First studies towards a cryo-cooled Phased Array Radar System for Space Surveillance

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Abstract. The amount of space debris orbiting the earth is increasing. More than 700 000 objects with critical sizes of more than 1 cm have the potential to cause severe damage to space-based infrastructure. As a consequence an improvement of the detection sensitivity of next generation phased array radar systems for space surveillance is of high importance. A key parameter for successful detection is the signal-to-noise ratio (SNR). The purpose of our study is to enhance the SNR of a radar system by cryogenic cooling of critical electronic devices of the receiver, contributing most to the system noise temperature. Cryo-cooling receiver systems and the underlying fundamental techniques are already known in Radio Astronomy. The Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR) has the goal to gain practical experience with low temperature techniques in order to find possibilities for implementing cryo-cooled electronics improving the SNR of phased array radar systems. Currently, the FHR team is in the early phase of adapting this technology to phased array radar systems. The final mechanical realization of a cryo-cooled antenna system for radar applications, including the corresponding electronics, will be an important contribution for future radar technologies

1. Introduction

In the last 50 years significant progress has been achieved on the development of low temperature electronics. Due to its improved reliability, moderate costs and development of cryocoolers, cryogenic electronics are now widely used. Main fields of application could be summarized as follows:

- Non-accelerator particle detectors [4, 5] working with semiconductors [6, 7], superconductor and metallic paramagnets materials. Non-equilibrium detectors include kinetic inductance detectors [8], superconducting tunnel junction and superheated superconducting granules. In many cases, for increasing the sensitivity, SQUIDs are applied
- Accelerator detectors [25]
- Cooled electronics including SQUIDs and SQIFs [19-24]
- Cosmic-ray detectors for astrophysics research [9-15]
• Low Noise Amplifiers (LNA) with/without cooled filters for high frequency applications, e.g. in radio astronomy [16-18, 26-31] or low temperature physics laboratories [1-3].

In order to use and evaluate cryogenic cooled LNAs and other electronics, which could be used to enhance the SNR of a radar system, the Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR) is developing cryogenic test facilities and related infrastructure. The near-term goal is to test and evaluate LNAs, that are available on the market and to perform feasibility studies for the antenna cooling at liquid helium (LHe) or liquid nitrogen (LN2) temperatures to increase the sensitivity of radar systems.

2. Cryogenic Requirements

The main cryogenic requirements for establishing an appropriate infrastructure and for performing LNA and antenna experiments are summarized as follows:

• Establishing a suitable experimental environment
• Identification of LNAs suitable for cryogenic applications
• LNA and connecting cables should have low to moderate heat load on cryogenic systems
• LNA temperatures should be < 20 K
• In order to keep the cryogenic system as simple as possible, a cryogen-free system is chosen. LNA casing will be thermally connected to the cryocooler over copper braids and straps. If the antenna is cooled, it will be connected to the first or second stage of the cryocooler.

As a next step, the design of a cold and warm antenna environment with supporting mechanical structures is considered. It is planned to develop and test a prototype cryostat with 7 antenna elements working in L-band.

The cryogenic design of support structures has to fulfil several requirements:

• Compactness of a cryostat in order to fit in the available space, which leads to small dimensions of components
• Low cryogenic heat loads, which require particular attention to the selection of materials with low thermal conductivities
• Easy assembly and low-effort maintenance
• Robustness to external influences, e.g. mechanical or electromagnetic ones, which lead to an increase of weight of the vacuum vessel
• In case a rotatable antenna is foreseen, the weight must be minimized in order to have reasonable mechanical support

3. Cryogenic Infrastructure

3.1. Cryogenic infrastructure and equipment

Figure 1 shows the experimental working area as installed at FHR site.

