INSTRUMENTATION FOR STUDYING THE POLARIZATION CHARACTERISTICS OF RADIATION SCATTERED BY THE ATMOSPHERE

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Description of a computer–controlled polarimetric system for atmospheric studies of scattered radiation of optical and radio–frequency ranges is presented. The system provides recording of temporal and angular distribution of the Stokes vector parameters in active and passive modes. In signal recording the measuring system starts automatically if a number of conditions set by the program for optical and radio pulses are met. The recorded signal is digitized with a variable step of timing beginning from 100 ns. *In so doing a background component preceding the signal is also stored in memory. Calibration and tests are conducted with digital metrological means generating pulses with preset temporal and polarization characteristics. The system control, data processing and presentation are made by a computer.*

INTRODUCTION

While studying optical and electromagnetic phenomena in the atmosphere more and more attention has been paid to the analysis of the field structure of the scattered polarized radiation bearing a great body of information. This is because the spatioangular and temporal distributions of the polarization characteristics of optical radiation bear the information on atmospheric transmission, its phase composition, turbidity zones in different directions from the observer, albedo of the Earth's surface, aerosol content, peculiarities of the absorption and scattering in the atmosphere, etc., as well as on the coordinates and parameters of optical radiation sources.[1–5] However, such studies are significantly holding back because of the lack of special–purpose polarimetric instruments and means for metrological provision of measurements. To solve the above problem, the measuring system for polarization analysis (MSPA) has been developed at the Institute of Physics of Academy of Sciences of Belarus. Its function is in experimental study of polarization characteristics of scattered radiation in the atmosphere as well as of radio waves (for instance, from lightning discharged).

DESCRIPTION OF THE SYSTEM

Figure 1 shows a block diagram of MSPA. It comprises a photoreceiving device (PhRD), radioreceiving device (RRD), data converter (DC), computer of DVK–3 type, and a calibrator (Cl) (Fig. 2). The system works in either passive or active mode, a laser being the source of radiation.

The photoreceiving device has four receiving channels with lens objectives of an input diameter of 100 mm and variable angular aperture. The lenses, colour and neutral filters, polarizers compensators, and other optical elements are installed co-axially in the channels. The optio–mechanical system (OMS) design provides for easy change of optical elements.

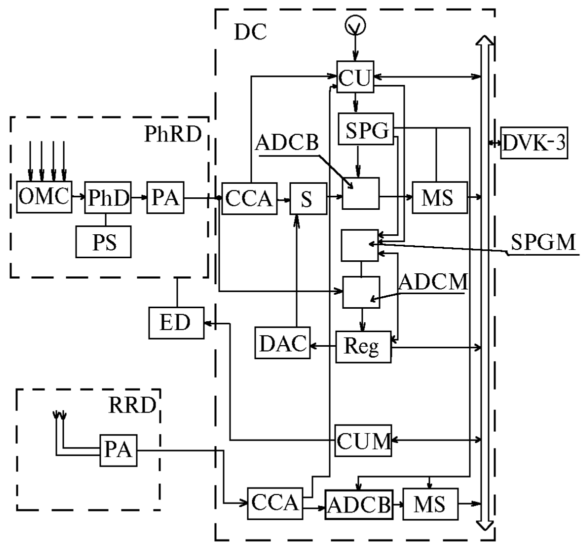

FIG. 1. Block diagram of the measuring system for polarization analysis.

As photodetectors (PhD), photomultipliers FEU-83 and FEU-84 are used for the visible spectral range, and photodiode FD–24K for the IR range. They are designed in the form of plug–in units with built–in preamplifiers (PA). The voltage across the photodetector is supplied from a power supply (PS) and may be stepwise varied within a prescribed limits. Opto–mechanical system allows the angular scanning of space to be performed in both manual and automated modes of operation within the range of elevation angles $\upsilon \in [0, 110°]$ and azimuth angles $\varphi \in [0, 360°]$. Scanning regime is set by a computer or by switches on the face plate of the data converter. The mobile part of the receiving system comprises a sighting device for visual inspection of the studied angular range of the sky. The electric drives (ED) are stepper motors providing an angular accuracy

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better than 6′. Photoreceiving device is installed on the measuring platform and connected to DC with a 25 m long multicore coaxial cable. Information exchange between the PhRD and a computer operator, in the course of experiments, is accomplished through two–way phone communication.

