# GROUND−BASED CONTROL-CALIBRATION INSTRUMENTATION COMPLEX FOR THE BALKAN−1 RUSSIAN SPACEBORNE LIDAR

**Yu.S. Balin, I.V. Znamenskii, V.E. Mel'nikov, and A.A. Tikhomirov**

*Institute of Atmospheric Optics,*
*Design and Technology Institute "Optika,"*
*Siberian Branch of the Russian Academy of Sciences, Tomsk*
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*This paper describes a complex of ground-based control-calibration instrumentation developed for a full cycle of ground tests of the BALKAN−1 spaceborne lidar including design and development tests of prototypes and factory approval tests of regular specimens, as well as inspection tests before lidar installation onboard the SPEKTR module of the MIR orbital station and prelaunch tests as part of the module at the spaceport.*

## 1. INTRODUCTION

To provide high reliability of scientific instrumentation destined to install onboard a piloted orbital station, it is necessary to carry out a full cycle of its ground tests. To do this, it is necessary to create a control-calibration instrumentation (CCI) that makes it possible to check the performance of satellite instrumentation under and after the effect of various external factors (mechanical, climatic, electromagnetic, etc.). It is also necessary to test the interaction of scientific instrumentation with a telemeter of the station used to send measurements to the ground. So the requirements to CCI are quite wide. It should imitate signals and commands for remote−controlled satellite scientific instrumentation and analyze its capacity for work from signals of telemetering control of directive execution. In addition, CCI should imitate the process of interaction with a medium in which the measurements are carried out and lidar returns are formed to provide the test of scientific instrumentation operation and measurement of its accuracy characteristics.

## 2. DESTINATION AND STRUCTURE OF THE CONTROL-CALIBRATION INSTRUMENTATION OF THE BALKAN−1 LIDAR

Control-calibration instrumentation created during the development and production of the BALKAN−1 lidar is destined to carry out design and development tests during execution of design plans and engineering specifications in the process of production of the lidar, acceptance tests of lidar blocks after their production and assembly, inspection test before mounting in the module and integrated tests as part of this module at the test station of the Russian Space Center "Energiya" and as part of the mounting-testing complex at the spaceport before injecting the module into orbit. CCI is also capable of periodic servicing at all stages of ground-based operation of the BALKAN−1 lidar.

Since the BALKAN−1 lidar consists of several functional blocks including a transceiver, an accurate range finder block, a system for recording lidar signals (SRLS), and a lidar control desk (LCD),[1–3] a decision was made to construct CCI from separate parts that can be used to test both individual lidar blocks and the lidar as a whole.

Testing of the electrical performance of lidar blocks is a purely electronic engineering problem, so we pay much attention to the description of the CCI parts destined to test optical and optical-electronic blocks of the lidar as well as to test the entire optical-electronic train of the lidar including the laser transmitter, optical-electronic receiving train, and SRLS. The last transfers a digitized lidar return signal to the satellite telemeter for subsequent transmission to the ground, where lidar return signals are finally processed and analyzed.[3]

The control-calibration instrumentation complex includes the following devices and benches: a bench for testing the errors in alignment of the optical axes, a device for measuring the energy characteristics of the transceiver, desks for testing electric performance of SRLS and LCD, and optical imitator of lidar signals. Three last devices are destined to test individual lidar blocks and the lidar as a whole, and the imitator of lidar signals is capable of testing the lidar as part of the SPEKTR orbital module.

In addition to the aforementioned testing benches, devices, and desks, imitators of pulsed and broadband periodic electrical noise created by a satellite power supply unit and a device capable of testing the level of noise produced by the lidar in input power supply circuits were developed. The lidar was tested as the power supply voltage varied from 24 to 32 V. Mean lidar supply power did not exceed 340 W.

To test and to measure the parameters of optical and electric signals produced by lidar blocks, the standard measuring devices and generators were used that were included in testing desks and benches of CCI. Mechanical and environmental tests of lidar blocks

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were carried out on the impact and vibration stands as well as in altitude chambers of the control-test station of the Design and Technology Institute "Optika" and at some other enterprises of Tomsk.

