Wideband waveguide power combiner for ALMA Band 7+8 (275-500 GHz) Local Oscillator

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Abstract— This paper describes the concept and design of a waveguide diplexer to combine the power of two Local Oscillator (LO) sources for different frequency bands. This diplexer is based on a novel design idea which uses two hybrid couplers combined with different waveguide filters. The proposed concept allows to input signals in two different frequency bands in two different input ports, and to have them combined in a common wideband port. At the same time, a signal at certain frequency is properly rejected at the input port which does not accept that frequency. This waveguide component allows the generation of a single high-power wideband LO signal with high spectral purity at sub-millimeter wavelengths for the first time. In particular, we are targeting the generation of a single LO signal for the full ALMA band 7+8 (275-500 GHz) by the combination of the LO sources used for ALMA band 7 (275-373 GHz) and band 8 (385-500 GHz).

INTRODUCTION

At NAOJ, we are developing high critical current density SIS mixers to cover two sub-millimeter ALMA [1] bands. In order to benefit from all equipment and know-how acquired during the design and production of ALMA band 8 receivers, we are aiming at covering ALMA band 7 (275-373 GHz) and band 8 (385-500 GHz) simultaneously. The fractional bandwidth of this target band is 60.7% at a central frequency of 370.8 GHz. For a typical 4-8 GHz 2SB IF signal, the required LO frequency coverage is therefore from 283 to 492 GHz. This represents a fractional bandwidth of 56%, which is too wide for typical LO sources at sub-mm wavelengths [2-3]. A possible solution to this problem is to combine the power of two different LO sources, one for each ALMA band, by means of a waveguide component. If a waveguide diplexer is used to combine the output power of two narrower band LO sources instead of a single wideband LO source, it is possible to achieve a single wideband high-power high-spectral-purity single LO signal at sub-mm wavelengths.

CONCEPTUAL IDEA

The 275-500 GHz diplexer is based on the conceptual design presented in Fig. 1. It uses two different hybrid couplers to divide and combine the LO signals coming from the different frequency band inputs. The two pass-bands of the diplexer have been defined by high-pass filters (HPF) between the two hybrids. The cross-over between the different pass-bands of the waveguide diplexer has been chosen to be at the 12 GHz frequency gap between the RF bands, where there is a strong atmospheric absorption line which prevents astronomical observations. The actual gap between LO sources will actually be 28 GHz for a 4-8 GHz 2SB IF bandwidth, which allows for certain tolerance in the fabrication of the diplexer.

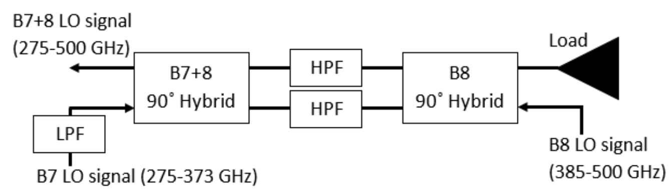

Fig. 1. Block diagram of the proposed wideband diplexer to combine two different LO sources at different frequencies. Band 7, 8 and 7+8 refer to the ALMA telescope bands, which are 275-373 GHz, 385-500 GHz and 275-500 GHz, respectively

The band 7 LO signal is divided in the B7+8 hybrid and reflected at the HPF between hybrids. The reflections are recombined in phase in the B7+8 LO signal port and 180-degrees out of phase in the B7 input port. The band 8 LO signal is divided in the B8 hybrid, passes the HPF and is divided again in the B7+8 hybrid. The combination of band 8 power will be in-phase in the B7+8 LO signal port and 180-degrees out of phase in the B7 input. A low-pass filter (LPF) has been placed at the B7 input port for extra protection of the B7 LO source from non-idealities in the design and fabrication. The hybrid close to the B7+8 port must be a wideband component, since it must work for both the B7 and B8 LO signals. However, the hybrid on the right-hand side, including the load connected to one of its ports, is only "seen" by the 385-500 GHz signal and can be therefore a simpler component with that reduced frequency coverage.

WAVEGUIDE DESIGN

The proposed LO combiner has been designed step by step. Firstly, the different building blocks in Fig. 1 have been designed independently, and then, connected together with appropriate waveguide lengths, and bends. Finally, extra waveguides have been added to finalize the mechanical design of a waveguide block with flanges to connect to other components. The diplexer has three different waveguide ports for each of the bands involved: WR-3.0 (760 x 380 μm) for band 7, WR-2.2 (558 x 279 μm) for band 8, and WR-2.3 (580 x 290 μm) for band 7+8, and it is therefore highly asymmetric, which represent an additional design challenge. The design has been performed with the hybrid Mode-Matching/Finite-Elements software WaspNET [4], and the performance has been verified with HFSS [5] Finite Element simulations. The designed waveguide structure and the corresponding simulation results are presented in Fig. 2 and 3, respectively.

