PHOTONICS TECHNOLOGY OBNINSK

Obninsk, Russia

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LIDAR LSA – 2C

(SMOKE ANALYZER)

Brief Technical Description

I. PREFACE

Atmospheric aerosol plays an important role in radiation balance and earth climate forming. Besides, it is an atmosphere contamination, which sometimes can produce a negative influence on people health. Therefore, investigations of aerosol origin, transfer and removal from the atmosphere are very important.

Laser sensing of the atmosphere is nowadays one of the most important tools of aerosol research and monitoring and is widely used in atmosphere study. Measurements are carried out using the method of remote laser sensing, whereby measurements are made of backscattered laser signals in UV, visual and infrared spectral range.

Benefits and advantages of laser sensing of the atmosphere:

- Remote laser sensing (without sampling and subsequent analysis).
- Opportunity of laser sensing of the atmosphere at any direction of a laser ray and at different altitudes.
- Good spatial - temporary resolution. It is caused by small pulse duration and high repetition rate. Laser sensing provides information along all atmospheric paths many times faster, than the state of the atmosphere changes.
- Opportunity of long and continuous measurements (monitoring of the atmospheric pollutants).

Aerosol Lidar (Smoke analyzer LSA-2C) is two wavelengths Lidar, which can be used for sensing the aerosol concentration, assessment of sizes of particles and providing monitoring of aerosol contamination in the atmosphere of large cities and industrial enterprises.

II. PURPOSE

1) **SMOKE ANALYZER** (hereafter SA) (Fig. 1) is intended for remote detection of aerosol in the earth atmosphere by means of lidar device operating **at 532 and 1064 nm wavelengths**.
2) Principle of SA operation consists in sending in the atmosphere a short light pulse and following receive of radiation scattered in the backward direction that provide backscattering signal as a function of distance of sensing.

   Normally observed backscattering signal is generated by air density fluctuations (Rayleigh scattering) and scattering by small aerosol particles always presented in the atmosphere. The presence of smoke aerosol particles gives rise to increase of backscattering signal and thus the aerosol flow can be detected on the background of surrounding clean atmosphere.

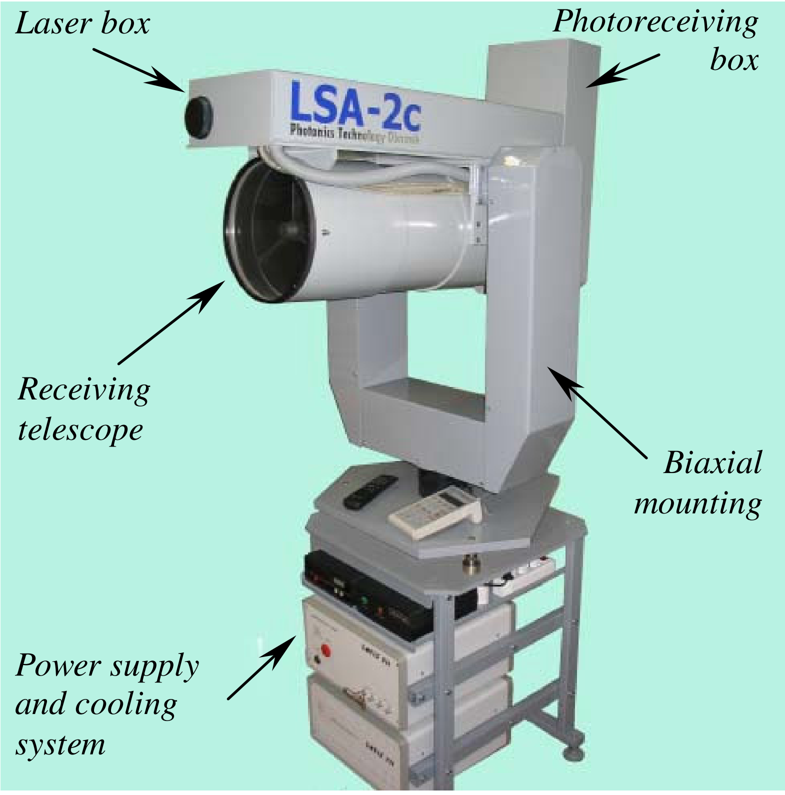


Fig. 1**. SMOKE ANALYZER:** External appearance.

Possible applications of the aerosol lidar

- Operative detection of pollutant emissions in an atmosphere from the industrial enterprises; evaluation of intensity of pollutants and their dispersion in space; long monitoring of emissions.
- Sounding of aerosol layers in an atmosphere with the purpose of definition of transport of pollutants on the large distances.
- Early detection of fires, especially in wood fires.
- Aerosol lidar can be successfully used in the educational purposes. The students will acquaint with the basic principles of quality control of air and modern methods spectroscopy, used for measurement of pollution of air.

