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Double Ridged 180° Hybrid Power Divider With Integrated Band Pass Filter

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***Abstract*—We describe the design, construction and performance of a 180° hybrid power divider with integrated band pass filter for L-band (1.3–1.8 GHz). The hybrid is based on a cavity and two novel broadband coaxial-to-double ridged waveguide transitions. The design was optimized using a commercial 3-D electromagnetic simulator.**

The device was tested at room and cryogenic temperature. At the physical temperature of 77 K the measured input reflection was less than -17 dB, the maximum deviation from the ideal -3 dB coupling and 180° phase difference were, respectively ±0.25 dB and $\pm0.9°$. The experimental results are in good agreement with simulation.

***Index Terms*—Band pass filter (BPF), coaxial transition, cryogenics, double ridge waveguide, hybrid, L-band, power divider, Sardinia radio telescope.**

I. Introduction

The 180° hybrid power divider is a fundamental component in microwave circuits used to split a RF signal into two equal amplitude out-of-phase outputs. Several structures have been proposed in the literature and utilize different technologies and configurations. The two main categories are the waveguide and the planar structures. Examples of waveguide structures are the magic T-junction [1], [2], the Y-junction [3] and the waveguide cavity [4], which all have excellent performance; their physical dimensions decrease with operating frequency. Examples of planar structures that can be fabricated in microstrip or coplanar waveguide technologies are the rat-race hybrid [1], and the slotline balun [5]. The main advantages of the planar over the waveguide hybrids are the smaller dimensions and the wider achievable bandwidth (50% or larger) although with slightly worst performance in terms of insertion loss and phase imbalance. Here, we describe the design construction and test results at room temperature (300 K) and a cryogenic temperature (77 K) of a novel three-port 180° hybrid power divider based on a double ridged waveguide transmission line. The double ridged waveguide (DRWG) [6], [7] is a standard waveguide with a pair of metal ridge inserts that protrude into the center of the waveguide, parallel to the short walls, with the E-field maximum between the ridges. The main advantages of the DRWG compared to a conventional waveguide operating in the same band are its reduced cross section ($\approx 2 \div 3$ times smaller) its wider separation between the cutoffs of its dominant and of its first higher order mode, and its lower impedance; this allows a simpler match to a standard 50 Ω coaxial connector to be achieved over a very broad band. Therefore, a DRWG transmission line can in principle be employed to design a 180° hybrid whose performance is as good as a waveguide device and whose physical size is much reduced. A DRWG hybrid finds application wherever device compactness and high performance are a primary requirement.

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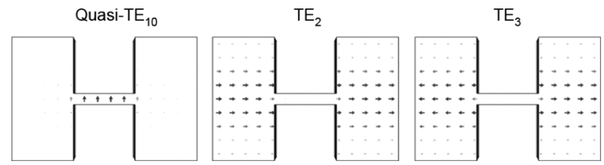

Fig. 1. Electric field distribution for the first three modes of a DRWG.

Our DRWG hybrid, developed for L-band (1.3–1.8 GHz,) is compact in terms of wavelengths ($\approx \lambda_g$) and is optimized to be well matched to N-type 50 Ω coaxial connectors and to have the lowest possible insertion loss with minimum deviation from the nominal -3 dB coupling and from the nominal 180° phase difference. Across the design band, the performance of the hybrid are largely superior to those of commercial devices. The device will be employed in a high-performance 1.3–1.8 GHz cryogenic radio astronomy receiver on the Sardinia Radio Telescope (SRT) [9]. The orthomode transducer (OMT) for the SRT L-band receiver is based on an orthomode junction (OMJ) and on two identical hybrids described in this letter. The OMJ separates each of the two input linear polarizations into two out-of-phase signals (four outputs). The two hybrids are used to recombine the out-of-phase signals in the OMT. A band pass filter (BPF) is integrated in the hybrid to help to reduce radio frequency interference (RFI) signals outside the 1.3–1.8 GHz band.