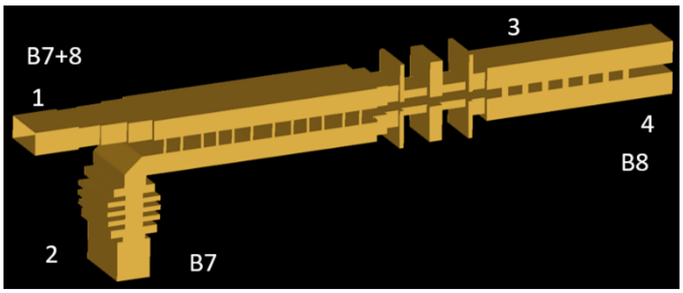

Fig. 2. Designed waveguide diplexer to combine the LO signals of ALMA band 7 and 8 individual LO sources. The band 7 and 8 inputs, together with the B7+8 output are clearly labeled, together with port numbers. Port 3 is to be terminated with a matched load.

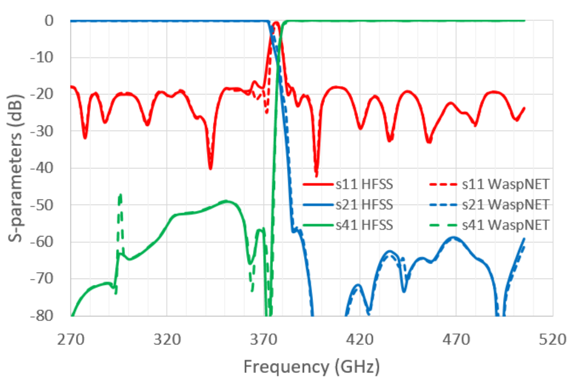

Fig. 3. S-parameter performance simulated by HFSS and WaspNET

For practical implementation, port 3 in Fig. 2 must be terminated with a matched load. This load has been implemented with an absorber of appropriate size and shape to minimize the s11 at the absorber input. The design and material of the absorber are the same as used for ALMA band 8 components.

For the simulation of effects related to loss, we have used the same loss model as derived from measurements of a waveguide multiplexer recently fabricated and for use in this frequency range [6]. Simulations considering loss have been performed with HFSS and are very demanding in terms of computer resources. Due to computer limitations, Microwave Office [7] has been used to add the effects of the extra loss in input and output waveguides in the actual waveguide block and the HFSS simulation results of the band 8 termination to the HFSS simulation of the diplexer considering loss. Rounded corners associated to fabrication by direct machining have also been added in these simulations. Results of the S-parameters of this 3-port simulation are presented in Fig. 5. The loss seen by the band 7 and 8 LO sources in the center of each band are -1.7 and -1.5 dB, respectively. The loss increases to around -2.0 dB at the lower end of band 7 due to the proximity of the waveguide cut-off. Frequencies close to the cross-over frequency range also see increased loss. The loss at 365 GHz and at 393 GHz are -2.3 and -2.2 dB, respectively. This loss is acceptable for the available input power levels. In terms of reflection loss, values are better than 19.2 dB at all frequencies of interest. Rejection of band 7 and 8 signals at band 8 and 7 input ports is better than -50 dB.

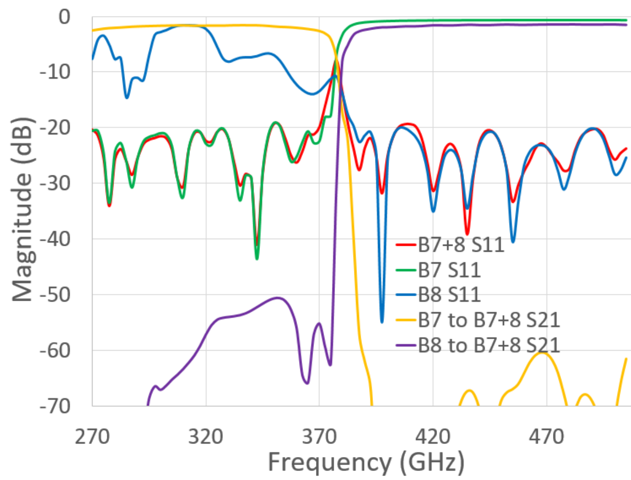

Fig. 5. S-parameter performance considering the effects of loss and with a load in the unused port of the band 8 hybrid. Simulations performed by HFSS and Microwave Office

Fabrication and Measurements

Two prototype diplexers have been fabricated by direct machining and S-parameters have been measured with good agreement with measurements. These results have been included in an extended paper submitted to the IEEE Transactions on Terahertz Science and Technology. One of the diplexers has been used in an ALMA band 7+8 SIS mixer noise measurement setup with good results. This will be the subject of a future publication.

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