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Description and evaluation of the analogue part of the prototype (frontend) of the BRAND receiver for one selected antenna

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1 Introduction

1.1 Background

The BRoad-bAND (BRAND) receiver with its enormous instantaneous band from 1.5 GHz to 15.5 GHz poses big design challenges in all elements of the analogue chain of the receiver. With no obvious feed solution available for such an ultra-wide band the feeds for the VLBI Global Observing System (VGOS) antennas (3–14 GHz) seemed like a promising start. We had proposed to use one high-temperature superconductor filter (HTSC) to suppress the strongest radio frequency interference (RFI), which would otherwise drive the low noise amplifiers (LNA) and the sampler into the non-linear regime. Next in the signal chain are LNAs as the first amplification stage, but non with the required bandwidth were readily available. After the LNAs the signal should be further amplified and filtered, and finally the signals should be sent as analogue radio frequency (RF) over fibre down to the backend room for sampling and digital processing.

For a bigger impact it was decided at the beginning of the project to develop the receiver for the Effelsberg 100m telescope. This should give the receiver as much visibility as possible in the radio astronomy community in Europe and elsewhere, as the aim beyond RadioNet was and still is to equip all European VLBI Network (EVN) telescopes with such or similar wide band receivers as soon as possible in order to offer new opportunities for new science to all astronomers.

The first stage of the BRAND project was a survey of the technical details of EVN antennas and measurements of the RFI environment at the radio observatories of the BRAND partners (D6.1). As a result from D6.1 it was determined that two frequency intervals (1.83-1.86 GHz and 2.11-2.17 GHz) had to be filtered out before any amplification was applied in order to avoid saturation, or even destruction of the cryogenic LNA.

In any research project, challenges, unforeseen obstacles, but also new developments elsewhere, requires a vigilant and dynamic team to solve the tasks presented. The very large opening angle of the Effelsberg telescope made the optics a challenge for the ultra-wideband feed design requiring innovative solutions. To match single-ended output ports over the full frequency range, the solution of balanced low-noise amplifiers were implemented. The large feed footprint requires a big window in the cryogenic dewar which was designed effectively. The fact that the planned transmission of the (still) analogue radio signal via optical fibre turned out to have too little dynamic range, affects transmission of signals with strong external radio interference which we have to cope with in the BRAND frequency range.

1.2 Summary of requirements for D6.2 and achievements in the analogue part

The deliverable D6.2 (Description and evaluation of the analogue part of the prototype (frontend) of the BRAND receiver for one selected antenna) covers all analogue parts of the BRAND receiver: the feed horn, high superconducting (HTSC) filters, a low noise amplification stage (LNA), an analogue signal processing unit, and a cooled dewar for the feed, HTSC filters, and LNA. Finally all parts including power supplies and auxiliary devices have to be mounted in a receiver frame.

The BRAND project has successfully developed:

- a feed horn for the full BRAND bandwidth for the primary-focus of Effelsberg. It is a dielectrically loaded Quad-Ridge Flared Horn (QRFH) feed that achieves better than 50% average aperture efficiency on the telescope (see section 2),
- HTSC filters for the BRAND bandwidth (see section 4),
- a balanced low noise amplifier which covers the full bandwidth with low noise temperature and good matching at its ports (see section 3),
- an amplification and filtering signal chain (see section 8),

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- a cryostat with a big window for the QRFH feed, the filters, and the LNA stages (see section 6),
- A receiver box with all analogue parts, power supplies, communication units. A digital frontend in a heavily shielded box to avoid self-inflicted RFI (not part of D6.2) will also be mounted in the receiver box.

Additional upgrades to the BRAND project in the analogue part of the receiver beyond the contract are:

- HTSC high pass filter, as the feed developed for BRAND does not cut sharp enough at the low frequency edge (f < 1.5 GHz) where there is very strong RFI (see section 4),
- Directional coupler for calibrating amplitude and phase of the receiver (see section 4),
- successful study about the potential analogue polarisation conversion, which can be implemented in the receiver through the use of a cryogenic 3dB/90° microwave hybrid (see section 3),
- sampling and initial digital processing in or close to the receiver with digital data transfer over fibre from the receiver cabin to the backend room (not part of D6.2, but related to the analogue part of the receiver).

2 The feed horn[1]

2.1 Requirements

The goal of this work was to cover over a decade in frequency bandwidth for continuous observational coverage with one single wideband (broadband) feed. The frequency band of interest is 1.5–15.5 GHz. This is "10.3 to 1" in fractional bandwidth, also written as 10.3:1, which indicates the highest operational frequency is 10.3 times larger than the lowest. The first feed prototype was tailor-designed for the prime-focus configuration on the 100 m Effelsberg telescope f/D=0.3, half-opening (half-subtended) angle: θ_0=79.6° (Fig. 2.1).

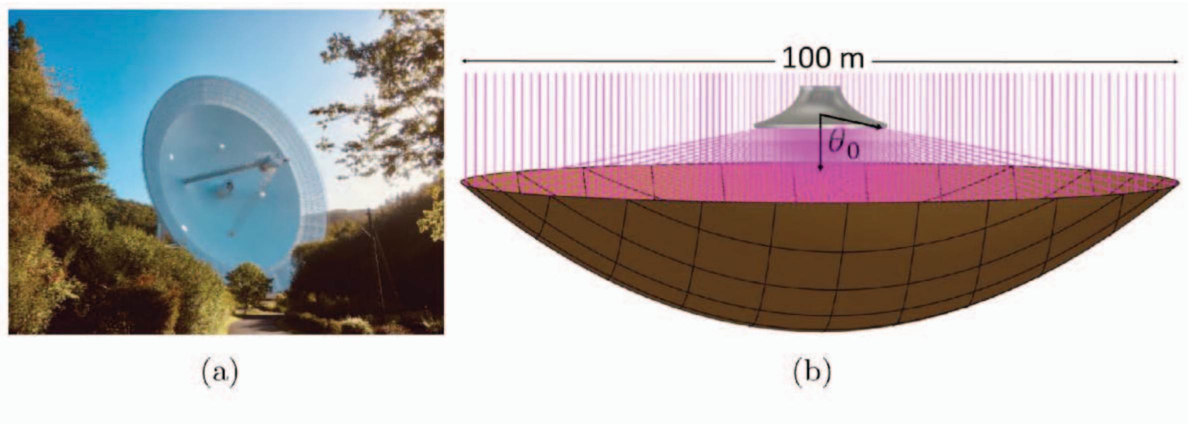

Fig. 2.1 (a) The 100 m Effelsberg telescope. (b) An illustration of half-opening angle, θ_0 = 79.6° for Effelsberg (feed size is highly exaggerated for illustration)

[1] *The full report can be found at: https://doi.org/10.5281/zenodo.3989396*

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In the early phase of this work a pre-study was performed of existing technologies with potential to extend the bandwidth to over 10:1 from previous state of the art fractional bandwidths of 6:1 and 7:1. Several wideband technologies were investigated such as the eleven feed and new developments of coaxial feeds. Finally, the decision was made to go for the Quad-Ridge Flared Horn (QRFH) due to the robust design, low-loss structure, matured technology, phase centre consistency, low-cost manufacture, and a well-known optimization scheme for this type of project. In addition the feeding can be done with either two single-ended 50 Ω ports or a differential four-port structure. The simplicity of the single-ended approach is attractive, too, because only two single-ended LNA in total are needed.

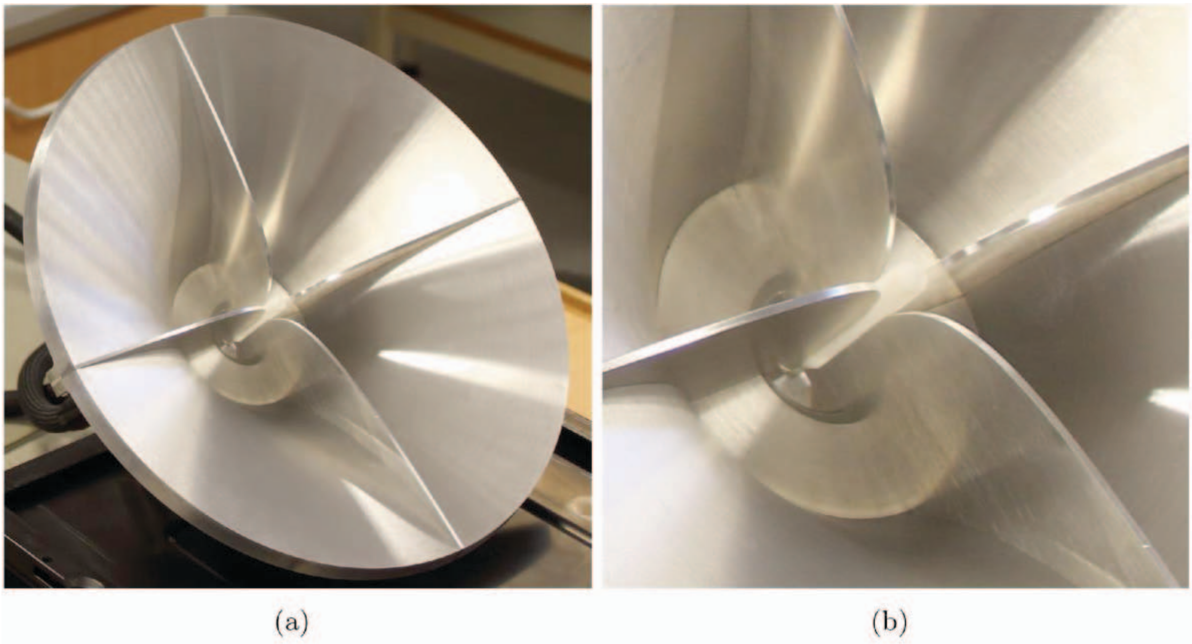

Fig. 2.2 (a) Manufactured prototype of the BRAND feed, here shown in the lab. (b) The dielectric load can be seen at the centre of the feed in white.

