Development Upgrades of the Atacama Millimeter/submillimeter

Study Proposal

Wideband Isolators for Submillimeter Astronomy

Closeout Report

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1. Introduction

At the Submillimeter Array (SMA), IF bandwidths higher than 16 GHz have been demonstrated. This achievement is attributed to the development of a wideband 4 - 22 GHz cryogenic edge-mode isolator at the Smithsonian Astrophysical Observatory (SAO). A wideband isolator ensures a good match between the SIS mixer and the cryogenic low-noise amplifier over wide bandwidths. While several ALMA bands employ commercially available isolators, these fall short of meeting the performance requirements for the Band6v2 project. The isolator developed by SAO has undergone rigorous testing at the Central Development Lab of NRAO, confirming it as a key component of the ALMA Band6v2 development. This ALMA study proposal aims to further improve its performance.

2. Goals

There are three main goals of this study:

a. Optimize the operation bandwidth coverage to fit the requirements of the Band6v2 project.
b. Increase the isolation to the upper end of the frequency band.
c. Reduce the physical dimensions and thermal mass of the isolators.

3. Unexpected Delays

This study experienced several unexpected delays. The first major delay occurred because the SAO R&G division was understaffed administratively. Material and service orders that were supposed to be placed at the beginning of the year were not placed until April 2023. The second delay was due to slower material supply and metal services, including machining and plating, following the COVID-19 pandemic. This caused a 3-month delay during the prototyping phase of the study. As a result, we requested a no-cost extension for this study from the end of 2023 to the end of April 2024.

4. Results

a. Bandwidth optimization

The isolator developed at SAO for the SMA project covered the frequency band from 4 to 22 GHz. However, the ALMA Band6v2 project requires coverage from 3.5 to 20 GHz. To adjust the band from 4-22 GHz to 3.5-20 GHz, this study employs the TTVG-1000 ferrite instead of the TTVG-1100 ferrite used for the SMA. Figure 1 demonstrates that the isolator with TTVG-1000 ferrite effectively covers the required 3.5 – 20 GHz range for the ALMA Band6v2 project.

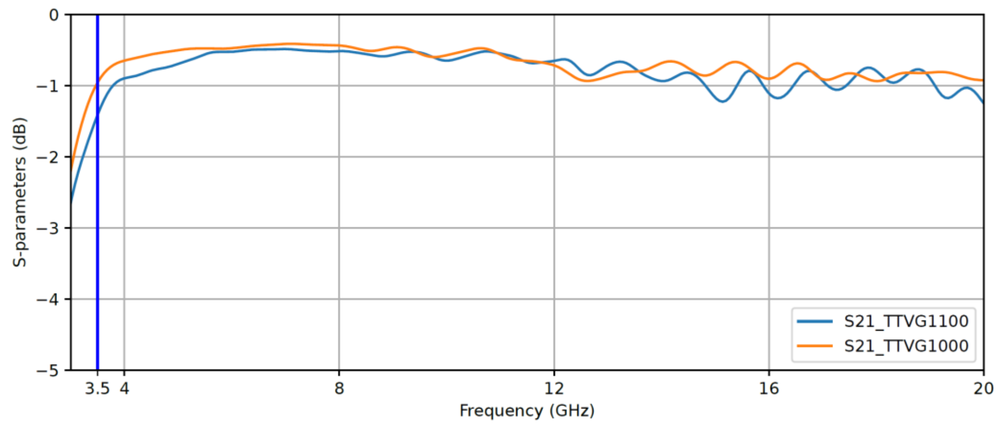

Fig 1. Measured insertion loss of the isolators using TTVG-1100 and TTVG-1000.

b. Improve the Isolation Performance

The second goal of this study was to enhance the isolation performance of the isolator from approximately 10 dB at high frequencies above 16 GHz to a level of 15 dB.

As shown in Figure 2, conventional isolators employ symmetrical circuits with curved tapers to achieve effective impedance matching for both input and output ports.

