Measurement of Emissivity of the ALMA Antenna Panel at 840 GHz Using NbN-Based Heterodyne SIS Receiver

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***Abstract*— We measured emissivity of sample presenting panel of ALMA antenna using Band-10 heterodyne SIS receiver as antenna switching balanced radiometer with 8 GHz instantaneous bandwidth. Receiver noise temperature measured with 80 K/300 K antenna loads was ≈560 K (DSB). Emissivity of the surface is detected at LO frequency about 840 GHz via the imbalance of the antenna switch due to extra reflection from sample of panel; absorption 0.25±0.10 % is calculated from measured emissivity. To confirm measured value, samples made of phosphor bronze and stainless steel are tested using the same technique. The values of 0.30±0.10 % and 1.10±0.10 % are obtained for these samples correspondingly that is consistent with previous data obtained using direct detector radiometers.**

I. INTRODUCTION

The surface finish of the main dish for ALMA telescopes is subject to a number of special requirements. For example, focusing of the infrared portion of solar radiation must be restricted via diffused scattering from the surface of the dish's panels, while RF loss, which causes in-band noise emission, must be below 1% at all frequencies. These are somewhat contradictory requirements, since the surface of the antenna cannot be polished and must have appropriate roughness (matte finish) providing the scattering of IR-radiation. The noise emission of a reflective surface is usually measured by a bolometer-based radiometer, which can provide a very high sensitivity [1], [2]. Another technique for measuring of absorption of highly reflective surfaces is evaluation of the Q-factor of a resonator formed by the reflector under test [3]–[5]. However, both techniques have some drawbacks. A sensitive radiometer suffers usually from the low dynamic range while the resonant method assumes precision design and careful adjustment. In spite the low absorption is specified as the figure of merit, the low background emission is meant in practice. For this reason one may suggest that radiometric methods can provide the most reliable (and practicable) data.

Since saturation level of a SIS mixer is usually higher than 300 K, the emissivity could be *calibrated* with conventional 300-K and 80-K antenna loads, if such SIS radiometer could be used efficiently. This paper is focused on a description of a particular experiment with sensitive submillimeter heterodyne SIS receiver as a balanced radiometer. The feasibility of the experimental method is discussed along with analysis of particular experimental data obtained for three commonly used reflecting materials: aluminum, phosphor bronze and stainless steel. The accuracy of the described technique is discussed, that includes the effects of non-thermostatic environment and scattered 300-K radiation.

II. THE SWITCHING RADIOMETER

The receiver is mounted within a vacuum 4-K cryostat and contains one of our experimental waveguide-type SIS mixers under development for ALMA Band-10. We used one of the optional SIS mixers, which employed the resonant type junction made of epitaxial NbN/AlN/NbN trilayer [6]. The receiver noise temperature at antenna loads was measured as ≈560 K (DSB, IF band 4-8 GHz) or ≈330 K at the window of the cryostat after correction for the 25-μm-thick Kapton beam splitter, which is used for injection of LO power from BWO (nominal range 696-938 GHz).

A. Principle of Switching Radiometer

The general idea of our measurement is to provide the receiver input with thermal emission from a 80-K absorber via two paths, which are different (separated) in space, but producing equal intensity. If the receiver input is switched between these two paths, the differential signal registered at the receiver output will be zero, unless extra emission is present in either of the two 80-K signal paths. The weak imbalance can be detected via well-known switching technique as presented in Fig. 1.

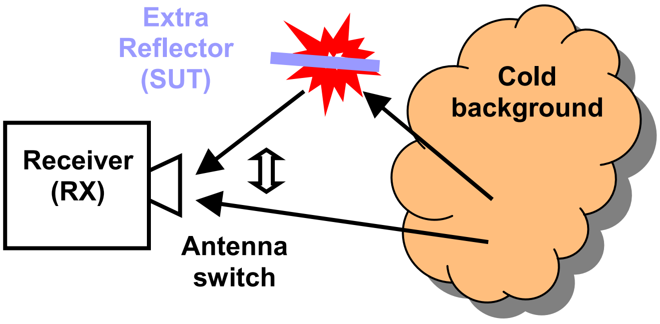

Fig.1 Principle of detection of thermal emission with switching radiometer.