II. Architecture and Mechanical Design

Our L-band 180° hybrid power divider is illustrated in Fig. 1, top panel. The device utilizes an architecture similar to the one described in [4] and is based on a DRWG cavity terminated at both ends by reactive loads (short circuits.) The hybrid consists of three different parts: an input coaxial to single probe DRWG transition, a DRWG BPF and an output DRWG to double probe coaxial transition. The three-port device utilizes standard 50 Ω coaxial connectors. We named Port 1 the input and Port 2 and 3 the two outputs.

The cutoff frequency of the fundamental quasi-TE_{10} mode [6], [7] is 0.84 GHz for the input DRWG and 1.0 GHz for the output DRWG. As the cutoff frequency of the DRWG first higher order mode is almost independent of the ridges distance and falls around 3.7 GHz, the maximum achievable operating bandwidth of the hybrid is in the range 1.07–3.77 GHz.

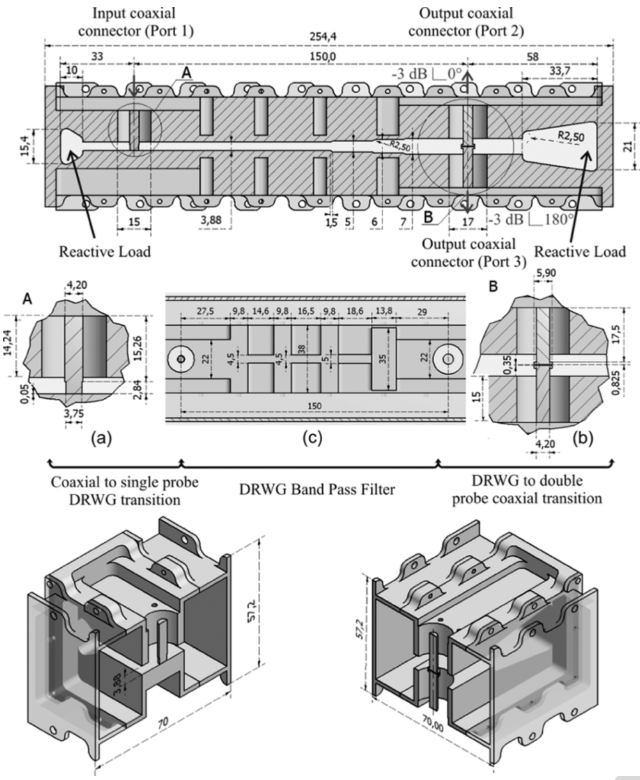

Fig. 2. Cutout view of the DRWG 180° hybrid. All dimensions are in mm.

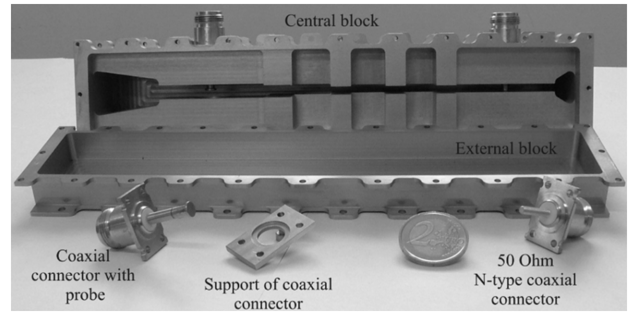

Fig. 3. Photo of unassembled DRWG 180° power divider showing one of the two external blocks and the main block (central block.) Coaxial connectors and one of their supports are also shown.

Each of the two N-type connector-to-Ridge Waveguide transitions as well as the filter was optimized independently to give optimum performance over the design frequency band. When connected together, the various parts resulted in a hybrid with good, but not optimum performance. The full hybrid structure was then optimized to provide best performance across the band of interest. The simulation were performed with the commercial 3D electromagnetic simulator CST Microwave Studio (Darmstadt, Germany) based on the finite integration technique.

