**The Institute of Applied Astronomy of the Russian Academy of Sciences**

# The Highly Sensitive Receiving System of S/X-band to Address the Problems of Astrometry and Geodesy on the Radio Telescope RT-70

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Fully steerable radio telescope RT-70 (Fig. 1) is made by the Gregory circuit with additional mirrors to switch the operating wavelength range. It is one of the two unique instruments in Russia at present with the largest diameter of the mirror. This telescope was built in 1985 and was intended to solve the various problems of nationwide economic scope: Deep Space Communication programs, the Study of Terrestrial Planets and the celestial bodies approaching the Earth (asteroids), the problems of space debris. To be able to apply it to coordinate-time support, the development of modern hardware and software was started in IAA RAS (St. Petersburg) , to ensure the compatibility of the operation of this radio telescope as a part of the "Quasar-KVO" VLBI-network (Very Long Baseline Interferometry) according to the plan of modernizing of this unique instrument [1].

Fig. 1. RT-70 (Ussuriisk )

The purpose of this work is to develop the radio astronomy receiver system (RRS) of 13/3,5 cm wavelength ranges (S/X band) with a cryogenic cooling system for RT-70 antenna system (Ussuriisk) and to measure its main characteristics.

The following problems were solved to comply with purpose stated:

- The analysis and the selection of the radio astronomy receiver system (RRS) circuits have been carried out in accordance with the requirements stated;
- The individual components (units) of the RRS have been developed and manufactured;
- Investigation of the basic characteristics of the manufactured units of the RRS has been done;
- Laboratory tests of the RRS developed were carried out in cryogenic temperature mode.

**Requirements for the RRS**

Selection of the RRS circuit was determined by the following requirements:

- The RRS should be compatible in its basic characteristics with the RRS of domestic radio telescopes working within the "Quasar-KVO" VLBI-network [2];
- The radio telescope should not only be intended for VLBI-network but operate as a separate tool (radiometric regime);
- Simultaneous reception signals of both circular orthogonal polarizations should be available, as well as the ability to receive the signal at two spaced wavelengths for VLBI observations (providing the possibility of accounting for the parameters of the ionosphere) [3];
- Full measurement automation should be carried out.

