Improved Quadrature RF Hybrid for 2SB and Balanced THz Receivers

Hawal Rashid, Denis Meledin, Vincent Desmaris and Victor Belitsky

***Abstract*— We present the design and implementation of two quadrature waveguide hybrids at mm-wave frequencies with improved amplitude and phase imbalance. The measured performance of the hybrids show good agreements, with amplitude imbalance of ± 0.15 dB and a phase imbalance of ±2.5 degrees over the 166-208 GHz frequency range.**

***Index Terms*— Waveguide hybrid, Millimeter and sub-millimeter component, THz component, Directional coupler**

I. Introduction

In recent years, 2SB and balanced receivers have proved to be a favorable option for Terahertz frontend providing suppression of the sideband noise or the LO AM noise [1-3]. Correspondingly, the performance and the design of quadrature RF hybrids has become of high relevance. The amplitude and phase imbalance of the 90° RF waveguide hybrid contribute to the degradation of the sideband rejection and noise suppression [4] . It is therefore important to minimize the imbalance of the RF hybrid for achieving ultimate performance.

The two most often used waveguide hybrids are probably the periodical and synchronous branch waveguide directional couplers. For THz frequencies, the periodical branch waveguide hybrid is the most feasible topology due to its ease of fabrication. One of the major drawbacks of the branch waveguide hybrids is that it exhibits the worst amplitude imbalance at the design center frequency, which further increases as the operational bandwidth is increased.

A typical design condition of a waveguide directional coupler is a maximized directivity / isolation. As suggested in [5], by relaxing the standard condition for maximum isolation, the classical layout of the hybrids can be modified such that interleaved ripples are introduced into S21 and S31 (cf. Fig.1 & 2), thus yielding minimum amplitude imbalance within the operating frequency band. Such a modified hybrid is a trade-off between the controllably degraded return loss and the improved amplitude imbalance.

In this paper, we present two hybrid designs, periodical and synchronous, based on the approach suggested in [5]

II. Hybrids design

The periodical branch waveguide hybrid design adopts the topology presented in [5] (Fig. 1).

The synchronous branch waveguide directional coupler consists of two four-branch 8.5 dB synchronous couplers, which are cascaded with a connecting quarter wavelength impedance-mismatched waveguide (Fig. 2). The hybrids were designed to operate in frequency band 166-208 GHz. This operation band was selected in order to measure the hybrid performance with existing in-house Vector Network Analyzer (VNA) extension modules, which operate from 140 GHz to 220 GHz.

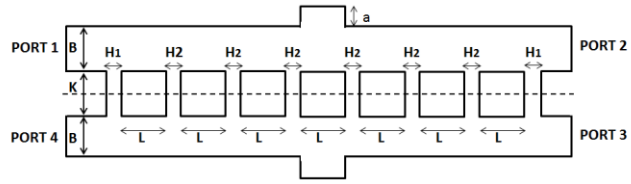

Fig.1. Cross section of the periodical eight branch waveguide hybrid in [5]. The dashed line shows the symmetry plane.

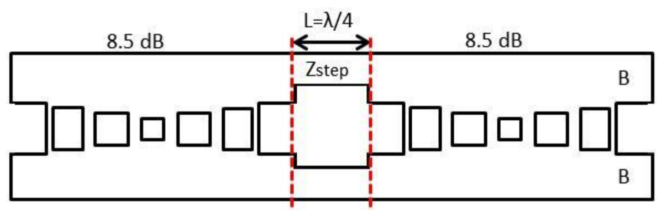

Fig.2.Cross section of two four branch 8.5 dB synchronous directional coupler with impedance mismatch at its geometrical center, which is marked with red dashed lines. The port configuration is the same as Fig.1.

III. Measurements

The waveguide hybrid was measured with Agilent two port Vector Network Analyzer (VNA) with OML 140-220 GHz extension transmitter and receiver modules. The VNA was calibrated with the OML standard TRL waveguide calibration kit. Subsequently, Ports 1 and 3 (coupled) were connected and measured while the remaining ports are terminated. Finally, Ports 1 and 4 were connected and measured while the through and coupled ports were terminated. In order to account for the conductive loss in the leading waveguides, a two port fixture with the exact shape and length as the hybrid through path was fabricated. The S-parameters from the fixture were measured and used to de-embed the losses (0.015 dB/mm) of the leading waveguides (between the calibration planes at the output of the extension modules to the input of the hybrid structure) from the measured hybrid S-parameters. The insertion loss of the hybrid itself is approximately 0.23 dB [5].