A. *Input Coaxial to Single Probe DRWG Transition*

Our coaxial to single probe DRWG transition is shown in Fig. 2, bottom left panel. The design is based on the one presented in [8], but is considerably reworked to simplify the mechanical construction and to provide excellent electromagnetic performance across our operating band. The input probe, attached to the central pin of a N-type connector, launches the fundamental quasi-TE_{10} mode in the input DRWG ($\lambda_g \approx 230$ mm at the central frequency 1.55 GHz). The probe is located at a distance of 33 mm (less than $\lambda_g/4$) from the end of a shaped reactive load. Different configurations of probes and reactive loads were attempted to maximize the return loss of the structure. The final design has an input probe consisting of two on-axis cylindrical sections that are screwed to the central pin of the N-type connector. The distance between the probe end and the lower ridge is only 0.05 mm and must be kept to within 0.01 mm of the nominal value for optimum performance. Although critical, this distance can be precisely adjusted to the required accuracy.

B. *Output DRWG to Double Probe Coaxial Transition*

We designed a new type of transition that splits a quasi-TE_{10} mode signal propagating in the DRWG between two independent coaxial outputs with equal amplitude (-3 dB) and 180° phase difference. This novel DRWG to double probe coaxial transition, shown in Fig. 2 (bottom right panel,) is simple to fabricate and assemble. The two identical output probes are aligned along the same axis and located at a distance of 0.35 mm. The probes are attached to the central pin of two N-type connectors located on opposite sides of the DRWG "b" walls. The fundamental quasi-TE_{10} mode in the output DRWG ($\lambda_g \approx$290 mm at the central frequency 1.55 GHz) couples to the probes located to a distance of 58 mm (less than $\lambda_g/4$) from the end of a shaped reactive load. Different configurations of probes and reactive loads were attempted to maximize the return loss of the structure. Each probe consists of two on-axis cylindrical sections that screws into the threaded central pin of the N-type connector.

C. *DRWG BPF*

The input and output transitions are connected through a BPF realized in DRWG. The lower and upper edges of the BPF are set, respectively by the 1 GHz cutoff of the fundamental mode in DRWG, and by a stepped impedance nine section DRWG low pass filter with cutoff at 2.5 GHz. The number of filter sections was chosen to have the highest value which was possible to integrate within the available external length of the device (254.4 mm). We found that, in such 150 mm distance, nine low pass filter sections could be integrated without deterioration to the in-band hybrid performance while improving the out-of-band rejection. There was no specification on the out-of-band filter rejection, as in the real implementation on the SRT receiver the filter role is to further improve the RFI rejection of an external filter which will be cascaded with the hybrid and which is not discussed in the present article. In this respect, the role of the BPF integrated inside the 180° hybrid is to provide an additional out-of-band filtering and to help to decrease the RFI signals which are already largely reduced by the external filter.

D. *Mechanical Design*

The hybrid, shown in Fig. 3, is based on three mechanical blocks fabricated in 6082 Aluminum coated with Alodyne 1200. Two identical external blocks are bolted to a central one with several M2.5 screws. The ridges of the filter and the input and output DRWG transitions are machined into the main block (central block). The body of the coaxial connectors are attached to the central block through a support fixture. Threaded holes along the cylindrical axis of the probes allow screwing in of the threaded central pins of the N-type connectors. The probe-con-

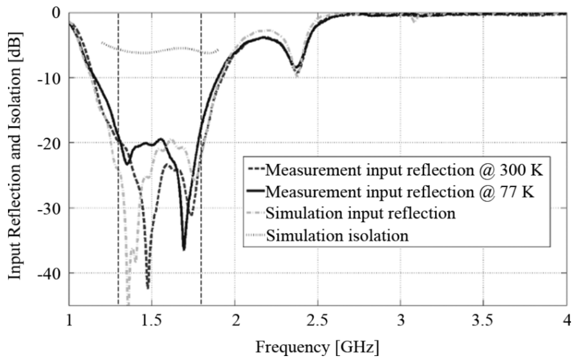

Fig. 4. Simulated and measured input reflection at Port 1 and simulated isolation between output ports (port 2 and Port 3).

