Waveguide Quadrature Hybrid

Power dividers and directional couplers are passive elements widely used in all technological fields where electromagnetic power needs to be transmitted and divided with little loss. One of such branches is radio astronomy with all of its instrumentation necessary to process weak EM signals.

This paper is dedicated to quadrature hybrid, which is a four-port device that splits input signal. An ideal quadrature coupler divides power incident on any port between two other ports with a 90° phase difference and equal amplitude. It also isolates the fourth port. In its typical form, a quadrature hybrid is made of two parallel waveguides and a series of apertures between them.

Within this paper, we consider a waveguide quadrature hybrid that employs branch waveguides, which has been proposed in ALMA Memo 343 from 2001 [1]. It was designed for ALMA receiver as a power combiner in the first local oscillation (LO) system and as an element of balanced sideband-separating superconductor–insulator–superconductor (SIS) mixer.

The considered waveguide quadrature hybrid has been designed and analysed with QuickWave FDTD software [2] and its dimensions are presented in the figure below.

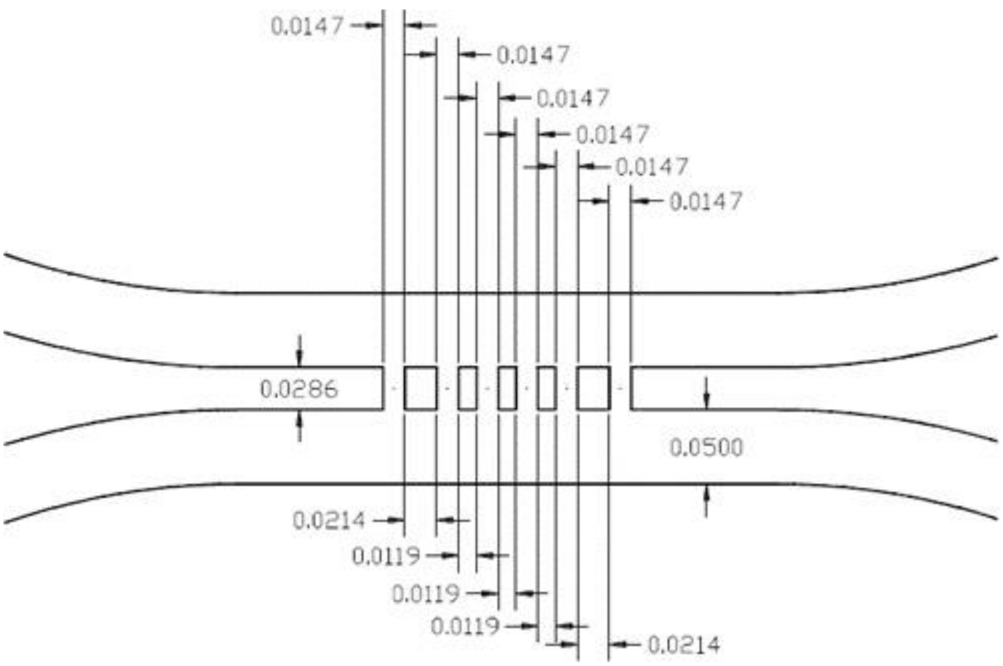


Fig. 1 Scheme of waveguide quadrature hybrid proposed in [1]. The hybrid is based on WR-10 waveguide and contains six branch lines. All dimensions are given in inches.

Simulation scenario

Simulation model consists of four input/output arms based on WR-10 waveguides (1.27 x 2.54 mm). The dimensions of the branch waveguides and spacing between them have been set according to their definition in [1]. The structure is excited in a frequency band of 75-110 GHz.

In order to simulate the model properly, a variable mesh size adjusted to geometry is utilized. A maximum cell size equals 0.14 mm in all three directions. Since present example is a non-radiating structure, the background medium is set to metal and only fields inside the structure are of interest.

The simulation scenario occupies around 92 thousands of FDTD cells, which results in 9 MB of memory occupation. The FDTD simulation with QuickWave 3D takes 10 seconds when performing multicore computations on AMD Ryzen Threadripper 2950X 16-Core processor.