The QRFH technology has been successfully applied for radio astronomy and wideband applications for many years - typically used for frequency bandwidths of 3:1 to 7:1 and reflectors with f/D=0.4 to 0.6. With an increasing bandwidth the challenge is to keep the beamwidth relatively constant over frequency to achieve a good illumination of the telescope surface; for the QRFH typically the beamwidth decreases with increasing frequency in a wideband feed.

The QRFH is a waveguide type horn - meaning it has a distinct lower-end cut-off frequency. The relatively sharp cut-off is beneficial because it works as a natural high-pass filter for RFI outside the lower end of the band. The input-reflection of the QRFH can generally be designed to better than S11< -10 dB across the band after optimization, which is a common target limit in the community of wideband feed design.

The main design goals of the project were to achieve an average aperture efficiency better than 50% across the frequency band 1.5–15.5 GHz for an f/D=0.3 reflector while keeping the input reflection lower than -10 dB. At the same time the beamwidth had to be stabilized over the frequency band and the impedance had to be matched for the 10:1 bandwidth. To achieve all of this we needed to introduce a novel concept in the QRFH design, and perform detailed and rigorous optimization for optimal performance.

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2.2 Feed design

The feed is an aluminium metal structure of a flared quad-ridge waveguide (see Fig. 2.2), where the ridge-technology makes the feed more compact and wideband - compared to other horn-type antennas. The ridges create intrinsically a dual-linearly polarized feed with two single-ended output ports connecting to corresponding LNAs. The polytetrafluoroethylene (PTFE or "Teflon") dielectric load (see Fig. 2.2b) inserted in the centre of the QRFH improves beamwidth control over the decade frequency band with low loss-contribution. The BRAND feed measures 87 mm in height and 292 mm in diameter at the aperture. The ridges are 2 mm thick and the dielectric load is 52.5 mm in total height with a maximum diameter of 7.5 mm. The shape of the horn and the ridges are optimized from exponential functions and the dielectric load is based on geometric shapes combined.[2]

The small dimensions present in the throat section of the BRAND feed made necessary a number of mechanical modifications from standard QRFH feeds which make the feed more robust and ease the manufacturing process. Due to the modification of the feeding-section, some added design features increased the isolation between polarizations, which was desired. For details and pictures see the report at https://doi.org/10.5281/zenodo.3989396

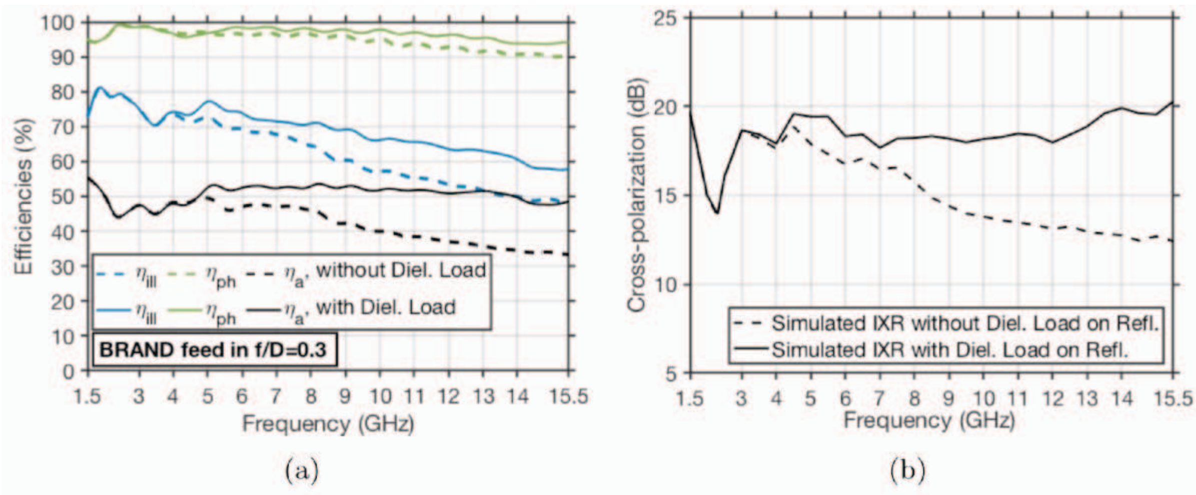

Fig. 2.3 (a) Improvement in phase efficiency (green), illumination efficiency (blue), aperture efficiency (black) due to the dielectric load presented (solid curve is the feed with dielectric load, dash curve is without). (b) Corresponding improvement in intrinsic cross- polarization ratio.(IXR) on-dish. Results are simulations f/D=0.3 reflector (Effelsberg).

2.3 Key Results

The QRFH design shows a simulated aperture efficiency average of 50.6% for both polarizations on the reflector (f/D=0.3), see Fig. 2.3, which should be considered a very good result for such a broad band. This is an improvement of previous very-low gain QRFHs for prime-focus. We see in Fig. 2.3a that by loading the QRFH design with dielectric (PTFE) we improve the aperture efficiency from mid to high frequency band substantially. The black curve is the aperture efficiency, η_a, and the green is phase efficiency, η_{ph}. The improvement in polarization efficiency can also be displayed in the form of intrinsic cross-polarization ratio (IXR) without and with dielectric load (Fig. 2.3b).

To estimate the observational sensitivity figure-of-merit we calculated the system noise temperature, Tsys to be between 35 K and 63 K over the frequency band. The resulting estimated sensitivity, in

[2] *Detailed description of design and optimization procedures for the BRAND feed are found in https://doi.org/10.1049/cp. 2018.0817 and https://doi.org/10.1109/TAP.2019.2940529. A tolerance analysis to achieve nominal performance in a manufactured feed is available in https://doi.org/10.1109/TAP.2019.2940529*

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terms of system equivalent flux density (SEFD), for the BRAND feed on Effelsberg is presented in Fig. 2.4. The result shows a SEFD between 25–45 Jy at a telescope elevation of 45° which is comparable to current narrowband receiver systems according to Effelsberg data. The increase of SEFD at the lower frequencies is a result of increased spill-over noise and reduced polarization performance in the total efficiency. The increase at the high frequencies is the result of slight reduction in total aperture efficiency.

The effect of differential shrinkage of the dielectric inset on the feed performance was estimated. From thermal data of several sources of PTFE (data in: http://www.rjchase.com/ptfe_handbook.pdf), and previous dewar-cooling cycles in our laboratory, it was estimated that a worst-case scenario of shrinkage when cooling from room temperature to 70 K would be 2-3%. Within this specification, the dielectric load was designed and cooling would not have any negative effect.

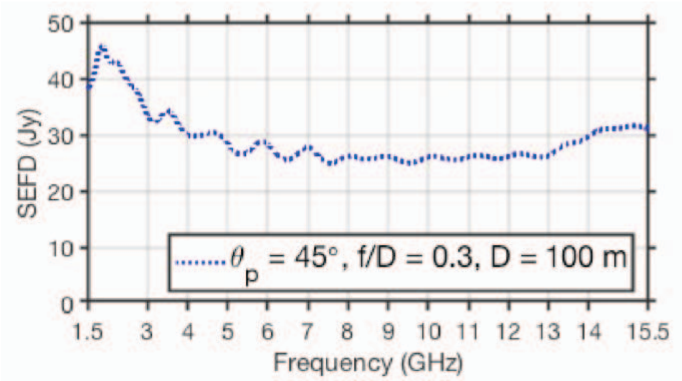

Fig. 2.4 SEFD estimation on 100 m prime-focus configuration of f/D=0.3 for elevation angle 45°.

2.4 Beam Pattern Measurements

The measurement of the feed beam pattern was performed in an anechoic chamber specified for farfield measurements. The pattern was measured in steps of 5° in ϕ (azimuth) and 1° in θ over the full sphere, sampled each 0.5 GHz. The simulated and measured beam patterns are in good agreement over the frequency band, with some discrepancies over 1.5–2 GHz. This is because the transmit antenna reference (ETS-Lindgren's Model 3164-05) and measurement chamber was unspecified over 1.5–2 GHz range, but still usable according to the suppliers specification. The desired widening of the beam in the upper frequency range due to the dielectric was confirmed with measurements, illustrated in Fig. 2.5 for 15.5 GHz. The prototype seen in Fig. 2.2a was delivered in November 2019 for integration in the cryogenic receiver.

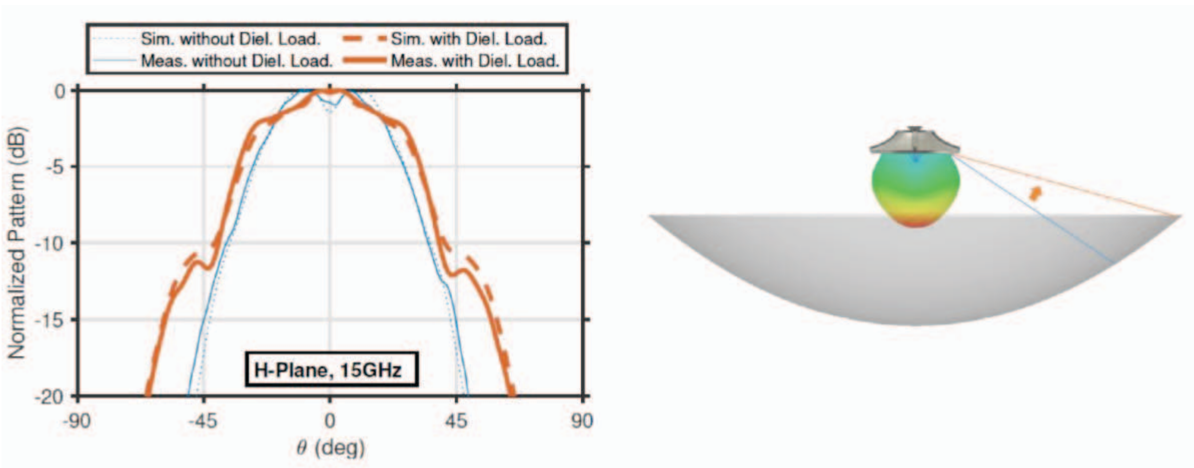

Fig. 2.5 Simulated and measured beam pattern in H-plane at 15.5 GHz to exemplify the widening effect of the beam due to the dielectric. The figure to the right illustrates (crudely) how the widening of the beam improves the reflector illumination.