The difficulty is that one has to be sure that the antenna switch, which is presumably a room-temperature (quite hot) reflector, does not introduce any emission by itself. For this purpose we have suggested and designed the well-balanced beam-switch, presented in Fig. 2. The idea of such switch is based on equal emission from both the chopper deflection blade (M1) and the following (fixed) deflection mirror (M2), which is seen by the receiver input while the chopper blade is open as presented in Fig. 2(a). The dashed traces in Fig. 2 explain the balance of thermal radiation in the switch. Note that the balance of emission in such system is possible for *two equal* 80-K loads (or for a single large-aperture homogeneous load). The sample of the antenna panel (SUT) is placed in the *sampling arm* providing just one extra reflection, which breaks the balance as shown in Fig. 3.

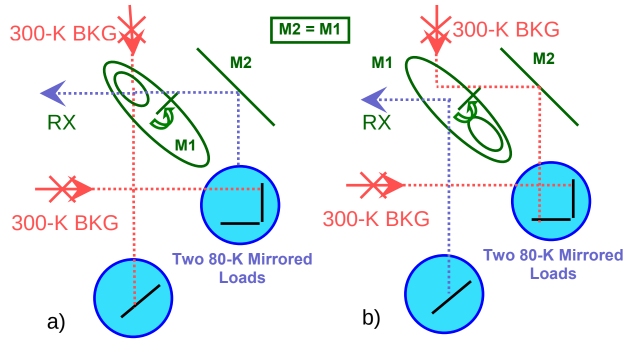

Fig. 2 Principle of balanced switch: (a) chopper blade is open towards M2 in referencing arm, (b) the chopper blade is closed deflecting input beam towards sampling arm.

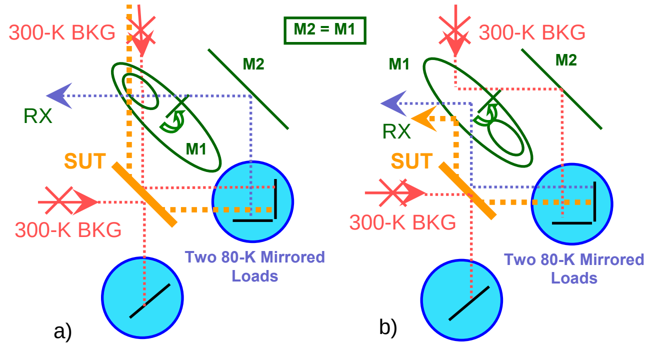

Fig. 3 Principle of emission detection: (a) chopper blade is open to read referencing arm (80-K emission), (b) the chopper blade is closed to read mixture of emission from sample and from 80-K load.

B. *Experimental Setup and Controlling Software*

We have tried two variants of the cold load, single large-aperture load and two “equal” loads made from the microwave absorber Eccosorb AN-72 [7] or from pyramidal plastic TK-RAM [8], immersed into liquid nitrogen (LN_2). The large-aperture load was inside the Styrofoam box (boxed load); the split-type load was in top-open stainless steel thermos containers. To prevent the water condensation, the outside wall of the boxed load was continuously dried (ventilated) by room-temperature (300-K) airflow. The photo of the most critical part of the experimental radiometer is shown in Fig. 4 for the case of two equal but separated cold loads placed in referencing and sampling arms. To provide two-beam coupling to the cold load in the reference arm, a special roof-top mirror is designed (right bottom corner in Fig. 4). Notice from Fig. 2 and Fig. 3 that both beam paths are of the same length, providing very similar aperture termination of the receiver antenna at both cold loads.

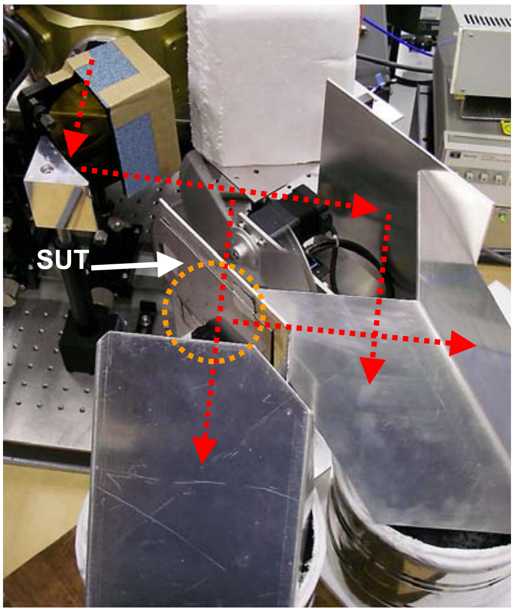

Fig. 4 Most critical part of the experimental switching radiometer: balanced switch (in the center) and mirrored cold (LN_2, T≈80 K) loads (at the foreground).

