Development of an instantaneous multiband digital 2SB receiver for the 67–116-GHz band

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***Abstract*— In this work we present the initial development of an instantaneous multiband receiver with digital sideband separation for an extended W Band (67-116 GHz). In particular, we present the design and construction of a frequency diplexer that, thanks to the inclusion of a novel waveguide quadrature hybrid, shows an excellent behavior in the entire bandwidth. Moreover, we present a non-linear simulation of the entire receiver, including digital sideband separation. The results show complete RF coverage into four parallel IF outputs.**

***Keywords*— Heterodyne receivers, waveguide components, frequency conversion, frequency diplexers.**

I. Introduction

The multiband heterodyne receiver proposed in [1] can be an alternative solution for the necessity of ultra-bandwidth systems in radio astronomy. It works with a frequency multiplexer that separates the RF bandwidth into a number of sub-bands that are down-converted independently. This architecture allows to obtain the relevant RF spectrum into several parallel IF outputs. Since the multiplexer is a key component in this type of receiver, the work presented in [1] also proposed a versatile design based in quadrature hybrids and filters. If several of them are concatenated, it is possible to achieve a multiplexer with any number of outputs.

Here we present a variation of this architecture that uses digital sideband (2SB) downconverters, and has been applied to an extended W band (67–116 GHz). The initial development includes the design and construction of a broadband frequency diplexer with relaxed mechanical constraints for easing the manufacture process. The diplexer uses a novel waveguide quadrature hybrid [3] with state-of-the-art performance.

II. Proposed Multiband Receiver

Fig. 1 presents a general diagram of the multiband downconverter proposed in this work, which has the potential of covering the entire RF spectrum instantaneously. The complete RF coverage can only be implemented using a digital IF hybrid since, in contrast to its analog counterpart, it is not limited at lower frequencies. Then, by placing the LO frequency at the center each sub-band, total RF coverage can be achieved. Since this architecture divides the analog RF spectrum into two bands with half of the bandwidth, it offers two additional advantages besides the instantaneous access to the entire RF spectrum. (i) Reduction of the operational bandwidth needed for the electronics of each sub-band. (ii) As a consequence of this bandwidth reduction, further optimization can be archive in the performance of the receiver, reducing its overall noise temperature.

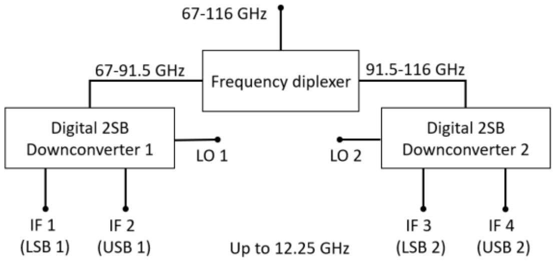

Fig. 1. Concept of a multiband heterodyne receiver with digital 2SB receivers for the extended W-band. The input RF signal is separated into two frequency bands with a diplexer, a device that is capable of selectively routing the signal depending on its frequency. The low (67-91.5 GHz) and high (91.5-116 GHz) RF ranges are transmitted to two independent digital 2SB downconverters, 1 and 2. Each downconverter, then, separates the signals even more to Upper sideband (USB) and Lower Sideband (LSB) with the use of a image-rejection configuration. In this way, the system allows instantaneous acces to the entire RF range.

Despite the possibility of solving various problems in radio astronomy, not much work has been done in developing this type of architecture. The main reason is the limitation of IF processing capabilities. However, in recent years, with the development of faster digital processing platforms, this limitation could be overcome in the near future.

III. Waveguide Quadrature Hybrid

In this section, we present a modified branch-line waveguide quadrature hybrid that besides achieving an excellent performance over a large fractional bandwidth, exceeding 50%, eases construction constraints. This breakthrough was accomplished by implementing the branch lines with a larger height than the main lines, which results in widening the former, and so, reducing the height-to-diameter ratio of the tool needed to mill them. We have applied this new concept to cover an extended W band because the frequency diplexer presented in this work needs a quadrature hybrid that covers its complete RF operational bandwidth at its input.

The modified waveguide branch-line coupler proposed in this work is presented in Fig 2. For this particular design, a tool with a ratio larger than 6.23 is needed, which is well below overmoded hybrids with similar bandwidths [3]. The proposed hybrid was simulated in ANSYS HFSS, showing a return loss over 20 dB, an amplitude imbalance below 0.5 dB, and a phase imbalance, $\Delta\varphi$, within $\pm1°$. Measurements are in good agreement with simulations. They show a return

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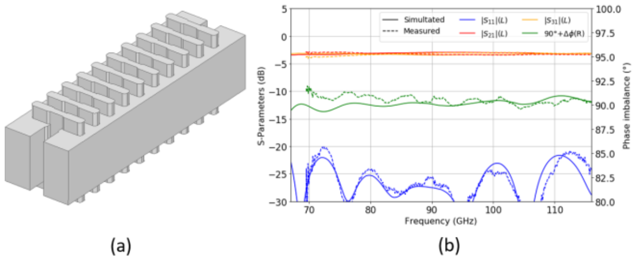

Fig. 2. Modified quadrature Hybrid. (a) CAD image. (b) Simulation and measurements results of the constrcuted prototype.

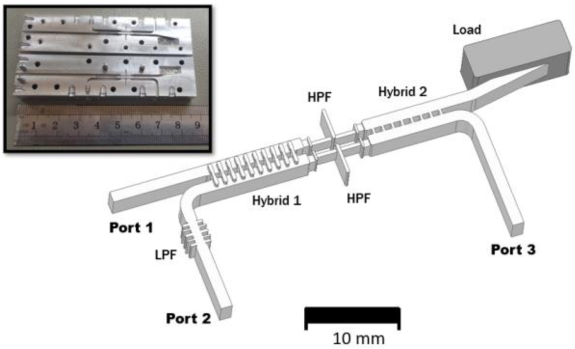

Fig. 3. CAD view of the complete diplexer, showing all of its components. The inset shows a photograph of its implementation as split-block.