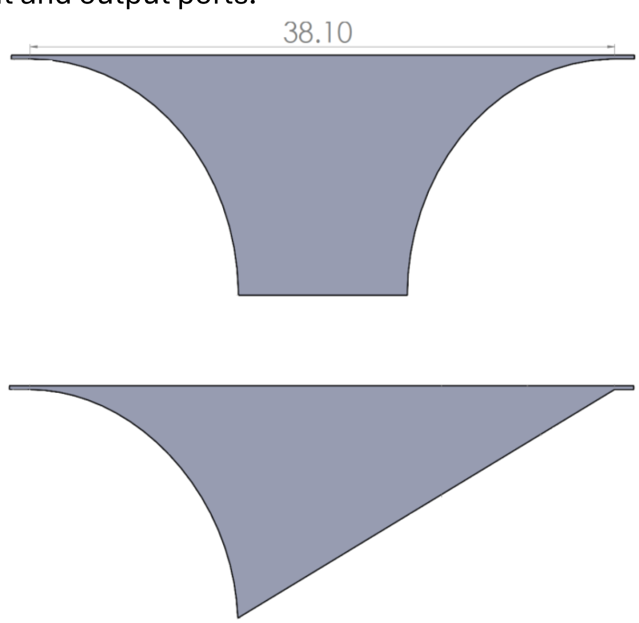

Fig 2. Top: Symmetrical circuit for wSMA isolators. Bottom: Asymmetrical circuit developed in this study

However, at frequencies above 16 GHz, the curved edge at the output port excites higher-order volume modes, which can propagate freely in the ferrite medium. This is the primary reason for the poor isolation performance of conventional isolators. In this study, we investigated the use of an asymmetrical circuit to replace the curved edge with a linear edge at the output port. Our study demonstrated that the new asymmetrical circuit significantly reduces the higher-order modes and achieves the desired 15 dB level of isolation for the new isolators. This finding has been published in reference [1], and the measured results of the new isolator are shown in Figure 3. The isolation is greatly improved, while the insertion loss and return loss are not significantly changed.

