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NEW CRYOGENIC CONTINUUM RADIOMETERS FOR THE RATAN-600*

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ABSTRACT. *Six new cryogenic radiometers for continuum work are now in operation at the RATAN-600: λ1.4, λ2.7 and λ3.9 cm radiometers with 15 K front-end cooling and a set of independent radiometers in the same dewar (1.0, 2.7 and 6.25 cm wavelengths) with 80 K front-end cooling.*

Switching mode for double-beam operation and noise injection with synchronous gain switching mode for single-beam operation is possible for each of radiometers. The main features are: straight receiver design, GASFETs as cooled and uncooled amplifiers, cooled latching circulators as input switches.

System sensitivities realized are: 12-16 mK for 1.0 cm, dependent on the atmospheric condition; 9 mK for λ1.4 cm; 4.5 mK for λ2.7 cm (15 K); 7 mK for λ2.7 cm (80 K), and 5 mK for λ3.9 cm and λ6.25 cm.

STATEMENT OF THE PROBLEM

A deep sky survey program was started at the RATAN-600 radiotelescope in 1990 ("Cold-90" experiment) to investigate the relic background small scale fluctuations.

This work was supported in part by the "Cosmomicrophysics" project.

A new λ2.7 cm radiometer, cryogenically cooled down to 15 K, was specially designed to solve some other astrophysical problems. Experimental operation of a set of three centimeter-wavelength radiometers (λ1.0; λ2.7 and λ6.25 cm) with liquid nitrogen (80 K) cooling was started in the same year. Since 1992 λ1.4 and λ3.9 cm wavelength radiometers have been in test operation.

The sensitivity, not far from limit, possible for this particular type of the amplifier used, was realised at λ1.4, λ2.7 and λ3.9 cm with GASFET amplifier and input latching circulator switch (Afanasiev and Berlin, 1985) cryogenic cooling. A closed-cycle refrigerator was used as a cooler and a set of problems closely associated with this fact have been solved. These problems are: cooled electronics and input feeder thermo-shock and vibration resistivity, heat transfer to the evacuated cryostat minimization, very complicated preventive maintenance and limited inter-repair time.

The input switches and amplifiers of the triple-frequency radiometric system are placed in the same liquid nitrogen cryostat. It is a compromise design from the standpoint of specifications combination: sensitivity, universality in application, size, weight and maintenance cost. The mechanical cooler absence led to the unlimited life time.

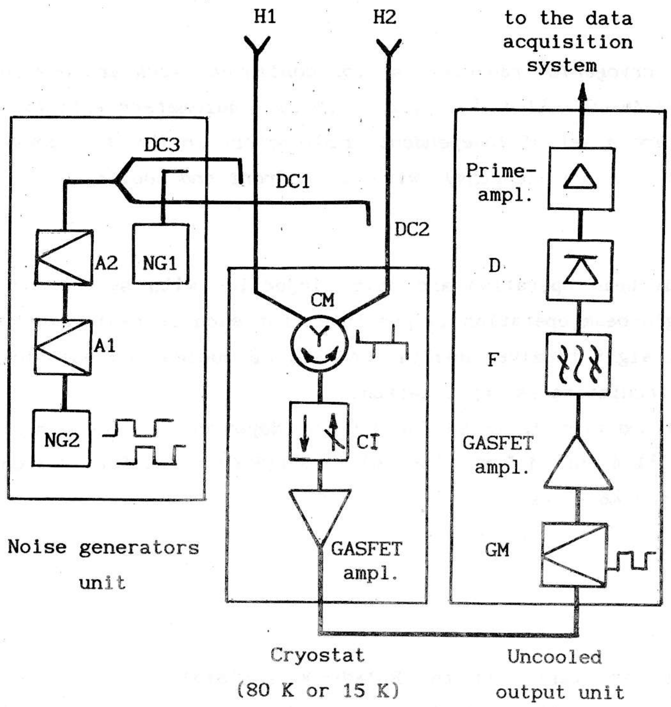

Fig. 1. *Simplified block-diagram of the radiometer.*
H1, H2 - *input feeds horns,*
DC1, DC2, DC3 - *directional couplers,*
CM - *cooled modulator (latching circulator switch),*
CI - *cooled ferrite isolator,*
GM - *gain p-i-n modulator,*
F - *band-pass filter,*
D - *square-low detector,*
NG1 - *noise generator for calibration,*
NG2 - *noise generator for balancing and pilot-signal injection,*
A1, A2 - NG2 *noise power levelling attenuators.*

