Design of a Radio Frequency Waveguide Diplexer for Dual-band Simultaneous Observation at 210-375 GHz.

Sho Masui, Shota Ueda, Yasumasa Yamasaki, Koki Yokoyama, Nozomi Okada, Toshikazu Onishi,
Hideo Ogawa, Yutaka Hasegawa, Kimihiro Kimura, Takafumi Kojima, Alvaro Gonzalez

***Abstract*—The 1.85-meter telescope has been operated at Nobeyama Radio Observatory to observe molecular clouds in nearby Garactic Plane in ^{12}CO, ^{13}CO, C^{18}O(J = 2-1). We are planning to relocate the telescope to the Atacama site (~2,400 m) and to newly install a dual-band simultaneous observation of CO lines at J = 2-1 and J = 3-2. To achieve this observation, we have designed a radio frequency waveguide diplexer to separate 211-275 GHz (ALMA band 6) and 275-373 GHz (ALMA band 7). The basic idea is to apply the waveguide frequency-separation-filter (FSF) [2], which has been successfully used for astronomical observations. However, the FSF has a narrow specific bandwidth, and we thus need to develop a new one with the wider bandwidth. A. Gonzalez et al. [3] reported the wideband diplexer with a fractional bandwidth of ~61% for the two-band local oscillator system covering the ALMA bands 7 and 8. We adopted this model and adjusted parameters for the ALMA bands 6 and 7. We obtained good performance of the FSF over the ALMA bands 6 and 7 in simulation.**

***Index Terms*—Atacama Large Millimeter/Submillimeter Array (ALMA), Frequency Separation Filter (FSF), 1.85-meter telescope, Radio astronomy, waveguide diplexer, wideband.**

I. INTRODUCTION

RECEIVERS of radio telescope for astronomy is required to have low-noise and high-gain over wide fractional bandwidth. The receiver noise and bandwidth is critically related with observation sensitivity and efficiency. To cover wideband RF range allows to reduce the total number of receivers and simplify maintenance and operation of telescopes. In addition, wideband RF range is enable to observe new science cases. In the Atacama Large Millimeter/Submillimeter Array (ALMA), the 35-950 GHz RF range is separated by 10 bands and these fractional band width of each band is nearly 30 %. However, recent advanced technology can be produce receivers which cover much wider RF ranges.

At Osaka Prefecture University (OPU), we have operated the 1.85-meter telescope at the Nobeyama Radio Observatory to observe molecular clouds in nearby star-forming regions and along the Galactic Plane in ^{12}CO, ^{13}CO, and C^{18}O (J = 2-1) (e.g., [1][2]). Now, we are planning to relocated the 1.85-m telescope to Atacama site (nearly 2,400 m) and to newly install a dual-band simultaneous observation of CO lines at J = 2-1 and J = 3-2. As a receiver system for dual-band simultaneous observation, we are developing radio frequency waveguide multiplexer in 210-375 GHz (the fractional bandwidth is 58.8% when its center frequency is 280.6 GHz). This multiplexer consists of (α) wideband waveguide diplexer (Fig. 1) to separate (β) 211-275 GHz (ALMA band 6) and (γ) 275-373 GHz (ALMA band 7) and other diplexers (Fig. 1) focused on CO lines at J = 2-1 and J = 3-2 to achieve 2 side band observation (Fig. 1). The basic idea of waveguide diplexers is to apply the waveguide frequency-separation-filter (FSF) [3], which has been successfully used for astronomical observations. However, the FSF has a narrow specific bandwidth, and we thus need to develop a new one with the wider bandwidth. A. Gonzalez et al. [4] reported the wideband diplexer with a fractional bandwidth of ~61% for the two-band local oscillator system covering the ALMA bands 7 and 8. We adopted this model and adjusted parameters for the ALMA bands 6 and 7. In this paper, we describe the design of wideband diplexer to separate ALMA band 6 and 7.

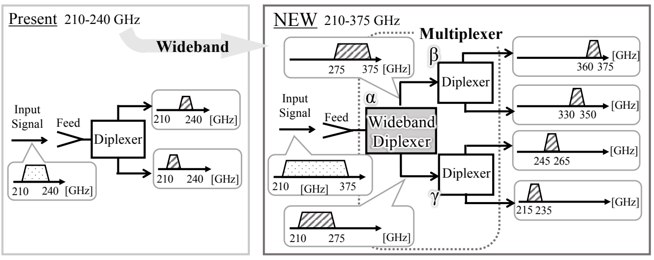

Figure 1. Schematic diagrams of present receiver and our new receiver to observe CO lines at J = 2-1 and J = 3-2. A diplexer installed in present receiver can separate 215-220 GHz and 230-235-GHz. Multiplexer which consists of three types of diplexer installed in new one can separate 4 bands (215-235, 245-265, 330-350, 360-375 GHz).

