Development of pressure acquisition system for cryogenic receiver

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Abstract. Receiver system is an indispensable signal receiving equipment for radio astronomical observation. By refrigeration, the noise temperature of the receiver is reduced to a great level, and the sensitivity of the receiver is improved. Therefore, the refrigeration link is particularly important. The cryogenic receiver system of radio astronomy usually adopts compressor compressed helium cycle refrigeration mode. When the compressor is in normal operation, the injected helium high pressure is between 280-300 Psi and the low pressure is between 70-100 Psi. The two pressure values will directly affect the refrigeration efficiency of the receiver. Because the compressor and cryogenic receiver system are both on the radio telescope, engineers are unable to check the pressure state at any time during the observation process. Sometimes, because of temporary power failure or pressure reduction, the receiver warms up and so on, which affects the whole receiving system. Combining with the refrigeration system of Nanshan 26-meter antenna, we have established 6 channels of helium pressure acquisition and remote monitoring, which can better ensure the operation of cryogenic receivers.

1. Introduction

Radio astronomy is an observational science [1]. Radio telescope reflect radio frequency signals from the universe and focus them on the receiver [2]. The receiver collects the signals and transmits them to the data backend for recording [3-5], as shown in Figure 1. The main function of the receiver system is to amplify, filter, polarize [6-9] and mix the signals which are gathered by the radio telescope. Its main performance parameter of receiver is sensitivity. The higher the sensitivity, the lower the noise temperature of the receiver, the stronger the ability of the receiver to detect weak signals [10, 11].

![RF Signal Transmission Link of Receiver](image)

**Figure 1.** RF Signal transmission link of receiver.
The system noise temperature of a receiving system includes the noise from the cold sky, ground, antenna loss and the inside of the receiver. The difference between the receiver used in radio astronomy observation and ground communication is that the radio signal received by the receiver used in radio astronomy is very weak. The receiver noise must be low enough to detect the signal [12, 13]. Taking the typical system noise temperature of the L-band phased array feed receiver newly developed by GBT(Green Bank Telescope) as an example, the overall budget is 19K, including 4K sky noise, 5K noise from ground, 5K antenna loss noise room temperature and noise of 5K cryogenic receiver. The ground communication signal is different from radio astronomy, because the ambient temperature will introduce a background noise of about 290K, which is close to the ambient temperature [14]. In order to ensure that the received signal is not submerged in the background noise, the signal intensity must be large enough to satisfy the needs of ground communication.

From this point of view, in radio astronomical observation, the slight increase of additional noise caused by the internal loss of the receiver will lead to a relatively large reduction in system performance. In order to improve the sensitivity of the receiver and reduce its noise temperature, refrigeration is generally used, because electronic devices exhibit ultra-low noise performance in extremely low temperature environment.

According to the different frequency bands, the size of receiver microwave devices is also different. Taking four bands of cryogenic receivers (L-band, C-band, S/X dual-band and K-band) of the Nanshan 26-meter radio telescope of the Xinjiang Observatory of the Chinese Academy of Sciences as examples, they are respectively used for observing and studying molecular spectral lines, active galactic nuclei, pulsars, very long baseline interferometry and deep space exploration. Because the first three bands belong to the long centimeter band, the front horn feed of the receiver is very large. For example, the diameter of the L-band horn feed is 1.05 m, so the whole refrigeration form of the feed can not be adopted. Therefore, the orthomode transducer, low noise amplifier, filter and other devices in the rear stage of the feed are placed in a dewar cavity to refrigerate, which has reduced the noise temperature of the receiver as a whole. Increase sensitivity. The K-band receiver belongs to the short centimeter band, and its feed and corresponding microwave devices are relatively small. It can be placed in the dewar cavity as a whole to adopt the overall refrigeration method, which will better enhance the sensitivity of the receiver, as shown in Figure 2.

![Figure 2. L and K-band cryogenic receivers.](image)

2. Refrigeration system of receiver

2.1. Principle of refrigeration system

Radio astronomical receiver system generally adopts compressor compressed helium cycle refrigeration mode. The refrigeration system composition of the receiver is shown in the Figure 3. The
compressor delivers compressed helium to the refrigerator through the helium hose, and then retrieves the expanded helium through the hose. The heat brought back by helium is cooled by the heat exchanger and compressed again to form a helium circulation system.

![Figure 3. Working principle of refrigeration system.](image)

**Figure 3.** Working principle of refrigeration system.

![Figure 4. The position of receivers and compressors in the radio telescope.](image)

**Figure 4.** The position of receivers and compressors in the radio telescope.

2.2. Composition of refrigeration system for nanshan 26 m radio telescope

Nanshan four cryogenic receivers are installed in the receiver room at the focus of the sub-reflector. As shown in the Figure 4, the space of the receiver room is limited, and the elevation of the radio telescope will be adjusted in the range of 0-90 degrees when tracking the radio source, so the compressor room for the compressor will be designed at the secondary platform of the antenna. This
position will rotate with the azimuth of the antenna, but it doesn't turn elevation like the receiver room does. The supply and return pipeline connected by the compressor is composed of the soft pipe and the hard pipe. The pipeline is connected to the elevation axi of the antenna along the antenna pedestal through the compressor room. Because the position changes with the elevation angle, the soft pipe connection is used in this position until the positions of the cryogenic receivers in the receiver room.