## 3. OPERATION OF CCI AND ITS PARTS

### 3.1. Bench for testing the error in alignment of the optical axes

Misalignment of the optical axes of the receiver and transmitter was tested at the bench shown in Fig. 1. The transceiver of the lidar *1* was mounted on a special aligner on two parallel optical benches (OSK–2). In so doing, a photodetector block and an interference light filter were dismounted from the transceiver. The collimation tubes *9* and *10* with a focal length of 1600 mm and an input aperture diameter of 160 mm were mounted on the optical benches. These tubes were arranged parallel to the optical axis of the receiving antenna *4*. For this purpose, the transceiver was equipped with the special plane alignment mirror *5* with the optical axis being rigidly bound with that of the antenna in the factory assembly. Using this mirror and aligners, the plane-parallel plate *8* was arranged parallel to the plane of the mirror *5*.

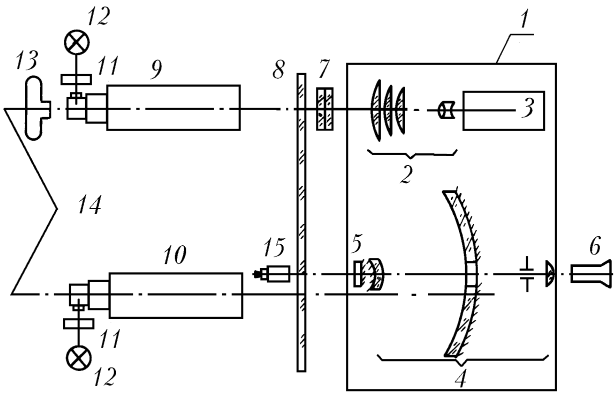


*FIG. 1. Bench for testing the error in alignment of the transceiver of the lidar: 1) transceiver, 2) transmitting optical antenna, 3) laser, 4) receiving optical antenna, 5) alignment mirror, 6) dioptric tube, 7) neutral attenuating light filter; 8) plane-parallel plate, 9) and 10) collimators, 11) interference light filters, 12) light sources, 13) microphotographic attachment, 14) optical axes of optical benches, and 15) telescope.*

In order to eliminate the chromatic aberrations, the collimator grids were illuminated through the interference filters *11*. The dioptric tube *6* was used for observing the field stop of the receiving antenna with the image of the collimator grid *10*. Using the aligners (not shown in Fig. 1), the center of the cross-hairs of the collimator grid *10* was set on the center of the field stop. From the number of lines of the collimator grid falling within the field stop of the receiving optical antenna, the angular field of view was determined that should not exceed 0.45 mrad.

The parallelism of the optical axis of the receiving antenna and the directional pattern of the laser transmitter was tested by means of the microphotographic attachment *13*. To do this, the autocollimation image of the collimator grid *9* from the plane-parallel plate *8* and the laser transmitter radiation burst were photographed simultaneously. The neutral light filter *7* was placed between the plane-parallel plate *8* and the transmitting optical antenna in order to attenuate the laser radiation density. The pictures so obtained were used to estimate the misalignment angle of the optical axes of the transceiver. To do this, the pictures of several bursts of laser radiation were statistically processed. In addition, the measurement cycle was repeated after rotation of the neutral light filter *7* through 180° in order to eliminate its effect. Taking into account the conversion scale (the ratio of the least division of the collimator grid to line spacing in the autocollimation image of the grid on a picture), misalignment of the optical axes was calculated from the mean displacement of the beam center from the center of the collimator cross-hairs. The main and reserve channels of the laser transmitter were tested. The acceptable error in alignment of the optical axes of the receiving and transmitting optical antennas after the factory assembly did not exceed ±5".

### 3.2. Desk for measuring the energy parameters of the lidar transceiver

The desk is destined to test the operation of the lidar transceiver and to measure its characteristics, such as the output energy of the laser transmitter and the threshold power of the receiving train, and to test the threshold sensitivity of the range finding channel. The diagram of the measurement desk is shown in Fig. 2.

When measuring the output energy of the lidar transmitter, the field stop *1* was excluded and the prism *3* was placed so that the laser beam after passage through the telescopic system *2* entered the condenser *4* and the sensitive element of the energy meter *5*. The IKT–1M device was used as a meter (maximum error in measuring was ±15%). The input diameter of the telescopic system *2* was 145 mm, which permits the operation with misalignment angles up to 3' relative to the axis of the transmitting optical antenna and with the accuracy of sighting ±5 mm. The coefficient of losses in the optical train of the energy meter, being equal to 0.5, was also taken into account. The output energy of the laser transmitter was 0.2 J.

