# Reflection measurement of absorption coatings using 600-670 GHz vector network analyzer

A.M. Baryshev, W. Jellema, R. Hesper, W. Wild

***Abstract*—This article describes several aspects of ALMA band 9 cartridges: design, development and characterization. We give special attention to the characterization of the system. In this context, we present the noise measurements of the first eight cartridges with an emphasis on the extremely large IF bandwidth (4-12 GHz). The IF gain slope, receiver linearity and saturation, receiver beam pattern and cross polarization level measurements are also presented.**

***Index Terms* — Heterodyne detection, vector network analyzer, sub millimeter wavelengths, calibration, reflecometer, black body**

## I. Introduction

VECTOR network analyzers (VNA) are common tool in microwave and millimeter wave laboratories. The capability in measuring not only amplitude but phase response of the circuit under test is a valuable asset for investigating RF properties of various systems. Progress in electronically tunable submm solid state sources allows for using them to extend a frequency range of VNA into submm/THz frequencies [1], [2].

In this report we present a construction and measurement of a single port quasi-optical VNA covering in the range of 600-670 GHz. This VNA was then used for measurements of frequency and spatially resolved reflection response of a SiC/Stycast absorption coating which is used both in ALMA and HIFI. The ability of spatially resolving the reflected signal allows for discriminating against contributions of other components of a test set up, thus greatly improving the measurement accuracy.

A Mihelson interferometer quasi-optical configuration was used to create a single port reflectometer. An ALMA band 9 x6 warm multiplier assembly was used as a signal source and a subharmonicaly pumped superlattice device has been used as a detector. These components allow to achieve dynamic range of 60 dB without using cooled detector. A spatial resolution of about 3 mm has been demonstrated.

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## II. Layout of measurement system

### A. Quasi-optics layout

The reflectometer is made by using the Mihelson interferometer scheme as shown in fig. 1, 2. Green dashed lines represents the main path of the signal and the red dashed line represent a parasitic channel which can be calibrated out using a standard calibration load (”matched load”, and “short”) techniques. A 40 micron thick Mylar foil beam splitter was used which corresponds to a 3 dB reflected - transmitted signal ratio for the frequency of interest. Main polarization of set-up is vertical (perpendicular to optical table plane) and is set by a polarization of detector and transmitter diagonal horns.

An ALMA x6 multiplier prototype made by NRAO and VDI has been used as a signal source [alma]. It has 610-712 GHz frequency coverage and 40 microwatt of peak output power. Its beam has been formed by a diagonal horn and an HDP lens. The source has an additional WR-8 coupling waveguide port which allows to pick part of the signal before x6 multiplier to create a reference for phase/amplitude detection circuit.

A subharmonically pumped (n=30..35) superlattice electronic device (SLED) was used as detector. It is mounted in to detector block with integrated diagonal horn. Its SMA connector DC/IF input was also used to provide a sub harmonic LO signal at 16…20 GHz. The same type of