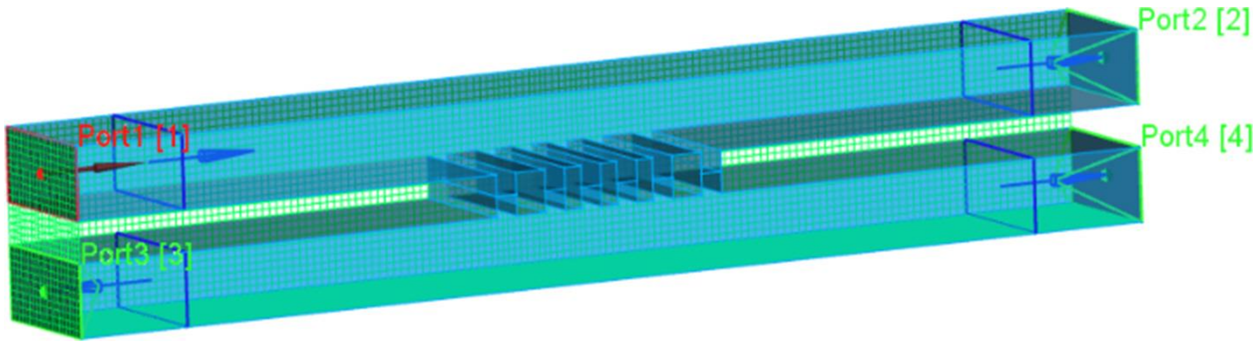


Fig. 2 Simulation model of WR-10 waveguide quadrature hybrid with six branch lines, prepared in QW-Modeller [3].

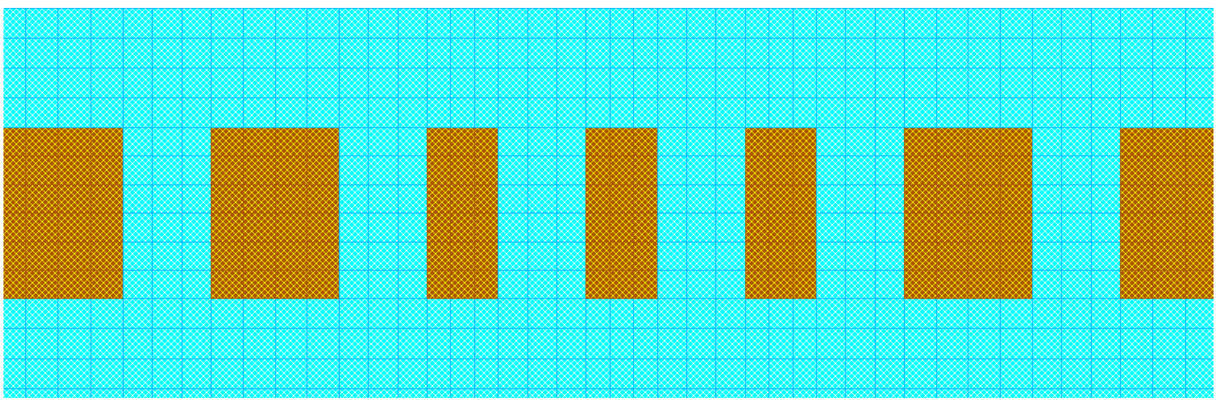


Fig. 3 FDTD mesh of spacing between branch waveguides.

EM simulation result

Due to the structure reversibility S_{k1} postprocessing is used in the frequency band from 75 to 110 GHz.

The ports for S-parameters extraction are numbered as follows:

