Performance of the Flight Model HIFI band 3 and 4 mixer units

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ABSTRACT

We describe the performance of the Band 3 and Band 4 Flight Model mixer units for Herschel/HIFI Instrument. These units are part of the Focal Plane Unit of HIFI. The band 3 and 4 mixer units cover the 800-960 GHz and 960-1120 GHz frequency range and have a 4-8 GHz IF frequency band. The sensitivities of the mixers within the HIFI setting are excellent and are the best reported to date. The DSB receiver noise performance in the HIFI FPU environment ranges from 150 K at 800 GHz to 350 K at 1120 GHz. This sensitivity and the absence of atmospheric attenuation will reduce the necessary observation time for astronomical observations in this frequency range by at least two orders of magnitude compared to ground based facilities.

Keywords: SIS mixers, heterodyne receivers, space instrumentation

1. INTRODUCTION

After several years of development and qualification the HIFI instrument for the Herschel Space Observatory (HSO) is now in the final stage of assembly and verification. The delivery to ESA is planned for fall 2006. The launch of HSO together with Planck is scheduled for early 2008. Once in orbit Herschel will provide a unique window to the sub-millimeter and THz frequency range. This frequency range is largely obscured for ground based astronomy due to the presence of water vapor in the earth's atmosphere. Herschel/HIFI will therefore make it possible to do detailed spectroscopic studies of water lines in the star forming regions of our galaxy.

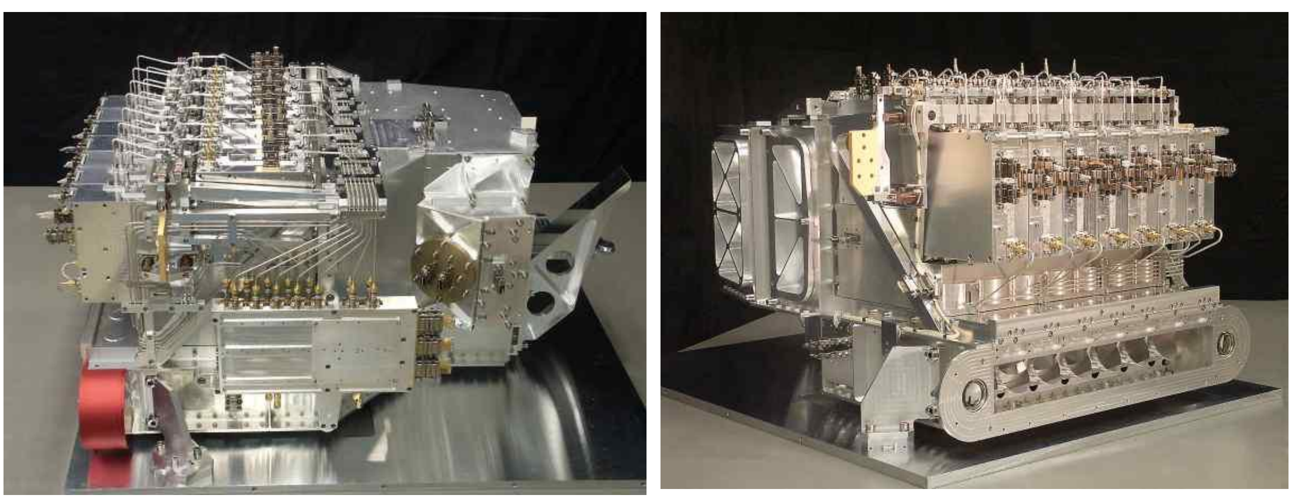

Figure 1 The Flight Model HIFI Focal Plane Unit. This unit will be on the cold plate of the Herschel Space Observatory. The unit contains 14 mixers (7 bands, 2 polarizations), IF amplifiers, the calibration source, and the common optics.