The radioreceiving device serves to detect radio signals, accompanying the optical effect and is supplied with two channels for receiving electric and magnetic field components.

Analog signals from PhRD and RRD arrive at the data converter input where they are processed, converted to a digital form, and transferred to the computer. The data converter rack consists of three units and a set of accessory modules. All the modules are connected electrically to the unit bus, which is connected to the computer line via a decoding module. Access to data converter modules is effected as if they are the computer external devices.

Block diagram of a DC shows the signal processing in one of four identical optical channels and in one of two identical radio channels. The measurement of the background optical signals is accomplished with a 12–bit analog–to–digital converter (ADCM). Triggering of the ADCM is performed from a synchropulse generator (SPGM) by data converter triggering pulse or by the computer.

Measurement of pulse a optical signals is performed with a 8–bit ADCB. The signal discretization period is assigned with a sync–pulse generator (SPG) in the duration ranges 100 and 500 ns, 1, 10, and 100 μs, 1 and 10 ms. Measurement results are recorded into the buffer main storage (MS). The total number of MS cells is 8192. Addressing to MS is performed "around a circle": after addressing to the 8191 cell comes the addressing to 0, 1, 2, ... , 8190, 8191, 0, 1, etc. cells. The sync–pulse generator provides measurement of the prehistory of a signal (a signal before the triggering pulse) and a signal after triggering. The amount of counts of the prehistory signal and the signal after triggering pulse is set by the computer. The total number of signal counts may not exceed the MS capacity, that is 8192.

To widen the dynamic range of the channel for measuring pulsed signals a computer–controlled amplifiers (CCA) (with 1/16, 1/4, 1, 4, and 16 gain factors) and a subtracter (S) have been designed. A count–down input of the subtracter is supplied with a signal corresponding to the background value at the time point preceding the emergence of the triggering pulse. This signal measured with an ADCM and recorded into the register (Reg) is fed to the subtracter input via digital–to–analog converter (DAC).

A clock unit (CU) allows triggering of the system in one of the following modes:

– upon attaining a preset level in one of six channels (four of them are optical and two are radio ones),

– by a preset signal rise rate in one of the channels,

– by coincidence of triggering level or signal rise rate in optical or radio channels,

– by a pulse from an external device,

– by a computer.

The signal in the radio channel is amplified with a CCA, digitized with an ADC, and recorded into the buffer MS for sending it to the computer.

Control over PhRD position in a space in program mode is accomplished with a computer via the control unit module (CUM).

METROLOGICAL SUPPORT OF MEASUREMENT

To carry out the calibration and tests, the measuring system is equipped with a calibrator. Figure 2 shows a block diagram of the calibrator. The calibrator comprises an optical–signal simulator (OSS) and an opto–mechanical unit (OMU). These two devices taken together provide for forming of four light beams with the required temporal and polarization characteristics by regulating the power supply of the light source of KGM type and light–emitting diode matrices (EDV) and (EDI) (emitting at the effective wavelength of 0.56 μm in the visible spectral range and 0.95 μm in the IR range) as well as the circuit of polarization of the output optical radiation.

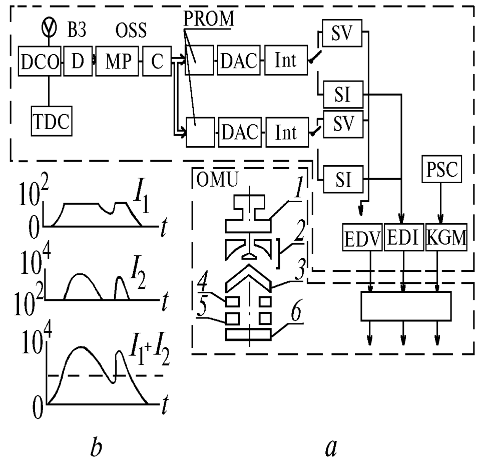

FIG. 2. Block diagram of a calibrator.