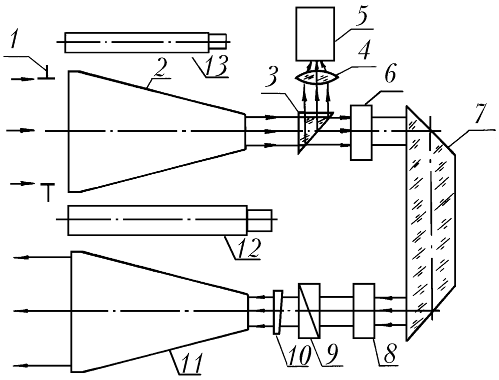


*FIG. 2. Device for measuring the energy characteristics of the transceiver: 1) field stop (D = 75 mm), 2) telescopic system, 3) prism, 4) condenser, 5) sensitive element of the energy meter, 6) constant optical attenuator, 7) rotating prism system, 8) variable optical attenuator, 9) wedge compensator for adjustment, 10) compensator for the velocity aberrations, 11) telescopic system, 12) collimator, and 13) sighting device.*

When measuring the threshold power of the receiving train and the threshold sensitivity of the range finding channel, the prism *3* was removed from the beam propagation path. The field stop *1* was placed in front of the objective lens of the telescopic system *2*. The field stop was used to eliminate uncalibrated vignetting in the receiving optical antenna of the lidar. The range of the transmittance variation in this operation mode was $0.2{\cdot}10^{-12} - 0.2{\cdot}10^{-15}$ with the transmittance setting step no more than 25% (maximum error in setting the attenuation of the measurement train was ±10%). The threshold power of the receiving train and the threshold levels of the range finding channel operation were determined by means of adjustment of the attenuation coefficient of the laser beam[3] (with the use of the variable optical attenuator *8*). The error in testing the sensitivity was ±30%. The collimator *12* clamped on the body of the device was used to align the optical axis of the desk parallel to the optical axis of the receiving system of the lidar, with the misalignment error no greater than ±10".

### 3.3. Desk for testing the electric performance of the system for recording lidar signals (SRLS)

The test desk is destined to receive, indicate, and transfer signals coming from SRLS to the standard measuring instruments. The desk also imitates electric signals corresponding to laser sounding pulse and lidar return signals with different time delays, durations and amplitudes, which makes it possible to certify metrologically the analog-to-digital converter of SRLS. In addition, the desk imitates signals of universal time and the serial number of measurement cycle necessary for certification of the lidar signal,[2,3] as well as the control commands coming from the control desk of the lidar. The test desk was equipped with the indication board displaying 8×31 bytes, with a 31-byte information string of the lidar return signal (see Fig. 6 of Ref. 3). Then the string was transferred to the radiotelemeter of the orbital station.

When testing the lidar as a whole by means of this desk, it also simulates the data exchange between SRLS and radiotelemeter.

### 3.4. Desk for testing the electric performance of the lidar control desk (LCD)

The test desk is destined to receive, indicate, and transfer signals coming from LCD to the standard measuring instruments. In addition, the test desk executes commands coming from LCD and responds to these commands as LCD does when it operates as part of the lidar. To do this, the test desk imitates signals from lidar parts electrically connected with LCD as well as commands and signals from systems and devices of the orbital station. The test desk included a device capable of its testing and self-testing. When carrying out the tests, the desk operated in two modes: a) measuring the parameters of pulses and signals generated by LCD, b) imitation of lidar operation on commands and signals from LCD.

When testing the lidar as a whole, this test desk imitated the operation of a set of devices of the orbital station on generation of control commands for the lidar and on reception of telemetering control signals of command execution.

### 3.5. Optical imitator of lidar signals

The optical imitator is destined to shape lidar signals during self-tests, tests, and control of the BALKAN–1 lidar operation, as well as during the test of the lidar as part of the orbital module. The optical imitator was capable of generating two signals, namely, the signal imitating the laser sounding pulse and the delayed lidar return signal. The optical lidar signal power could vary in the range from $5{\cdot}10^{-8}$ to $2{\cdot}10^{-7}$ W (in four steps) with an error of ±30%. In addition, it was possible to regulate the duration of the pulse and its leading and trailing edges, which provided the range of variation of pulse duration from 400 to 1500 ns with a 50-ns step at a level of 0.1 of the pulse amplitude and from 500 to 1100 ns with the same step at half amplitude. The lidar signal delay relative to the laser pulse was regulated from 1.2 to 3.0 ms (in four steps). The errors in setting the parameters of the imitation signal were ±10%.