Port 1 – input port,

Port 2 – output (transmitted) port,

Port 3 – isolated port

Port 4 – coupled port

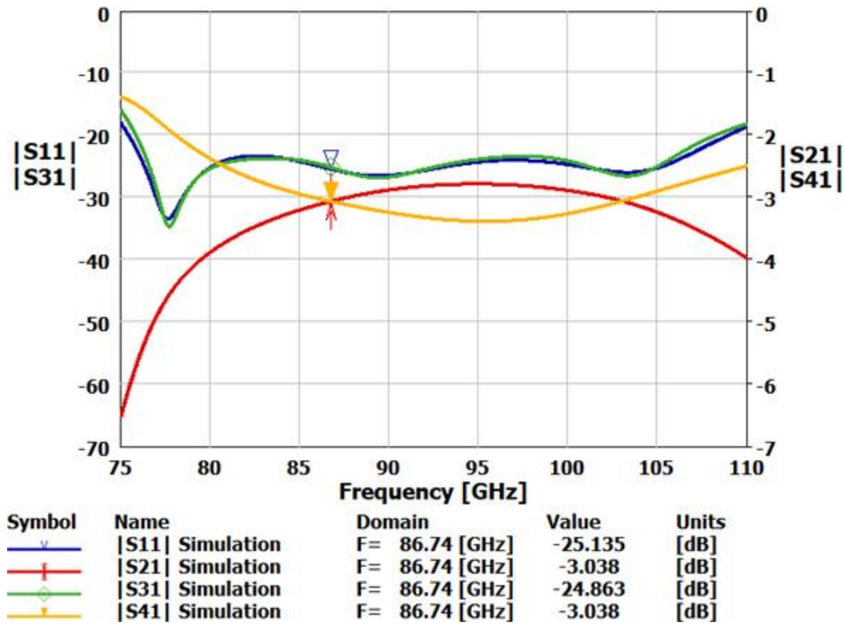


Fig. 4 Magnitude of reflection (|S11|) and transmission (|S21|, |S31|, |S41|) coefficients of WR-10 quadrature hybrid computed with QuickWave 3D.

From Fig. 4 it can be noticed that transmission to transmitted and coupled ports (|S21| and |S41|) are on similar level for frequencies from the middle of the band of 75-110 GHz. For frequencies 