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# 1/F-NOISE STUDIES OF 70 GHZ CONTINUOUS CORRELATION RECEIVER

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## 1. ABSTRACT

A split block mounted 70 GHz pseudo correlation receiver was build to study 1/f-noise behavior. The receiver was a demonstration version of Planck satellite 70 GHz receiver, which is based on cryogenic INP-HEMT-LNAs (Indium Phosphide High Electro Mobility Transistor Low Noise Amplifier) ref. 1. Continuous comparison was done with one phase shifter and with full foxtrot method where phase shifters in the both amplifier chains are switched synchronously. DC-detected signal were stored from the both channels in the both switching modes with the ADC-card to the computer. Measurements were done with 20 K cooled frond end with 0-14 K temperature difference in the input signals. Different phase modulation frequencies and different r-value calculation methods were also compared.

With one channel phase switching and optimum r-value 20 mHz knee frequency was achieved. Foxtrot gives <10 mHz knee frequency with same temperature difference and with optimum r-value calculation method. White noise (? V/V) level was measured to be ~2e-5 with 0.5s post detection integration time and 20% frequency bandwidth.

**Keywords:** Radio astronomy, receiver, 1/f-noise

## 2. INTRODUCTION

The purpose of the Planck satellite is to measure the most detailed map of the cosmic microwave background (CMB). The satellite covers frequency band from 30 GHz to 850 GHz. The first four center frequencies (30,44,70,100 GHz) are called LFI (Low Frequency Instruments) and the receivers are INP-HEMT-MMIC-LNA based continuous comparison receivers. The higher frequency receivers are bolometers.ref. 2

A split block mounted demonstration version of the Planck 70 GHz receiver was built to prove the operation of the cryogenic INP-HEMT-LNA based continuous comparison V-band receiver. The continuous comparison receiver was selected because of the operation where rather high 1/f knee frequency of the INP-HEMT-LNAs will, in ideal case, cancel out in the differentiation of two output signals. Other slowly, t > 1min, chancing properties, offset and other drifts, can be removed and suppressed by using the spacecraft spin modulation.ref. 2 For a required relative sensitivity ~3.6?10$^{-6}$ of 70 GHz receivers with 20% frequency bandwidth, about 40 second integration time is needed. The 1/f knee frequency $f_k$ have to be <20 mHz because of the integration time.ref. 3

## 3. TEST SYSTEM

The block diagram of the demonstration receiver is shown in Fig. 1. The FM (flight model) receiver has two LNAs after first hybrid and all components before last LNAs are mounted in one physical block in 20 K temperature. The demonstrator is made with split block mounted components and it has only one LNA in 20 K temperature.ref. 4

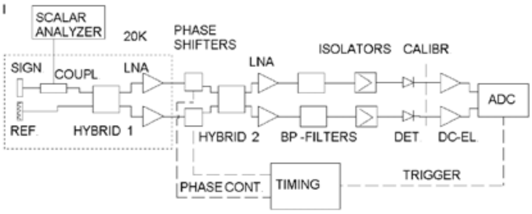

Fig. 1. A block diagram of the 70 GHz Planck satellite demonstration receiver and the associated 1/f-noise test system.

The signal and the reference in the figure 1 represent sky and reference signals of the receiver. Both are implemented with a matched waveguide load having a return loss lower than –35 dB across the entire WR-15 waveguide frequency range. The multihole directional coupler has 20 dB coupling and lower than 0.4 dB insertion loss. The hybrids are Millitech CMT-12-R60S0 magic-T's. The first LNAs are TRW INP-MMIC-HEM-transistors designed by Ylinen Electronics ref. 1. Phase shifters are Pacific mm-Product 6090m. The second warm LNAs are older design of TRW INP-HEMTs. The detectors are ELVA ZBD-15 zero biased diode detectors.

The DC module, which includes DC-amplifiers, integrators and sample&hold circuits was specially constructed as a separate printed circuit board for these measurements. Much of this hardware has been described in ref. 5. The ADC-card in use is Microstar DAP4000a/112. Dedicated external timing electronics was designed to give control voltages to phase shifters, a trigger signal to the ADC-card and integrate/reset and sample/hold commands to the external electronics.

### 3.1 The 1/F Behavior of the Test System

The overall layout of the test arrangement with the demonstration receiver mounted in the cryostat is illustrated in Fig. 2. A 50 ? load was directly connected to CH1 and CH2 inputs of the external electronics for an 1/f measurement of the test system itself. Naturally, the same trigger frequency was used as would appear during the final receiver measurements with a data acquisition rate of 1 kHz. About 2 million points were recorded for later analysis. During the analysis the noise spectrum was created according to the Welch method by using a 1000 points overlap between data from different FFTs for the r-value calculation. 0.5s post integration time was used to create more accurate low frequency region of the spectrum. A boxcar window was used for the calculations. As an illustrative example channel 1 "signal" and "difference" are shown in Fig. 3. The knee frequencies of the signal and the reference are both at about 4 Hz, but the knee frequency of their difference is less than 4 mHz. Similar results were observed with an open load and detector diode connected to the system input. Channel 2 showed confirming performance.