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The Herschel Space Observatory will fly two cameras/medium resolution spectrometers (PACS and SPIRE) and the heterodyne instrument HIFI[1,2,3]. An international consortium led by the PI institute, SRON, is building HIFI[4]. Within HIFI, 7 frequency bands cover the spectral range from 480-1250 GHz (SIS mixers) and 1.41-1.91 THz (HEB mixers). During observations a single frequency band will be operational. SRON is also responsible for the development of the mixer units for band 3 (800-960 GHz) and 4 (960-1120 GHz)[5]. Each of these bands contains two tuner-less waveguide mixers to measure both signal polarizations simultaneously. The mixer units are mounted on a 2 K platform in a mixer console that thermally isolates the mixer units from the Focal Plane Unit (10 K ambient temperature). Within the Focal Plane Unit, each of the SIS mixer units is connected to a 4-8 GHz IF chain consisting of two isolators (one at 2K and one at 10 K) a low noise first stage IF amplifier close to the mixer unit, and a common second stage IF box (see Figure 1). The second stage IF box provides further amplification, signal equalization, and finally power combining of the 10 separate SIS IF channels into two coax lines that run between the cold and warm (outside the dewar) IF back-end. In the back-end a Wide Band Spectrometer and a High Resolution Spectrometer are available for IF spectral analysis. During observations, the instrument will run in an autonomous mode. Optimal settings of the mixer units (bias voltage, magnet current, LO power) therefore have to be available from look-up tables or simple optimization routines.

The mixer units for band 3 and 4 were delivered during 2005 and have been integrated into the Focal Plane unit. The performance of the mixer units was first tested in a laboratory cryostat and corrections for the effects of warm optics and vacuum windows were applied to determine the performance in the HIFI instrument. The actual performance measurements within the configuration of the Flight instrument has recently been started. In this paper we briefly describe the mixer unit and show the laboratory measurements on the noise performance, together with some measurements in the Flight configuration.

Table 1 Summary of the main requirements of the HIFI band 3 and 4 mixer units

T_{mix} DSB	**Band 3**		**Band 4**	
Frequency	*800 GHz*	*960 GHz*	*960GHz*	*1120 GHz*
Baseline	119 K	158 K	158 K	190 K
Goal	99 K	129 K	129 K	151 K

Sensitivities, excluding contributions from IF chain and optics losses

•Withstand shelf life, bake-out, launch and in-orbit operation (9 years)
•Mass < 75 grams
•Envelope 32x32x45 mm
•IF range 4-8 GHz, ripple < 2dB/1 GHz
•De-flux heater operating at current < 20 mA
•Magnet current < 10 mA for second minimum in the Fraunhofer pattern
•Beam quality
•Optical alignment tolerances (goal): x,y: 42 μm, tilt 0.2°
•ESD protection, EMC shielding
•Bias circuit isolation > 30 dB in IF range

2. REQUIREMENTS

A summary of the design drivers for the mixer units is given in Table 1. The two main requirements for the instrument are reliability and sensitivity. Note that the challenging goal sensitivities of the mixer units given in Table 1 are the sensitivities of the mixer unit only, without noise contributions from the optics and IF. Constraints on mass, envelope, magnet current, and heater current are mainly determined by the need to minimize the dissipation and heat load on the 2 K and 10 K level. The choice of materials and procedures in the assembly of the unit is driven by the environmental conditions of the instrument during shelf-life (several years), bake-out (80 degrees for 72 hrs), thermal cycling (approximately 25 times), launch (vibration levels, 20 G rms in qualification) and in-orbit operation (>3 years). To allow the use of a magnet current look-up table it is necessary to be able to remove trapped flux from the SIS device and superconducting electrodes. A de-flux heater that can warm up the superconducting layers above their critical temperatures (in Band 3 and 4 this is about 16 K) is therefore implemented. The potential high levels of electromagnetic fields within the instrument (specified as 2 mV/m in 3-9 GHz range, 2 V/m outside this range) require that the mixer units have proper shielding for EMI, especially in the 4-8 GHz IF range. Protective circuitry to avoid ESD damage during handling and operation is also required.