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3 Low Noise Amplifier[3]

3.1 Introduction and Requirements

The design of a low noise amplifier for the ultra wide band of BRAND is a challenge. For single ended LNAs it is not possible to optimize simultaneously the noise temperature and the input reflection (IRL), and there is a severe tradeoff between these two parameters, especially at the lower end of the band. As a result, the input return loss is usually poor at low frequencies.

The benchmark for any LNA solution though is set by the low noise of a single ended LNA, while the IRL should be better than -10 dB. The Yebes LNA group has developed a wide band amplifier (see Fig 3.2 right) for the next generation of VGOS2 geodetic receivers, which has already been tested successfully in its RAEGE radio telescopes, and other VGOS receivers for Ny-Alesund and Metsahovi.

3.2 Balanced amplifier realisation

Several ultra-wide band cryogenic low noise amplifiers were designed, fabricated and tested by Yebes Observatory in the framework of the BRAND EVN project. A balanced amplifier configuration is a practical alternative with several advantages. It comprises of two 3 dB 90° microwave hybrid couplers, two LNAs and a couple of matched loads assembled according to Fig. 3.1. If hybrids with low unbalance are used, the input and output reflection of the balanced amplifier depend on the return losses of the input and output hybrids respectively, and the noise temperature is approximately that of a single amplifier degraded by the insertion loss of the input hybrid. Therefore, counting with good hybrids, it is possible to obtain an LNA with low input reflection and noise temperature simultaneously. An additional benefit of the balance configuration is the improvement of the linearity range in 3 dB. The drawbacks are the aforementioned noise penalty and the increase of cost, complexity, size and power consumption.

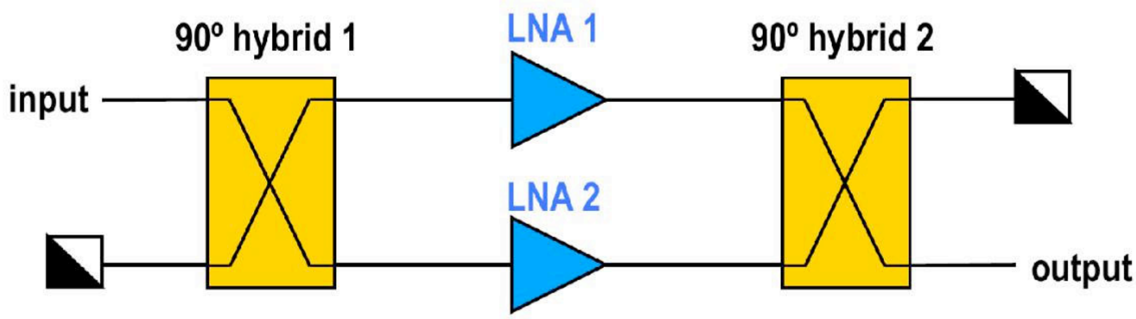

Fig. 3.1 Schematic of a balanced amplifier.

[3] *Detailed reports with measurements and results can be found at: https://doi.org/10.5281/zenodo.3980987 and https: //doi.org/10.5281/zenodo.3980993*

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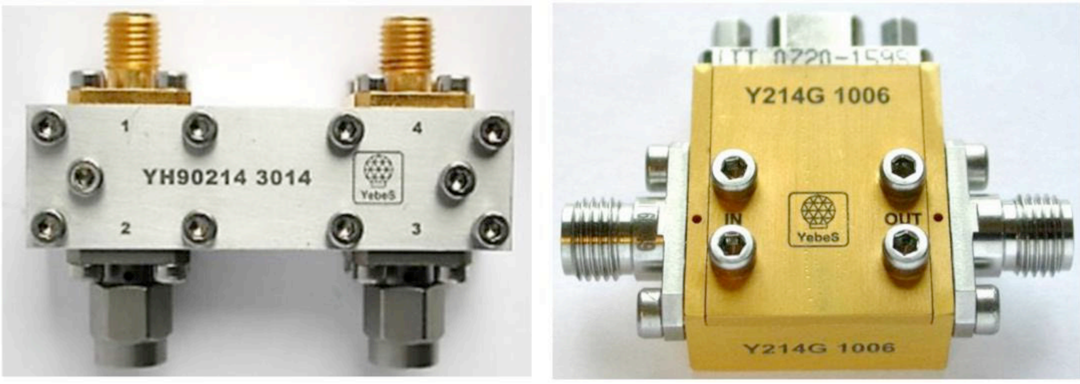

Fig. 3.2 Left: External view of a YH90 hybrid coupler. Right: External view of the single ended LNA Y214G. Dimensions excluding connectors are 20×22×9 mm.

The balanced amplifier configuration chosen comprises of two 3 dB 90° hybrid couplers YH90 (Fig. 3.2 left) especially developed for BRAND, two LNAs Y214G (Fig. 3.2 right) and a couple of matched loads assembled according to caption of Fig. 3.3.The low noise cryogenic amplifiers Y214G are ultra-wide-band amplifiers designed for the VGOS next generation geodetic VLBI band, with an average noise temperature in the 1.5-15.5 GHz band of 6.5 K. YH90214 are 5 stages 3 dB 90° hybrid couplers originally designed for the 2-14 GHz band and modified for best performance in the 1.5-15.5 GHz band. They yield an amplitude unbalance lower than ±0.7 dB in 95% of the band, insertion losses lower than 0.4 dB and return losses below 17 dB.[4]

Noise and gain of the balanced amplifiers is between 10K and 22K for most of the band (see Fig. 3.4). The return losses are less than 20 dB for nearly the whole bandwidth (see Fig. 3.5). Two sets as per Figure 3.3 were delivered to the BRAND project for integration into the dewar.

Fig. 3.3 Assembled balanced amplifier picture (without the matched loads). Length of the assembly excluding connectors is 82mm. Input is on the left and output on the right. Matched loads can be placed both on ports 1 or both on ports 4 of the hybrids in the picture, leaving the other couple of ports for input and output.

[4] *For more details see: https://zenodo.org/record/3980975 and https://zenodo.org/record/3980969*

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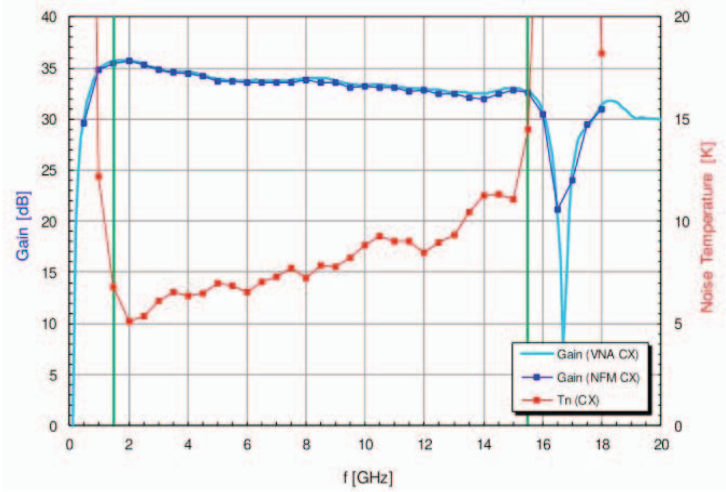

Fig. 3.4 Gain and noise temperature over frequency of one of the balanced amplifiers at 16 K.

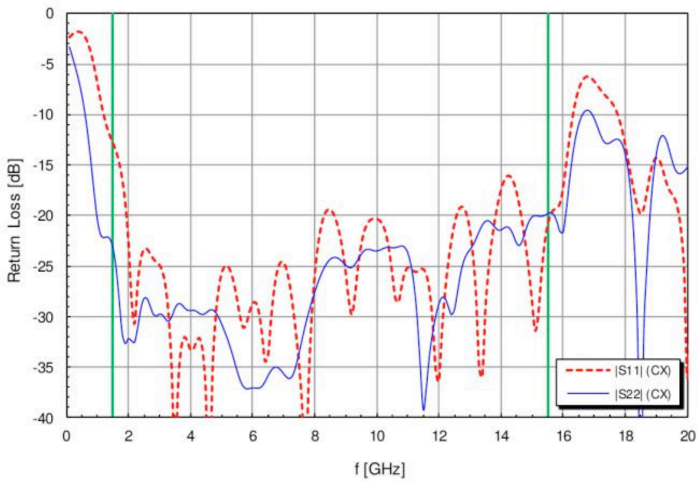

Fig. 3.5 Input return loss as a function of frequency at 16 K.