2.2.1. Refrigerator and compressor. Our cryogenic receiver selected the M350 helium refrigerator, which is manufactured by Trillium Company of the United States, as shown in Figure 5(left). Refrigeration cycle for this kind of helium refrigerator selected two-stage G-M cycle; operating conditions: indoor, ambient temperature 5-35°C, maximum capacity loss of about 5%; refrigeration power: 20W@77K, 5W@20K; cooling time to 20K: 65 minutes/50Hz.

We selected the M600 air-cooled compressor manufactured by OXFORD Company of the United States, as shown in Figure 5(right). Compressor pressure: high pressure 300 Psi, low pressure 70 Psi; power requirements: 50 Hz, 380 V +10%, 13 A, 12 KA; power consumption: about 7.2 kW; noise: about 63 dB; maintenance: every 30,000 hours after the replacement of adsorber.

2.2.2. Pressure acquisition requirement for cryogenic receiver. Because the refrigeration system needs to be running all the time to ensure the refrigeration temperature of the receiver, it is still necessary to ensure the good operation of the cryogenic receiver when the antenna is observing (when it is rotating). Because the engineer can not always be on duty at the receiver operation site, nor to enter the receiver room when the antenna is running, and can not know the operation status of the receiver refrigeration in real time, it is necessary to monitor the helium supply and return pressure of the receiver refrigeration system remotely at the terminal of the observation room.

3. Design of pressure acquisition system

3.1. Composition of pressure acquisition system

According to the refrigeration system design of Nanshan 26 m radio telescope, there are three compressors, namely three groups of helium supply and return pipelines, which correspond to a total of six pressure values to be monitored. One group of helium supply and return pipelines is used for L-band and K-band cryogenic receivers, the other one is used for S/X dual-band and C-band cryogenic receivers, and the last group of helium supply and return pipelines is connected with the third compressor for backup. Now the compressor room is using two compressors and the corresponding refrigeration pipelines, as shown in the Figure 6.
Figure 6. Compressor room of Nanshan 26 m radio telescope.

We installed a tee in each pipeline and then a pressure sensor on the branch of the tee to detect helium pressure in each pipeline. We chose the MBS 3000 pressure sensor (accuracy, typical +/-FS [%] 0.5%) manufactured by Danfoss company, as shown in Figure 7. This sensor has a testing range of 0-4 Mpa (fully satisfy the high-pressure requirements of 300 PSI). The interface is a custom self-sealing interface, which is specially used for refrigeration pipeline installation, but the sensor does not have digital output, only with analog output of 4-20 mA. If we want to achieve remote monitoring, we must convert the analog voltage corresponding to the pressure value into digital output.

Figure 7. MBS 3000 pressure sensors.

3.2. Realization of pressure acquisition system
The pressure acquisition system is designed firstly converts the 4-20mA analog current of the pressure sensor into analog voltage, and then chooses AT90CAN64 microcontroller of ATMEL Corporation which has 8-channel analog-to-digital conversion function, it can collect the analog pressure values of six helium gas pipelines converted before, and convert the pressure values into digital ones, which are transmitted by CAN bus to the observation room. The structure of pressure acquisition system is shown in Figure 8.

Figure 8. Structure of pressure acquisition system.
Circuit design schematic, layout and physical diagram of pressure acquisition system is shown in Figure 9.

Figure 9. Circuit schematic, layout and physical diagram.

4. Laboratory test of pressure acquisition system

We built a pressure acquisition system test platform in the laboratory and RS 232 interface was used for communication between acquisition system and computer. The normal high pressure of compressor is 250-300 PSI and the low pressure is 50-100 PSI, and the pressure acquisition range of system is 0-400 PSI. First, we added pipeline to 350 PSI pressure helium, as shown in Figure 10. The whole tee pipeline is equipped with Danfoss pressure sensor along the way, analog pressure monitoring meter on the other way, and manual valve on the last way. At the beginning of the test, it is responsible for injecting high-pressure helium into the tee, while during the test, it is responsible for slowly releasing helium manually to satisfy the complete sampling from 0-350 PSI.

Figure 10. Pressure acquisition system test platform.

By manually reducing the pressure, 34 points are selected to fit the pressure value of the analog pressure monitoring meter and the voltage value of the sensor output corresponding to the conversion. The linearity of the curve fitted is very good, as shown in the Figure 11.

Figure 11. Voltage value corresponding to pressure value.
Finally, the output value of the pressure acquisition system is compared with the pressure indication value of the analog meter. As shown in the Figure 12, the 96 PSI pressure value (left figure) collected by the monitoring system is very close to the pressure value (right figure) measured by the analog meter.

![Figure 12. Pressure value of acquisition system and meter.](image)

5. Conclusions
The Nanshan 26 m radio telescope of Xinjiang Observatory of the Chinese Academy of Sciences is equipped with four cryogenic receivers, which is very important for monitoring the operation of refrigeration system. This paper collects the supply and return pressure of the compressor used for refrigeration, through remote monitoring, we can better understand the operation status of the equipment. Through the pressure acquisition test of a pipeline in the laboratory at 0-350 PSI, the test value of the pressure acquisition system is very close to the display value of the analog meter, which can satisfy the requirements of pressure acquisition and monitoring of cryogenic receiver. The next step is to carry out relevant tests on the 26 m radio telescope and further improve the early warning function of the system.

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