3. MAIN FEATURES

Some pictures and details of the mixer units are shown in Figs. 2 and 3. Details of the mixer unit design and the design strategy are given in Refs 5,6. The heterodyne elements in the mixer units are Nb/Al_2O_3/Nb SIS twin junctions with Al and NbTiN top and bottom electrodes, respectively. The devices are fabricated at the Delft University of Technology[7,8,9,10]. For band 4 we use NbTiN films grown at the Jet Propulsion Laboratory by J. Stern.
The mixer units for band 3 and 4 are identical, except for the dimensions of the waveguide, horn, and the SIS device structure.

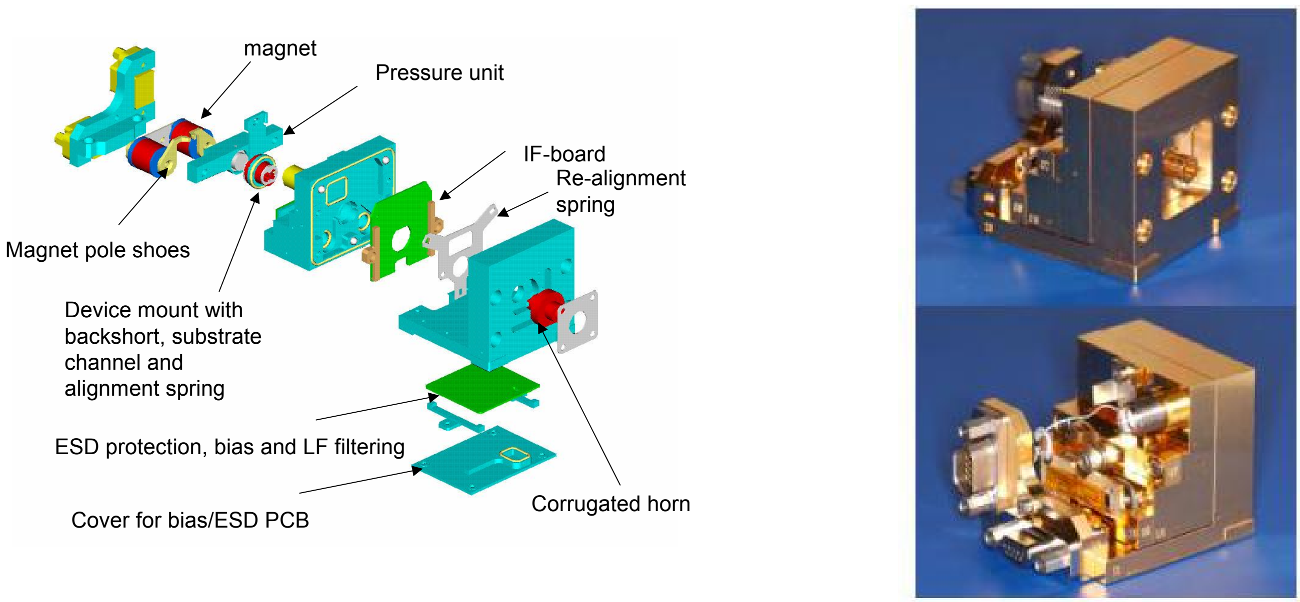
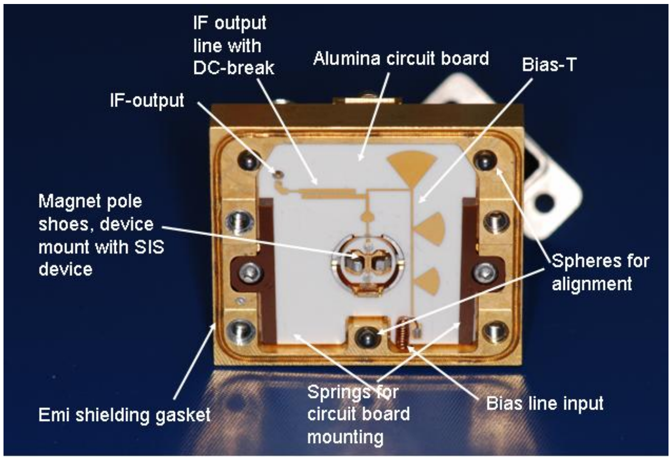


