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A Cryogenic Microwave Measuring System for Satellite Receiver Testing

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***Abstract* — A cryogenic microwave test system for the 70 GHz Planck satellite receiver has been built. It consists of 4 K and 20 K active helium coolers mounted in large 2x 10^{-7} mbar vacuum chamber. Special RF-components have been designed for the tests, e.g. a 4 K load for the continuous comparator reference temperature stimulus. External electronics has been constructed to measure the two orthogonal polarizations from two parallel receiver units. The noise temperature measurement uncertainty is better than 4 K and the test system's post-detection noise characteristics with a matched load is better than $1.6 \cdot 10^{-6}$ V/√Hz from 15 mHz, when the integration time constant is 0.5 s.**

I. INTRODUCTION

The Planck satellite mission in 2007-2009 is devoted to Cosmic Microwave Background (CMB) measurements using 30-850 GHz radiometers. Total power/continuous comparator receivers in INP HEMT technology, called Low Frequency Instruments (LFI), will be used at 33, 40, 70 and 100 GHz for two orthogonal polarizations [1]. At 70GHz there will be twelve Front End Modules (FEMs) and six Back End Modules (BEMs), each with 4 diode detectors. Orthogonal polarizations from a single horn antenna are separated into two channels Whereby two separate front ends are needed in every FEM. Antennas, OMTs and FEMs are mounted at 20 K physical temperature to minimize the system noise level, while the BEMs will be operated at 300 K. The FEM and BEM will be connected using about 1 m long WR-12 waveguides. Each receiver has a horn antenna looking at a 4 K temperature reference. The 70 GHz FEM and BEM, see [1], have been developed and manufactured in Finland in co-operation with YLINEN Electronics, VTT Millilab and HUT Metsähovi observatory. The Cryogenic Microwave Test System described in this paper has been designed and built to test the 70 GHz receiver in a realistic space environment. The needed vacuum is about 10^{-5} mbar and ideal 3 K and 4 K wide band noise stimuli simulate CMB radiation and the reference source. A monitoring system has been included for all operational parameters i.e. physical temperatures, bias voltages and RF-performance.

II. CHAMBER DESIGN CONSIDERATIONS

The stainless-steel vacuum chamber provides a low out-gassing level and low emissivity. The size was dictated by the physical distance from FEM to BEM in the flight model. Vacuum is maintained below $2 \cdot 10^{-7}$ mbar by a backing pump and a diffusion pump and monitored with a mass-spectrometer. Because electromagnetic compatibility measurements inside the chamber are complicated, two receivers will be tested together to demonstrate the inter-compatibility between them. Cooling power for these is provided by separate closed-cycle helium coolers at the "ideal" 3 K (antenna), the 4 K reference and the 20 K receiver temperature. The radiation shield inside the chamber was made to approximate the in-flight conditions, where 20 K FEMs are surrounded with a 70 K radiation housing on one side and the 4 K external surface of the HFI dewars on the other. The temperature controller and eight calibrated diodes give an uncertainty of 20 mK at 20 K. The complete chamber for two full receivers is shown in Fig. 1 (upper).

Eight FEM soft-start bias voltage supplies were built to get the in-flight tuning characteristics, synchronized phase switching up to 20 kHz and computer monitoring. The radiometer is required to give more than 90 per cent of effective measurement time, and very little is allowed for integration or can be wasted on phase switching and measurement electronics housekeeping. Therefore, the designed data acquisition system (DAU) provides a fully synchronous timing scheme with constant integration time. The sampled signals are optically isolated from the data acquisition computer to provide separate electrical grounds. The measured white noise level ΔV/V of this test system is $1.69 \cdot 10^{-6}$ 1/√Hz from 15 mHz, when a bandwidth of 14 GHz and an integration time of 0.5 seconds are used. A more detailed analysis of satellite 1/f-noise can be found e.g. in [2].

III. RF-MEASUREMENT SYSTEM

FEM gain, channel isolation, noise temperature and power consumption are measured. Vector network analyzer (VNA) calibration reference planes were fixed outside the chamber due to drifts during cooling. Losses were measured at room temperature, vacuum and at cryogenic temperatures separately and used thereafter as corrections. Waveguide losses decrease by about 20 per cent when one end is connected to 20 K physical temperature whilst the other end stays outside the chamber. There was no measurable difference between the waveguide losses at room temperature vacuum and NTP operation. Magic-T's were mounted between FEM and BEM to enable real time gain and channel isolation measurements also when both active units are inside the vacuum chamber. The overall arrangement is shown schematically in Fig. 1 (lower). The 4K load was made of absorber material [3]. The reflection was measured at 20K physical temperature through a waveguide window, which limited the accuracy. A typical result is highlighted in Fig. 2.