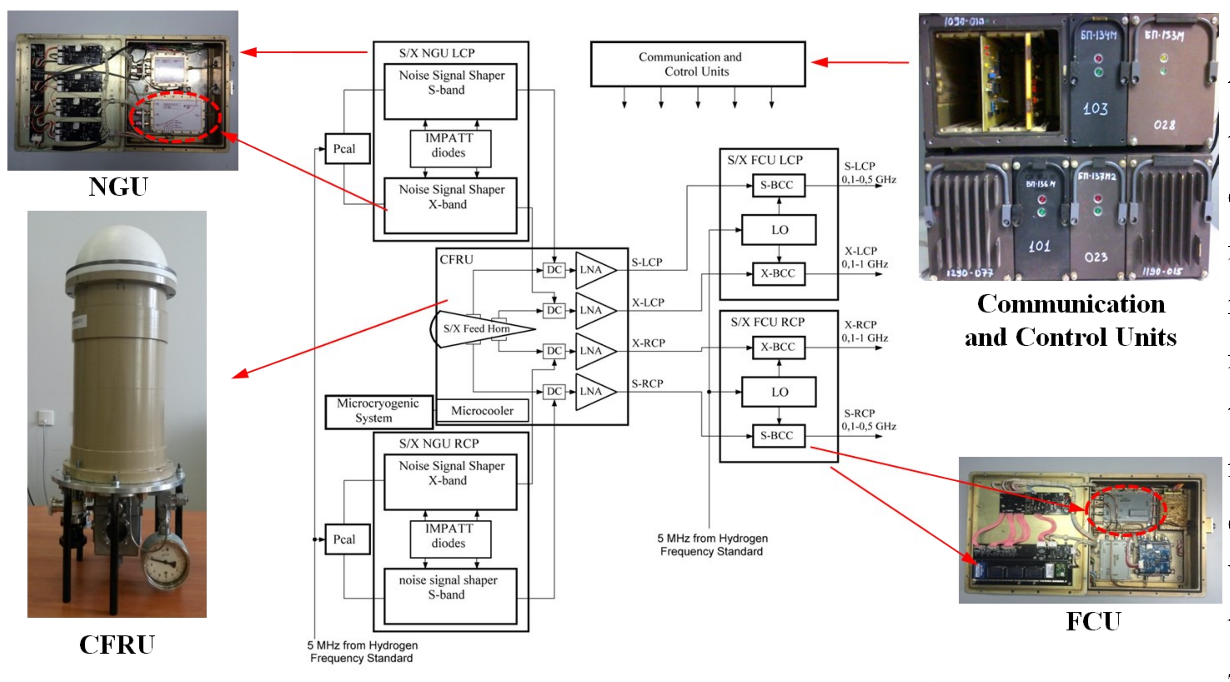



Fig. 2. Functional diagram of the RRS

The RRS developed complies with these requirements. The system is based on the circuit with the noise pilot-signal. This circuit combines the capabilities of the modulation reception for a single telescope mode and the reception in the VLBI-network mode (see. Fig.2). The absence of the modulator at the input of the RRS makes an additional advantage of this circuit [3]. The receivers in each band have been made two-channel ones - for receiving both the right and the left polarizations. The input stages cooling is carried out by microcryogenic system (MCS) to the level of hydrogen (15 K). The management of the receiver modes and the parameters monitoring are remotely controlled from a special host computer. Fig. 3. presents the RRS developed, its main elements being: a cryogenic focal receiving unit (CFRU), two dual-band frequency conversion units (S/X FCU), two dual-band noise generators units (NGU), as well as communication and control units.

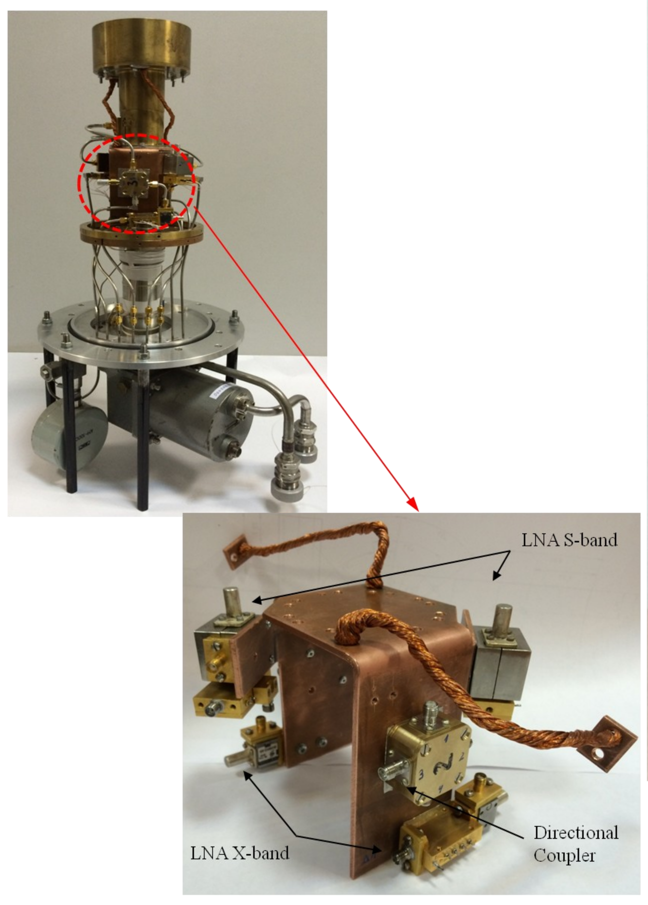


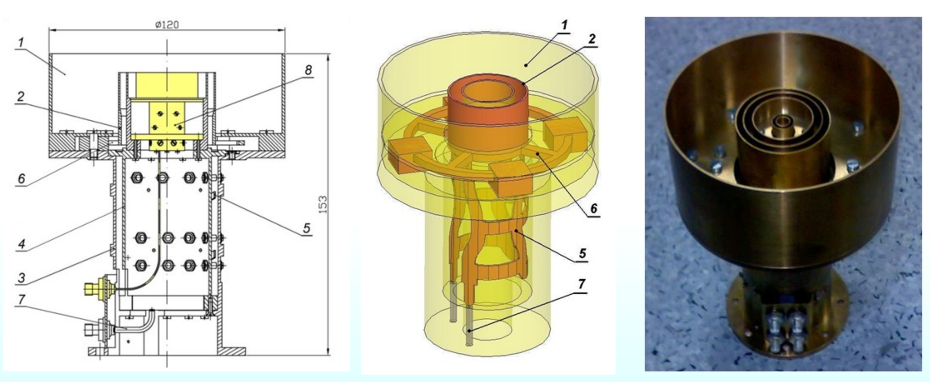

Fig. 4. CFRU without cryostat


Fig. 3. The radio astronomy receiver system (RRS)

The principle of operation of this system: the dual-band feed, located behind the radio transparent window of the cryogenic focal receiving unit (CFRU) performs simultaneous reception of the right and left circular polarization signals in the S and X bands. The signal from output of the feed by the coaxial paths reaches the low-noise broadband amplifier (LNA) , through directional couplers (Fig. 4) in the microwave path injects the signals of amplitude and phase calibration and compensation from the noise generators unit (NGU). The output signal from CFRU falls into frequency conversion unit (FCU) where it is amplified finally and converted to an IF signal. In this receiving system, it was decided to use the S/X dual-band feed [4], the feed of the space radio telescope, designed to "RadioAstron" project served as a prototype. The design of the feed and a three-dimensional model of one of its frequency channels are shown in Fig. 5.

