

Radio Telescope Focal Container for the Russian VLBI Network of New Generation

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Abstract

This article considers the development of the structure of receivers for Russian radio telescopes. The development of these radio telescopes is undertaken within the project for creating a Russian small-antenna-based radio interferometer of new generation. It is shown that for small antennas (10–12 meter) the principal unit, which provides the best SNR, is the so-called focal container placed at primary focus. It includes the primary feed, HEMT LNA, and cryogenic cooling system down to 20° K. A new multi-band feed based on traveling wave resonators is used. It has small dimensions, low weight, and allows working with circular polarizations. Thus it can be placed into focal container and cooled with the LNA. A sketch of the focal container, with traveling-wave-resonator feed, and calculations of the expected parameters of the multi-band receiver are presented.

1. Introduction

The so-called focal container (FC) is one of the key elements of the antenna of the radio telescope of the new generation Russian VLBI network. Located at the focal point of the antenna, the FC provides the required quality of the received signal. The FC contains the antenna feed, low-noise amplifiers, and microwave isolators, all cooled to cryogenic temperatures inside a dewar. As electromagnetic waves should freely get to the antenna feed within the dewar, the FC front wall should be transparent in all working frequencies of the radio telescope.

According to the requirements for the equipment of the above mentioned VLBI network, the reception path of a radio telescope should adhere to the recommendations of the IVS VLBI2010 Committee. That is, the FC should provide signal reception in several (from three to five) frequency bands (up to 1 GHz bandwidth, each situated within the range from 2 to 14 GHz). These requirements can be met when either a broadband antenna feed working in the full range (2–14 GHz) or a multiband feed accepting signals in several fixed frequency ranges lying in the specified limits are used. For the creation of the radio telescope, the second variant of construction of a feed was accepted: the multiband feed should contain five frequency channels and receive signals of two circular polarizations — left and right. The following borders of operational frequency bands were defined: 2.15–2.50 GHz (S-band), 3.3–4.3 GHz (C-low-band), 4.8–6.2 GHz (C-high-band), 7.5–9.7 GHz (X-band), and 11–14 GHz (Ku-band).

2. Focal Container Feed

The FC multiband feed is supposed to be built on the basis of traveling wave ring resonators (TWR). Such a feed consists of a set of cylindrical microwave units (the relevant frequency bands)

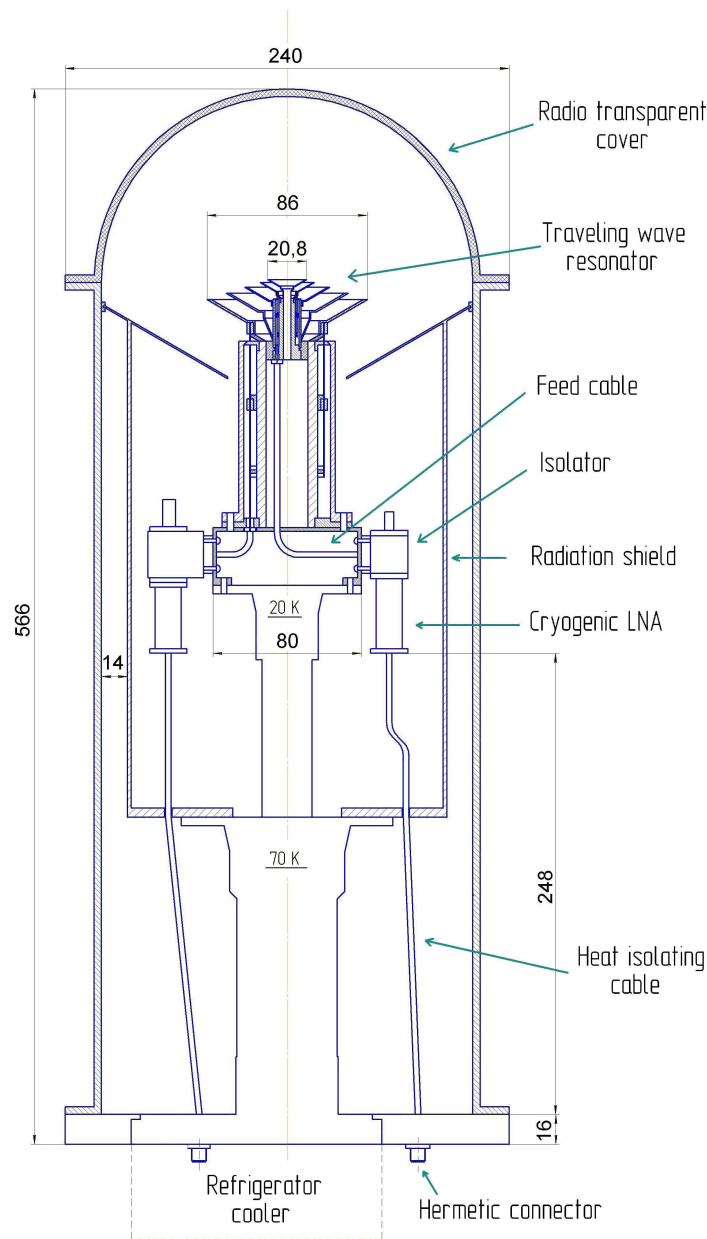


Figure 1. General view of the focal container with TWR feed.

placed coaxially — the C-low-band unit is placed inside the S-band unit, etc. (Figure 1).