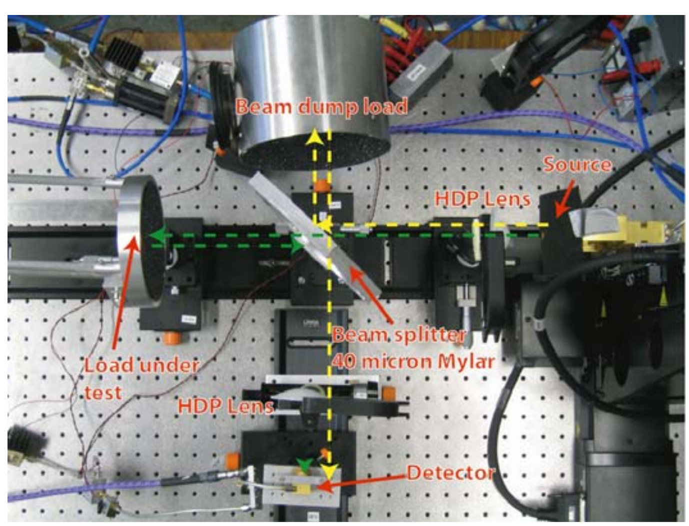

Fig. 1. Layout of single port quasi-optical VNA

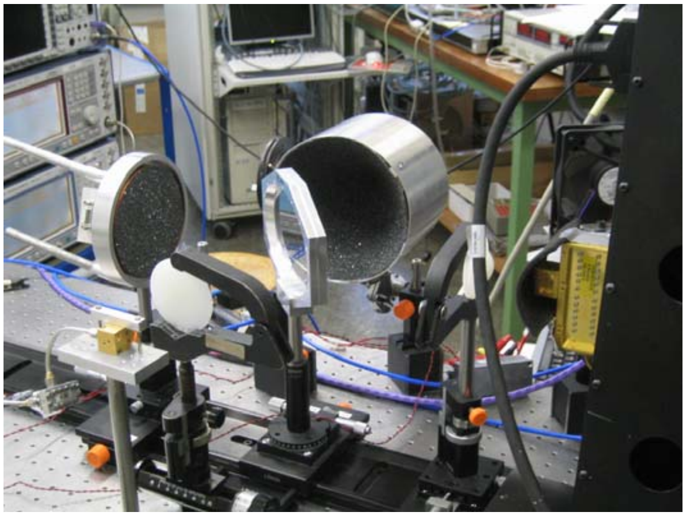

Fig. 2. Layout of the experiment in 3D.

detector was used in room temperature beam pattern measurements of ALMA band 9 optics [3].

The parasitic channel path of the interferometer shown in yellow line in fig. 1 has been terminated by a beam dump. The absorption coating has been made out of carbon loaded Stycast epoxy with SiC grains as the top layer [4]. Coating was deposited on the aluminum cone shape substrate (see fig. 2).

### B. Phase and amplitude detection circuit

The homodyne scheme similar to one used for ALMA [5] and HIFI [6] beam pattern measurements was used. A simplified signal diagram is presented in fig. 3. The source was driven by a frequency synthesizer S1. Another frequency synthesizer S2 was used both for pumping a detector SLED as well as Schottky mixer for creating reference system. Both S1 and S2 are Rohde & Schwartz SMP-20 type. The primary IF was 1 GHz. The IF signal of mixer M1 is amplified and multiplied by 6 to create a primary reference signal.

An additional mixer pair M3, M4 was used to take out coherent phase noise introduced by synthesizers S1 and S2 and allow for using extremely narrow detection bandwidth of 100 Hz. A Rohde & Schwartz microwave VNA in time sweep mode has been used as signal detection unit. Its internal reference oscillator was used as S3. All S1, S2 and S3 have been phase locked to each other.

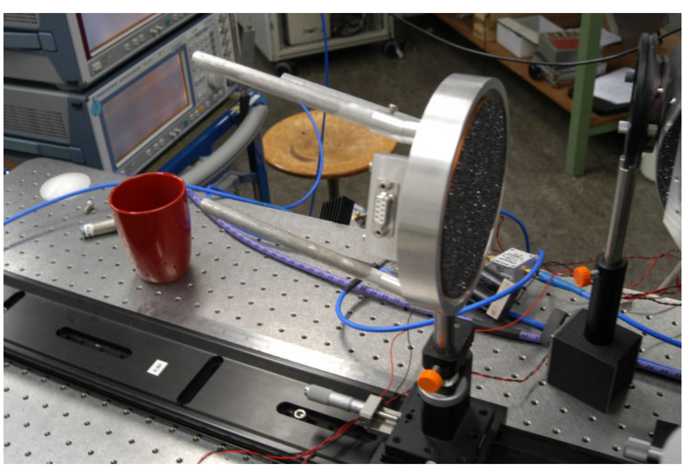

Fig. 4. ALMA test load.