The time gated [6] performance of the synchronous coupler shown in Fig. 3 does not agree as well with simulations due to large dimensions offsets caused by malfunction of the CNC milling machine. The depth difference between the main waveguide (**B**) and branch guide (**H**) (refereed as step) was approximately 28 μm, while the **K** and **H** values was off by approximately 10 μm. Figure 4 show the measured

All authors are with the Group of Advanced Receiver Development (GARD) at Chalmers University of Technology, Gothenburg, Sweden. (email:Hawal@chalmers.se)

performance and EM simulations for different steps. The red solid line in Fig. 4 includes the average offset in the **K** and **H** values of 10 µm together with the step length of 28 µm. With these values, we were able to explain the reduced agreement between simulation and measurement.

Fig. 5 and 6 show the simulated and time gated [7] measurement performance of the periodical branch waveguide hybrid manufactured with the CNC milling machine after necessary service and repair. The measured performance of the periodical hybrid demonstrates excellent agreement with the simulations.

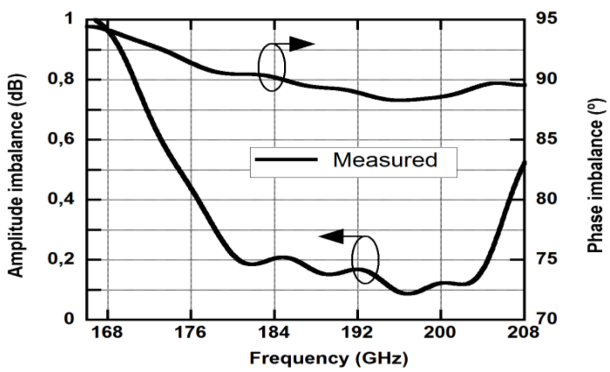

Fig. 3. Measured amplitude and phase imbalance of the synchronous hybrid shown in Fig.2.

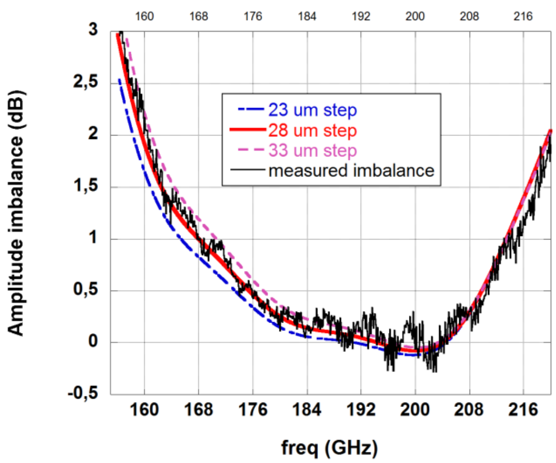

Fig. 4. Simulated performance for different step length lengths.

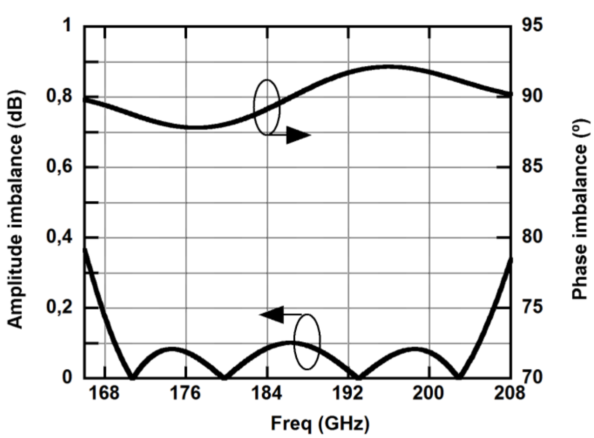

Fig. 5. Simulated through and coupled performance of the modified periodical waveguide hybrid [5].

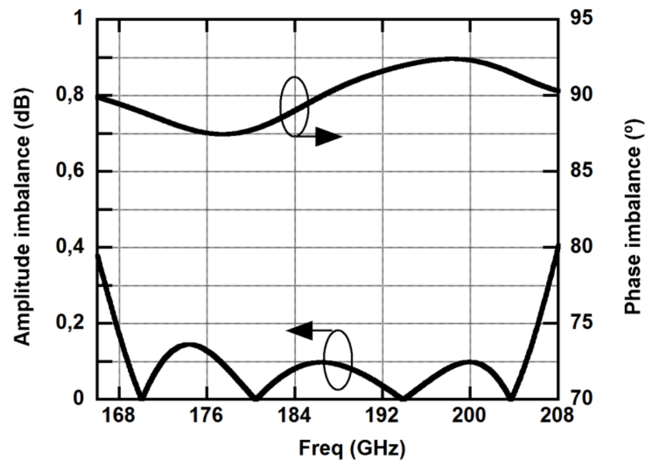

Fig. 6. Measured through and coupled performance of the modified periodical waveguide hybrid [5].

IV. Conclusions

We presented two implementation of the novel design concept for the realization of 90° synchronous waveguide hybrid for 166 – 208 GHz band. The measured performance of the periodical hybrid show excellent agreement with simulation, with amplitude imbalance of ± 0.15 dB and a phase imbalance of ±2.5 degrees over the 166-208 GHz frequency range.

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