The experimental system is operated under PC control using IRTECON software [9]. This software enables presets for multiple biasing and measuring devices, including SIS mixer; it collects and evaluates automatically both dc and RF/IF data from the receiver according to user’s prescription. We have configured the chopper for positive respond, if the *sampling arm* is loaded with a hotter load. The chopper (hot-cold) rate is 2.5 Hz; the IF power is read 20-40 times per second by the power meter Agilent-E4419. The Y-factor is calculated for each cycle of the chopper using a special software lock-in routine within the IRTECON program. Then the Y-factor is averaged 10 times providing successive graphic output points every 5-10 s. This rate means averaging of the Y-factor for about 12-25 times that equal to effective integration constant of 1-2 s.

A. Calibration Procedure

Since the SIS junctions from epitaxial NbN are operating quite far from their gap frequency, we did not expect essential saturation effects for the antenna temperature 300 K. To calibrate the radiometer, we placed the LN_2-soaked Eccosorb AN-72 material in the sampling arm instead of SUT assuming the emission temperature equal to 78 K. The same absorbing material at the ambient room temperature is placed in the referencing arm of the radiometer. The example of calibration data is presented in Fig. 5; the error bar for measured levels is about 4.6×10^{-4} dB.

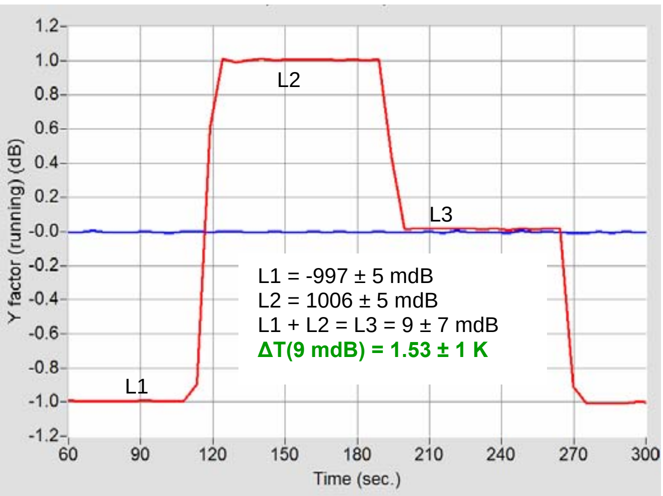

Fig. 5 Calibration of the SIS radiometer at 842 GHz. Horizontal (blue) line presents fully balanced output. Levels of step (red) line present: L1 for cold (80 K) positive arm and hot (295 K) negative arm, L2 for swept loads in respect to hot and cold arms, L3 present slight misbalance due to SUT.

To find the intrinsic misbalance of the switch (zero emission offset), the following experiment has occurred quite useful. We used slightly different absorbing materials, which provide a bit different emission coefficients for two cold loads: AN-72 and TK-RAM. This gave us a very small differential signal, which must be somewhat wrong due to the unknown offset. Swapping the cold containers with these two LN_2 loads (but not swapping their mirrors!) we have seen change of the sign of the response of our differential radiometer similar to that of regular semiconductor operational amplifier if its input polarity is swapped. The result of this procedure is presented in Fig. 6 giving the precision offset value of -0.00487 dB or -0.73 K.

III. RESULTS AND DISCUSSION

A. Efficient Noise Temperature of Cold Loads

Experimenting with offset measurements, we found that reflection and absorption of walls of boxed load made from Styrofoam can give a significant effect, due to different temperature of the walls in few degrees. To measure the reflection of the Styrofoam boxed load (or any other flat-surface, not diffusing, load), the 300-K background beams, as shown in Fig. 2, can be blocked with a cold load, thus introducing misbalance presumably originated from the only reflection from either wall. The evaluated reflection is 1% and absorption is in the range of 4-10%. To conclude on the balancing procedure of the switch (and on final accuracy), the blockage of 300-K background radiation with extra LN_2 loads can be recommended.