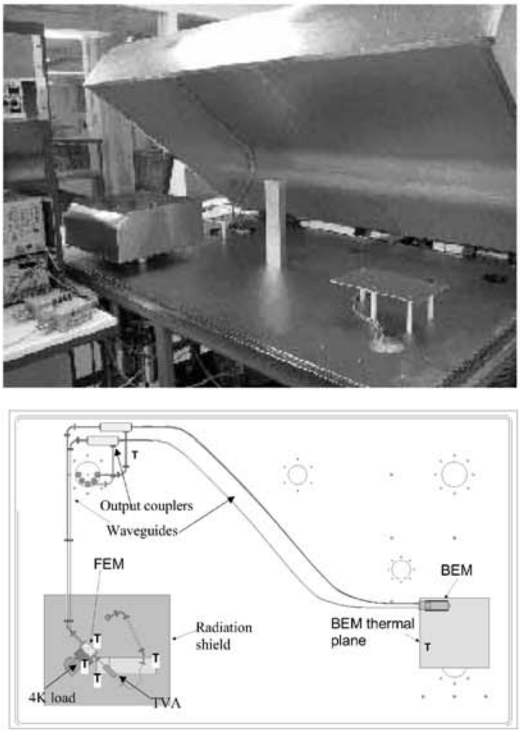

Fig. 1. The vacuum chamber with a radiation shield and BEM temperature plate (upper). Dimensions are 1.6 x 1 x 0.3 m. Radiometer mounting inside the chamber (lower). "T" indicates a temperature sensor.

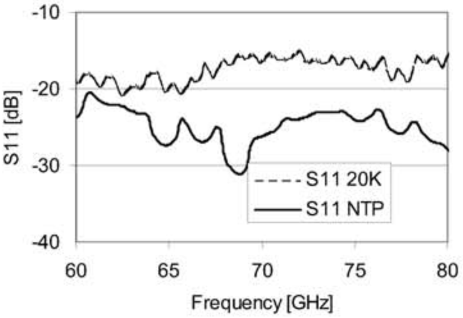

Fig. 2. Typical 4 K load reflections inside chamber at 20 K (horn antenna) and similarly at NTP.

A 25 dB Temperature Variable Attenuator (TVA) was designed following the procedures described in [4]. It gives acceptably low leakage of the room temperature noise to the FEM input but allows a reasonable T_{hot} noise power input from an external noise diode. Noise measurement was always done with the TVA and a diode having an optimized ENR of about 17 dB at the center frequency. It was calibrated with liquid nitrogen and room temperature absorber material jointly with the respective receiver. The measured noise temperature of the noise receiver was 500 K over the entire band. Noise was measured with TVA heating (from 5K up to 19K) to have an appropriate Y-factor with the noise receiver. Total SSB power was recorded with the noise test set receiver. By taking the input reflections of the DUT into account, the noise measurement accuracy can be improved. [5,6]. The most important effect comes from input losses and the root sum square uncertainty according to [7] was found to be about 10 K both with the TVA and noise diode, see Fig. 3 (upper). The most significant contribution of the noise measurement uncertainty is due to the restricted Y-factor measuring accuracy. This was an absolute maximum value without heating the DUT, whereby an increase in ΔT_{sys} with small Y-factors is unavoidable. A Monte Carlo analysis gives an uncertainty of 4K at 10-90 % limits for the TVA method and 5 K for the noise diode method at 70 GHz. Very identical results were obtained both with the noise diode and the TVA as is illustrated in the lower plot of Fig. 3.

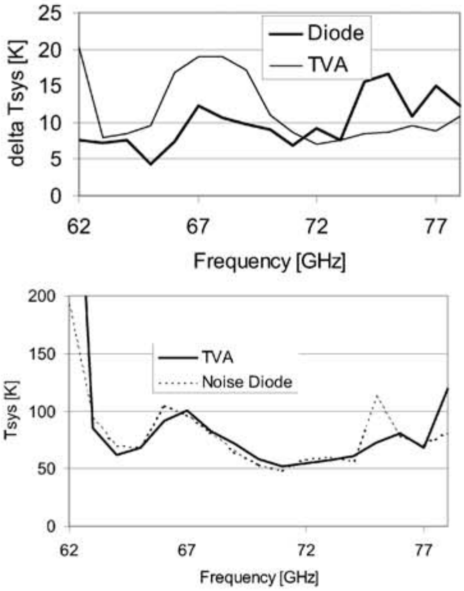

Fig. 3. Noise measurement uncertainty ΔT_{sys} as RSS-values for the noise diode and TVA methods (upper). FEM noise measured with an externally calibrated noise diode and the TVA (lower).

IV. CONCLUSIONS

A cryogenic measuring system for an ultra low noise continuous comparator space-probe receiver has been described. It includes a monitoring and data acquisition system for the two complete continuous comparator channels. Essential hardware was tested to ensure the capability of validating all necessary receiver requirements. Many special microwave components were designed and evaluated, e.g. a 4K cryogenic load and TVA, which enable these cryogenic measurements. A good agreement at around 1K mutual discrepancy in the noise temperature was achieved with an externally calibrated noise diode and the designed TVA. The most important source of the noise measurement uncertainty is the uncertainty of the Y-factor.

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