One cryostat (also called “dewar”) was procured from CryoVac mbH & Co. KG, see Figure 2. It has one Sumitomo Cryocooler RFD 415DP, which was separately bought by Fraunhofer FHR and supplied to the cryostat manufacturing company, with cooling power of 1.4 W @ 4.2 K and 35 W @ 50K. The cryocooler is installed inside the vacuum vessel entering from the bottom of the dewar. The cryostat has a height of 1.4 m and a diameter of 0.7 m. It is equipped with one thermal radiation shield and offers possibility for a second one. An experimental plate (also called “4 K plate”) has a diameter of 0.4 m and allows the installation of several experiments for simultaneous measurements. For performing appropriate experiments, several additional design details were applied, e.g.:

• Additional flanges for installation of HF cables
• Passivation of surfaces (SurTec 650)
• Careful elimination of vacuum and RF leaks, e.g. due to conductive rubber-O-rings and small openings
• Demountable upper flange of the vacuum vessel in order to install RF transparent vacuum window, see Figure 2
The commissioning of the cryostat at the manufacturing company as well as at customer site was successful. At present time, it is extensively used for different experiments, e.g., tests of RF transparent vacuum window materials, cryocooler cooling power, vacuum tests, cross-check of temperature sensors, test of prototype components and LNA tests.

In addition, a small cryostat, capable to reach temperatures of around 12 K is currently under maintenance in order to prepare it for the operation after a long stand-by period.

Other infrastructure includes typical components of cryogenic laboratories like for example a gas-handling system for supplying pure helium or nitrogen, LN2 transport dewars, small dewars for experiments with LN2 and leak detectors.

It is planned that other cryostats will be acquired in order to be able to perform measurements of different system layouts simultaneously.

4. Measurements

4.1. General

It took one year to procure important components (like the appropriate cryostat), to design and realize the infrastructure and to gain first operational experience. During that time, several supplementary measurements like temperature sensor cross-checkings, vacuum measurements, material stability experiments and measurements of the cryostat performance were performed.

For maintenance reasons it was decided to use cryogen-free cryostats, i.e. cryostats cooled by cryocoolers without any use of liquid or gaseous helium.

4.2. Cryogenic components

First measurements were mainly devoted to the cooling of the antenna structure as well as to the development and test of the supporting elements (also called support structure) for the antenna and the LNAs. Such support structure has the requirement to provide an optimized thermal isolation between the LNA and the antenna.

Figure 3 shows a prototype of a support structure for the LNA and the Bow Tie-antenna.

Other types of antennas, e.g. dipole (different configurations), cavity-backed slot or -patch as well as planar microstrip ones are under investigation. It is worth to mention that in case of a cooled antenna, effective cooling is a challenge due to the complicated geometry of antennas.

Different types of supporting structures are also under investigation.

4.3. Dewar with RF-Window

The stability and vacuum tightness of an RF-window made of PMMA (Plexiglas®), see Figure 2, was tested during thermal cycling of the experimental set-up. No damage was noticed. The lowest
temperature of the experimental plate was around 12 K, which is sufficient for further measurements of LNAs or warm/cold antennas.

4.4. Electronic components
Currently, two types of electronic components are considered for cryogenic measurements: LNAs and limiters (which are used for the limitation of maximal admissible inlet power for LNAs).

Measurements of S-parameters and noise temperature were carried out in order to measure the performance of LNAs at cryogenic temperatures, while for the limiter only S-parameters were obtained. For that the measurement set-ups were developed.

Details on the measurement set-ups and results will be presented in a future paper.

5. Present Status and Future Activities
Presently, a cryogenic infrastructure has successfully been installed for performing first experiments. In the future additional infrastructure will be built in order to conduct simultaneous measurements.

First measurements of LNAs, limiters and prototypes of mechanical holding elements for LNAs and antennas have been done.

RF-window material was procured and successfully tested.

As a next step, further antenna support structures as well as cooling concepts for a 7 antenna element phased-array will be designed, realized and tested. For that, different materials for the RF-window will be further investigated and the performance of different antenna types will be analysed. The supporting structure for the LNAs and the cold/warm antenna will be optimized and applied to a 7-element phased-array.

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