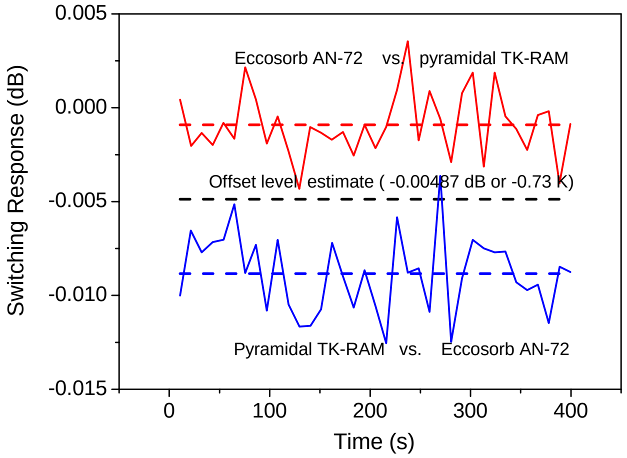

Fig. 6 Measurement of offset emission of switching (differential) radiometer with two slightly different cold loads.

B. LO Stability

It is found that stability of the LO is an important issue. The IRTECON program allows for real-time noise analysis for virtually any process in the measuring system. The stability of the bias current of the SIS mixer is chosen to be the merit. It was found that stability of the bias is related to the particular frequency point (voltage) of the BWO oscillator. The choice of "wrong" frequency point does not affect noticeably the measured value of T_{RX}, but the instability of the Y-factor measured at the scale on milli-dB can be drastically increased.

C. Emission measurements

Experimental data on emission from a few frequently used materials are presented in Fig. 7 and summarized in Table I.

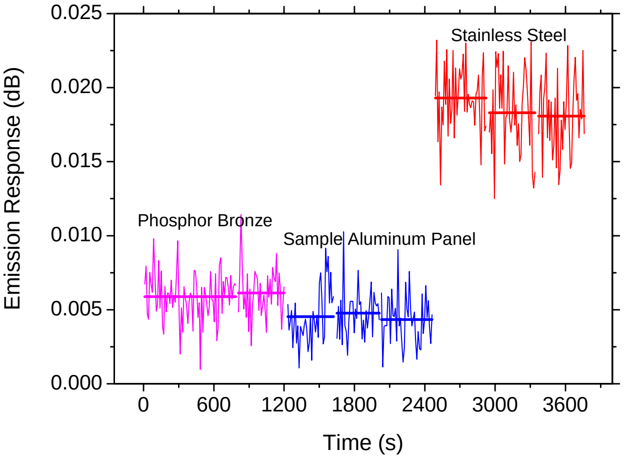

Fig. 7 Measured emission from phosphor bronze, ALMA sample panel and from stainless steel.

The emission response of ALMA panel made of aluminum with matte finish is found as 0.7 K or 0.25 % after evaluation; for phosphor bronze we measured emission of 0.9 K and evaluate it as 0.3 % of absorption; for sample of stainless steel these values are 3.1 K and 1.1 % correspondingly. The accuracy of 0.25% is measured as a standard deviation. In spite the offset can be made quite low as shown in Fig. 5, changes in configuration can result in change of scattered 300-K background radiation, which can be also measured quite accurately as seen from Fig. 6. Trying to be on the safe side, about 0.7 K of growth in emission temperature that is equal to 0.25 % growth for absorption coefficients have to be added. Slight saturation, if any, would make our emission measurements *overestimated*. It seems that RF properties of a Styrofoam box can be spread over wide range, sometimes making boxed load hardly acceptable for sub-mm applications.

TABLE VIII
EMISSION AND ABSORPTION MEASURED FOR A FEW POPULAR MATERIALS

Material	**Parameters at 840 GHz**	
	Emission (K)	**Absorption (%)**
Aluminium panel with matte finish (ALMA)	0.7	0.25
Phosphor bronze (polished)	0.9	0.3
Stainless steel (matte)	3.1	1.1
Eccosorb AN-72 immersed in LN_2	82.5	98
TK-RAM immersed in LN_2	81.3	98.5
Styrofoam box with AN-72 absorber	85-100	-
Styrofoam wall of boxed load (2 cm)	-	4-10

III. CONCLUSIONS

A switching radiometer based on a wide IF-band heterodyne SIS receiver is tested for accurate measurement of noise contribution from reflecting and absorbing surfaces. Standard deviation error ± 0.25 K in temperature scale or ±0.1% in absorption scale is found. Since large saturation power of a SIS receiver the emissivity of about 0.25% + 0.25% (or $T_e = 0.7$ K + 0.7 K) or *below* can be concluded for the sample of ALMA antenna panel near 840 GHz.

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