3.3 Analogue polarisation conversion

In the proposal stage of the project it was thought that it would only possible to convert the linear polarisation of the BRAND receiver to circular polarisation as desired for VLBI in the digital domain. (This is a subtask of our partner ASTRON). It was realised though by the Yebes group that the microwave hybrids they developed for BRAND can also be used for analogue polarisation conversion (see: https://doi.org/10.5281/zenodo.3980979). When fed from the feed with both linear polarisations such a hybrid will deliver RCP and LCP provided the cables to the hybrid are assembled with very careful length control (fractions of a mm). The measured performance of the 5-stage hybrid is such that the difference between the amplitude of the direct versus coupled way (called “unbalance”) is less than 1.2 dB over most of the band, and reaches a maximum value of 3 dB at the high end of the band. The phase unbalance is less than 2.5° in the whole band. This is would yield quite acceptable polarisation leakage between LCP and RCP.

This result is quite remarkable and has impact not only on BRAND but also on future VGOS receivers.

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4 HTSC filters and coupler

The transition region in the reflection coefficient below and around the cut-off frequency at 1.5 GHz in the feed described in Section 2, can cause LNA saturation from very strong RFI present in the region. Therefore in addition to two notch filters at the two frequencies identified for Effelsberg in WP6.1 a high pass filter had to be added to suppress the very strong RFI below 1.5 GHz.

As an enhancement to the project, directional couplers for amplitude and phase calibration were desired early on to be fitted as part of HTSC block. This is because they have to be placed right after the feed. As a single HTSC element between the feed horn and the LNA would have had least impact on the receiver temperature and the losses at input and output of the device, this solution was researched initially. Unfortunately, in collaboration with the manufacturer, we were unable to design and manufacture a HTSC component, which can satisfy all three requirements: high pass filter, two notches, directional coupler. It was therefore decided to realise the three requirements in three individual HTSC elements. This leads to somewhat higher noise and to more losses due to reflections, but still within acceptable levels.

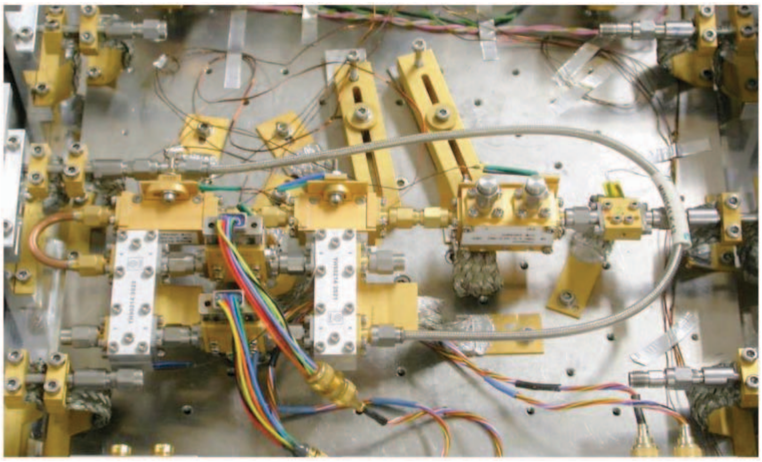

Fig. 4.1 Setup 2 - Coupler + Highpass filter + Notch filter + "U" cable + Balanced amplifier. Input and cold attenuator are on the right. The two male to male SMA transitions are included in the results.

The measurements of the HTSC components, which were produced, were done both at Onsala and Yebes and yielded similar results (https://doi.org/10.5281/zenodo.3980975 and https://doi.org/10.5281/zenodo.3980969).

The complete chain was measured at 16K in a test dewar (see Fig. 4.1). Note that the feed was too large for the existing test cryostats available, and as a consequence it was not possible to include the feed in the lab-test measurements.

The results are coherent and repeatable. The choice of connector gender affects losses and interconnection issues.

Results are:

- With a lot of effort and research it was possible to achieve good to acceptable results for the HTSC filters. In relation to the huge covered bandwidth this is an enormous achievement.
- The HTSC coupler is not usable above 11.5GHz (see Fig. 4.2). So this coupler is not acceptable. Other couplers were suggested by Yebes and were found to work satisfactorily for the BRAND band (see below)[5].

[5] *Couplers were not included in the proposal and contract. They are an additional technical treat of the receiver.*

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- The high pass filter shows an unwanted ripple near the cut-off band (see Fig. 4.3). This is acceptable for the prototype, but has to be improved.
- The bandwidth of the two notches is larger than required and the first notch is shifted somewhat in frequency. The notch filters are acceptable but should also be improved as spurious bands appear at 9-11 GHz and 14-14.5 GHz with a 20% noise increment (see Fig. 4.3).

The Yebes group found a commercial 30 dB coupler for VGOS[6], which should work well enough for BRAND. Their measurements (Yebes internal report: IT-CDT-2020-16 (https://doi.org/10.5281/zenodo.3997099) show that this coupler works quite well for this large bandwidth. When cooled to 20 K some sharp changes in group delay occur, but they correspond to at most 3/4 of a turn of phase at the highest frequencies. At least for astronomy this should not be a problem as these phase changes can be calibrated out.

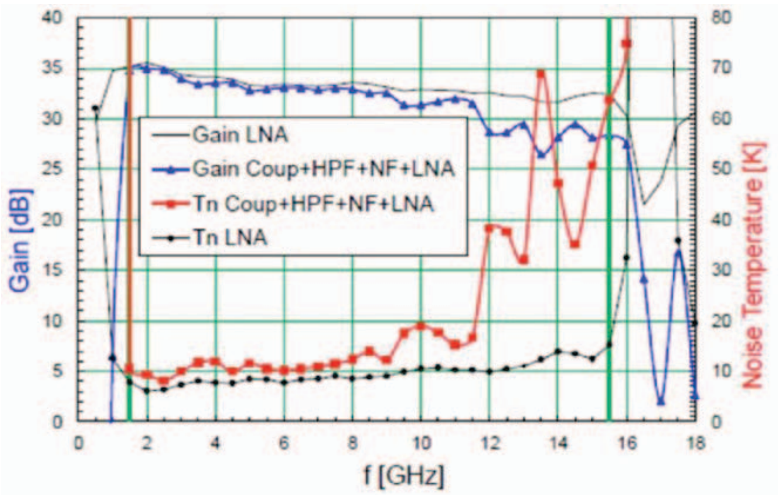

Fig. 4.2 Coupler + high pass + notch +LNA. The high peaks in the temperature at high frequencies are due to the coupler: red line. LNA alone: black line.

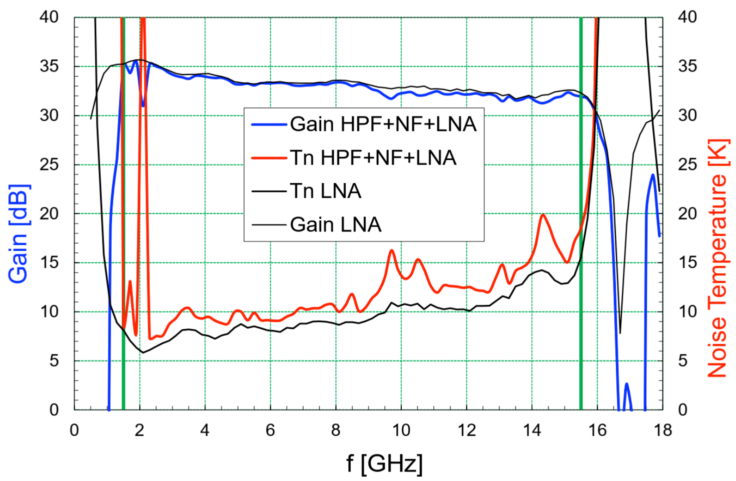

Fig. 4.3 Gain and temperature without coupler: red line. LNA alone: black line.

6 *30 dB coupler: Krytar 1825*

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5 Frontend System Overview

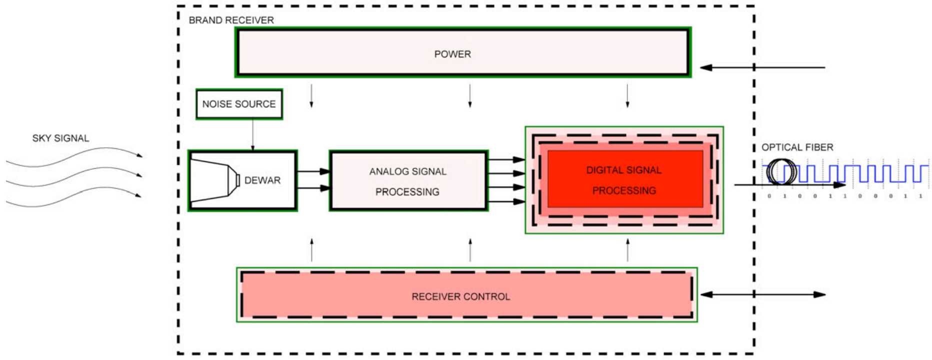

Fig. 5.1 block diagram of BRAND receiver frontend

Figure 5.1 shows a plain block diagram of the receiver. The signal path consists of

- A cryostat (DEWAR) containing the cooled components (feed horn, LNA etc.)
- A noise source for calibration
- An analogue signal-processing unit for signal conditioning and
- A digital signal-processing unit to create a digital image of the sky signal.