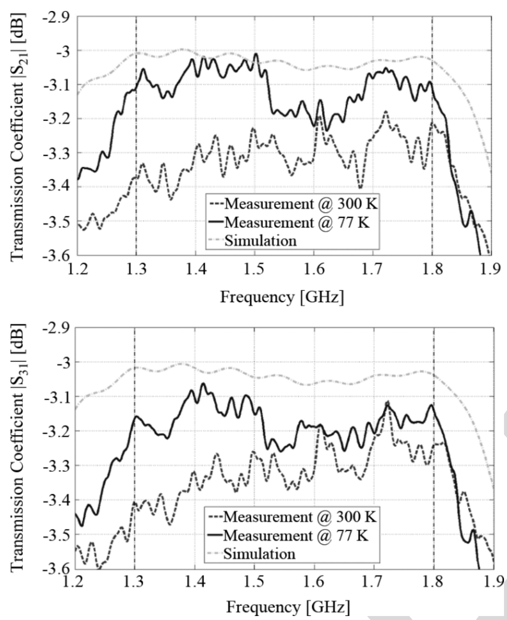

Fig. 5. Simulated and measured transmission loss between Ports 2-1 (top) and 3-1 (bottom).

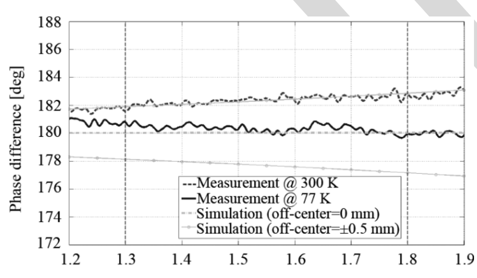

Fig. 6. Simulated and measured differential phase.

nector assembly allows for easy mechanical tuning of the probes length inside the DRWG cavity and can be adjusted to the specified values to high accuracy. Because of thermal contraction of the connector-probe assembly after cooling, the position of the probes need to be mechanically retuned by properly unscrewing them so that their total lengths inside the cavities are readjusted to optimize the device performance a cryogenic temperature. Whereby the mechanical design allows to operate the hybrid both at room temperature and a cryogenic temperature. The external dimensions of the hybrid, excluding the coaxial connectors, are: 70 mm × 57.2 mm × 244.4 mm.

III. Simulation and Experimental Results

The hybrid was tested using a HP8720C Vector Network Analyzer (VNA). The experimental results are shown in Figs. 4–6 together with the electromagnetic simulation. The measurements were performed at room temperature and at the cryogenic temperature of 77 K by immerging the device in liquid Nitrogen.

The results for the input reflection at the hybrid input (Port 1) and the isolation between output ports (port2 and port 3)are illustrated in Fig. 4. The measured return loss across L-band is less than −20 dB and −17 dB at, respectively room and cryogenic temperature. The simulated isolation is of the order of −6 dB. Fig. 4 shows also the response of the device outside 1.3–1.8 GHz. The transmissions between the input and the two outputs are shown in Fig. 5: the maximum deviation from the nominal −3 dB coupling is 0.4 dB at room temperature and 0.2 dB at 77 K. The lower losses at 77 K are due to the increase of the material conductivity a lower temperature. The reason for the measured dips in the two transmissions between ∼1.53–1.68 GHz are not clearly understood but they are probably related to the calibration of the VNA. Fig. 6 shows the results for the differential phase between the S21 and S31 transmissions. The measured phase difference at room and cryogenic temperatures have an average of, respectively, 182.5° and 180.5° with deviations ±0.5° across L-band. A 180° phase shift requires the two output probes to be exactly centered between the ridges. Electromagnetic simulations predict a deviation from the nominal 180° phase difference of ±2.3° with ±0.5 mm off-center of the output probes.

IV. Conclusion

A novel 180° hybrid power divider with integrated BPF utilizing a double ridged waveguide was developed for 1.3–1.8 GHz. The device has excellent performance and the measurements agree well with simulation. The insertion loss and differential phase are flat across the nominal band.

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