PROGRAMMABLE SPECTROPHOTOMETRIC COMPLEX FOR AN AIRBORNE LABORATORY

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Received June 5, 1989

An automated spectrophotometric complex for the AN-30 airborne laboratory is described. This complex permits recording and processing background signals due to the outgoing atmospheric radiation and the radiation from the underlying surface in the short-wavelength (0.44–1.6 μm) and infrared (8–15 μm) ranges of the spectrum with different viewing angles taken into account corrections for the instantaneous value of the rolling and pitching angles of the aircraft. A number of programmable operating regimes of the complex are studied.

A characteristic feature of passive methods of atmospheric sounding is acquisition and utilization of information about the regularities of the spatial (angular) and (or) spectral distribution of the brightness of the background radiation of the atmosphere and the underlying surface, i.e., from the methodical viewpoint, passive sounding is virtually identical to experimental studies of the backgrounds formed by the outgoing and downwards radiation of the atmosphere and underlying surface.

In implementing passive methods from moving carries (for example, from an aircraft) it is also necessary to monitor or take into account the spatial position of the direction of sounding. In addition, the rapidly changing conditions of observation and the difficulties of restoring the spatial position of the photographic system and pointing it toward the object being observed require better control of the experiment and higher reliability of operation of the airborne apparatus. With this in mind, a programmable spectrophotometric complex (PSC) was developed at the Research Center "Institute of Atmospheric Optics" for the AN-30 airborne laboratory for the following purposes:

– investigation of the spatial characteristics of the brightness of the outgoing radiation:

– determination of the optical thickness and vertical profiles of the atmospheric transmission by methods of passive sounding; and,

– forming synchronous subsatellite control and calibration measurements of the radiation temperature.

The PSC was developed based on experience in the development and operation of a semiautomatic airborne complex[1] installed in the IL-14 airborne laboratory.

The distinguishing requirements imposed on the new complex are the following:

– completely automated operation and preliminary signal processing based on previous programs;

– recording of digitized information on amagnetic tape with preliminary visual monitoring on a TV monitor; and,

– use of a vertical gyroscope for precise control of the pointing angle of the photographic system.

– The PSC (Fig. 1), like the previous apparatus,[1] includes two autonomous and functionally identical devices – a filter spectrophotometer for the short-wavelength range (λ = 0.4–1.6 μm) and an IR radiometer, operating in the spectral range 8–15 μm. The technical design of the complex provides for both autonomous operation of each device and simultaneous operation of both devices according to fixed programs. Angular scanning of the photometer and radiometer is performed with the help of plug-in scanning units (scanners), consisting of rotating mirrors placed in front of the objective lenses of the devices at an angle of 45 to their optical axis.

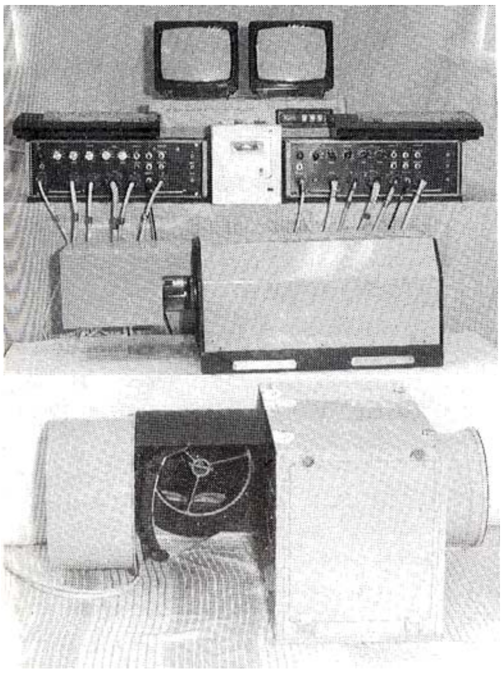

FIG. 1. Appearance of the measuring complex.

