LNA FOR MULTICHANNEL RECEIVER 8-MM RANGE INPUT CRYO-BLOCK FOR SPECTRAL OBSERVATIONS

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The results of 8-mm range low-noise amplifiers creation, with stable operating temperature $T_{AMB} = 20-30$ K in quad input cryo-block multichannel receiver for spectroscopic observations RT-22 FIAN are presented in this paper. Work was carried out within the framework of the modernization program of receiving complex RT-22 FIAN. Designed LNAs have noise temperature $T_n \leq 50$ K, gain $GAIN = 29.5 \pm 2$ dB in operating frequency band $\Delta F = 34-37.5$ GHz at $T_{AMB} = 22$ K. Four independent receiving data are formed in the input cryo-block formed, that will increase the amount of data of the radio telescope after the commissioning of the new converter unit 4 times during observations of molecular radio lines and 8 times during observations of recombination radio lines.

Keywords: low noise amplifier, multichannel receiver, cryo-temperature, radio telescope, recombination radio lines

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Introduction

The main goal of modernization of cooled receivers RT-22 FIAN [1] is the sufficient increase in the effectiveness of observations, in particular – 8-mm range spectral observations, on several orders.

Main parameter of receiving device, determining the effectiveness of observations, is sensibility, which is determined by minimal detected signal equal to standard error of measurement on the receiver input. Cooled receivers RT-22 FIAN are modulation receivers with symmetric modulation diagram, that allows to significantly reduce the influence of atmospheric radiation and other distributed noise sources on radiometer.

For modulation receiver formula for determining the sensitivity is:

$$\Delta T = 2 \times T_n \div \sqrt{\Delta f \times t},$$

where system noise temperature $T_n$ is summed up from the noise of receiver, antenna and atmosphere, $\Delta f$ – receiver passband till detector, $t$ – signal accumulation time.

It is obvious that the most effective way to improve efficiency is to lower system noise temperature $T_n$. On the other hand, for spectral receivers passband to detector is determined by required frequency resolution. Besides, there is an option to methodically increase the signal accumulation time $t$, by adding information receiving channels.

Receiver multichannel structure

Double increase in accumulation time performance is achieved by modernization of modulation system. Until present time observations were conducted by diagram modulation, in which feed horn, symmetrically passed out of radio-telescope Cassegranian focus, are serially connected to the receiver input. In that case one feeder receives radiation from source and the other from test area spaced at 23 ang. azimuth. Change of input Y-type switch to X-type allows to simultaneously receive radiation of both feeders, when on each modulation frequency
semi-period, information from object will be translated to one of the receiver channels.

New method of both space RF radiation polarization is realized in a new input cryo-block. As each of polarization coming to the specific X-type switch, 4 channels of independent receive are formed (Fig.1).

Utilizing of LNA in multichannel cryo-block, cooling by micro-cryogenic system of closed-loop cycle hydrogen level cooling (with set cooling capacity and corresponding dimensional constraints) inflict additional requirements on LNA design.

8-mm range low noise transistor cryo-amplifiers

Main goals for project of LNA modernization for multichannel cryo-blocks can be determined as follows:

1) choice of LNA active element base, sustainable at cryogenic temperature;
2) reproducibility of noise and amplitude-frequency characteristics of LNAs at cryogenic temperature;
3) suppression of mirror receiving channel for reduction of noise power level on detector input;
4) minimization of modules energy consumption to, firstly, minimize the cryo-unit time out to stationary regime and, secondly, decrease LNA modules own temperature;
5) minimization of LNA modules overall dimensions to decrease thermal resistance and lower overall dimensions of cryo-unit.

During preliminary researches constructive and schematic design was made, along with prototyping of cooling LNAs on GaAs discrete transistor and monolithic integrated circuits (MIC) [2]. Choice of microwave elemental base is determined by repeatability of microwave characteristics and sustained performance of MIC in a wide range of temperatures and, what is most important, in cryogenic temperature.

Solution to the tasks number 1 and 2 – namely the choice of elemental base, confirmation of efficiency and characteristics reproducibility at $T = 20$ K, became the use of MIC XL1000 (company MimixBroadband) [2, 3] as active element in LNA modules. Studies have shown that:

- MIC XL1000 is capable of operation at cryo-temperatures;
- MIC XL1000 is steadily operational with input and output loads as bandpass filter;
- Microstrip valve 1IMC-37.5-4-37BW8.1 (CJSC «Argus-ET») being a broadband devices are slightly changing their parameters at cryo-temperatures, which allows to substitute interstage and output waveguide valves, constitute a significant part of LNA overall dimensions.

LNA module design is made in accordance with requirements determined by the authors on the basis of long standing development of products functioning on hydrogen level temperatures:

1) construction should provide transmission of microwave signal from waveguide of corresponding section to MIC die (eg. microstrip-waveguide junctions) [4, 5];
2) LNA have filtration network and power supply (and secondary external sources of supply);
3) matching networks and MIC output impedances are included to LNA modules microwave paths – these networks are necessary, because MIC dies have wave resistances different (sometimes significantly) from standard microwave path impedances;

4) disposition of microstrip transmission lines and active elements in outer waveguides, which allows to successfully endure the distribution of higher type oscillation and lower the chance of occurrence of self-excitation conditions, that are especially dangerous when operational temperatures are decreasing, due to increase in internal steepness of microwave transistors;

5) use of microstrip valves to provide regularity of microwave path and minimize the overall dimensions of LNA modules.

It should be noted that with the same reliability of HEMTs, reliability of LNA on GIS with discrete HEMT are significantly lower than MIC LNA due to the high number of microconnections, making of which is highly dependable on professional skills of assembly and setup specialists. The same applies to reproducibility of mm-range multistage LNA characteristics.