Feed Characteristics:

- Bandwidths– $S$: (2150-2350) and $X$: (8200-9100) MHz;
- Beamwidth on the level of minus 10 dB - about 120°.



**1- Coaxial Cavity, 2- Circular Emitter, 3- Body, 4- Insert, 5- Quadrature Divider, 6- Shorted Trail, 7- Output, 8- X-band Feed**

Fig. 5. S/X dual-band Feed

**The technique and the measurement results of the RRS noise temperature.**

The test measuring bench was assembled (Fig. 6), which includes: the Agilent N9030A signal analyzer, the Agilent N1914A power meter, the 8487D power detectors and two low-temperature noise generators (LTNGs). The technique is based on the method of two point sampling [5]:

1) At the input of the RRS, a "warm" LTNG (without nitrogen) is mounted and the level of the output signal $P_h$ is measured (Fig. 7). Control linearity of the measuring tract is carried out by calibration signals (passing from the noise generators unit through a directional coupler of CFRU) using both "warm" and "cold" LTNGs. The value of the calibration is measured ($P_{ch}$= $P_{ngh}$-$P_h$). The physical temperature of the absorber is measured by Fluke 62 mini infrared temperature meter at the center and the edge of the absorber and resulting average value $T_{ph}$ is calculated.

2) At the input of the RRS, a "cold" (filled with nitrogen) LTNG is mounted and the level of the output signal $P_c$ and the calibration value $P_{cc}$=$P_{ngc}$-$P_c$ are measured. The difference between the $P_c$ and $P_h$ calibrations is calculated as a percentage.

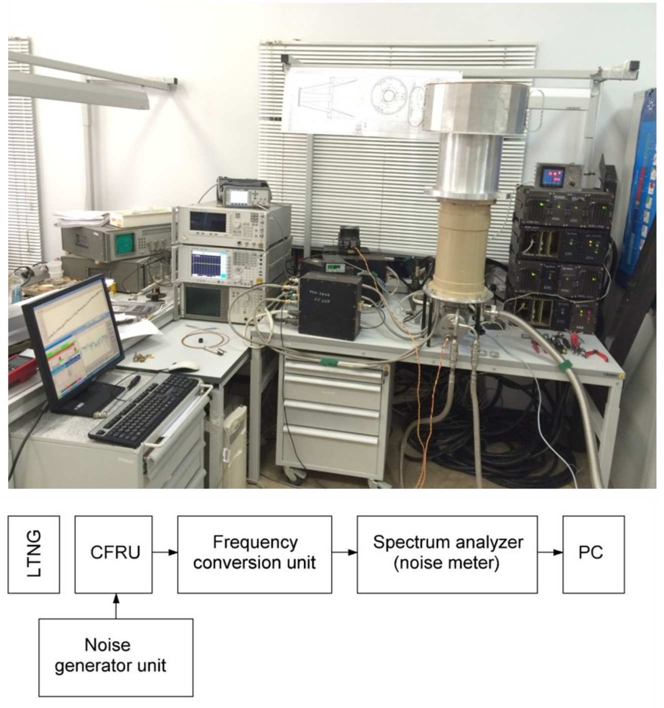



Fig. 6. Test bench for measuring the noise temperature

The effective noise temperature of RRS is calculated using the formulas (see Table 1) with contribution of the registration system noise being negligible:

$$\alpha_1 = G\cdot(T_1 + T_{RS}) \qquad \alpha_2 = G\cdot(T_2 + T_{RS}) \qquad T_{RS} = \frac{T_2 - n\cdot T_1}{n-1} \qquad n=\alpha_2/\alpha_1$$