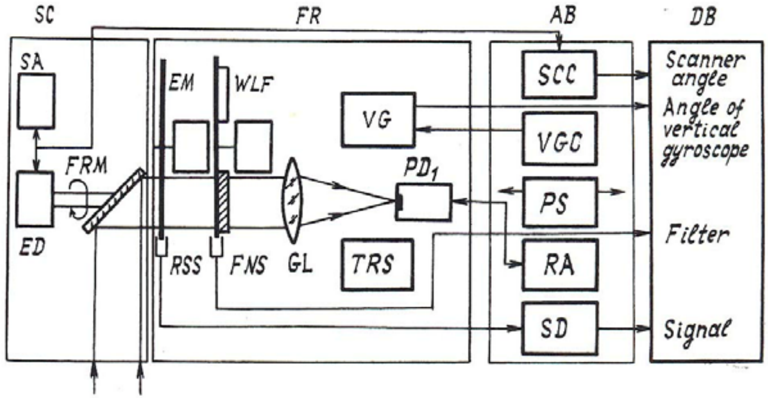

FIG. 2. Structural layout of the IR radiometer: FRM — flat rotating mirror; ED — electromechanical drive; SA — sensor of the angular position of the rotating mirror; EM — electromechanical modulator of the measured radiation; RSS — reference signal sensor; WLF — wheel of interchangeable light filters; FNS — filter number sensor; GL — germanium miniscus lens; PD1 — pyroelectric photodetector; VG — small aviation vertical gyriscope of the type MGV-1SK; TRS — temperature regulator-sensor; SCC — scanner control unit based on a BU-12 stepping motor control unit and a control module; VGC — vertical gyroscope control unit; RA — regulatable amplifier; SD — synchronous detector; PS — power supply for the electronic circuits and apparatus.

The IR radiometer, whose 'structural layout is shown in Fig. 2, is divided into four parts: a scanner SC, a filter radiometer FR, a unit for analog signal processing and control AB, and digital control and processing unit DB.

The radiometer operates as follows. Optical radiation from a given direction in space is reflected by the rotating mirror FRM (45 mm in diameter) into the input of the radiometer FR. The electromechanical modulator EM, placed on the input, modulates (with a frequency of 200 Hz) the amplitude of the received radiation. The modulator consists of a metallic disk with openings, which is put into motion by a DPM-25 dc motor, and in addition the opaque darkened parts of the modulator disk fix the reference level of the thermal radiation relative to which the measurement is performed.

The pair "photodiode-LED, " which is a constituent part of the RSS, is placed near the EM so that as the disk turns the photodiode forms the reference signal necessary for the operation of the synchronous detector SD.

The spectral selection of the optical radiation is performed with band-pass dispersion light filters, placed in the WLF in front of the converging objective lens GL. The installation of the correct filter is monitored by an electric circuit based on three optronic pairs "LED-photodiode," separated by coded openings in the WLF. The code of a given filter is compared in a coincident circuit with the code degenerated by the optronic pairs (filter code sensor FCS), and when they coincide a signal for stopping the monitor is formed.

Next, the germanium lens GL focuses the optical radiation on the pyroelectric photodetector PD1.

After preamplification in the PD1 the measured signal is fed into a regulatable amplifier, which consists of an active high-frequency filter and a digital-to-analog converter with a gain switch, which allow switching of the gain by two units.

The information signal from the output of the regulatable amplifier is fed into the synchronous detection block, which consists of a synchronous resonance filter, a low-frequency filter, a phase inverter, and a synchronous detector. The resonance filter and detector are synchronized with a driving oscillator with a phase-locked loop. The necessary phase ratio between the reference signal (from the RSS) and the information-carrying signal is established by the switches "FAZA GRUBO" (45°step and "FAZA PLAVNO" (5.6°step).

The pointing accuracy and the flexibility in controlling the scanning are achieved by the fact that the scanner is built based on a ShDR-711V electric stepping motor with a 1/60 gear (the step of the output shaft is equal to 3′), while the sensor SA sensing the angular position of the output shaft and the vertical gyriscope VG give complete control of the direction of viewing relative to the true' vertical. The sensor SA consists of a pair ''LED — four-sector photodiode," coupled optically with the mirror, placed on the second end of the output shaft of the electric drive ED. The signals generated by the photodiode are used to generate in the control module of the SCC signals indicating the angular position and direction of scanning.

The angular position of the entire measuring system (and the carrier — aircraft or ship) is controlled by the vertical gyroscope VG, which generates analog signals indicating the rolling and pitching angles for subsequent correction of the true direction of viewing.

Main technical characteristics of the radiometer:

Diameter of the objective, mm	28
Focal length, mm	56
Angle of the field of view, deg	1
Working spectral range, μm	2–15
Number of light filters	6
Angular scanning rate, deg/s	0–20
Elevation range, deg	0–90
Error in maintaining the vertical (monitoring of the true angular position), ang. min. up to	±15
Range of measured radiation temperatures, K	250–320
Threshold temperature sensitivity, deg	0.2
Time constant, s	1

The filter spectrometer (Fig. 3), like the radiometer, includes the following basic units: a scanner SC, a spectrophotometer SP, and analog AB and digital DB signal processing and control units.