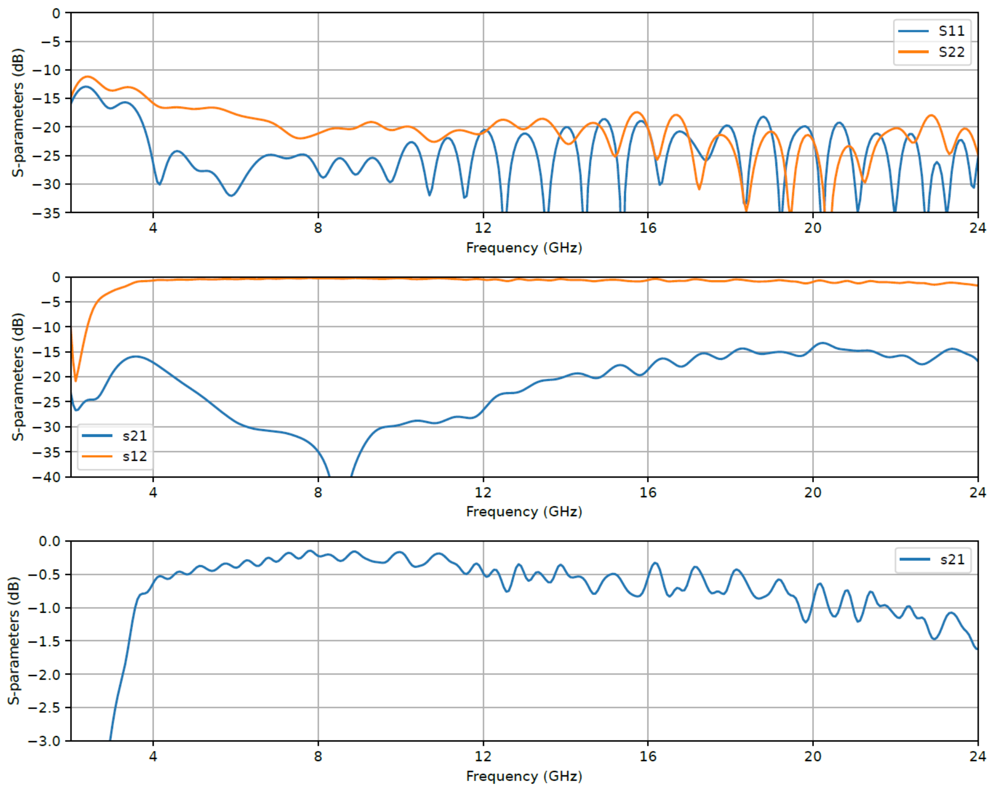

Fig 3. Measured S-parameters of the new isolator using the asymmetrical circuits.

c. Size and weight reduction

During this study, we explored various options to reduce the size and weight of the isolators. This makes them more suitable for cryogenic operations, which are essential for future multi-detector deployments. As shown in Figure 4, the size and weight of the R10 isolators are significantly reduced compared to the previous generation R7. The R7 measures 45.0 x

35.7 x 14.8 mm and weighs 155.7 g, while the final production run of R10 measures 40.6 x 30.2 x 14.9 mm and weighs only 85 g.

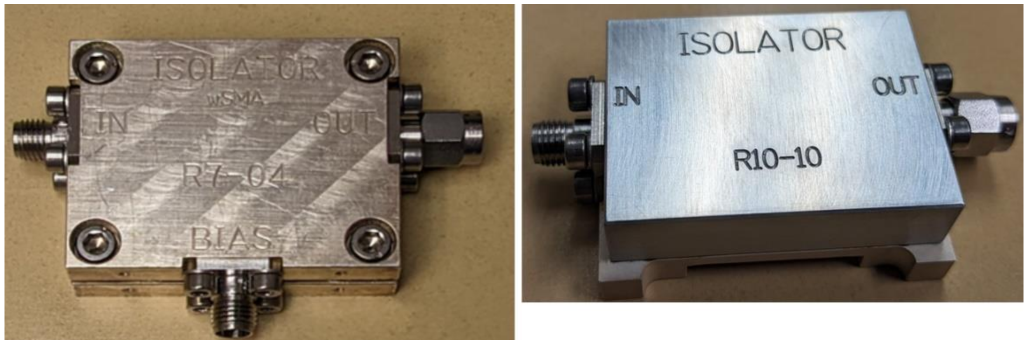

Fig 4. Photos of R7 and R10 isolators

d. Phase matching between isolator pairs

Achieving consistent phase performance between a pair of isolators is crucial for a 2SB receiver system. Factors such as fabrication and assembly tolerances, as well as material consistency, are dominant in affecting phase mismatching performance. Figure 5 shows the phase mismatching in degrees as a function of frequency measured for the R10-21 and R10-24 isolator pairs. The typical value achieved is about ±4 degrees up to 20 GHz.