The diagram of testing the lidar by means of the optical imitator is shown in Fig. 3. The electron generator *7* can be switched on by three ways: a) by a laser pulse of the lidar transmitter, b) by an external electric signal, and c) by a button on the imitator front panel. During self-test of the lidar, the cover with the imitator photodetector *6* was clamped on the output aperture of the lidar transmitting antenna, and during the test of the lidar as part of the orbital module, it was clamped on the window *5* opposite to the transmitting antenna. The optical light source block *8* (the light diode matrix) was placed in a special technological window of the lidar photodetection block *4*. Once the laser transmitter was switched on, the optical signal received by the photodetector *6* was converted to the electric one and then was transferred to the generator *7*, where it was delayed by the time of signal transfer from the orbital station to the ground and back and was shaped as the given lidar signal. The optical signal coming to the light source block *8* was used to test the operation of the entire receiving-detecting train of the lidar. The signal from the output of the system for recording lidar signals was either displayed on the information board of the desk *10* or transferred to the radiotelemeter of the orbital station. Thus, the operation of the lidar as a whole was tested as well as the accuracy characteristics of SRLS (for the given shape of the imitational optical signal).

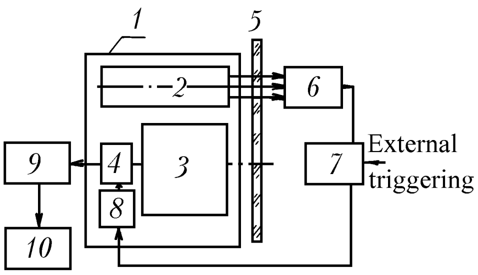


*FIG. 3. Diagram of testing the lidar using the optical imitator of lidar signals: 1) transceiver, 2) laser transmitter, 3) receiving optical antenna, 4) photodetector block with interference light filter, 5) window of the orbital module, 6) photodetector, 7) electronic generator, 8) radiation source block, 9) SRLS, and 10) desk for testing SRLS.*

The presence of the light source imitating lidar signals made it possible to test the receiving optical-electronic train of the lidar without the lidar transmitter, what keeps the laser resource.

## 4. CONCLUSION

The developed control-calibration instrumentation was used to carry out a full cycle of tests of the BALKAN–1 lidar under the program of ground-based experimental work that included the laboratory tests of the electrical prototype of the lidar and its parts, acceptance tests, and design and development tests of the lidar. The tests confirmed that the lidar complies with the requirements for satellite instruments and is suitable for installation onboard the SPEKTR orbital module. The lidar can operate in the air medium with the following parameters: pressure in the range 510–970 Torr, temperature from 5 to 35°C, relative humidity from 30 to 70% at a temperature of 20°C, oxygen content up to 40%, helium content of 0.01%, and hydrogen content up to 2%. The lidar keeps its specifications after the effects of a vacuum down to $10^{-4}$ Torr, of atmospheric air with temperature ranging from –50 to 50°C, as well as after the effect of mechanical loads of sinusoidal vibration up to 10 g in the frequency range from 5 to 2000 Hz during 600 s and 100 impulse loads up to 40 g along each of three coordinate axes and acoustic load of 145 dB in the frequency range 200–2000 Hz.

The reliability and capacity for work of the lidar were also confirmed by implementation of the program that ensures the reliability of the instrumentation and safety of the personnel. The possible extraordinary situations during lidar operation have been listed as well as recommendations on ways out. The lidar was installed onboard the SPEKTR module in 1990. The integrated ground tests of this module were carried out. The electromagnetic compatibility of the lidar with devices and instrumentation of other systems of the module was tested.

The BALKAN lidar was dismounted from the module in 1994, and its blocks were retested by means of CCI followed by integrated tests of the SPEKTR module. The tests confirmed the capacity for work of the lidar after its putting in prolonged storage. The lidar was delivered to the Baikonur spaceport as part of the module, where its prelaunch tests were carried out in April of 1995 using the imitator of optical signals. The lidar was injected into orbit as part of the SPEKTR module and joined with the MIR station in May of 1995.

Some parts of CCI were developed and produced at the Design and Technology Institute "Optika" of the Siberian Branch of the Russian Academy of Sciences and at the Scientific-Research Institute of Satellite Instrumentation.

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