STRUCTURE AND MODES OF OPERATION OF THE RADIOMETERS

A straight receiver design and GASFET amplifiers were used for all radiometers. The block-diagram is identical for any radiometer described and shown in Fig. 1.

The radiometers can be operated either in double-beam balanced switching mode (Esepkina et al., 1973) or in one-beam noise adding with synchronous gain modulation mode (Berlin et al., 1982).

Output transistor amplifiers, gain modulators, calibrating, balancing and noise-adding noise generators are housed in the same temperature-controlled box.

For double beam mode of operation the cooled latching-circulator CM is working as a periodical switch (modulator). Balance is achieved by the noise generator NG2 power regulation with p-i-n diode attenuators, controlled digitally. Noise power from NG2 is injected to the input feeder arms through the directional couplers DC1 and DC2 permanently. The noise power is square shape pulse-modulated in phase or in reverse phase with respect to CM switching voltage. Depending on phasing, we have an equivalent NG2 power injection into one (H1) or another (H2) input feeder arm. Gain modulator is out of use for this mode of operation, it is in "open" position.

For one-beam mode of operation, only input horn H1 is in use, and the modulator CM is in static position as an isolator. Noise-adding mode is realised by modulated NG2 noise power injection. Gain modulator GM is activated in phase with NG2. The NG2 noise power level for balance for one-beam mode is about two orders higher than for beam-switching mode. Balance is achieved by NG2 power level adjustment with two digitally controlled p-i-n attenuators A1 (fine tuning, 10 binary digits) and A2 (coarse tuning). The NG2 power stability is much better with separate attenuators control, but not with noise diode current control. The noise diode current is optimised and stabilised to ensure NG2 noise power stability.

The second noise generator NG1 is used for calibration signal (1-3 K) injection into one of the input feeder arms through directional coupler.

Radiometer control (balance, calibration) is completely remote by means of CAMAC interface with the data acquisition computer or manual control panel. The same computer can carry out a radiometer check program (sensitivity, gain, stability) as a special routine or in-observations monitoring.

COOLED TRANSISTOR AMPLIFIERS

The FET amplifier stage at the 1 cm wavelength is designed on the basis of a double-ridge waveguide with an amplifier microcirquit and transistor mounted at the ridge side wall. Comb-structures at the input and output microcirquit are formed at the copper plate substrate of 0.5-1 mm thickness with a computer-controlled electro-spark machine. A ridged waveguide transmission line provides good impedance matching from 300-400 Ohm down to 1 Ohm at 15-20% bandwidth.

The amplifier microcirquit includes microwave isolator elements, power supply filters and resistive elements, manufactured by hybrid technology, based on MIM structures formed on copper substrates. Multicomponent oxide glass SiO_2-Al_2O_3-CaO-BaO-MgO-B_2O_3 with $\varepsilon = 5\text{-}6$ and tg $\delta = 1 \cdot 10^{-3}$ of 4-6 microns thickness was used as the isolator layer, evaporated on a copper substrate with high-frequency magnetron-induced process. A chromium-copper metal layer is thermal evaporated over the isolator layer. In addition, a chromium adhesion sublayer is used as a base for thin-film resistors. Next, the microcirquit elements were formed with photolithography process.

FETs for the amplifier were developed by "Saturn" corporation. The multistage assembly of the amplifier is provided by sequential connection of the elementary stages with ferrite isolators coupling. The amplifier consists of 4 or 5 stages, depending on the version.