Figure 2 Left: Exploded view of the mixer block. Right: Front and backside view of an assembled mixer unit



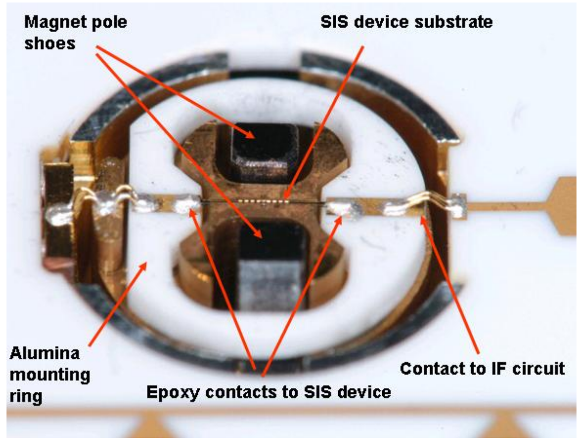


Figure 3 Details of the 'IF-box' of the mixer unit (left) and the device mounting and contacting (right)

5 PERFORMANCE

5.1 IF circuit

The mixer units have an internal 4-8 GHz bias-T and an IF output circuit with a DC-break. The IF-box with the device mount and the 625 μm thick alumina board with IF circuitry are shown in Fig. 3. The IF circuit contains a bias-T with three radial stubs and an IF-output coupling line with a planar 4-8 GHz band-pass filter. Results of receiver noise measurements within the IF band are shown in Fig. 4. The noise within the IF band is very flat, except for some remaining ripple due to standing waves at the Local Oscillator Frequency. Within HIFI a Martin-Pupplet diplexer will be used to couple the LO and signals to the band 3 and 4 mixers. This has as a consequence that the noise within the IF band will not be as flat as shown in Fig.4, but will have a parabolic shape with noise temperatures at the band edges approximately 20-30 % higher than the noise temperature at the IF band center.

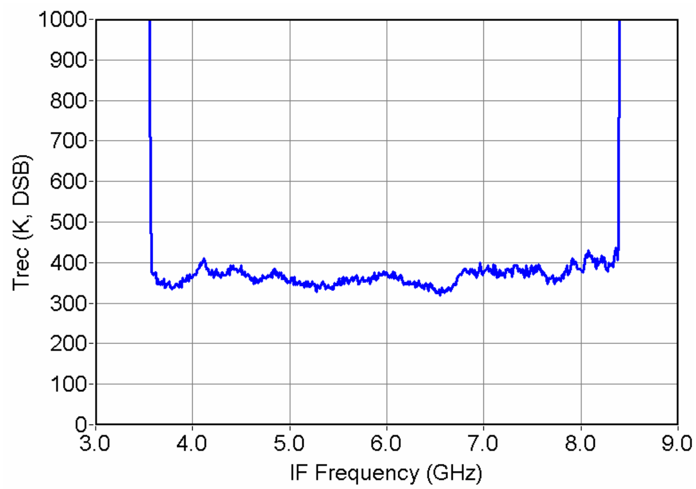


Figure 4 Typical plot of the receiver noise versus IF frequency of a band 3 mixer (not corrected for the warm optics). The noise shows some minor ripple within the IF band, and actually extends the required 4-8 GHz bandwidth. The sharp increase at the band edges is caused by the bandwidth of the IF amplifiers.

5.2 Sensitivity status

Figure 5 shows the noise temperature versus RF frequency of the four band 3 and 4 mixer units that have been inserted in the HIFI Focal Plane unit. The noise temperature is corrected for the warm optics losses in the laboratory receiver and the plotted noise temperatures show the expected performance in the HIFI setting. The noise temperature is measured with the full 4-8 GHz IF-band. The measurements are performed at 2 K (the operating temperature in the HIFI Focal Plane Unit). The stars indicate the initial calibration measurements that have been performed with the Flight Model Focal Plane Unit. These measurements use the internal calibration source (10 K cold, 100 K hot) and the Flight Model IF chain. These preliminary calibration points show that the final HIFI performance will indeed be close to the values based on the corrected laboratory measurements. The overall expected HIFI noise temperature ranges from 150 to 350 K DSB. These are the best sensitivities reported to date. Taking into account that ground based observations within the band 3 and 4 frequency range are hampered by atmospheric transmissions of order 10-40 % (e.g. at the ALMA site in Chile) and that the two mixers within the frequency band will be used simultaneously, the HIFI instrument can reduce observing times by several orders of magnitude. A mixer unit identical to the HIFI band 3 FM units is currently in use for astronomical observations at the Apex Telescope at the Atacama Desert (the site for the ALMA project) [11].