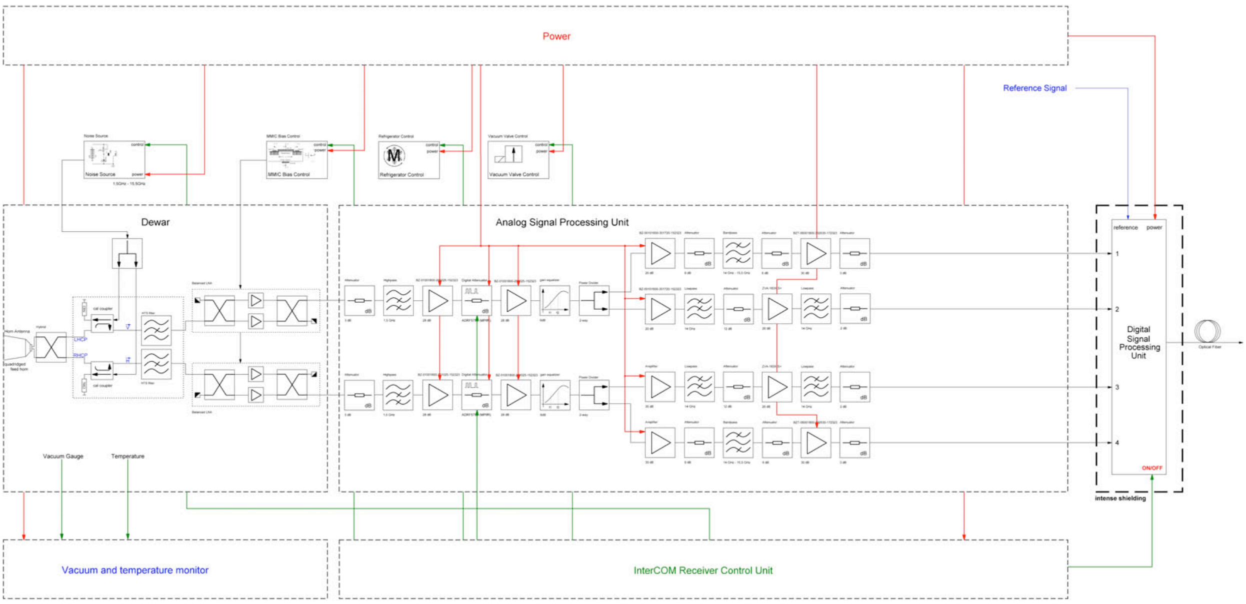

Fig. 5.2 detailed block diagram of BRAND Receiver

A more detailed block diagram shows that many peripheral devices are also needed to integrate the above mentioned components into the receiver. Some of them are commercial parts, others have to be developed especially for the Effelsberg telescope and the corresponding receiver.

The focus of this report is on the main components of the analogue signal chain (Cryostat, Noise Source and Analog Signal Processing Unit).

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6 BRAND Receiver Cryostat

6.1 General Description

A high technical effort is necessary to process radio signals of very low power. To measure these signals the receiving system has to be sensitive enough. Every electronic device produces thermal noise, an unwanted disturbing signal caused by the random movement of free charge carriers inside the device. It can reduce the sensitivity of a system to a point, where weak radio signals can no longer be measured. Thermal noise is independent of the applied voltage but proportional to bandwidth and the devices temperature. The higher the temperature, the higher the energy of the free charge carriers. This results in a higher thermal noise power. Cooling the devices reduces thermal noise power significantly.

To achieve the required sensitivity for the BRAND receiver the first components of the front end are cooled down inside a cryostat to a temperature of 20K. Such low temperatures cannot be reached without evacuating the cryostat, because air molecules would lead to a heat transfer by convection. Heat radiation from the outer walls (at a temperature level of about 300K) to the cooled components (at a temperature level of about 20K) must also be considered.

A vacuum window must be developed. A window made of a material that allows electromagnetic waves to pass and leaves air molecules outside. It must be as small as possible to withstand the enormous air pressure, but as large as necessary to guarantee the optimal function of the receiving system.

6.2 Cryostat design

With the telescope's f/d = 0,3 results in a full opening angle of 160°. Since the feed horn is to be cooled, a very large vacuum window is necessary. The physical dimensions of the horn and the wide opening angle result in a window with a diameter of more than 50cm.

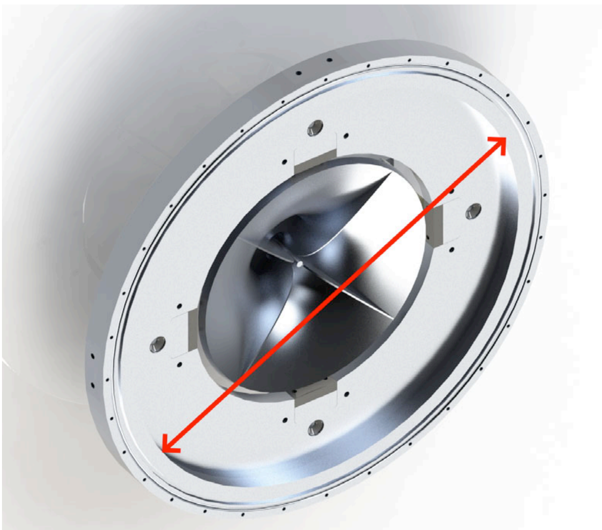

Fig. 6.1 Vacuum window opening (model view)

Usually a foil is used as vacuum window. It separates the evacuated- from the air pressure side. With this size, a pressure of 2300 kg is applied to the surface of the window. A foil would burst under this enormous pressure so a supporting structure for the foil is absolutely necessary. Factors such as heat conduction, material deformation and permeability to electromagnetic radiation must be taken into account during the design of the structure.

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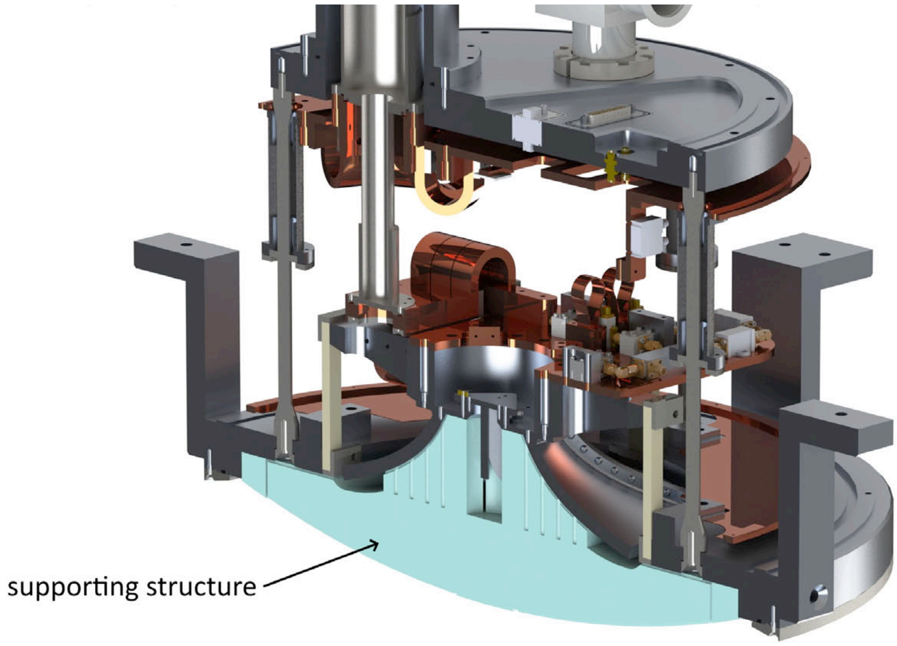

Fig. 6.2 Supporting structure for vacuum window (model view)

Figure 6.2 shows a sectional view of the cryostat 3D model with vacuum window support structure. The refrigerator has two cooling stages. One stage is at 20K. The cooled components are placed on a copper plate that is tied to the 20K stage to achieve lowest temperatures for the signal path devices.

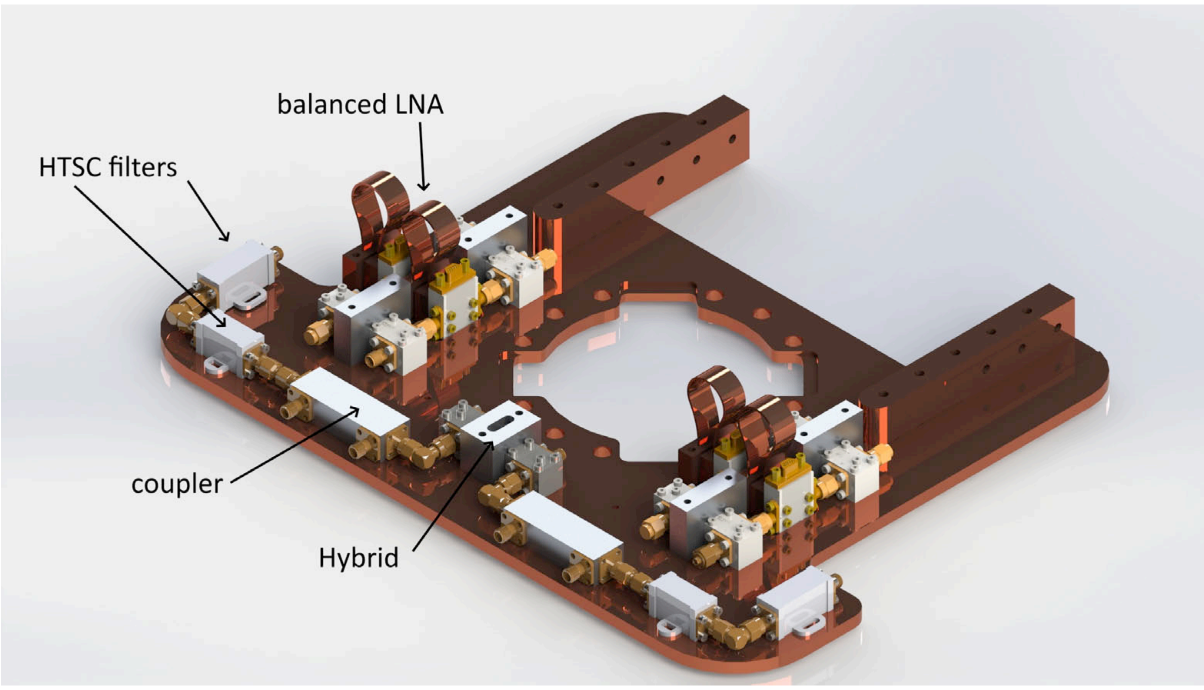

Fig. 6.3 20K plate with cooled devices (model view)

The components were placed as close as possible to each other to minimize signal loss over cables and connections. Due to a component change the first design of the plate had to be completely

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redesigned. The first selected coupler could not be used for the design due to poor measurement results, and the finally chosen one had different physical dimensions.