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S. Masui, S. Ueda, Y. Yamasaki, K. Yokoyama, N. Okada, T. Onishi and H.Ogawa are with Osaka Prefecture University, 1-1 Gakuen-cho, Naka-ku, Sakai, Osaka, 599-8531, Japan (e-mail: s_s.masui@p.s.osakafu-u.ac.jp).

Y. Hasegawa is with Institute of Space and Astronautical Science, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa, 252-5210, Japan.

K. Kimura is with Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi, 464-8602, Japan

T. Kojima, A. Gonzalez are with the National Astronomical Observatory of Japan (NAOJ) and also with the Graduate University for Advanced Studies (SOKENDAI), Mitaka, Tokyo 181-8588, Japan

II. CONCEPTUAL DESIGN

The conceptual design of FSF [3][5] is presented in Fig. 2. The FSF consists of two 3-dB quadrature hybrid couplers and two identical high pass filters (HPF). The hybrid coupler employs a branch-line coupler (BLC) with several branches whose height and interval should be close to the quarter wavelength. An input signal to the 3 dB BLC is divided into two, and then delivered toward two output ports 3' and 4' with the almost same magnitude, having a 90˚ phase difference between them. When the frequency of the input signal is higher than the cutoff frequency of the internal HPFs, all the signal goes to port 4. When the input frequency is lower than the cutoff frequency, all the signal goes to port 2(Fig. 2).

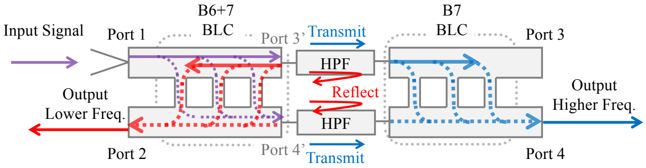

Figure 4. Schematic diagram of frequency separation filter. An input signal (purple lines) to the 3 dB BLC is divided into two, and then delivered toward two output ports 3' and 4' with the almost same magnitude, having a 90˚ phase difference between them. When the frequency of the input signal is higher than the cutoff frequency of the internal HPFs, all the signal (blue lines) goes to port 4. When the input frequency is lower than the cutoff frequency, all the signal (red lines) goes to port 2.

III. DESIGN OF BUILDING BLOCKS

The individual components of the diplexer have been simulated separately, and then carefully connected together. The performance and parameters of optimized components have been obtained using finite-elements software HFSS [6].

A. *Band 6 + 7 Branch Line Coupler (B6+7 BLC)*

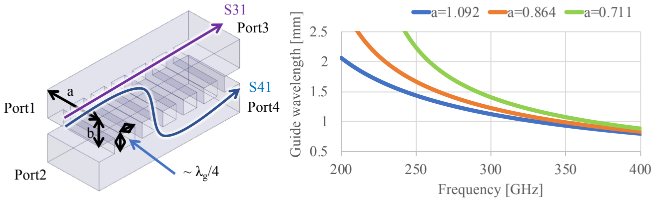

Figure 5. Left figure shows structure of BLC. The long side of waveguide is a and the short side of waveguide is b. The height and interval of several branches is set to quarter guide wavelength. Right figure shows the frequency dependence of guide wavelength. Blue line is a = 1.092, orange line is a = 0.864 and green line is a = 0.711. The larger the long side of waveguide, the smaller the amount of change of guide wavelength.

The major role of BLC is to propagate an input signal by half the intensity with phase differences of 90 degrees. It is important to set the height and interval of several branches to quarter guide wavelength. However, since guide wavelength depend on the long side (a) of waveguide and input frequency (Fig. 3), in wide frequency band it is difficult to define the height and interval of several branches. Therefore, we have tried to change the long side (a) of waveguide. Fig. 3 shows three types of the frequency dependence of guide wavelength. Orange line is fundamental size to transmit radio frequency from 170-340 GHz. Green line is smaller waveguide, and blue line is larger. As you can see, blue line is very flatten compared to other lines and it is easy to set quarter guide wavelength. However, since large waveguide cannot suppress high order mode, the performance is significantly worse. In order to solve this problem, we have tried to decrease the short side (b) of waveguide, and high order mode have been suppressed (Fig. 4). Final model and performance of Band 6 + 7 BLC is shown in Fig. 5. This waveguide size is 1.092 × 0.3 mm, and this design has 9 slots with 50 μm width. Return loss is higher than 21 dB in 210-375 GHz.