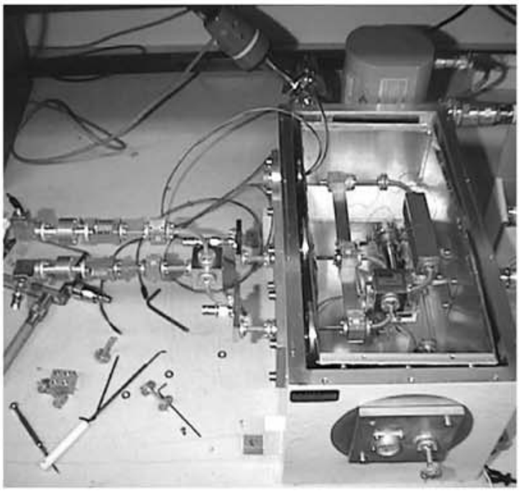

Fig. 2. Demonstration receiver mounted in the cryostat.

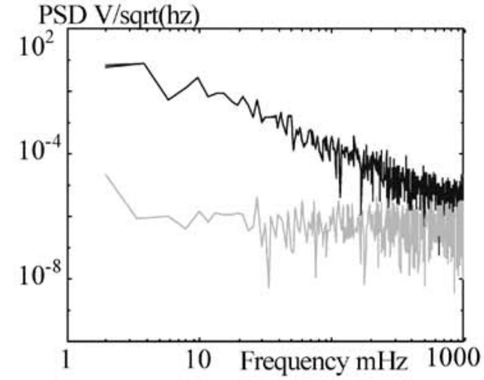

Fig. 3. The measured 1/f spectrum of the test system with 0.5s post integration time. The black line represents the signal and the grey, lower one shows the difference between signal and reference.

## 4. THE 1/F CHARACTERISTICS OF THE RECEIVER

The first LNAs of the receiver were measured individually to optimize their bias points for noise, gain and power dissipation. The demonstrator amplifier chains were brought to a gain balance through scalar analyzer measurements and by simultaneously tuning their bias voltages. These bias points were selected as close to the optimum combination of gain, noise and power dissipation of individual amplifiers as possible in terms of repeatability and measuring uncertainty. The phase switches were tuned to give a similar treatment and here the bias voltage did not affect the switching operation. The electrical lengths of the amplifier chains were also matched with waveguide shims to reach the best isolation over the entire operating frequency band.

The system noise temperature of the receiver was measured next with a commercial noise measurement system (HP 8970B) making use of the built-in heater resistor of the matched loads (signal or reference). If the total noise of the receiver was not low enough the bias points of the first LNAs were tuned and the gain and phase matching processes were repeated. Typical noise behavior is shown in figure 4.

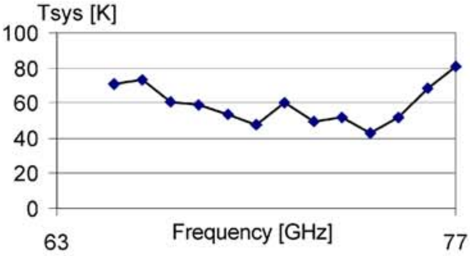

Fig. 4. Typical noise response of the Planck demonstrator receiver at 20 K measured with heated wavequide loads.

After these steps, the 1/f-noise was measured as a function of signal and reference temperatures and at different phase switching speeds. In all cases the measurements were done as foxtrot that is used to indicate that both phase switches were simultaneously activated and performed just one phase switching cycle at a time. The basic idea in this phase switching scheme is the enhanced cancellation of 1/f noise in the test system. Because signal and reference both go through the two parallel amplifier chains, back ends and DC amplifiers, the system 1/f noise can be minimized computationally. Data was recorded from both diode detectors.