86.74 GHz and 103.09 GHz these values are exactly the same. Checking the phases of those two transmission coefficients (Fig. 5) it can be seen that the signals are effectively shifted by 90°, which confirms that we deal with quadrature coupler.

The results presented in Fig. 4 show that only ca. 1% of the power is transmitted to Port 3, which directly confirms that it is an isolated signal output.

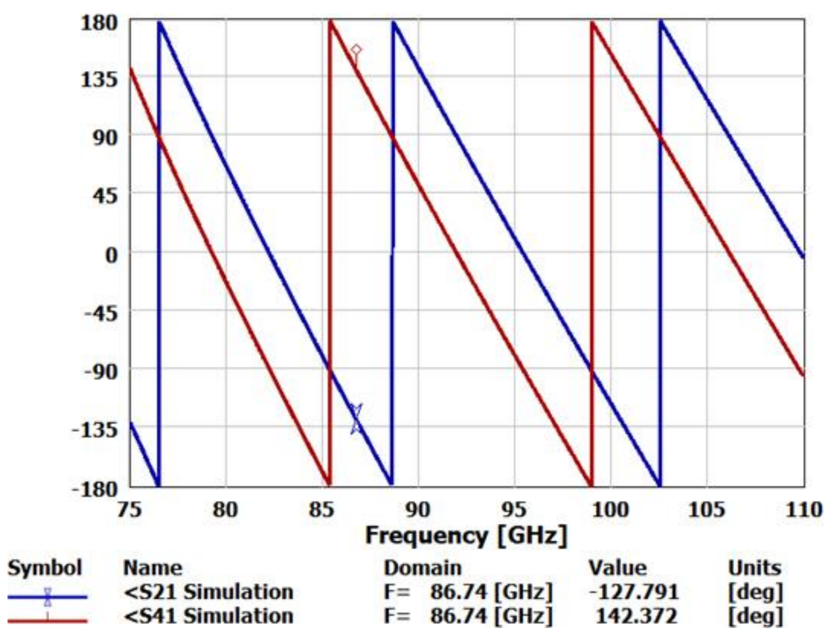
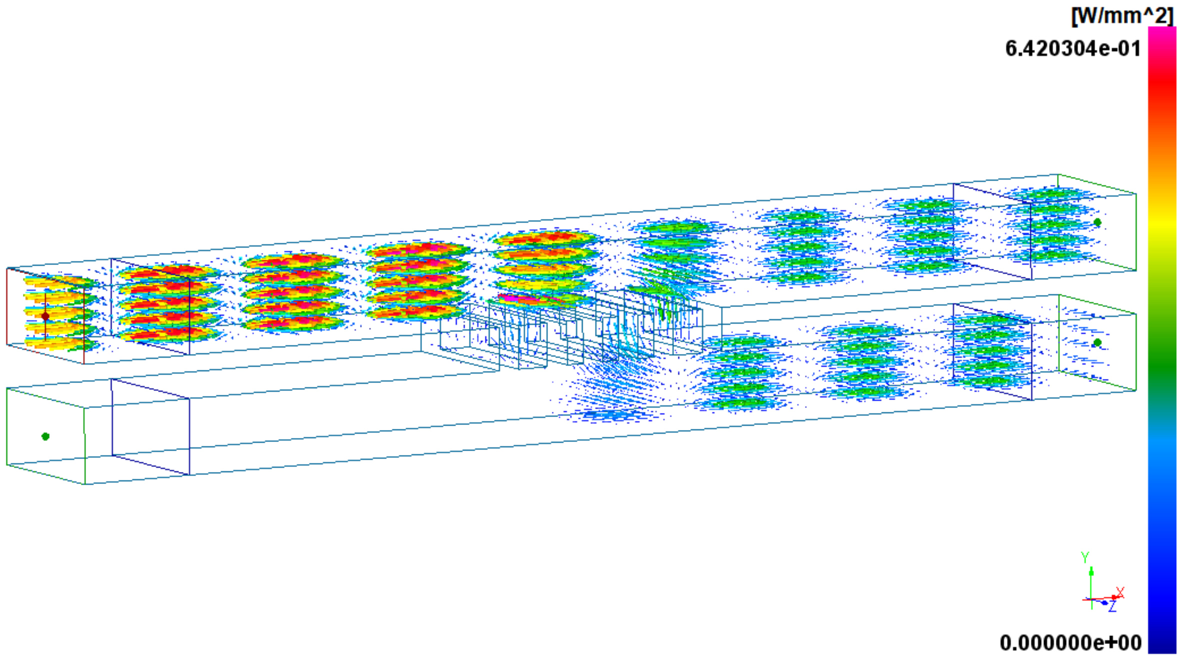


