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L. I. MATVEENKO, G. S. MISEZHNIKOV, M. M. MUKHINA,

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Fig. 1

Figure 1: Fig. 1

Abstract

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PHYSICS

L. I. MATVEENKO, G. S. MISEZHNIKOV, M. M. MUKHINA,
V. B. SHTEINSHEIFER

APPLICATION OF A QUANTUM PARAMAGNETIC TRAVELING-WAVE AMPLIFIER FOR RADIO-ASTRONOMICAL INVESTIGATIONS AT A WAVELENGTH OF 8 cm

(Presented by Academician D. V. Skobeltsyn on 24 XI 1964)

The fluctuation sensitivity of modern radio telescopes at centimeter wavelengths is determined mainly by the intrinsic noise of the radiometer. In this connection, in recent years much attention has been devoted to the development of microwave amplifiers (1). The minimum level of intrinsic noise has been achieved in quantum paramagnetic amplifiers (QPA).

Fig. 1. Block diagram of a radiometer with a QPA.
1 –parabolic reflector; **2** –irradiator; **3** –noise generator; **4** –connecting waveguide; **5** –ferrite modulator; **6** –smooth attenuator; **7** –waveguide load at liquid-nitrogen temperature; **8** –QPA; **9** –circulator; **10** –directional coupler; **11** –heterodyne; **12** –preliminary UHF amplifier; **13** –UHF amplifier with quadratic detector; **14** –narrow-band amplifier of the modulation frequency; **15** –synchronous detector; **16** –DC amplifier; **17** –recording device; **18** –phase shifter; **19** –modulation-frequency generator; **20** –power amplifier.

In October 1963 we began radio-astronomical observations at a wavelength of 8 cm using a traveling-wave QPA.

The general block diagram of the radiometer is shown in Fig. 1. Compared with a resonator-type amplifier, the traveling-wave amplifier has a broader passband, a lower level of intrinsic noise, and a more stable gain coefficient, which is especially important when it is used in radio astronomy. In the amplifier, ruby with a chromium concentration Cr^{3+} equal to 0.036%, optimal for this wavelength, is used as the active material. The angle between the direction of the trigonal axis of the crystal and the direction of the external magnetic field is 90°. The signal frequency corresponds to the transition between the first and second energy levels, and the pump frequency to that between the first and fourth. Such a pumping regime makes it possible to obtain the maximum gain coefficient (2). The ruby crystals are located on both sides of the pin-type

of the slow-wave system. To absorb the reflected wave, nonreciprocal elements are used in the form of plates of polycrystalline yttrium iron ferrite with a garnet structure. The plates are placed under the ruby rods along the slow-wave system. The slow-wave system, together with the feeding coaxial cables, is placed in a metal cryostat that ensures continuous operation of the TWA for 8 hours without refilling with liquid helium. The design of the amplifier is analogous to the design of the TWA described in work (3). The amplifier operates at the temperature of liquid helium, 4.2° K, and has a gain $G = 20$ dB with a bandwidth $\Delta f = 20$ MHz. The intrinsic noise temperature of the amplifier is $T_{sh} < 15°$ K. If necessary, the gain of the TWA can be increased to $G = 35$ dB by lowering the boiling temperature of the liquid helium to 2° K by pumping off its vapors. The amplifier parameters in both operating modes are given in Table 1.

Table 1

Operating temperature, °K	G, dB	Δf, MHz	T_{sh}, °K
4.2	20	20	<15
2	35	15	<15

The amplifier permits tuning over ±50 MHz. The use of the TWA reduced the intrinsic noise of the switching radiometer, which with the mirror channel was equal to 1350° K, by more than 15 dB. In this case the technical sensitivity of the radiometer became determined not by its intrinsic noise, but by such effects as “parasitic”modulation, pickup, instability of the gain of the switching radiometer, and the temperature of the high-frequency path. In this connection measures were taken to eliminate the indicated effects. The use of a circulator before the mixer to prevent the local-oscillator signal from passing to the input, as well as careful adjustment of the modulator, antenna, and equivalent load, reduced the level of parasitic modulation to a level below 0.5° K. It should be noted that, owing to the isolating properties and broad bandwidth of the traveling-wave TWA, no additional isolators were required at its input. The load-equivalent in the form of a horn, widely used in radio astronomy, was replaced, because of its low interference immunity, by a waveguide load immersed in liquid nitrogen. The load was carefully matched. Over the entire radiometer bandwidth the VSWR of the load was < 1.06. To eliminate changes in the load impedance due to liquefaction of air, the load waveguide is filled with gaseous helium under

Figure 2

Figure 2: Figure 2

Fig. 3. Recordings of radio emission. a –planet Jupiter, 21 X 1963, time constant $\tau = 10$ sec; b –galaxy M-82, 13 IV 1964, time constant $\tau = 4$ sec

Figure 3: Fig. 3. Recordings of radio emission. a –planet Jupiter, 21 X 1963, time constant $\tau = 10$ sec; b –galaxy M-82, 13 IV 1964, time constant $\tau = 4$ sec

a slight pressure. The load is connected through a variable attenuator. This makes it possible to select the temperature of the load-equivalent equal to the antenna temperature, which, as is known, reduces the effect of instability of the radiometer gain on the sensitivity. The radiometer units are supplied by plate-voltage stabilizers with a stabilization factor of 3000 and by a filament DC stabilizer current with a stabilization coefficient of 1000. Thanks to these measures, stability of the radiometer gain over 1 hour of operation better than 2% was achieved. The comparatively high modulation frequency of 179 Hz, the narrow passband of the modulation-frequency amplifier, equal to 10 Hz, and the use of a dc filament voltage practically eliminated pickup. The application of all these measures made it possible to realize the calculated fluctuation sensitivity of the radiometer with the QPA. The total noise temperature of the radio telescope with the QPA is 120°K. The fluctuation sensitivity then attained, at a time constant $\tau = 3.2$ sec, is $\delta T = 0.03$°K. The sensitivity of the mixer radiometer at the same time constant is $\delta T = 0.27$°K, i.e., use of the QPA increased the sensitivity by ~ 10 times. This is clearly seen in Fig. 2.

Fig. 2. Records of radio sources at time constant $\tau = 2$ sec. *a*–Cygnus A, radiometer without TWA, $F = 540 \cdot 10^{-26}$ W/m^2 Hz; *b*–3C 273, radiometer with TWA, $F = 30 \cdot 10^{-26}$ W/m^2 Hz.

Fig. 3. Recordings of radio emission. **a** –planet Jupiter, 21 X 1963, time constant $\tau = 10$ sec; **b** –galaxy M-82, 13 IV 1964, time constant $\tau = 4$ sec

The figure shows recordings of the radio sources Cygnus A on the mixer radiometer and 3C 273 with use of the QPA. The radio-emission flux of 3C 273 is 18 times smaller than that of Cygnus A. The high sensitivity and stability of operation of the radiometer with the QPA made it possible to carry out observations of the occultation by the Moon of the radio sources Taurus A and 3C 273. The results obtained make it possible, with high resolution, to determine the distribution of radio brightness over Taurus and to separate the emission components of the double radio source 3C 273. The high sensitivity makes it possible to record confidently, in a single trace, the radio-emission fluxes from weak radio sources.

Figure 3 gives a recording of the radio emission of the planet Jupiter and of the galaxy M-82. The radio-emission flux of Jupiter was found to be $13.1 \cdot 10^{-26}$, which corresponds to a brightness equivalent temperature of the disk of 680 ± 27°K. Thanks to the high sensitivity, the effective size of Taurus A in α was determined with high accuracy. It is 3.27 ± 0.05 arc min.

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