$\times \sum_{n=1}^{\infty} \frac{2b(\gamma_n^2 + k_c^2)}{(n\pi)^2 \gamma_n \sinh k_{nx} l} \sin \frac{n\pi d}{b} \cosh(\gamma_n x) \sin \frac{n\pi y}{b}$$
(5)

$$e_y = h_x = \frac{E_y}{E_0} = \frac{-\eta k}{\beta} \frac{H_x}{E_0} = \frac{d}{b} \frac{\cos\frac{k_c s}{2}}{\sin k_c l} \sin k_c x$$
$$+ \sum_{n=1}^{\infty} \frac{2\sin\frac{n\pi d}{b}}{(n\pi)\sinh\gamma_n l} \cos\frac{k_c s}{2} \sinh(\gamma_n x) \sin\frac{n\pi y}{b} \qquad (6)$$
$$h_z = \frac{-j\eta k}{k_c} \frac{H_z}{E_0} = \cos\frac{k_c s}{2} \left[\frac{d}{b} \frac{\cos k_c x}{\sin k_c l}\right]$$



Fig. 3: Directivity values versus position of the hole in three different frequencies.

$$\times \sum_{n=1}^{\infty} \frac{2k_c \sin \frac{n\pi d}{b}}{n\pi \gamma_n \sinh(\gamma_n l)} \cos \frac{k_c s}{2} \cos \gamma_n x \cos \frac{n\pi y}{b}$$
(7)

where

$$\beta^2 = k_0^2 - k_c^2, \ \gamma_n^2 = \left(\frac{n\pi}{b}\right)^2 - k_c^2.$$
(8)

The values of the directivity as a function of the position of the coupling aperture are shown in Fig ??. This figure indicates that the directivity decreases when the operating frequency is increased and that the coupling aperture must be located as close as possible to the waveguide wall to obtain the desired value of 15 dB. In principle, this design approach is applicable to other frequency ranges, however, one should bear in mind that below 1 GHz the dimensions of the waveguide increase dramatically and above 30 GHz mechanical fabrication tolerances are very challenging. To reduce the reflection coefficient, the ridges of the waveguides have been tapered using a particle swarm optimization (PSO) algorithm, as it is implemented in the CST software. This results into a profile is similar to an exponential tapering, (see Fig ??). Another parameter that was optimized with the PSO algorithm to reduce the reflection coefficient is d_q , which is shown in Fig ??.

III. FABRICATION AND MEASUREMENT

The UWB double ridge cross waveguide coupler was designed using both HFSS and CST, fabricated according to the optimized dimensions reported in Table I, and it is shown in Fig ??. Scattering parameters were measured to verify the validity of the design with a HP8722D network analyzer and the measurement results are given in Fig ??. The measured directivity is shown in Fig ?? and it satisfies the design goal by exceeding the minimum requirement of 15 dB. There is an excellent agreement between the measured and the simulation results obtained with CST and HFSS. The differences between simulation and measurements may be due to mechanical tolerances and the SMA connectors used, which were of low loss type. Measured and simulated results have been shown in



Fig. 4: Measured and Simulated results of (a)Insertion Loss, (b)Coupling Coefficient, (c) Return Loss of the coupler

Fig ??. As shown in Fig ??, one arm along the direct pass is longer than other arm. The reason is that in the trough pass higher evanescent modes are created near the aperture hole and, with one arm longer than the other, these modes cannot reach the trough port. Another reason is that the ridge taper can be designed to be smoother so that S_{11} improves for high power pass.



Fig. 5: Measured and simulated directivity.



Fig. 6: Photo of the the coupler.

IV. CONCLUSION

A new UWB directional coupler has been proposed. The coupler works in the 6 GHz -18 GHz band and the VSWR of each port is under 1.5 and the minimum directivity is 15 dB the coupling coefficient is -50 dB. To reduce the return loss, the ridge has been designed with an exponential taper and some gaps have been added to the connector pins. This structure has been fabricated and an excellent agreement between measured and simulated results are achieved. In principle, this design approach is applicable to other frequency ranges, however, one should bear in mind that below 1 GHz the dimensions of the waveguide increase dramatically and above 30 GHz mechanical fabrication tolerances are very challenging.

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