The second temperature stage of the refrigerator is at 70K. This stage is tied to a shield that surrounds the inner parts on the 20K plate. It functions as a barrier between the outer wall at 300K and the inner parts at 20K. So heat radiation from the outer wall has no direct effect on the inner parts.

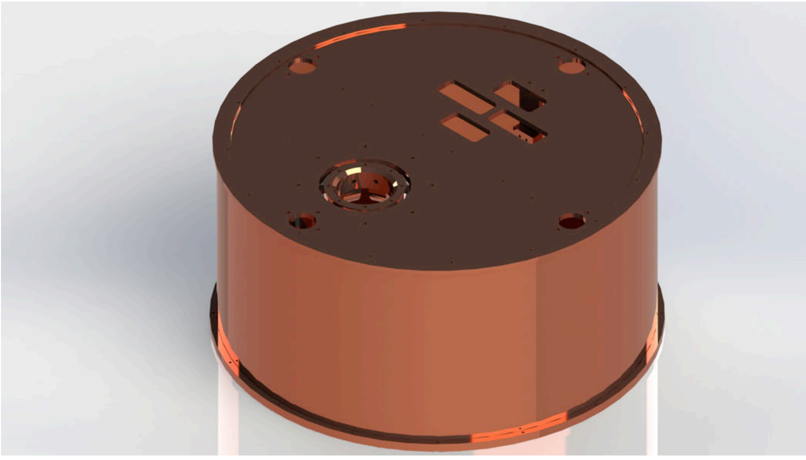

Fig. 6.4 70 K shield (model view)

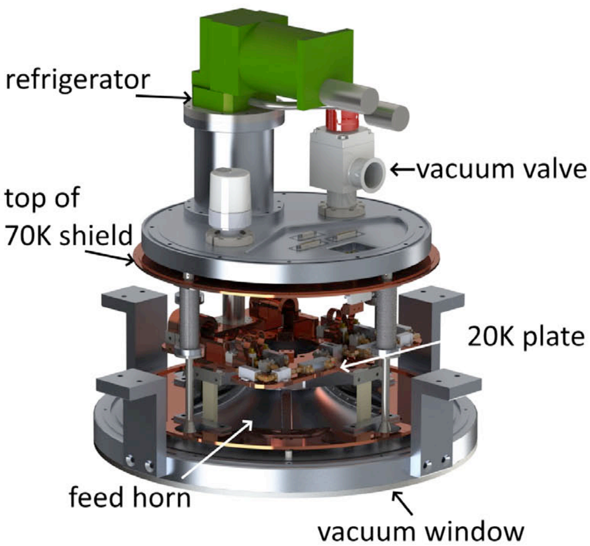

Fig. 6.5 Inner parts of cryostat (model view)

Figure 6.5 shows the inner parts of the cryostat. The side wall of the 70K shield is switched to transparent to give a clear view of the inner components.

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6.3 Cryostat hardware

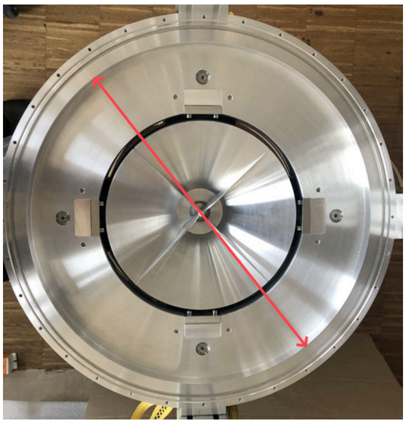

Fig. 6.6 vacuum window opening (hardware view)

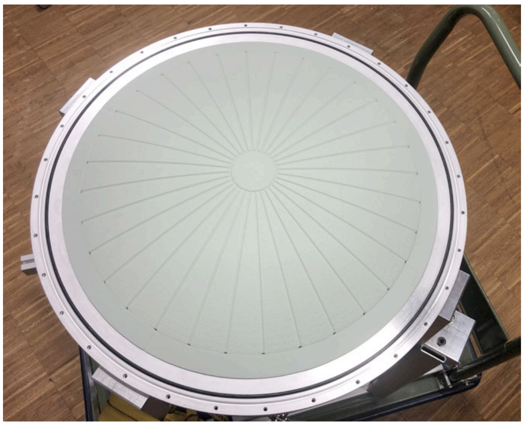

Fig. 6.7 Styrodur support structure (hardware view)

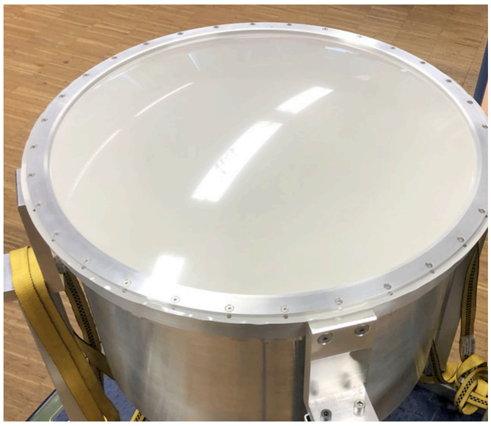

Fig. 6.8 cryostat ready for cooling test

6.4 Results of cryostat cooling test

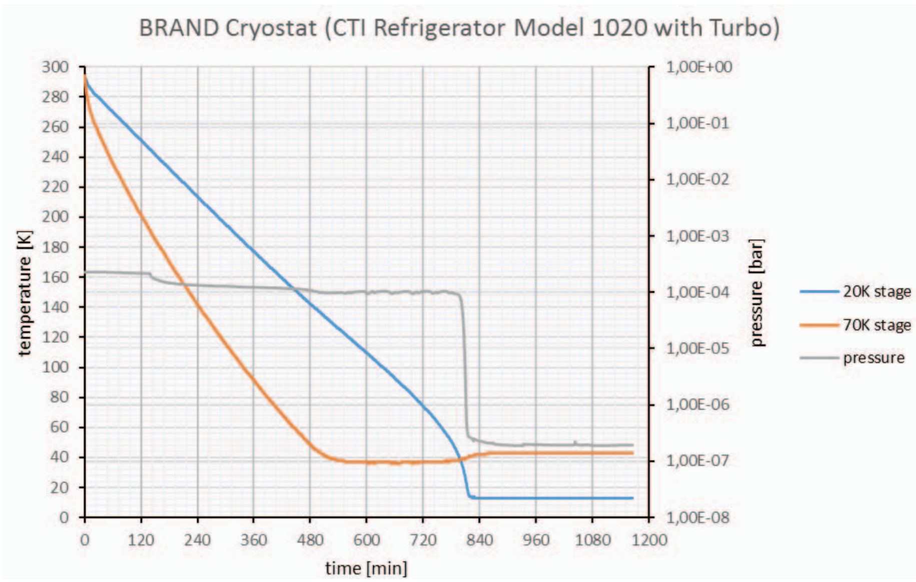

Fig. 6.9 Result of cooling test

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Sensors inside the cryostat measure the temperatures at the two different stages and the gas pressure. Air molecules freeze below a certain temperature. In this frozen state they have no effect on the gas pressure. As a result the gas pressure drops sharply, which further reduces the heat transfer by convection. In the stable state, after 840 min. of cooling, the temperature at the 20K stage is about 13K while the temperature on the 70K stage is about 43K.

7 Noise Source

7.1 General description

A noise signal can be fed into the signal path for calibration purposes. For the BRAND receiver it was required to be able to feed a noise signal with two different powers. The different noise signals are switched by the receiver control. It should also be possible to feed in another calibration signal, for example from a comb generator.

For this purpose a noise generator, working from 1 to 16 GHz, was designed and built at the MPG/MPIfR.

7.2 Noise generator design and hardware

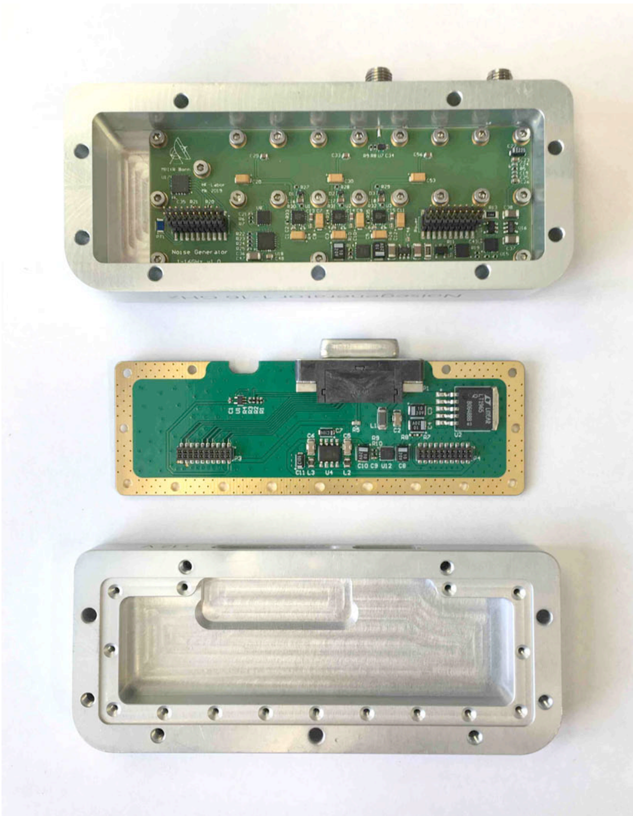

Fig. 7.1 Noise generator with bias pcb

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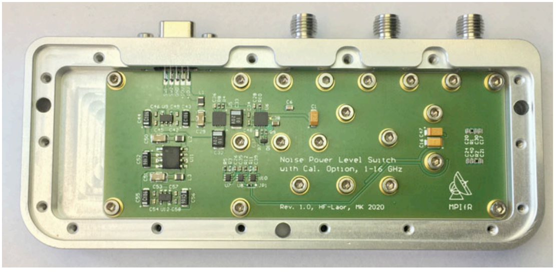

Fig. 7.2 Switching unit

Noise generator and bias board can work as a 'stand alone' unit or they can be stacked with the switching unit. When stacked the noise source can provide a noise signal with two different power levels or a comb signal, and is able to communicate with the receiver control electronic.