Given thoughts shows that the benefits of discrete HEMTs are not obvious for their use in cooled LNA due to its microwave characteristics (noise temperature Tn, gain, gain non-uniformity). At the same time the use of MIC makes the process of assembly and setup easier and increases the overall operational reliability of amplifier.

Suppression of LNA mirror receiving channel is achieved by the use of thin-film microstrip passband filter (PBF) fabricated on quartz substrate 200 microns thick. Preliminary electromagnetic simulation of amplitude-frequency characteristics (AFC) of PBF with maximally flat characteristic in Microsoft Office environment shows the potential to realise the required characteristics [2]. External type of microstrip PBF and its simulated and measured AFC on waveguide equipment with and without valves are shown on Fig. 2 and Fig. 3.

Difference in AF characteristics of simulated and measured filter performances can be explained by several reasons:

1) real gap size (10 micron) was 12±1.2 micron;
2) weight of microstrip inductance was 32±1.5 micron instead of 26 micron during simulation;
3) flaws (fringe) in microstrip lines in critical points: gap and inductance;
4) additional losses in microwave equipment.

Nevertheless, as AFC PBF requirements corresponding to the given task in general, designers decided to use them in LNA. Besides, microstrip PBF has overall size 20-30 times less than waveguide filter with the same characteristics, that allows to complete the 5th task.

Processes described above have led to the creation of cryo-LNA in a single-section variant, which contributed to the significant decrease in overall size of the device (Fig. 4) and a 4-channel cryo-unit in general.

AFC and noise characteristics of each of the 4 cryo-LNA, measured at \( T_{\text{AMB}} = 22 \) K, are shown in Fig. 5. Noise temperature
$T_n = 50 \text{ K}$ is shown in red line and the range of acceptable irregularity change of LNA gain $\text{GAIN} = 3 \text{ dB}$ is shown in red rectangle. Obtained experimental results confirm the conformity to required conditions and show the availability of LNAs for 4-channel input cryo-unit. Set includes four LNAs with $T_n \leq 50 \text{ K}$, $\text{GAIN} = 29,5\pm2 \text{ dB}$, $\Delta F = 34-37,5 \text{ GHz}$ with $T_{\text{AMB}} = 22-30 \text{ K}$.

Use of 4-channel input cryo-unit in 8-mm range receiver RT-22 FIAN

Receiver noise temperature with input cooled to cryogenic temperatures is determined not only by the LNA noises, but also by the losses of microwave signal on the input path elements of the receiver prior to LNA.

Simulated contribution of cryo-unit nods noise to the overall noise temperature of the receiver

<table>
<thead>
<tr>
<th>Microwave path nod</th>
<th>Gain, dB</th>
<th>Temperature, K</th>
<th>Contribution to receiver $T_n$, K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealed lead-in with heat bridge</td>
<td>- 0.3</td>
<td>295</td>
<td>23</td>
</tr>
<tr>
<td>PS</td>
<td>- 0.3</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>DCr</td>
<td>- 0.15</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>Waveguide path</td>
<td>- 0.15</td>
<td>40</td>
<td>2</td>
</tr>
<tr>
<td>MMS</td>
<td>- 0.4</td>
<td>40</td>
<td>6</td>
</tr>
<tr>
<td>LNA</td>
<td>30</td>
<td>30</td>
<td>62*</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

* Amplifier noise temperature: 45 K

For modulation radio-meter input unit layout shown on Fig. 1, these losses are significant, complex cooling of all microwave paths to cryogenic temperatures becomes necessary. To make quantitative evaluation of noise performance of microwave nods on receiver input path we provide table of simulated noise temperature of a new cryo-unit.

As it can be seen from the table noise input of microwave path nods operating at cryogenic temperatures is insignificant. It is GWS noises that determine the noise temperature of the receiver.

Since noise contribution of input paths directly dependent of their temperature, the above applies when cryo-system provides necessary operational temperatures for receiver nods. Measurements confirmed the results of thermo-physical simulation for input cryo-unit: overall heat gain are not
LNA for multichannel receiver 8-mm range input cryo-block for spectral observations

exceeding nominal performance of microcryogenic closed loop systems produced by «Sibkriotekhnika» company (about 3 W).

As a result modulation radiometer noise temperature, linked to the input of round sealed lead-in, is $T_{n,inp} \leq 150$ K on the worst path of any channel, accounting necessary noising. With the first spectral tests carried at summer 2014 by PRAO ASC FIAN with the new input cryo-unit, output signal from one of the channels was sent to the converter unit, providing a parallel receive of two spectral lines in operational range 34-37,5 GHz [6]. Spacing frequency of two receiving areas of input strip may vary from 0 to 1,9 GHz. Hereby given the results of measurement of two recombination radiolines (RRL) of hydrogen H56a and H57a on frequencies 36,466 and 34,596 GHz (Fig. 6), which are in a good agreement with simulated sensitivity of multichannel receiver with a new input cryo-unit.

At present PRAO ASC FIAN is creation a new 4-channel input and 8-channel output converter unit which will use all 4 channels of input cryo-unit.

**Conclusions**

1. Cooled low-noise amplifiers with $T_n \leq 50$ K, Gain $= 29,5\pm2$ dB at operating frequency range $\Delta F = 34-37,5$ GHz with $T_{AMB} = 22$ K, has been designed and produced for 4-channel input cryo-unit of 8-mm range receiver RT-22 FIAN. With the contribution of receiver to the system overall noise temperature has reduced by 50 K in contrast with the single-channel input cryo-unit.

2. Four independent information receiving channels are formed in input cryo-unit to increase information content of radio-telescope 4 times for molecular radioline observations and 8 times for observations of RRL.
References