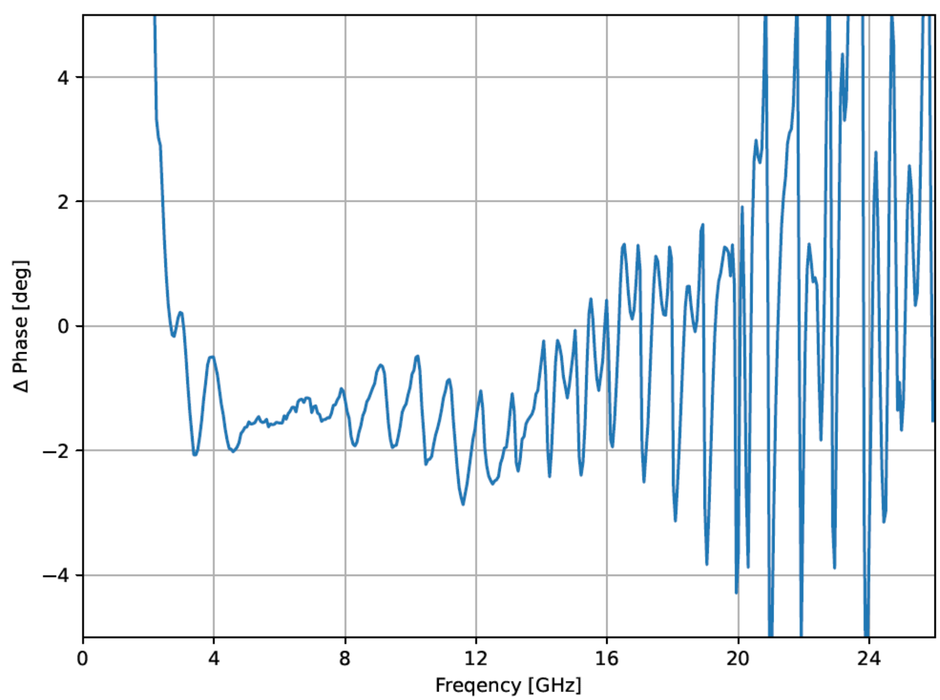

Fig 5. Phase matching between R10-21 and R10-24 isolators

5. Conclusions

Table 1 lists the target specifications from our proposal alongside the values from the final measurements of this study. Final values highlighted in green indicate that we met the target value; blue indicates that the final values are very close to the target value; red indicates that we didn't meet the target value.

Table 1. the target and actual specifications of the isolator

Spec number	Specification	Target Value	Final Value	Frequency range [GHz]
1	Insertion loss	< 1.0 dB < 0.5 dB < 0.8 dB	< 1.0 dB < 0.8 dB < 1.0 dB	3.5 < f < 4.0 4.0 < f < 18.0 18.0 < f < 20.0
2	Input return loss	< -18 dB < -20 dB < -18 dB	< -18 dB < -20 dB < -18 dB	3.5 < f < 4.0 4.0 < f < 18.0 18.0 < f < 20.0
3	Output return loss	< -18 dB < -20 dB < -18 dB	< -13 dB < -15 dB < -15 dB	3.5 < f < 4.0 4.0 < f < 18.0 18.0 < f < 20.0
4	Isolation	> 15 dB > 15 dB > 12 dB	> 15 dB > 15 dB > 15 dB	3.5 < f < 4.0 4.0 < f < 18.0 18.0 < f < 20.0
5	Amplitude match for isolator pairs	< 0.3 dB	< 0.3 dB	3.5 < f < 20.0
6	Phase match for isolator pairs	< 3 deg	< 4 deg	3.5 < f < 20.0

In our proposal, we set the threshold to meet at least 50% of the target specifications to declare the study successful. Now, we meet (or get very close to) most of the targets, except for the output return loss, insertion loss and the phase matching for the isolator pairs. The reason for the poorer output return loss is that we use a linear taper at the output port, which doesn't provide good impedance matching. However, we believe the current ~15 dB output impedance is sufficient for the Band6v2 project, given that the isolation is higher at high frequencies. Achieving <0.5 dB insertion loss is very challenging, especially at high frequencies above 14 GHz, the typical insertion loss we achieve is shown in Figure 3, which is not far away from the target value listed in Table1. Regarding the phase match for isolator pairs, we declare the measurement of 4 degrees as the mean value; however, we achieved better than 3 degrees for some isolator pairs. To make it more consistent, we need to improve the machining tolerance of the isolator parts, including the plates, ferrite, and absorber loads. That will be part of the future development plan for this work.

6. Deliverables

We will send a pair of R10 isolators with the above specifications and a measurement report to NRAO CDL before April 30, 2024.

References:

[1] L. Zeng, C. -Y. E. Tong and S. N. Paine, "A Low-Insertion Loss Cryogenic Edge-Mode 0Isolator With 18 GHz Bandwidth," in *IEEE Journal of Microwaves*, doi: 10.1109/JMW.2023.3307297.