7.3 Measurement results

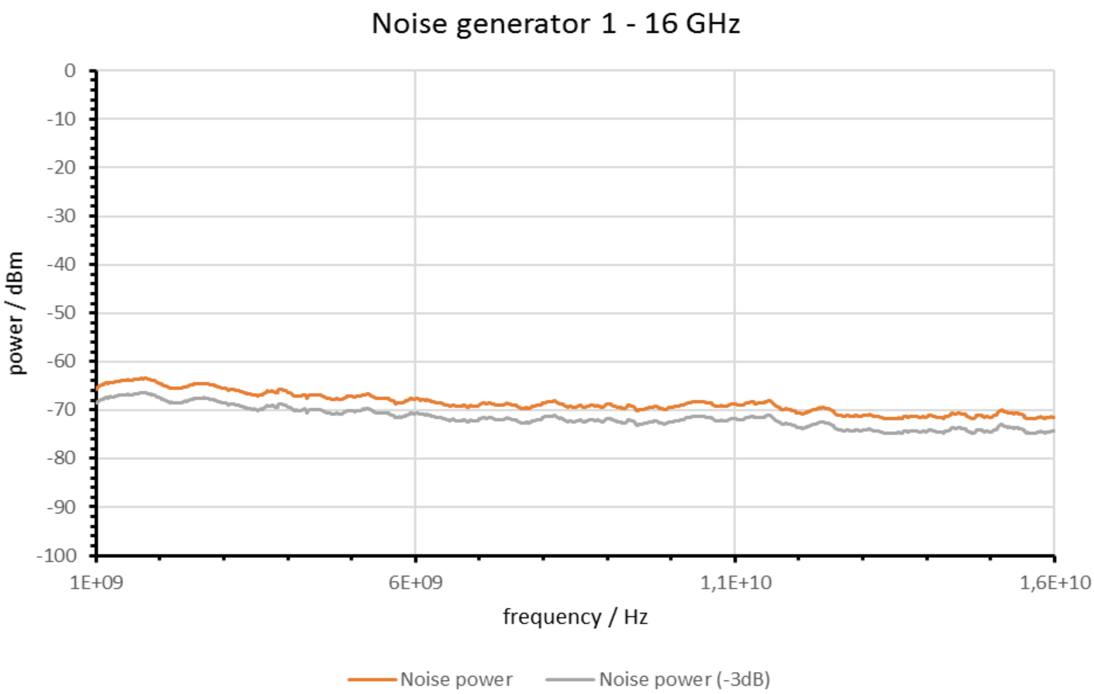

Fig. 7.3 Noise signal (2 different power levels)

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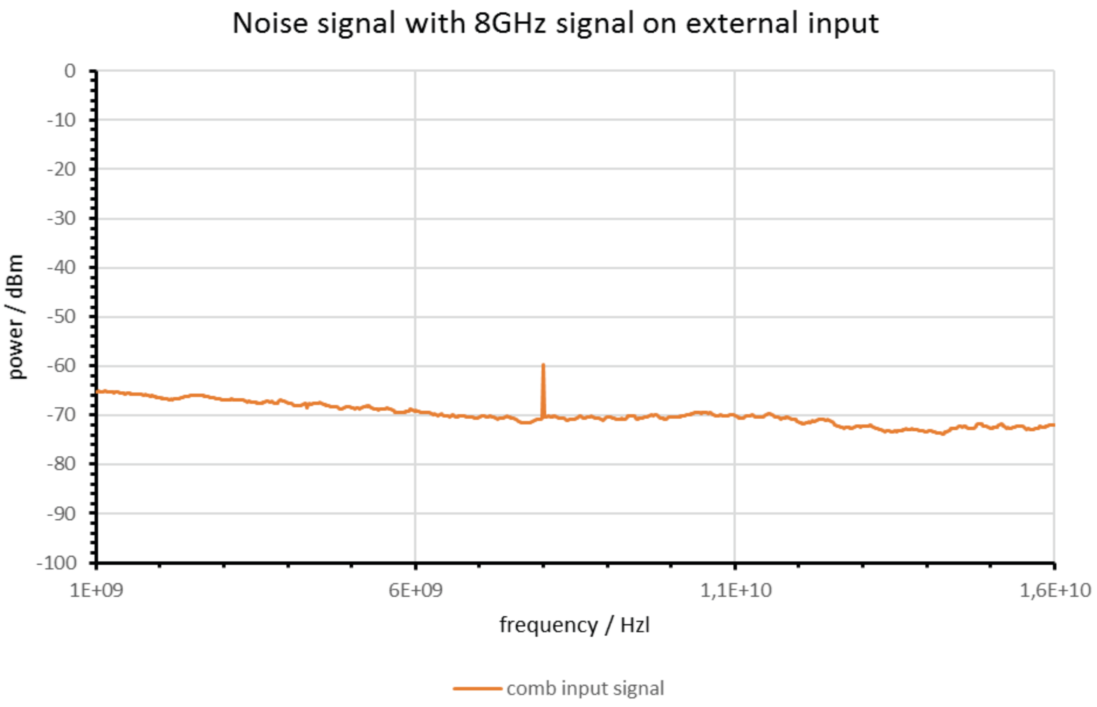

Fig. 7.4 Noise source with external 8GHz signal

8 Analogue signal processing unit

8.1 General description

At the output of the amplifier the signal still has a very low power level. To be able to process it digitally it has to be conditioned further. This includes careful filtering of the desired signal frequencies and further amplification of the signal. Cooling of the components is no longer necessary, but the concept must be designed in such a way that the noise figure of the entire system does not decrease.

8.2 Design and hardware of the analogue signal processing unit

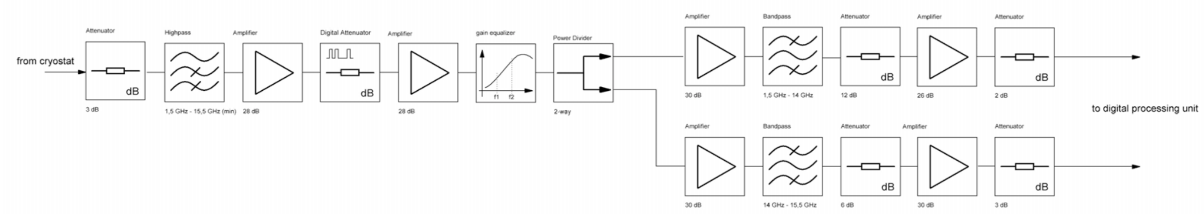

Fig. 8.1 Block diagram analogue signal processing unit (1 channel)

It was decided to split the band in two sub bands. One from 1.5GHz to 14GHz, the other from 14GHz to 15.5GHz or higher. There is a lot of RFI in a frequency range from nearly DC to 1.5GHz that is capable of driving the amplifiers into saturation. If this happens, the receiver would no longer produce valid data. That's why there is a strong need for a highpass filter with good stopband attenuation.

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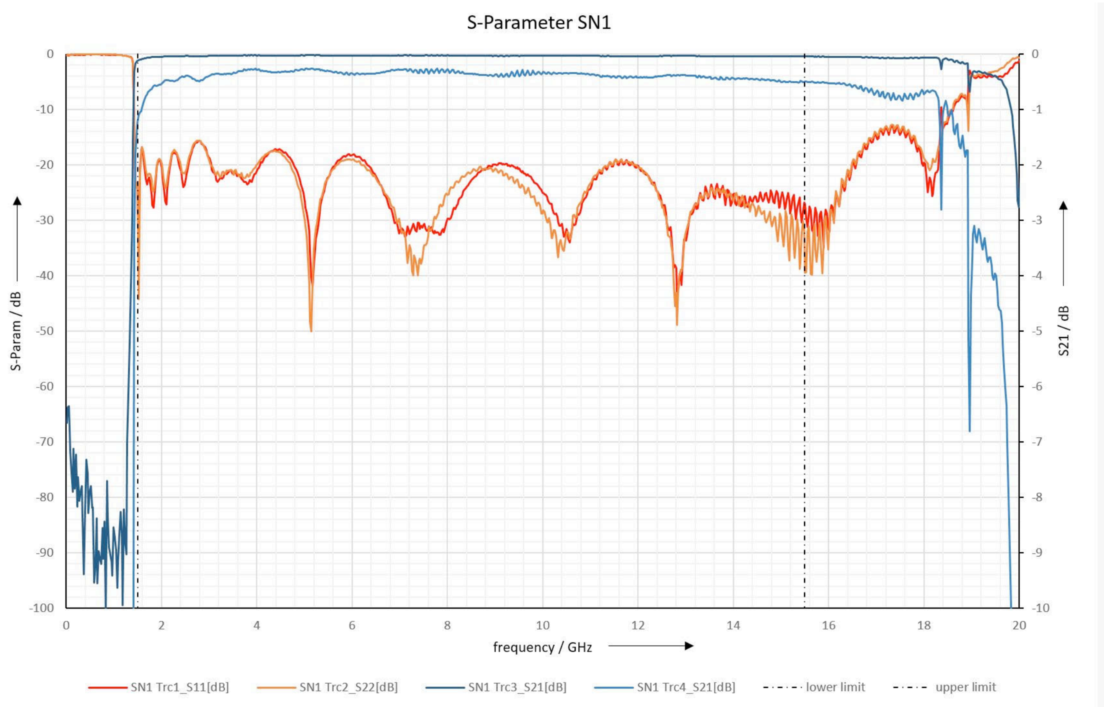

Fig. 8.2 Frequency response of highpass filter

Figure 7.3 shows, that signals with the desired frequency can pass through while unwanted signals below 1.5GHz are attenuated by more than 60 dB.