The scanner is distinguished by the fact that the flat rotating mirror is much larger (200×300 mm).

The objective lens of the spectrophotometer is built according to Newton's scheme with a spherical mirror SM 200 mm in diameter and a flat mirror FM, oriented at a angle of 45° to the optical axis. The received radiation is directed by the rotating mirror FRM onto the Newtonian objective lens (SM/FM), and is then modulated by an electromechanical interrupter EM with a frequency of 1000 Hz, after which it is fed through an interference light filter, placed in the wheel WF, onto a FD-7G (FD-10G) photodiode. In contrast to the radiometer, the temperature in the spectrometer is not controlled. The remaining units of the spectrophotometer operate identically to those of the IR radiometer.

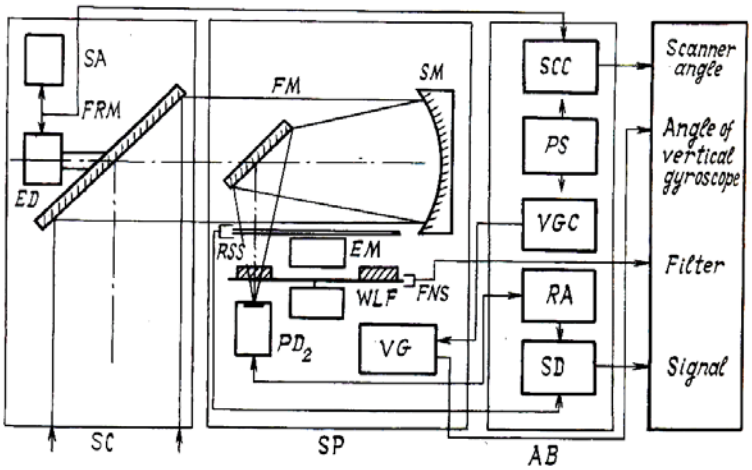

FIG. 3. Structural layout of the spectrophotometer: SM — spherical mirror; FM — flat mirror; PD2 — photodetector based on a germanium photodiode. The rest of the notation is the same as that used in Fig. 2.

Basic technical characteristics of the spectrophotometer:

Diameter of the objective, mm	200
Focal length, mm	400
Angle of the field of view, deg	0.4
Working wavelengths, μm	0.44, 0.55, 063, 0.87, 1.06, 1.2, 1.6
Number of light filters	7

(The remaining technical characteristics are analogous to those of the IR radiometer).

In performing studies from the AN-30 aircraft the optoelectronic parts of the apparatus (the scanners SC, the radiometer FR, and spectrometer SP) are placed above the illuminator in the portholes of the first and second camera windows. The analog-digital units AB and DB of the PSC are mounted in a common instrumentation rack.

To realize the program-controlled operating regime of the complex it is necessary to control the following functions and information flows:

– the spatial "angular" scanning in a given range of angles at a given rate;

– spectral selection (change of the wavelength);

– introduction of corrections for the pitching and rolling in the instantaneous angular position of the aircraft;

– organization of a test experiment with indication of the conditions and the running time;

– measurement of the signal with a given sampling rate and averaging time;

– control of external devices (tape recorder, TV monitor, and printer); and,

– preprocessing of signals.

In addition to performing the functions the listed above, it is obvious that in order to ensure high reliability and smaller masses and sizes the control units DB must be optimized with respect to the complexity. Taking this into account, the DB units were built based on the "ELEKTRONIKA-BK 0010" microcomputer, which makes it possible to connect a standard TV monitor and magnetic tape storage. A BASIC compiler installed in three microcircuits of the plug-in read-only memory provides the program support for the microcomputer.

Functionally the digital processing and control unit consists of two identical channels, each of which contains the following units (Fig. 4): a three-channel ten-digit analog-two-digital converter ADC, which prepares the analog signals from the synchronous detector and the vertical gyroscope for subsequent computer processing; an interface unit, which controls the scanning block (by forming a signal fixing the velocity code and commands setting the rotation of the mirror), as well as the wheel of interchangeable light filters; the ELEKTRONIKA-BK 0010 microcomputer, connected to an ELEKTRONIKA-404TV monitor, a NML magnetic storage cassette of the RK-1 type, and an ISKRA-001-45 printer. The controlling programs, written in BASIC and ASSEMBLER, are stored on magnetic tape.