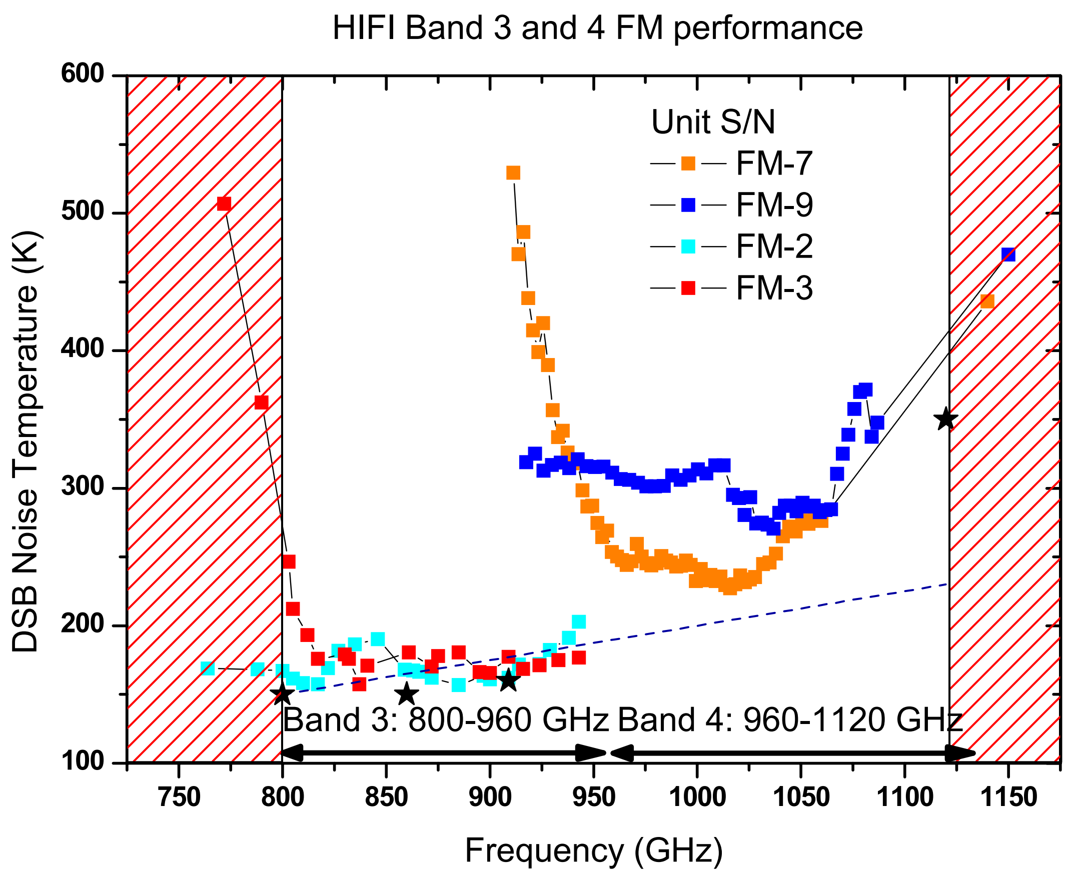


Figure 5 Corrected DSB receiver noise temperatures of the band 3 and band 4 mixer units at 2 K He bath temperature. The stars represent the measurements of the preliminary calibration of the HIFI instrument. The corrected sensitivity from the laboratory measurement is very close to the actual measurements within the HIFI FPU instrument.

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