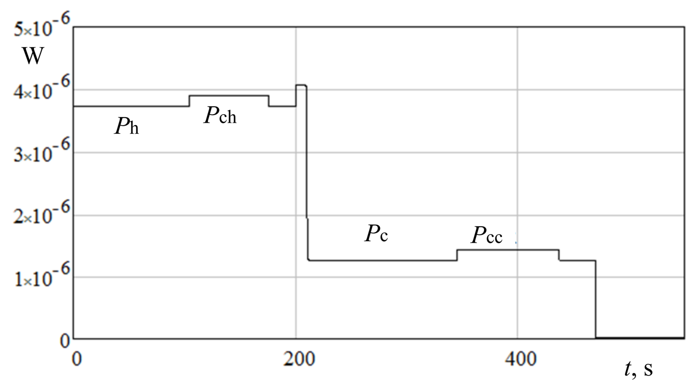



Fig. 7. The level of the output signal from RRS

Table 1. The RRS parameters

| Frequency band, GHz | The RRS noise temperature , K | | The RRS gain factor, dB | |
|---|---|---|---|---|
| | cold | warm | cold | warm |
| 2,1-2,5(S) | *22 K* | *140 K* | *67 dB* | *65 dB* |
| 8,2-9,1(X) | *28 K* | *300 K* | *63dB* | *60 dB* |

**The main FCU and NGU characteristics**

The main characteristics of the FCU are the dependency of the gain (power) $G$ and the noise factor $F$ on frequency $f$ (Fig. 8a and 8b for S and X bands, respectively). The average value of the gain was 35 dB within the operating frequency range with irregularity being not more than 2 dB for S-band. For this range the noise factor proved to be no more than 4 dB. Similarly for X-band, the average value of the gain was 36 dB within the operating frequency range with irregularity being not more than 3 dB. In this case, the noise factor does not exceed 5dB.

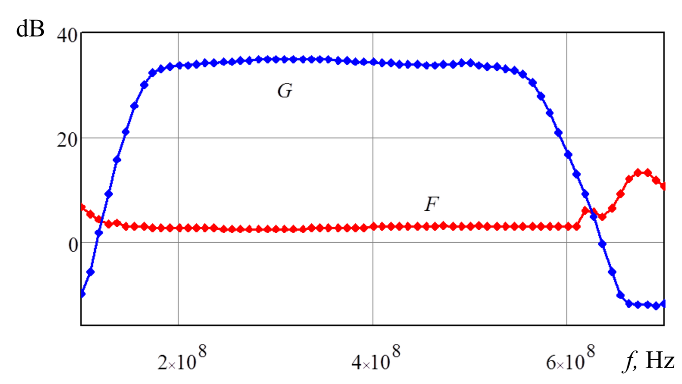



Fig. 8a. FCU parameters for S-band

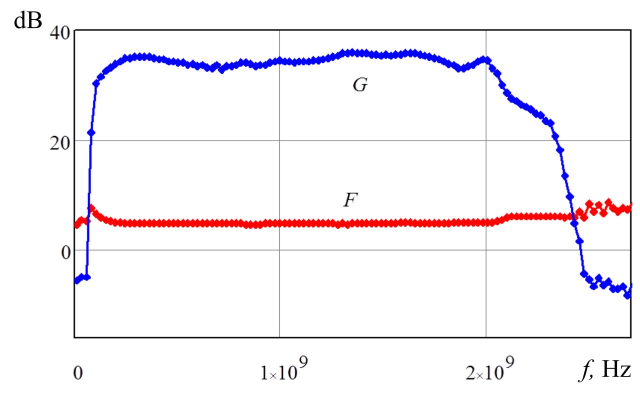



Fig. 8b. FCU parameters for X-band

The NGU main characteristic is the dependence of the noise power spectral density (NPSD) of calibration and compensation signals on frequency. Fig. 9a and 9b show the experimental dependence of NPSD $T_{com}$ and $T_{cal}$ on frequency for the S and X bands, respectively. The mean value $T_{com}$ for S-band was 350000K, $T_{cal}$=20000K. For X-band the mean value $T_{com}$=120000K and $T_{cal}$ = 8000K.