Three-stage and two-stage amplifiers were designed with TEM-transmission line elements for 2.7; 3.9 cm, and 6.25 cm frequency bands, respectively. There is a waveguide-type isolator at the input for the 2.7 cm design, then a waveguide-to-coaxial adapter (WG-T-C) (Fig.2) follows. For 3.9 and 6.25 cm the WG-T-C adapter is the first, then the coaxial ferrite isolator and the amplifier section follow. Chip GASFETs with the gate size from 0.35x200 to 0.5x300 microns, developed by "Saturn" corporation, were used for these frequency bands (Gassanov et al.,1985).

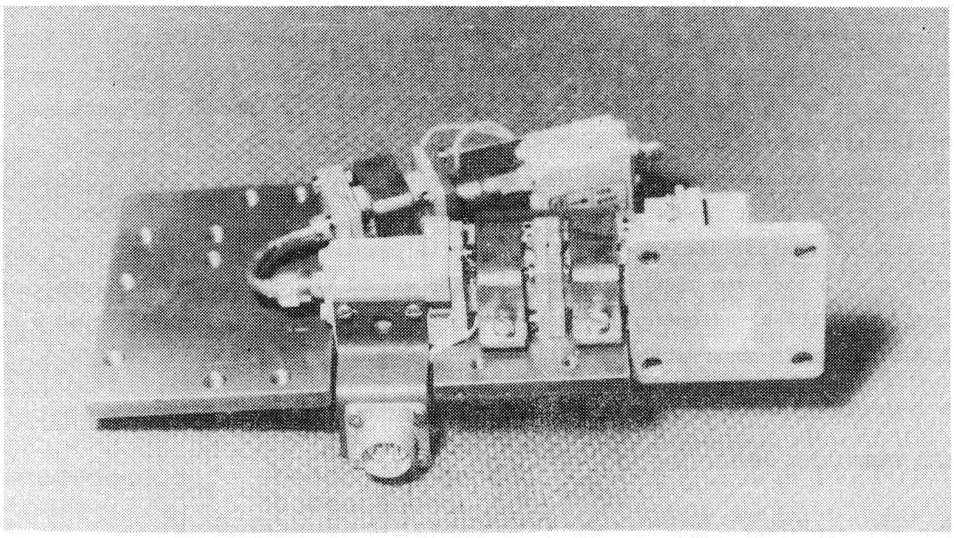

Fig.2. *Cooled GASFET amplifier at 2.7 cm for 15 K cooling temperature level. From right to left: waveguide-to-coaxial adapter (WG-T-C), two stages of the amplifier, ferrite isolator, third stage of the amplifier, output ferrite isolator.*

The amplifier technical data and the radiometer sensitivities realised for the mean elevation of the RATAN-600 antenna are presented in Table 1.

Table 1.

Wave-lengths cm	Center frequency GHz	Band-width GHz	T_{phys} K	Number of stages	Gain dB	T_{noise} of the ampl. K	T_{syst} K	Sensitivity realised $mK/s^{1/2}$
1.0	30.0	2.0	80	5	35	150	350	12-16
2.7	11.2	1.0	80	3	30	60	140	7
6.25	4.8	0.8	80	2	26	35	95	5
2.7	11.2	1.0	15	3	28	45	100	4.5
1.4	21.6	2.1	15	4	32	75	150	9
3.9	7.7	0.8	15	3	32	30	85	5