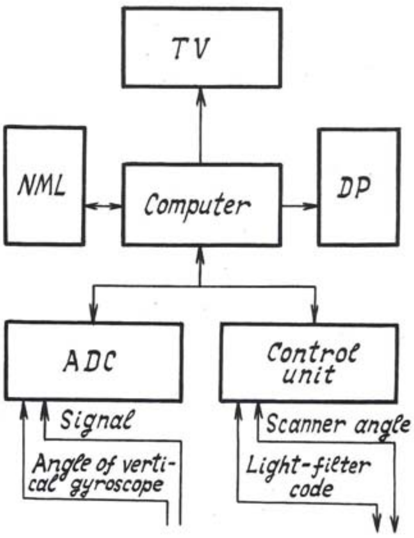

FIG. 4. Functional diagram of the digital processing and control unit.

The currently developed programs which, naturally, do not exhaust all of the existing possibilities, can be divided into three basic types according to the character of the dependences obtained and the type of problem solved. First, these programs make it possible to determine the angular distribution of the brightness for different vawelengths taking into account corrections, obtained from the vertical gyroscope, for the instantaneous inclination of the aircraft. The measurements in this case are stored on a magnetic tape or are printed out for subsequent analysis and processing. Programs of another type make it possible to obtain the spatial-temporal dependences of the background brightness of the underlying surface (US) with a fixed averaging time of the recorded signal and to prepare the data for further statistical analysis. Programs of a third type permit extracting information about the vertical transmission of the atmosphere from measurements of the brightness contrasts of the underlying surface at different angles of viewing relative to the nadir. In this regime, the operator can, aside from monitoring visually the recorded signal on a monitor screen, instantaneously transfer the rotating mirror into the next given angular position and thereby measure the brightness of the section of the underlying surface of interest (for example, the "land-sea" interface) again. The processing program for this regime makes it possible for the operator to perform comparative analysis of data obtained with two different viewing angles and presented in a graphical form on a TV screen as well as to separate the required sections for further calculation of the extinction coefficient in the atmosphere using a known algorithm.[2]

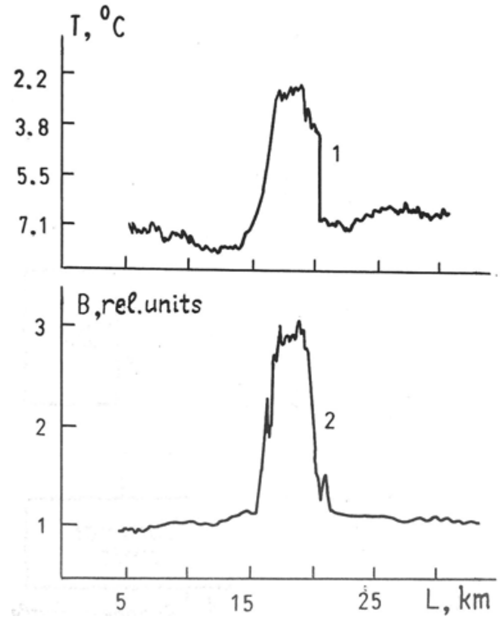

FIG. 5. Fragment of the background brightness signals B and the radiation temperature T recorded on December 24, 1988 above the Caspian Sea at an altitude of 300 m in the direction of the nadir: D data from the IR channel; spectrophotometer data.

The spectrophotometric complex described above was employed in a complex subsatellite experiment, whose purpose was to perform control and calibration measurements of the IR radiometer, placed on a satellite, as well as to refine the algorithms used for atmospheric correction of the data obtained from satellite sounding of the temperature of the sea surface.[3] The flights were performed on an AN-30 aircraft in the period from November 17 to December 24, 1988 above the Black, Aral, and Caspian Seas at altitudes of 300–500 m. Figure 5 shows a fragment of the recorded signals in the visible (0.55 μm) and IR (10.2–12.4 μm) ranges of the spectrum. The rapid increase in the amplitude of the signals (see Fig. 5) was caused by an island in the flight path.

The operation of the programmable spectrophotometric complex in the course of the experiment on the whole confirmed that it meets the requirements of reliability and efficiency of control under different operating conditions and demonstrated that this complex would be useful for investigations of the spectrophotometric characteristics of the background radiation of the atmosphere and the underlying surface.

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