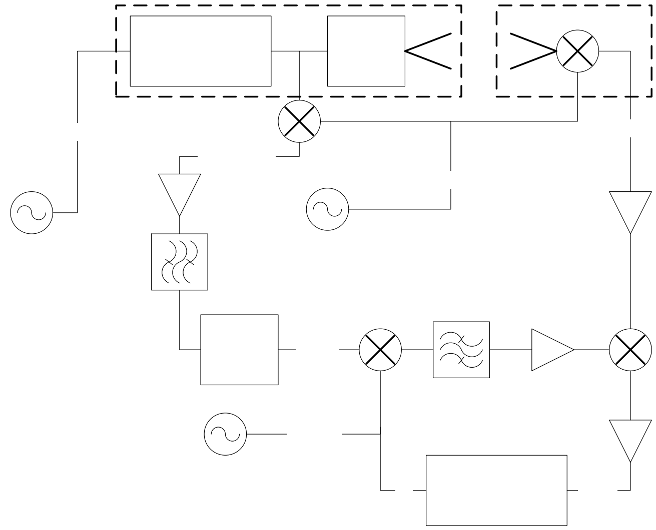

Fig. 3. Signal detection scheme

During measurements, for each point of signal frequency a oscillators S1 and S2 have been tuned such as the primary IF stays 1 GHz; output power of S2 is adjusted to maximize S/N at SLED detector and time sweep of VNA is taken. This procedure is repeated for each frequency following a table lookup procedure in control computer. It was found that frequency and output power setting repeatability is sufficient for doing frequency sweeps.

### C. Calibration procedure

A quasi-optical VNA calibration has been achieved by measuring amplitude and phase response of the system while two calibration loads were presented to its input beam. A flat mirror was mounted and presented a “short” calibration load. An absorber material sheet mounted at large distance in the input beam served as a “matched load” equivalent. Any consequent measured traces $A(f)$ were corrected by the calibration information as follows:

$$A_c(f) = \frac{A(f) - A_{load}(f)}{A_{short}(f) - A_{load}(f)},$$

where $A(f)$ is the complex measured response, $A_{load}(f)$ is matched load response, and $A_{short}(f)$ is a “short” response.

This calibration procedure is used for all the data presented in this paper. For creating a spatial response of test objects a Fourier transform of complex amplitude $A_c(f)$ is used to create complex spatial response $A_c(x)$.

### D. ALMA 100 C test load

ALMA 100 C test load is shown in fig. 4. It is made of a copper disk suspended in an aluminum case and provided with temperature sensor and resistive heater network for temperature control. Its surface is coated by a carbon loaded Stycast epoxy with SiC grains to provide an optimum

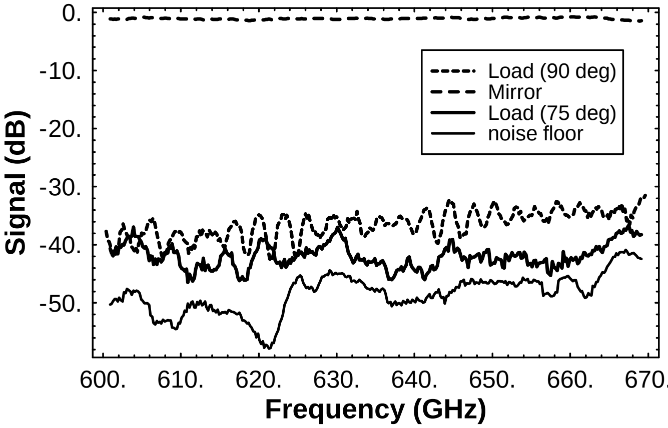


Fig. 4. Measured amplitude frequency response of strait load “Load (90 deg)”, mirror, tilted load “Load (75 deg)” and noise floor of the system