Fig. 5 Phase of S21 and S41 .

In Fig. 6, distribution on instantaneous Poynting vector in the considered coupler at 86.74 GHz is presented. It can be seen that the power is equally distributed between Port 2 and Port 4 and the signal is in quadrature. As a comparison, the distribution of the Poynting vector at 77.6 GHz is presented in Fig. 8. It is clearly visible that in this case the power is not equally divided between output ports.

a)



b)

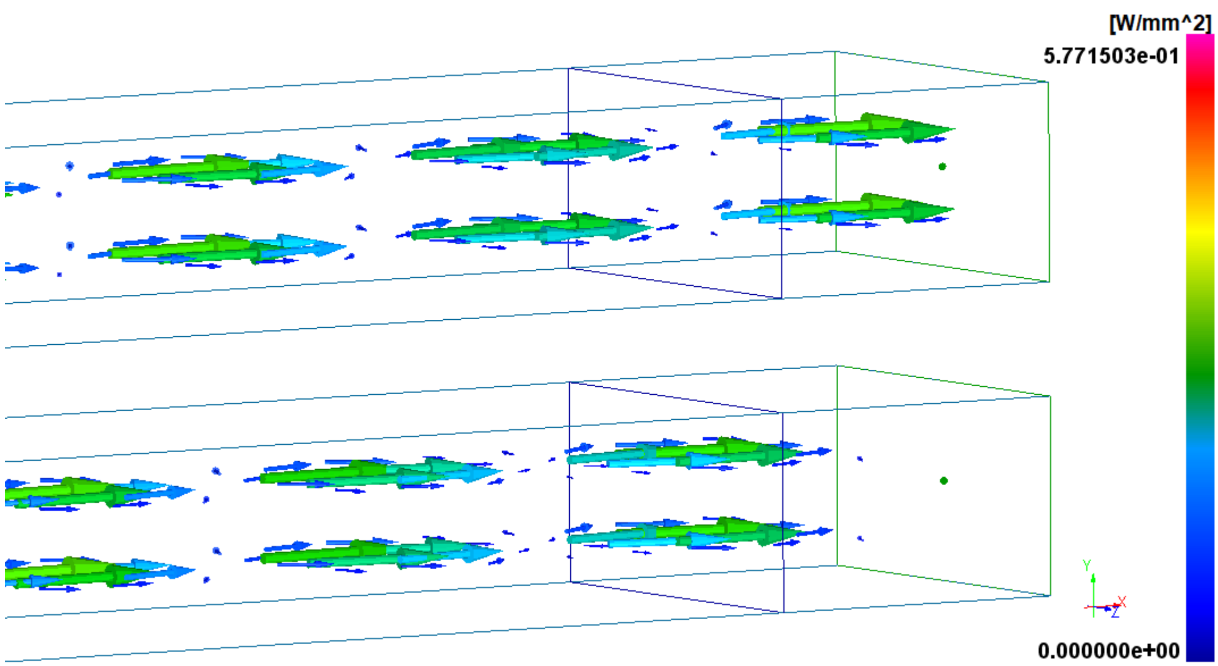


Fig. 6 Distribution of momentary Poynting vector at 86.74 GHz: a) full structure. b) zoom on ports 2 and 4.

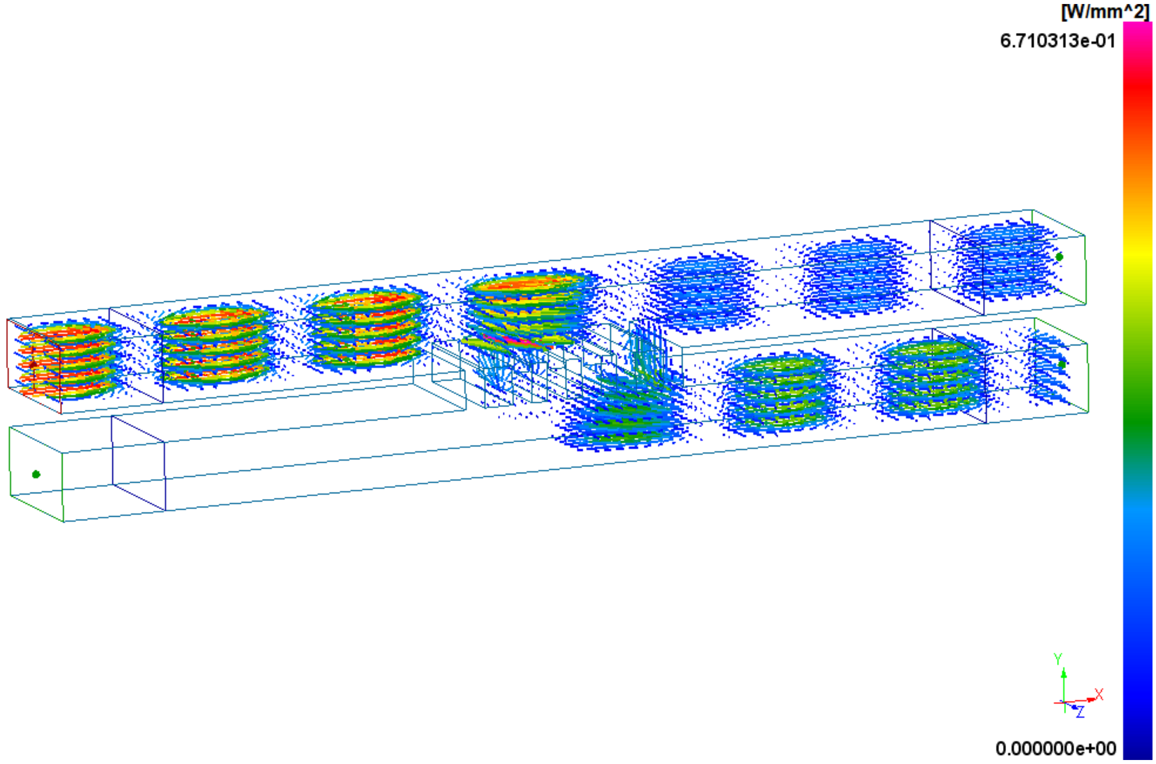


Fig. 7 Distribution of momentary Poynting vector at 77.6 GHz.

Measurement results

The comparison between our simulated results and measured values of magnitude of reflection and transmission coefficients is shown in Fig. 9. The measurements were performed by Sivasankaran Srikanth and Anthony R. Kerr and results are given in [1]. A very good agreement is observed between both sets of compared data, proving capabilities of QuickWave software to handle analysis of components designated to space technology.