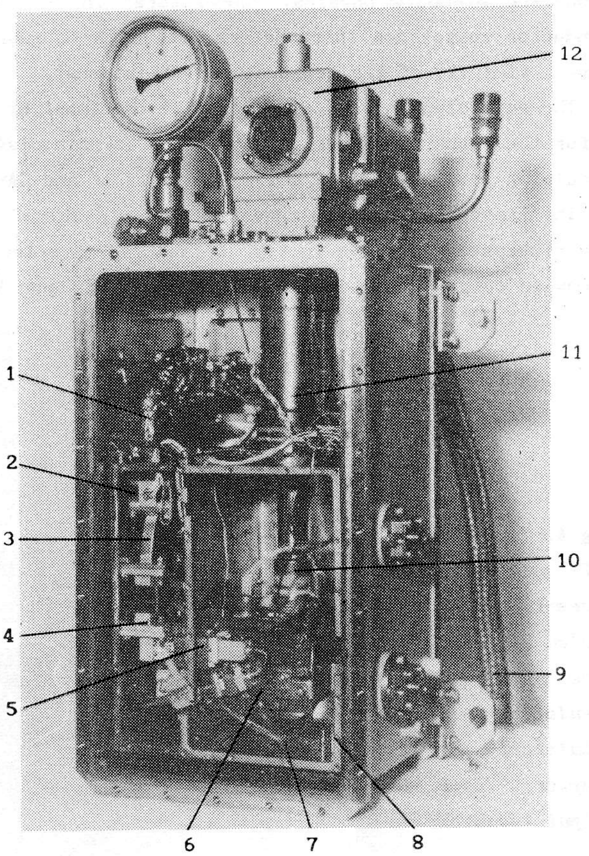

Fig.3. *Interier of the 15 K cryostat of the 2.7 cm radiometer.*
1 - one of the input waveguides, 10x23 mm size,
2 - cooled modulator (latching circulator switch),
3 - thin-wall thermoinsulating waveguide,
4 - waveguide ferrite isolator,
5 - cooled GASFET amplifier,
6 - heat-conducting copper plate,
7 - flexible copper heat conductors,
8 - anti-radiation shield (gold-plated copper),
9 - metallic flexible house to evacuating pump,
10 - second stage of the cooler (14 K temperature level),
11 - first stage of the cooler (50 K temperature level),
12 - cooler of the closed cycle refrigerator.

By the time of preparation of this article two more RATAN-600 radiometers at 1.4 and 3.9 cm of more or less identical to the 2.7 cm radiometer design are under primary test. Their parameters are included in Table 1 for completeness.

DESIGN FEATURES

The 2.7 cm front-end hydrogen temperature level cryostat is shown in Fig.3. A temperature level of 50 K is provided by the first stage of the closed-cycle cooler for the cooled modulator CM, and GASFET amplifier is cooled down to 15 K with the second stage of the same cooler. A thin-walled stainless steel thermoinsulating bent waveguide, silver-plated inside, is placed between the CM and the input WG-T-C adapter. In order to reduce heat transfer to the first stage of the cooler, the metallic gold-plated anti-radiation shield is covered with a few metal-coated mylar layers. The front-end elements physical temperatures in the cryostat were measured with semiconductor resistance thermometers with high-steepness operational characteristics in the vicinity of the temperatures of interest.

The equivalent noise temperature at the input of the cryostat was 58 K including 7 K for the input waveguide window with termoinsulating waveguide, 3 K for the cooled modulator (switch) and 48 K for the isolator and GASFET amplifier.

The front-end (to be placed in the cryostat) of one of the triple-frequency radiometric system is shown in Fig. 4, and the exterier of the full system together with uncooled output stages and power supplies is shown in Fig. 5.

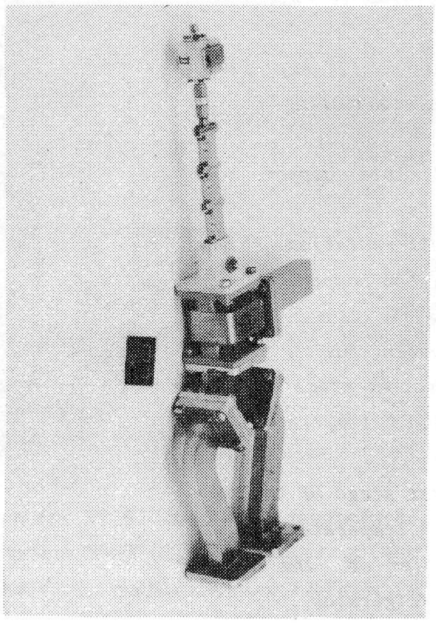

Fig.4. *Cooled front-end of the 2.7 cm radiometer of the three-frequency nitrogen-cooled radiometric system. From right to left: thermo-insulating waveguides, cooled modulator, isolator, WG-T-C adapter, amplifier stages, output isolator.*