TWR represents a stripline coiled into a ring [1]. Resonator excitation is carried out by means of a directional coupler. Two TWRs are cascaded to improve the feed gain-frequency characteristic. Only one of the TWRs (open TWR) radiates an electromagnetic wave of circular polarization. Both TWRs and the excitation line are connected by quarter-wavelength segments. The form of the gain-frequency characteristic of the TWR feed is defined by the link between the ring lines. Each of the coaxially placed frequency channels has two outputs of circular polarization—LCP and RCP. This TWR feed has a width of a far field pattern near $(120\text{--}130)^\circ$ on a level minus

(10–12) dB, and is intended for axial-symmetric parabolic antennas with an f/D ratio of about 0.3–0.4.

The reception path between the TWR feed and the low-noise amplifiers (LNA) contains ferrite isolators. They serve to eliminate the negative influence of a mismatch between feed outputs and LNA inputs. The isolators possess certain losses and, hence, raise noise temperature of the system a little. However, when using the TWR feed, utilization of the isolators is obligatory, as outputs of the right and left polarization channels of this feed are not completely isolated.

3. Low-noise Amplifiers

The input cascades of the low-noise amplifiers (LNA) define the key parameters of the radio astronomical receiver such as noise temperature and sensitivity. LNA noise temperature is largely dependent on the physical temperature of the amplifier. Therefore, input amplifiers need to be cooled to cryogenic temperatures. Among the manufacturers of cryogenic LNA, whose products basically correspond to the requirements, there are such companies as QuinStar Technology Inc. (USA), B&Z Technologies (USA), Low Noise Factory (Sweden), and SPE “Saturn” (Ukraine). Amplifier characteristics of these manufacturers are listed in Table 1.

Table 1. Characteristics of low-noise amplifiers

Manufacturer/model	Band, GHz	Noise figure, K	Gain, dB
Low Noise Factory/LNF-LNC1.8_2.8A	S: 1.8–2.8	3	43
SPE “Saturn”/13 cm	S: 2.3–2.64	3	35
QuinStar Technology Inc./C-4.0-30H	C-low: 3.5–4.5	8	30
SPE “Saturn”/7.6 cm	C-low: 3.7–4.2	4	30
QuinStar Technology Inc./C-5.0-30H	C-high: 4.8–5.1	3	28
SPE “Saturn”/5.8 cm	C-high: 4.8–5.5	4	30
Low Noise Factory/LNF-LNC7_10A	X: 7.0–10.0	6	35
SPE “Saturn”/3.5 cm	X: 8.0–9.2	5	30
B&Z Technologies/BZ0812CR1	Ku: 8.0–12.0	15	24
SPE “Saturn”/2.5 cm	Ku: 11.2–12.8	6	30

The most widespread cooling systems for input low-noise amplifiers of radio telescopes are two-stage systems, based on a cycle of Gifford-McMahon (GM). Such systems are currently used in the Russian VLBI network “Quasar” and will be introduced to the new VLBI network.

4. Radio Transparent Window

Electromagnetic waves, focused by the radio telescope antenna, should freely propagate to the cooled antenna feed, situated inside the cryogenic dewar. That is, the dewar should be equipped with a radio transparent (RT) window or cover. The following demands should be applied to the window:

- Active losses and reflections of electromagnetic waves from the material of the window in a range of frequencies from 2 to 14 GHz should not raise the noise temperature of the system

more than 1–3 K.

- The feed cover should prevent penetration of infrared radiation into the dewar.
- The cover should be strong enough to maintain external atmospheric pressure.
- The cover material should not pass or exhale gases into the dewar.

There is experience in the creation of a flat radio transparent dewar window. In [2], the design of a radio transparent window for X- and Ka-bands is described. This window is a three-layer structure, with a 0.08-mm Kapton layer for strength, backed by a 25-mm polystyrene layer for additional strength and thermal insulation, with a 0.38-mm Teflon over-layer to protect the Kapton, which will lose strength after long periods of exposure to the Sun. The window adds less than 1 K of noise temperature to the system in each band.

The width of pattern of the above mentioned multiband TWR feed is equal to $(120\text{--}130)^\circ$. To exclude the influence of the edges of the radio transparent window on the performance of such a feed, it is required that the cover should have a dome-shaped form. This complicates the problem of creating the cover and demands serious study.

5. Noise Temperature of the Receiver

We made a calculation of the noise temperature of the radio telescope receiver, considering losses in the radio transparent cover, TWR feed, internal and external cables, connectors, microwave isolators, and also the noise temperatures of the LNA and RF/IF convertor. The results are presented in Table 2. As real losses of RT cover and TWR feed have not been measured yet, expected values were used.

Table 2. Contribution of parts of the receiver to resulting noise temperature (K)

Part of the receiver	S-band	C-low-band	C-high-band	X-band	Ku-band
RT cover	3	3	3	3	3
TWR feed	3	3	3	3	3
Feed cable	0.11	0.37	0.55	0.85	1.04
Isolator	1.53	0.76	0.77	0.78	0.79
LNA	3.47	4.49	4.54	5.78	7.02
Heat isolating cable	0.01	0.01	0.01	0.01	0.02
Hermetic connector	0.01	0.01	0.01	0.01	0.01
External cable	0.01	0.02	0.03	0.04	0.04
RF/IF convertor	0.06	0.26	0.40	0.60	0.88
Total noise figure, K	11	12	13	14	16

References

- [1] Diki, D. V., Printed Antennas Based on Travelling Wave Resonators, Nice, France, November, JJINA-98.
- [2] Gatti, M., W. Imbriale, D. Hoppe, H. Reilly, J. Prater, M. Britcliffe, X/Ka-band feed for the DSN array, In: DSN Microwave Array Peer Review: Feeds/LNA/Crypto, Pasadena, CA, December 18, 2003.