### 4.1 The 1/F Performance at Different Temperatures

The "reference" signal was warmed to four different temperatures from 20 K to 36 K with a resistor and a laboratory power supply because the external temperature control system (Lake Shore 330) generates about 1 Hz noise, which adds to the measurement signal. This gave the differences as -0.6 K, 1.5 K, 5.5 K and 14.5 K, respectively. LNA temperatures were also recorded and the worst case change from 19 K to 23 K was observed while heating. Both measured diode detector voltages gave similar results. The diode voltage is proportional to the sum of one input noise temperature and average noise temperature of the amplifiers. In order to computationally null the system 1/f-noise, the result from one of the states has to be multiplied by a constant r, which is calculated from the end of the measured spectrums just at the point when white noise first appears. Mathematically this constant is a rational function of the input noise temperature, the reference noise and the averaged noise temperature of the amplifiers, see e.g. ref. 5. Calculations were made with one detector diode output and one phase switch modulating at 500 Hz (sampling at 1 kHz). The measured knee frequency as a function of respective r-values shows a parabolic nature as indicated in Fig. 5. The knee frequency was obtained visually which causes some error to the shape of the curve. The calculated optimum r-value of the test data was 1.0816. Power spectrums of the measured data at different reference load temperatures and optimum r-value are shown in Fig. 6.

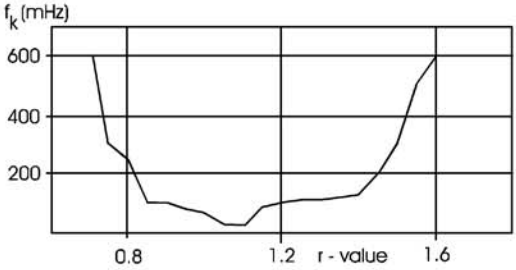

Fig. 5. Behavior of the r-value. Temperature difference was –0.6 K between signal and reference. Calculated optimum r-value was 1.0816.

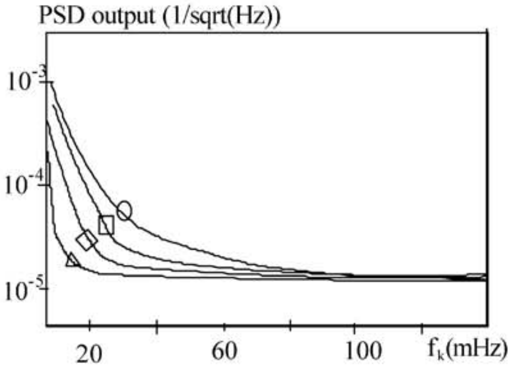

Fig. 6. Smoothed 1/f power spectrums at different temperature differences between signal and reference loads. An optimum r-value for each case was used. Triangle indicates –0.6K, diamond 1.5 K, square 5.45 K and circle 14.49 K difference between signal and reference loads. Note: scale is 1/sqrt(Hz) i.e. PSD spectrum value was divided with measured diode voltage. The ideal white noise level (? V/V) with one phase shifter is 2,4?10$^{-5}$ 1/sqrt(Hz) with 0.5s post integration time and 14 GHz effective frequency bandwidth.

## 5. THE EFFECTS OF THE SWITCHING CONCEPT

The reference load temperature was increased and both foxtrot (with two modulating phase shifters) and single channel measurements were performed using the same sampling rate for all tests. We observed an increase in the PSD amplitude near 200 mHz. This might be due to the fact that, with the averaged r-value, the influence of the back end electronics and unbalance of the receiver is inadequately cancelled. This in turn happens because of the long time intervals between samples at which the r-value is fitted and possible different drifts between back end electronics. Dedicated r-values minimize the influence of the back end electronics and temperature. The knee frequency with different r-values for each phase state is above 10mHz with 1.5 K temperature difference between signal and reference. Knee frequencies with "averaged" and dedicated r-values and single channel measurements are shown in Table I. Three different phase switching frequencies were used in the measurements: 500 Hz, 250 Hz and 125 Hz. At 125 Hz switching frequency and with the foxtrot method the measured data was corrupted because of saturation in the back end amplifiers.

Table I. Comparison of knee frequencies (in mHz) when using different r calculations, different switching methods and at different speeds.

| Temperature difference | $f_k$ single channel, optimum r (500Hz/250 Hz) | $f_k$ foxtrot, averaged r (500 Hz/250 Hz) | $f_k$ foxtrot, dedicated r ( 500 Hz/250 Hz) |
|---|---|---|---|
| -0.6 | 20 / 70 | 10 /30 | <10 / 10 |
| 1.5 | 40 | 10 | 10 |
| 5.45 | 60 | 80 | 20 |
| 14.49 | 120 | 200 | 50 |

## 6. CONCLUSIONS

The demonstration version of the Planck satellite receiver gives promising results. It seems that the 1/f knee frequency can be significantly reduced with a proper choice of the r-value. The overall noise behavior of the demonstration receiver is not mature yet but the additional cryogenic amplifiers in the final flight model receiver will decrease the noise level. As expected, a combination of foxtrot switching and different r-values for each phase state gives the best 1/f behavior and the required 20 mHz knee frequency looks feasible.

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