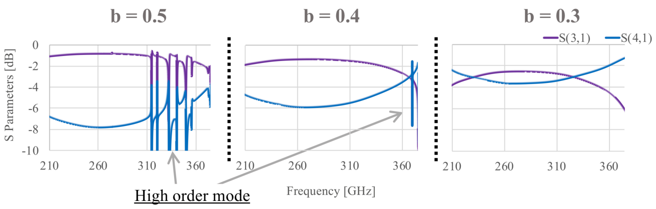

Figure 2. The short side (b) of waveguide is changed (b = 0.5, 0.4, 0.3). This figure shows that the smaller the short side (b) of waveguide, the more hi order mode is suppressed.

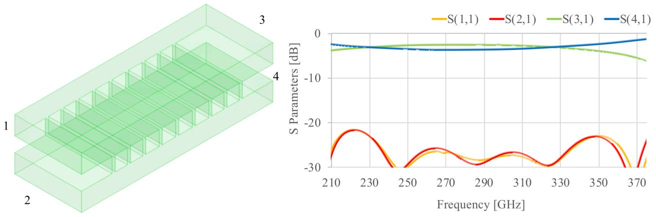

Figure 3. The model and performance of Band 6 + 7 BLC. This waveguide size is 1.092 × 0.3 mm, and this design has 9 slots with 50 μm width. Return loss is higher than 21 dB in 210-375 GHz.

B. *High Pass Filter*

Conventional design of HPF is used a small size straight waveguide. However, this type HPF has high insertion loss to obtain a sharp increase of the reflection loss at the upper end of B6. And it is difficult to match characteristic impedances in wideband. Therefore, we applied a compact cavity filter [7]. This filter formed by cavity and iris resonator has wide pass band with a sharp increase and low insertion loss. Final model and performance is shown in Fig. 6. This design is very compact with thin cavities with 50 μm width and a thick cavity with 140 μm width. In 210-275 GHz, S(2,1) is higher than 27 dB and in 280-375 GHz, return loss is higher than 20 dB.

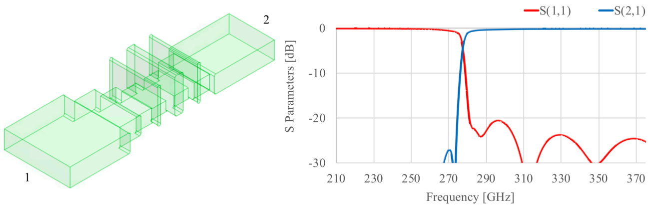

Figure 6. The model and performance of HPF. This design is very compact with thin cavities with 50 μm width and a thick cavity with 140 μm width. In 210-275 GHz, S(2,1) is higher than 27 dB and in 280-375 GHz, return loss is higher than 20 dB.

C. Band 7 Branch Line Coupler (B7 BLC)

B7 BLC is only used at B7 frequencies and fractional band width is 30 %. Therefore this BLC optimized in 275-373 GHz. Standard BLC is applied to simplify the structure. Final model and performance is shown in Fig. 7. This model had 7 slots with 60 µm width and waveguide size is 0.74 × 0.29 mm. In 275-373 GHz, return loss is higher than 22 dB.

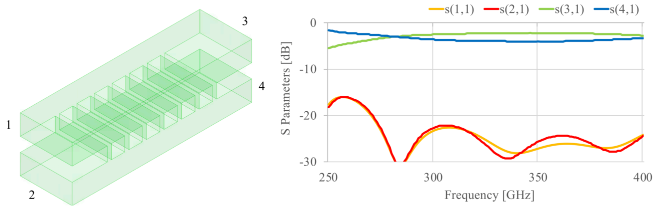

Figure 7. The model and performance of B7 BLC. This model had 7 slots with 60 µm width and waveguide size is 0.74 × 0.29 mm. In 275-373 GHz, return loss is higher than 22 dB.

IV. Design of Waveguide Diplexer

After above components have been designed separately, these components were assembled together. We have optimized all parameters included the length between these components and obtained good performance to separate Band 6 and Band 7 with low insertion loss. If this diplexer is made of aluminum, in 210-265 GHz, return loss is higher than 20 dB and insertion loss is less than 0.15 dB at 4 K, and in 280-375 GHz, return loss is higher than 17 dB and insertion loss is less than 0.25 dB at 4 K. This design is very compact and this length from port 1 to port 3 is about 6 mm.

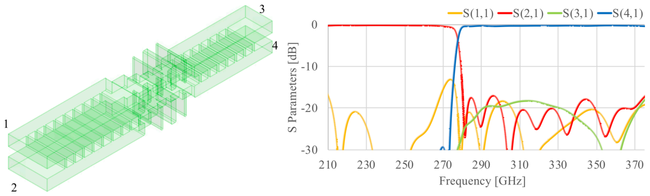

Figure 8. The model and performance of wideband waveguide diplexer. In 210-375 GHz, return loss is higher than 17 dB. If this diplexer is made of aluminum, the insertion loss is 0.25 dB in 210-375 GHz at 4 K.

V. References

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