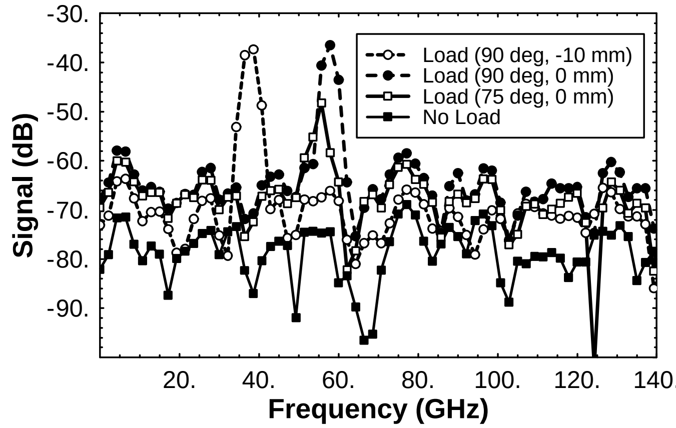


Fig. 5. Measured spatial response of different objects

absorption at submm frequencies. The same type of load was used in HIFI and ALMA band 9 receiver absorbers [4]. The goal of these measurements was to characterize the reflection coefficient of this type of absorber.

## III. Measurements and Discussion

### A. Frequency response

Fig. 4 shows measured amplitude frequency response of ALMA band 9 calibration load compared with the response of a flat mirror mounted at the load position. In order to investigate the specular/diffuse reflection, the load has been tilted by a 15 degree angle and measured again. The S/N leval of 50 dB has been achieved and load reflection of -33 dB across the frequency band has been demonstrated for specular reflection. If the load is tilted its reflection coefficient improves by 3-5 dB.

### B. Spatial response

A spatial response of ALMA calibration load is presented in fig. 5. It was obtained from the same measurement as in fig. 4 with an addition of a strait load which was shifted towards the VNA by 10 mm. As it is clearly seen from the fig. 5, reflection from the load can be resolved spatially with the accuracy of about 3 mm. The amplitude of the response corresponds to an average value in fig. 4.

Data shown in fig. 6, which corresponds to fig. 5 in the linear scale, demonstrates the ability of this method to spatially resolve the reflection even for relatively low level signal. It can also be seen in fig. 5 that response from tilted load is wider in distance space than response of the strait load as it is expected.

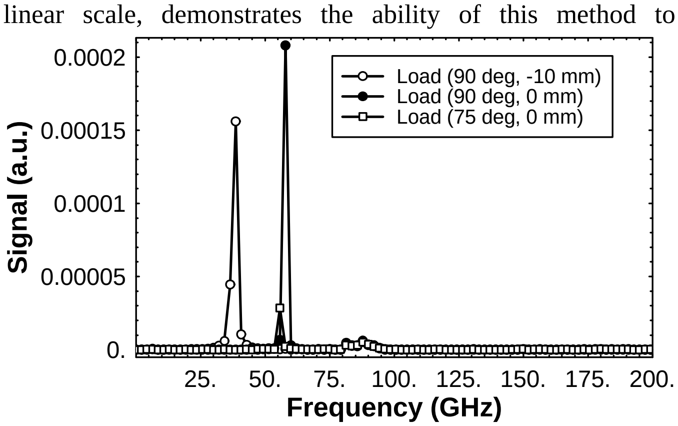


Fig. 6. Measured spatial response of different objects, linear scale. Data from fig. 5 is used.

## IV. Conclusion

We have demonstrated a quasi-optical single port vector network analyzer configuration over frequency range of 600-670 GHz with signal to noise ratio of about 60 dB. A spatial resolution of about 3 mm can be reached in this configuration allowing to analyze the reflection response of the device under test in greater detail.

Performance of ALMA test load was measured to be of -32 dB reflection level over 600-670 GHz which is localized at the surface of the load. The tilted load shows wider spatial response and approx 5 dB lower reflection signal amplitude.

## Acknowledgment

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