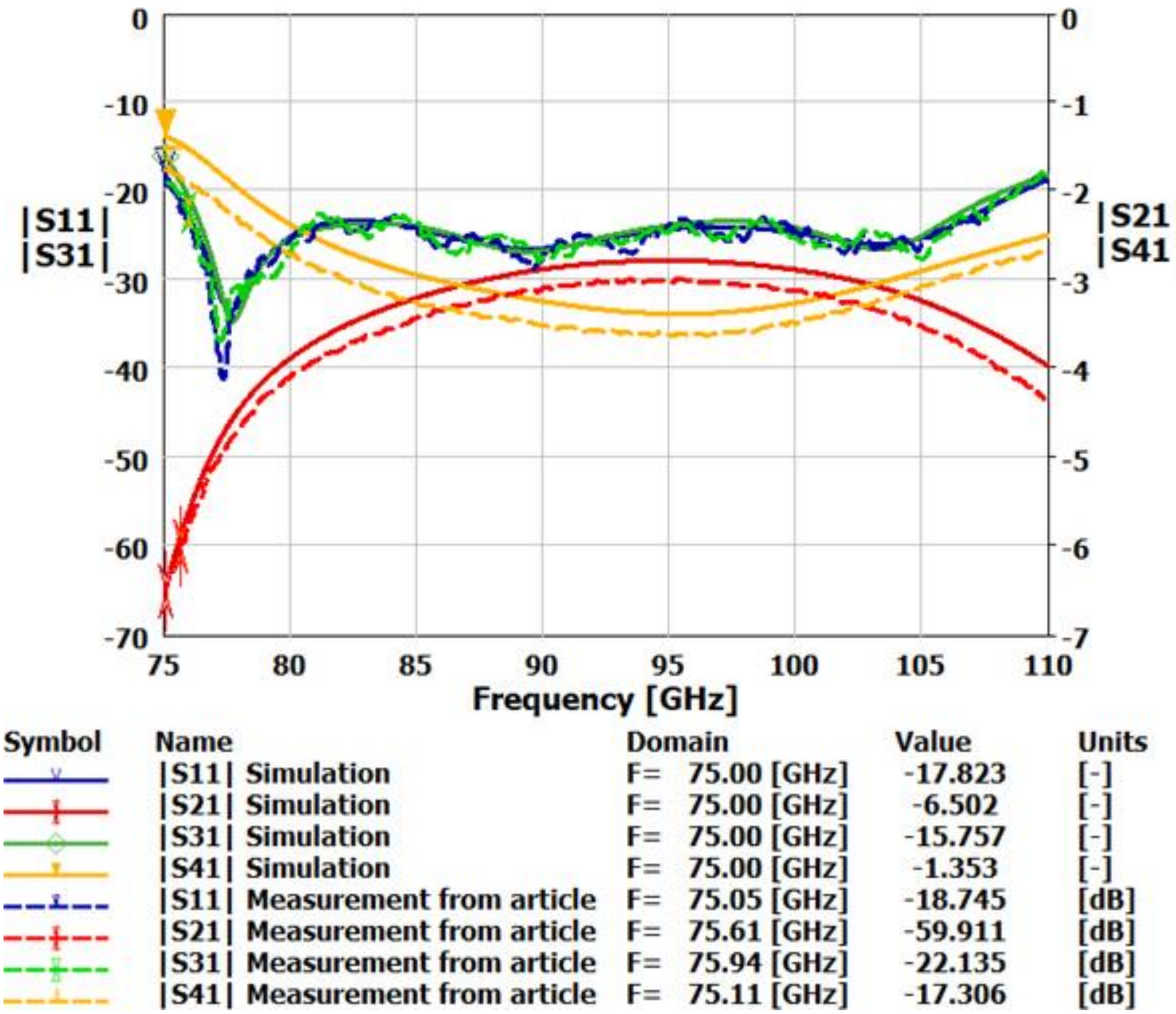


Fig. 9 The magnitude of reflection (|S11|) and transmission (|S21|, |S31|, |S41|) coefficients of WR-10 quadrature hybrid – simulated data and measurements from [1].

References

[1] S. Srikanth, A. R. Kerr, *Waveguide Quadrature Hybrids for ALMA Receivers*, ALMA Memo 343

[2] QuickWave software, http://www.qwed.eu

[3] QW-Modeller for QuickWave software, http://www.qwed.eu/qw_modeller.html