Triggering of the calibrator is performed manually by pressing the button B3 or from an external source. A driving crystal oscillator (DCO) with the frequency of 1 MHz and a divider (D) form the frequencies of 1 MHz, 200, 20, and 2 kHz, 20, and 2 Hz. A multiplexer (MP) passes 10 pulses at 1 MHz frequency and 18 pulses at each frequency of the series to the output. The pulses are fed to the counter (C) at the output of which 8–bit input code of address of the programmable read–only memory (PROM) is formed which produces the code of amplitude values of the time dependence given by the computer. Using the button on the face panel of the optical–signal simulator any preset dependence may be selected, for example, the dependence shown in Fig. 2*b*.

The second channel PROM–DAC–Int serves to extend the signal dynamic range to four orders. In this case the preset shape of the time dependence is divided by amplitude into two subranges as Fig. 2*b* shows. In the first subrange the current values of amplitude I_1 varies from 0 to 10^2, and in the second one I_2 varies from 10^2 to 10^4. At every instant t the input code of the PROM address is fed into the first or second channel depending on the transmitting subrange. Then the curve code $I(t) = I_1(t) + I_2(t)$ is fed to DAC operating in bipolar mode, and then to the integrator (Int). The switching of integration time constant is performed by a microcircuit controlled with the signal fed to the multiplexer. At the integrator output a piecewise linear approximation of the preset curve is done. The time delay circuit (TDC) provides checking of the signal shape at various stages. In a stationary mode PSC–KGM unit is used as a source. Depending on the spectral range (visible or IR) the electric signal is fed to one of the final stages (SV or SI) to supply the light–emitting diode matrices with the current of relevant time shape. One of the light–emitting diode is connected to the first channel output and 100 light–emitting diodes are connected to the second channel output. The resulling light pulse $I(t)$ (see Fig. 2*b*) is formed due to emission of them. Light pulse $I(t)$ preset in a digital form for a scattering model is one of the main elements needed for direct testing of the system.

The preset spatioangular and polarization structure of the light beams is formed in the optio–mechanical unit of the calibrator. This unit comprises an irradiator *1*, a telescope system *2*, a set of plates *3*, a plate of milk glass *4*, a set of polarizing elements *5*, and a flange *6*. The design of OMS allows the replacement of elements, their turn around their axes, fixation and control of their angular positions with the accuracy on the order of 1′. Apart from the light source, the irradiator *1* has a polarizing device allowing the generation of a collimated light beam with a desired linear polarization. Using the telescope system *2* the light beam from the irradiator is converted into a beam of a large diameter (200 mm) with the angular divergence of ± 1.5°, four identical, spaced light beams aligned with the receiving channels of PhRD are then separated from it. Thus simultaneous illumination of the channels occurs. The telescope system is designed to provide minimum polarization distortions due to small angles of beam incidence. To add the polarization, a set of polarizing plates *3* is used if necessary which are made in such a way that the incidence of the elementary beams occurs at the Brewster angle. The set *3* may be used as a polarizer itself. In the absence of polarizing elements a milk glass plate *4* provides the feasibility of creating the beams of unpolarized light needed for calibration measurements. The set *5* of polarizing elements (including a compensator) is installed to create the light beams with a preset elliptical polarization[6] at the calibrator output. The flange *6* provides a fixed joint of the calibrator and photoreceiving device. The angular matching of their mutual orientation is performed by matching of zero scale division on the calibration ball–bearing with a zero scale division of PhRD azimuth using a prism light guide installed in the hole of the cone of the ball–bearing vernier. When joined, the calibrator forms the light beams with the preset parameters: unpolarized, partially polarized with a linear and elliptical polarization, fully–polarized at the PRD output.