OPERATION FEATURES

At design process, considerable attention was paid to the operation reliability and the operational maintenance simplification problems. The cryogenically cooled radiometers are in permanent twenty-four-hour operation for a few years with a mean annual operational period of 7000-8000 hours for each. A special system was designed to start coolers and compressors automatically after the main power short-duration failures or overvoltages. We practise simultaneous operation of two cryogenic radiometers with closed-cycle coolers with one and the same compressor unit in order to save the mean lifetime of the refrigerating systems.

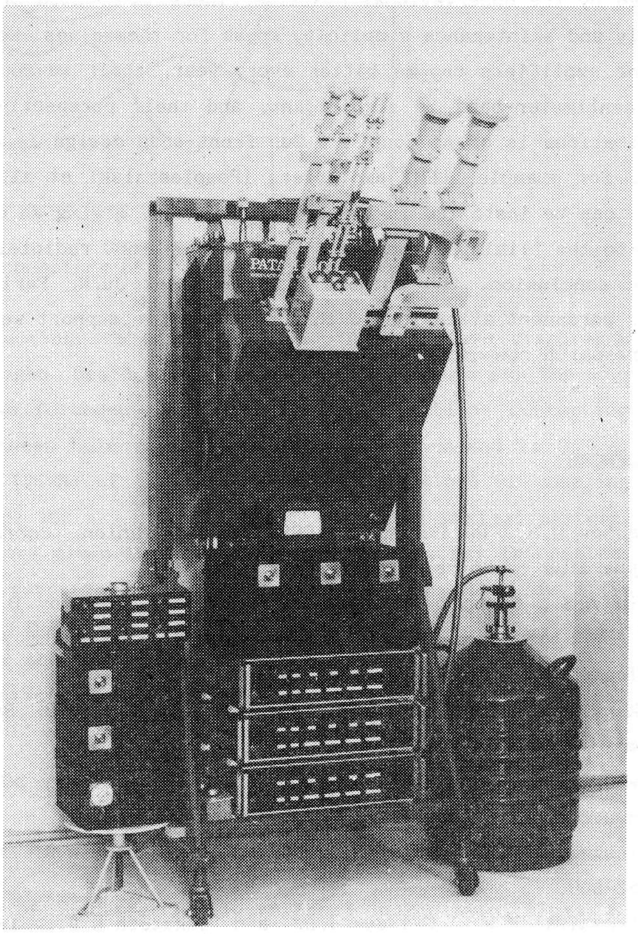

Fig.5. *Exterier of the three-frequency radiometric system.*

The triple-radiometer cryostat is of 42 liters of liquid nitrogen capacity and keeps the coolant not less than 75 hours. We employ a three times per week refilling from a 500-liter tank, placed outside of the RATAN-600 feed cabin. The refilling of that tank, in its turn, is done once per two weeks from a transporting tank of the same type.

There exists a problem for one-beam mode of operation: as a result of finite speed of the gain modulators (which are, in fact, commercial p-i-n attenuators), it is a powerful pilot-signal leakage at the beginning and at the end of each square-wave modulation pulse. Transient 10-20 μs pulses can be observed at the detector output, which are of instable origin and represent a strong spurious signal for the interference-supression system. To overcome this problem, a special post-detector prime-amplifier with transient blanking has been designed.

A good stability and a high reliability of the cryotransistor FET amplifiers are proved by the observational practice. There is no need of additional trimming, power supply and maintenance simplicity speak for themselves. Noise parameters of the transistor amplifiers become better every year, their advance to the short-wave end of the centimeter-band is significant, and their perspectivity for the radioastronomy applications is of no doubt Our front-ends design is open for amplifier improvement; for example, HEMT amplifiers (Pospieszalski et al., 1988, 1990), when available, can be installed in the cryostat easily, giving an opportunity to make one more step to the "limit radiometers" for the RATAN-600 radiotelescope.

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