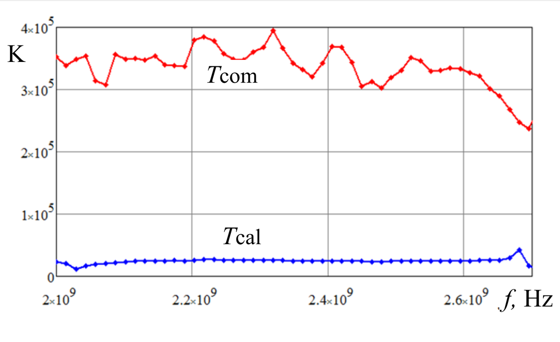



Fig. 9a. NGU parameters for S-band

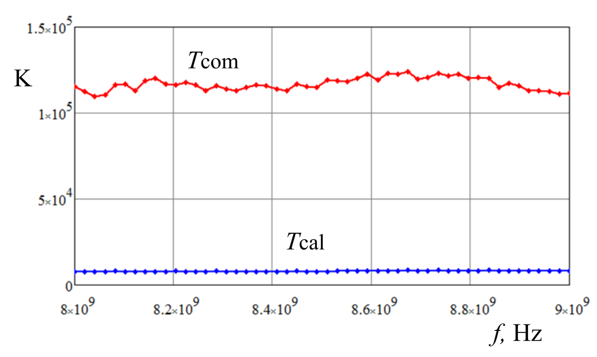



Fig. 9b. NGU parameters for X-band

**Non-linear distortion in the RF path of RRS**

Figure 10 shows the transfer characteristic of the microwave channel of the receiving system in X-band, as measured by biharmonic signal with frequencies $f_1$ = 8,630 GHz and $f_2$ = 8,660 GHz. It shows the level of the first harmonic (line 1), the level of the components of the third order intermodulation (line 2), and also noise $S_n$ recorded at the receiver output in the band 100 kHz. Measured receiver transfer coefficient $G$ = 62,4 dB. compression point (Figure 10b.) $P_{1dB}$ = -62.7 dBm - a deviation from the linear transfer characteristic by 1 dB.

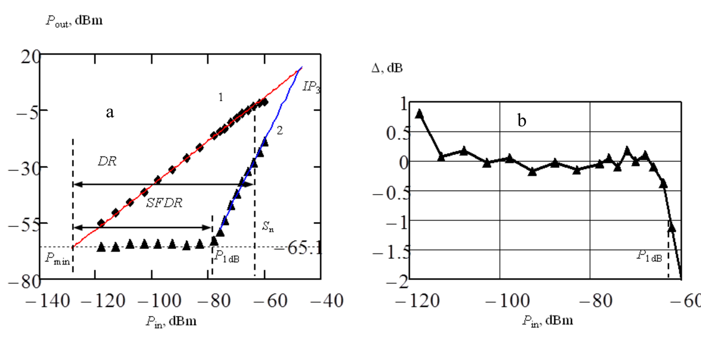


Fig.10. Transmission characteristic of the X-band receiver.

Thus, the dynamic range of the receiving system given in lane 1 Hz, is evaluated as $DR$ = 108 dB. Spurious-Free Dynamic Range $SFDR$, also given in lane 1 Hz is 79 dB, IP3 is - 47.5 dBm (crossing lines 1 and 2 on fig. 10a). Figure 11 shows a functional diagram of the stand for the measurement of non-linear distortion of the receiving system in the S and X band.

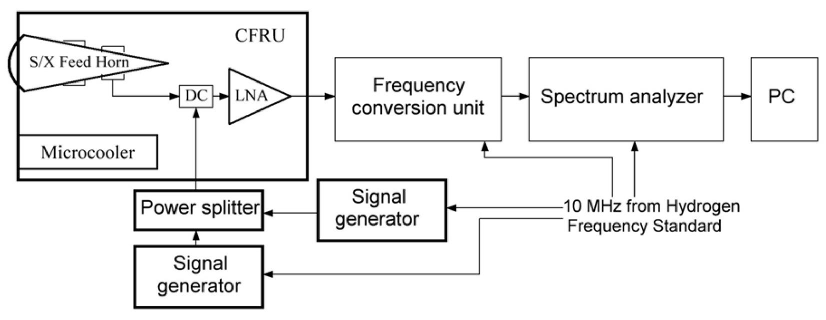



Fig. 11. Functional diagram of the measurement stand

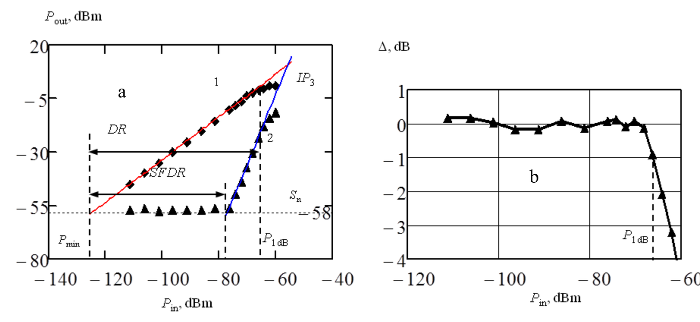


Fig.12. Transmission characteristic of the S-band receiver.

Figure 12 shows the transfer characteristic of the microwave channel of the receiving system in S-band, as measured by biharmonic signal with frequencies $f_1$ = 2,250 GHz and $f_2$ = 2,270 GHz. One can see the parameters of the microwave tract of this range are similar in value to the corresponding parameters of X-band.

**References**

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