USE OF THE SYSTEM FOR CALIBRATION AND MEASUREMENTS

The calibration of MSPA is performed with the calibrator according to a special program including the following operations: control of homogeneity and isotropy of light beams at the calibrator output, measuring of the quality parameters of the polarizers and compensators of PhRD and calibrator, determination of dark currents as well as the channel sensitivity and temporal characteristics of the through path. Thus obtained data are used as input while testing and exploring. Thus, the polarizer quality depending on the wavelength λ is determined by two parameters: transmittance $T(\lambda)$ and polarizability $P(\lambda)$. For an ideal polarizer $T = 1/2$ and $P = 1$. The parameters $P_p(\lambda)$ and $T_p(\lambda)$ of PhRD polarizers are determined by measuring transmission of a polarized incident beam using the equations:

$$P_p(\lambda) = \big((I_{max} - I_{min})/(I_{max} + I_{min})\big)^{1/2}, \quad T_p(\lambda) = I/I_0, \quad (1)$$

where I_{max} and I_{min} are the light beam intensities at the output of the system of two identical polarizers, I is the intensity at the polarizer output, I_0 is the intensity at the polarizer input.

The polarizability of polarizers $P_c(\lambda)$ of the calibrator is determined in a similar way using the equation

$$P_c(\lambda) = \frac{I_{max} \$ I_{min}}{(I_{max} + I_{min})\, P_p(\lambda)}. \quad (2)$$

Measurements of other characteristics are performed in the corresponding modes of the calibrator.

When performing the tests, a pulse or a constant light flux, homogeneous over cross section, with a preset temporal and polarization characteristics is created at the calibrator output. The receiving optical system of PhRD is designed according to the scheme where polaroids with the polarization angles of 0, + 60, and – 60° relative to the reference plane are installed in three optical channels. The fourth channel comprises a compensator with the delay angle of 90°. The Stokes vector components I, Q, U, V, and corresponding polarization parameters (polarization P, azimuth angle χ, and ellipticity angle β) are calculated based on the recorded signals I_1, I_2, I_3, and I_4 using Eqs. (3)–(9):

$$I = (2/3)(I_1 + I_2 + I_3)(1/2\, T_p); \quad (3)$$

$$Q = (2/3)(2 I_1 - I_2 - I_3)(1/2\, T_p P_p); \quad (4)$$

$$U = (2/3)\sqrt{3}\,(I_2 - I_3)(1/2\, T_p P_p); \quad (5)$$

$$V = (I + Q\cos 2\chi - 2 I_4)/\sin 2\chi; \quad (6)$$

$$P = (Q^2 + U^2 + V^2)^{1/2}/I; \quad (7)$$

$$\chi = (1/2)\arctan(U/Q); \quad (8)$$

$$\beta = (1/2)\arcsin(V/I). \quad (9)$$

The parameters described by the Eqs. (3)–(9) are compared to known beam parameters at the calibrator output in a computer. If data disagreement does not exceed 5% for P, 30′ for χ, 2° for β, and 2% for I, the system is certified to be applicable for *in situ* experiments.

To perform the *in situ* experiments, processing the measurement results and schematic presentation of the dependences obtained, a package of specialized programs is created. The experimental results are represented in the form of tables and diagrams showing the parameters (3)–(9) as functions of t and sighting direction (v, φ) specified by polar, v, and azimuth, φ, angles.

As an example, Fig. 3 shows the angular distribution of polarization $P(\nu, \varphi)$ of the sky measured over the ocean at the Sun elevation of (60°, 0°) and meteorological visibility range of 30 km.

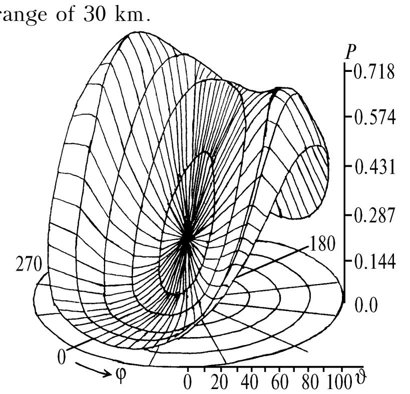

FIG. 3. The angular distribution of polarization of the sky.

CONCLUSION

The system has been checked through in the *in situ* tests, it has been used during the ocean expedition and proved its ability to operate under severe operation conditions. The system allows one to perform the computer–controlled experiments on studying stationary and nonstationary atmospheric optical and electromagnetic effects, to obtain the angular and temporal distributions of polarization parameters of radiation scattered by the atmosphere in various regions of visible and IR spectral ranges and in radio frequency range. Use of a computer allows the processing and presentation of a large amount of data in the form suitable for further analysis.

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