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Abstract

Full Text

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APPLICATION OF A QUANTUM PARAMAGNETIC AMPLIFIER IN RADIO ASTRONOMY

The use of quantum paramagnetic amplifiers (QPA) makes it possible to sharply increase the sensitivity of radio-astronomical equipment. The capabilities of QPAs can be used especially well for spectral radio-astronomical studies, for which a wide receiver passband is not required.

Fig. 1. Block diagram of the high-frequency part of a radiometer with a QPA. 1 –noise generator, 2 –directional coupler at 18 dB, 3 –waveguide, 4 –antenna, 5 –crystalline modulator, 6 –matched load, 7 –liquid nitrogen, 8 –25 dB decoupler, 9 –circulator, 10 –coaxial rotary transition, 11 –liquid helium, 12 –liquid nitrogen, 13 –QPA resonator.

At the end of 1963 a QPA was installed on the 22-meter radio telescope of the Lebedev Physical Institute of the Academy of Sciences for observations of the radio line of neutral hydrogen at wavelength $\lambda = 21$ cm. The general block diagram of the high-frequency part of the radiometer with the QPA is shown in Fig. 1. The low-frequency part of the radiometer was a radiospectrometer previously used for observations without a QPA (^{1}).

The radiometer operated on the principle of antenna-equivalent switching. As the equivalent we used a matched load at the temperature of liquid nitrogen. The entire high-frequency part of the radiometer, including the mixer and the local oscillator, was placed in the upper cabin of the radio telescope (^{2}). The received radiation was transmitted from the focus of the radio telescope by means of a large-section waveguide with small losses (0.1 dB). The quantum paramagnetic amplifier consists of two coupled resonant circuits at the signal frequency (^{3}), which makes it possible to obtain a maximally "flat" frequency characteristic with a passband of about 8 MHz at a gain of 18 dB. The product of the passband and the gain of such a system is four times greater than for a single-circuit QPA (^{4}).

Chromium corundum ($Al_2O_3 : Cr^{3+}$) in the perpendicular orientation $\theta = 90^\circ$

was used as the active substance (θ is the angle between the direction of the trigonal axis of the crystal and the direction of the external magnetic field). The necessary magnetic field of strength $H = 2000$ oersteds was obtained by means of a solenoid with a superconducting winding, which ensured stable operation of the QPA. The power of the auxiliary radiation was selected so that the amplifier operated near the saturation threshold with respect to the auxiliary radiation. In this case the amplifier becomes less sensitive to changes in the frequency and magnitude of the power of the auxiliary radiation.

The amplifier cooling system consists of two glass Dewar vessels mounted in a special casing. The capacities of the nitrogen and helium vessels were 5 and 2.5 liters, respectively, which ensured continuous operation for 10 hours.

In realizing the theoretical sensitivity of a radiometer with a QPA, the question of "parasitic" modulation is very important—the change in the QPA parameters in step with the modulation frequency owing to the asymmetry of the antenna and equivalent arms. This phenomenon leads to deflection of the output instrument in the absence of a useful signal and very substantially worsens the actual sensitivity of the radiometer.

In a spectral radiometer the most dangerous type of "parasitic" modulation is deformation of the frequency characteristic of the amplifying channel. This effect was studied by us in fairly great detail under laboratory conditions (^{5}), as a result of which the necessary requirements for decoupling the QPA from the input channels were determined. With a gain of 18 dB, the required decoupling was $\sim$ 40 dB, which, in addition to a circulator, required the use of a ferrite isolator.

Fig. 2. Recording of the radio source Lebel-A in the continuous spectrum. 1—with QPA, 2—without QPA.
$\alpha = 19^h58^m13^s,\ \delta = 40°37'13''$

Noise measurements of the entire system were carried out using a noise generator, calibrated in turn by the radiation of input loads at room and nitrogen temperatures. The total noise temperature of the entire system T_c can be expressed as:

$$T_c = T_a + \frac{T_o(1-\eta)}{\eta} + \frac{T_p}{\eta},$$

where T_a is the noise temperature of the antenna, T_p is the noise temperature of the radiometer, η is the transmission coefficient of the microwave channel to the amplifier, and T_o is the ambient temperature.

Fig. 3. Recording of the profile of galactic neutral hydrogen. Frequency marks every 10 kHz.
25 XII 1963. $\alpha = 20^h28^m,\ \delta = +39°$

The antenna temperature was 40° K. However, we artificially raised it to 85° K in order to bring it to the temperature of the equivalent located at the temperature of liquid nitrogen.

The intrinsic noise temperature of the radiometer with the QPA was about 35° K, of which $\sim 24°$ was the noise of the mixer receiver and 10° the noise of the QPA. The total losses of the microwave channel were about 0.85 dB, of which ~ 0.6 dB were losses in the circulator and isolator.

Thus, the total noise temperature of the entire system was 180° K. With a total noise temperature of the entire system of 180°, it was possible experimentally to realize the theoretical sensitivity of the radiometer with the QPA. In the continuous spectrum, with the receiver bandwidth

$\Delta f = 8$ MHz, a fluctuation sensitivity of 0.12° was achieved (with a time constant $\tau = 1$ sec), and in observations of the hydrogen radio line, $\sim 0.35°$ (with $\Delta f = 20$ kHz, $\tau = 30$ sec), which is in good agreement with the calculated data. Examples of recordings in the continuous spectrum and in the hydrogen radio line are given in Figs. 2 and 3.

The observations carried out show that the use of a quantum paramagnetic amplifier makes it possible to distinguish confidently small details in radio-line profiles and, consequently, to reveal fine structure in the distribution of hydrogen.

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Note: Figure translations are in progress. See original paper for figures.