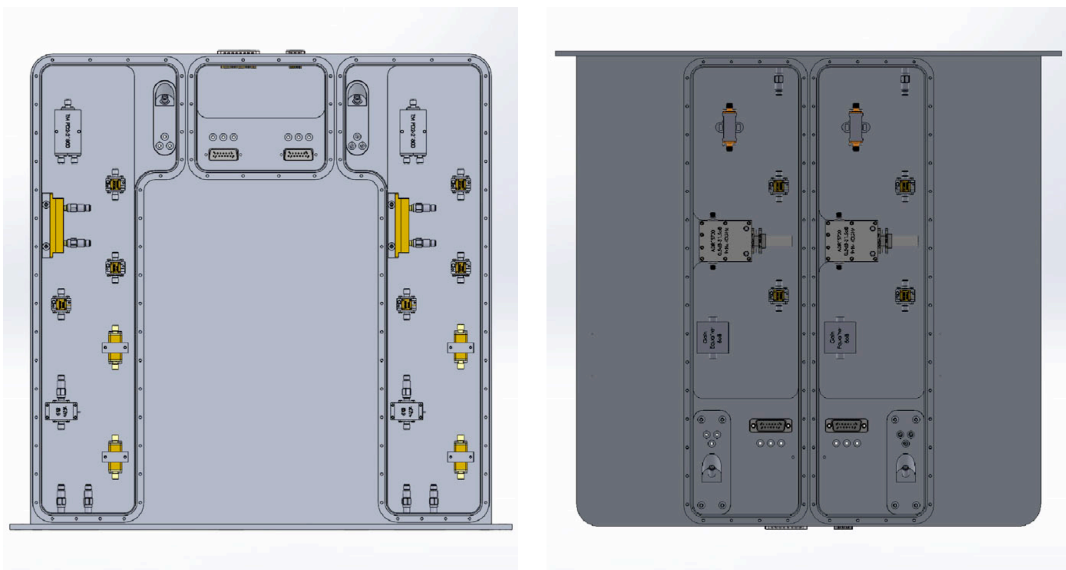

Fig. 8.3 Design concept of the analogue signal processing box

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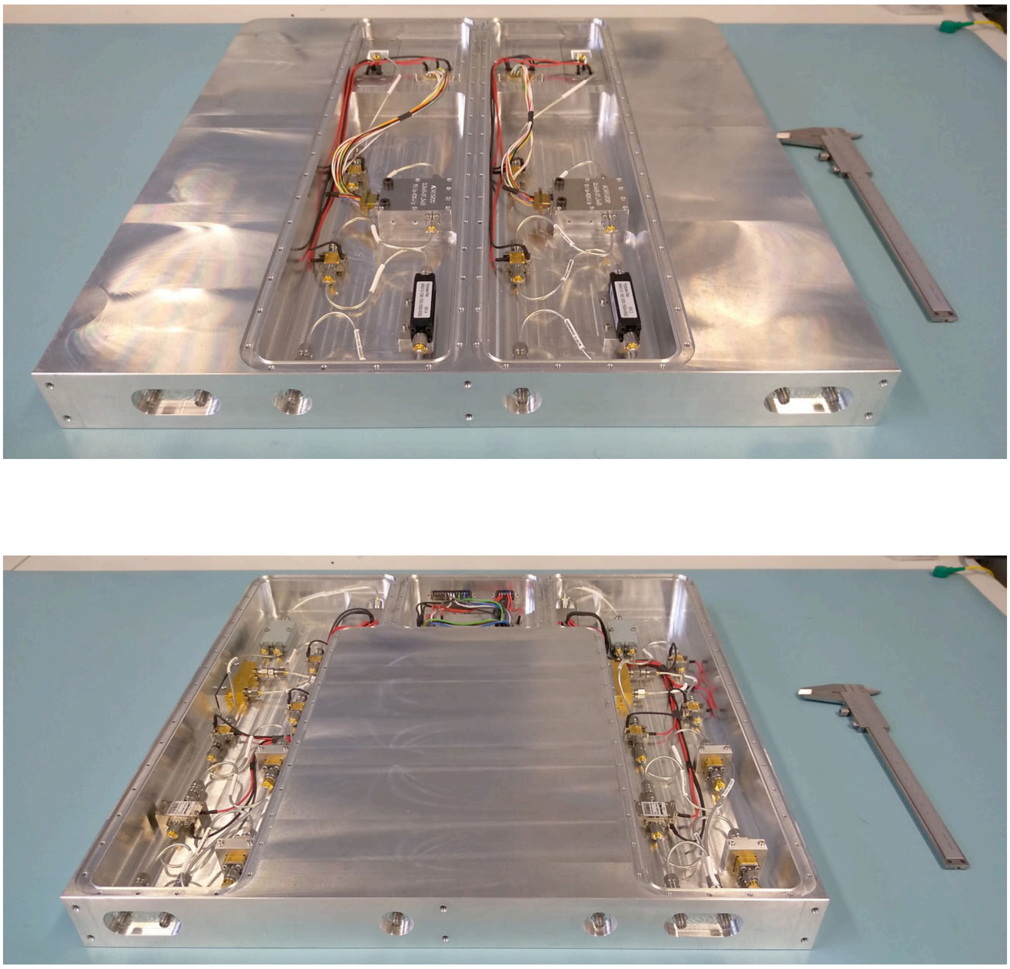

Fig. 8.4 E-box hardware

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8.3Measurement results

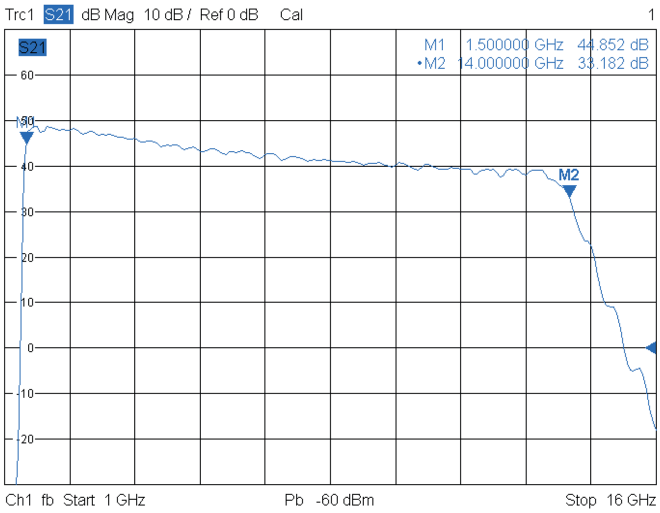

Fig. 8.5 Analogue signal 1.5 -14GHz

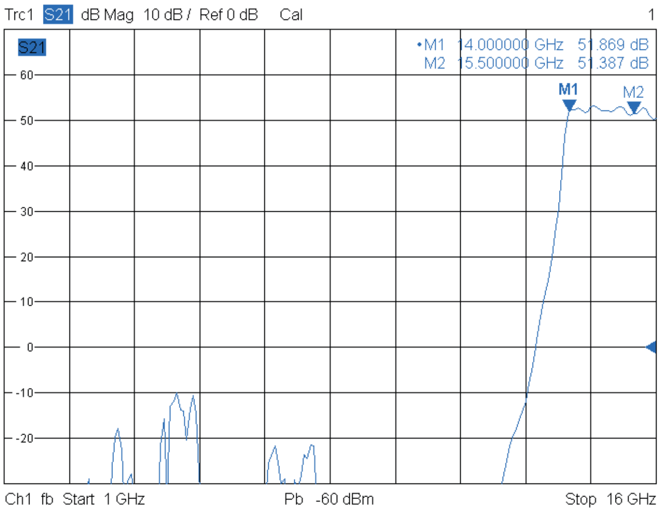

Fig. 8.6 Analogue signal 14-15.5GHz

Output signals of one channel are shown in figures 8.5 and 8.6. Figure 8.5 shows a negative slope in signal power from lower to higher frequencies. This is a normal effect but it would degrade the dynamic range. Therefor the frequency response will be equalized. In the block diagram in Figure 8.2 a component named gain equalizer is shown. It will have an opposite frequency response, means a positive signal power slope from lower to higher frequencies. The two parts together will create a flat bandpass frequency response.

The plots here were measured without a gain equalizer, because it makes sense to design this component at the very end, when the slope of the whole system is known.

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9 Acronyms

BRAND	BRoad-bAND
DC	direct current
EVN	European VLBI Network
HTSC	high-temperature superconductor
IXR	intrinsic cross-polarization ratio
LCP	left circular polarization
LNA	low noise amplifier
PTFE	Teflon
QRFH	Quad-Ridge Flared Horn
RAEGE	Red Atlántica de Estaciones Geodinámicas y Espaciales
RCP	right circular polarization
RF	radio frequency
RFI	radio frequency interference
SEFD	system equivalent flux density
Tsys	system noise temperature
VGOS	VLBI Global Observing System
VLBI	Very Long Baseline Interferometry

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