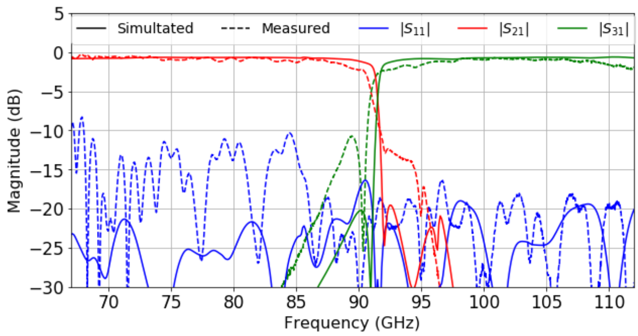

Fig. 4. Simulated and measured S parameters of the diplexer.

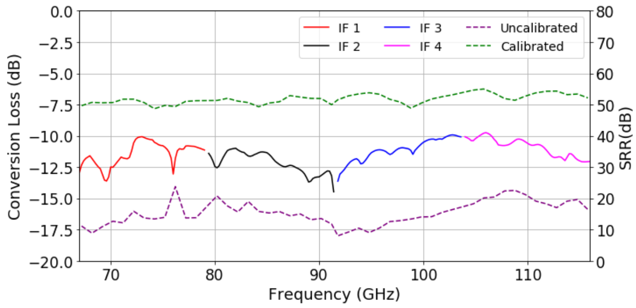

Fig. 5. Results of non-linear simulation of the convertion loss of the reciever and SRR with the digital sideband separation.

loss over 20 dB and amplitude and phase imbalances below 0.8 dB, and between $-0.5°$ and $+2°$, respectively.

IV. Frequency Diplexer

A frequency diplexer, based on [4], was designed and a prototype was manufactured. Fig. 3 shows the complete design. The components are an input quadrature hybrid that covers the entire input bandwidth (67–116 GHz), two high-pass filters with a frequency cutoff of 91.5 GHz, a second quadrature hybrid with an operational bandwidth of 91.5 to 116 GHz, and a low-pass filter to increase rejection between the two output bands.

The diplexer was simulated in ANSYS HFSS and the results are presented in Fig. 4. The simulations used a finite aluminum conductivity boundary condition and an ideal RF load. The $|S_{21}|$ and $|S_{31}|$ parameters show the transmissions of the lower band and the upper band respectively, with an interception point exactly at 91.5 GHz. The cutoff slope for each band matches the behavior of the bandpass filter. The $|S_{11}|$ parameter presents good behavior with a reflection below -20 dB in the majority of the band.

Fig. 4 also presents the scalar S-parameter measurements of the constructed prototype of the diplexer. In the $|S_{21}|$ and $|S_{31}|$ parameters, we can see two well-defined transmission bands for the lower and upper-frequency outputs. The interception point between the two frequency bands is at 90.98 GHz, approximately 500 MHz apart from its expected value. However, the shape of the cutoff slope of the $|S_{21}|$ and $|S_{31}|$ parameters differ from the simulation. We can explain these differences due to manufacturing errors in the high-pass filter sections of the constructed block. These errors could also partially explain the behavior of the $|S_{11}|$ parameter, as the lower-frequency band presents an overall higher value in comparison with the upper-frequency band. This difference is produced by asymmetries between the two band-pass filters, producing an ineffective cancellation of the reflected wave at the input port. Another possible cause for the increment in reflections is the poor performance of the low-pass filter placed at port 2. The diplexer losses possess an average value of 1.5 dB for the entire band and have good agreement with the simulations, only increasing at points of high reflection for the lower-frequency band and at the lower and upper edges in the upper-frequency band. The increase in the upper band can be also explained by asymmetries in construction, dissipating the remaining power at the load.

V. Receiver Simulations

In a three-step simulation, we have studied the response of a receiver using the previous diplexer in conjunction with realistic Schottky-based 2SB downconverters using a digital IF hybrid [2]. The first step uses ANSYS HFSS to simulate the majority of passive components such as the diplexer, waveguide-to-microstrip transitions, and microstrip IF paths. The second step is to use Cadence AWR in conjunction with the imported HFSS results to simulate the entire analog receiver using the harmonic balance nonlinear method, this includes MMICs I/Q mixers. The results (in Fig. 5) show that the receiver's conversion loss allows complete RF bandwidth coverage over the four IFs. In the final step, utilizing the information of harmonic content, the IF outputs were reconstructed as input data for a simulation utilizing the digital sideband separation method [5]. Results (also in Fig. 5) show an excellent performance after calibration, with a sideband rejection ratio (SRR) of 50 dB, allowing each IF channel to receive the signal for its specific sub-band with excellent isolation.

VI. Conclusions & Future Work

In this work, we have presented a multiband receiver architecture with digital 2SB that shows the feasibility of total broadband RF coverage through parallel IF outputs.

One of the key components, a fully functional waveguide diplexer, that utilizes a state-of-the-art waveguide hybrid, was also presented.

As a future work we plan to manufacture a new diplexer prototype without the low-pass filter to study its effect in the diplexer performance. Then, we propose to build the downconverter prototype and test it utilizing a second down-conversion stage with smaller IF bandwidth and a mobile LO, and implement digital sideband separation in a FPGA-based backend.

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