III. SPECIFICATIONS

Measurement scheme

- Measurement scheme .... remote sensing
- Open path .... up to 10 km
- Time interval for one aerosol profile measurement .... not more than 15 min

Laser block

- Emitter .... Nd:YAG laser LS-2131
- Working wavelengths .... 1064, 532 nm
- Pulse energy at 1064 nm .... up to 100 mJ
- Pulse energy at 532 nm .... up to 50 mJ
- Pulse repetition rate .... up to 20 Hz
- Pump energy .... up to 25 J
- Beam expander 52-35-5XA magnification .... 5^X

Receiving telescope

- Receiver of backscattering radiation .... telescope of Quasi-Cassegrain type
- Main mirror diameter .... 260 mm
- Focal length .... 1050 mm
- Range of elevation angles positioning of the telescope .... from -10° up to +90° from horizontal
- Range of azimuth angles positioning of the telescope .... from -180°up to +180°

Photoreceiving unit

- Number of receiving channels .... 2 (1064 & 532 nm)
- Photoreceivers:
  - at 1064 nm .... avalanche photodiode (APD module) with quantum efficiency of photocathode 40%
  - at 532 nm .... PMT-100 with quantum efficiency of photocathode 10%
- Halfwidth of the interference filters 1064 nm at 0.5 level .... 3 nm
- Halfwidth of the interference filter 532 nm at 0.5 level .... 2 nm

Data registration unit

- Mode of signal processing .... analog
- Digital capacity of ADC .... 12 bit
- Sampling frequency .... 30 MHz
- Spatial resolution .... 5 m
- Number of measurement points 2048
- SMOKE ANALYZER is supplied with SOFTWARE for control of ADC operation and signal processing.

Outline dimensions and weight

- Transmitting and receiving device (at telescope directed horizontally) .... 960×630×1160 mm
- Compartment with power supply and cooling systems (so called rack table) .... 530×530×660 mm
- Mass of LSA as a whole .... not more than 180 kg

Site

- The SMOKE ANALYZER is to be at laboratory condition at:
  - air temperature .... (288 – 303) K
  - relative humidity at 298K .... (40 – 80)%
  - atmospheric pressure .... (84 – 108) kPa

Power

- Power supply network .... single phase AC, (220 ± 20)V, (50–60)Hz, 5A
- Power consumption .... not more than 0.75 kW

IV. STRUCTURE AND PRINCIPLE OF OPERATION

A. Structure

SMOKE ANALYZER consists of three main units (Fig. 2):

- **Transmitting and receiving device (TRD)** containing the following elements:
  1. laser box with laser emitter LS-2131;
  2. telescope for receiving of backscattered radiation;
  3. two-channel receiving box with a beam splitter, turning mirrors, interference filters, and PMT-100 and avalanche photodiode (APD) as detectors of backscattered radiation.
- **Power supply and cooling system (PSCS)** containing the following elements:
  4. laser power supply (with remote control);
  5. laser cooling system;
  6. high voltage power supply of PMT;
  7. low voltage power supply of PMT amplifier;
  8. low voltage power supply of APD module.
- **Data registration and processing system (DRPS)** containing the following elements:
  9. two-channel analog-to-digital converter (ADC)
  10. computer (PC) with software for control of the device, measurement conducting and data processing.

Note: PC is not delivered.

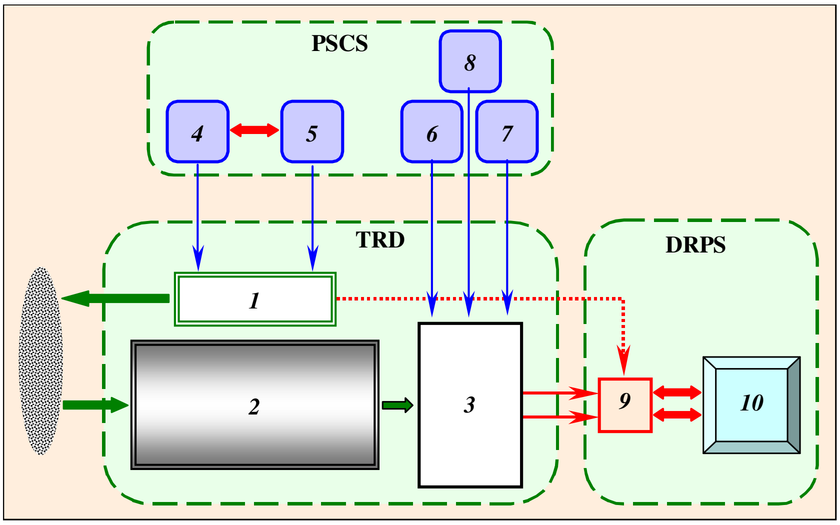


Fig. 2**. SMOKE ANALYZER:**
The function chart.

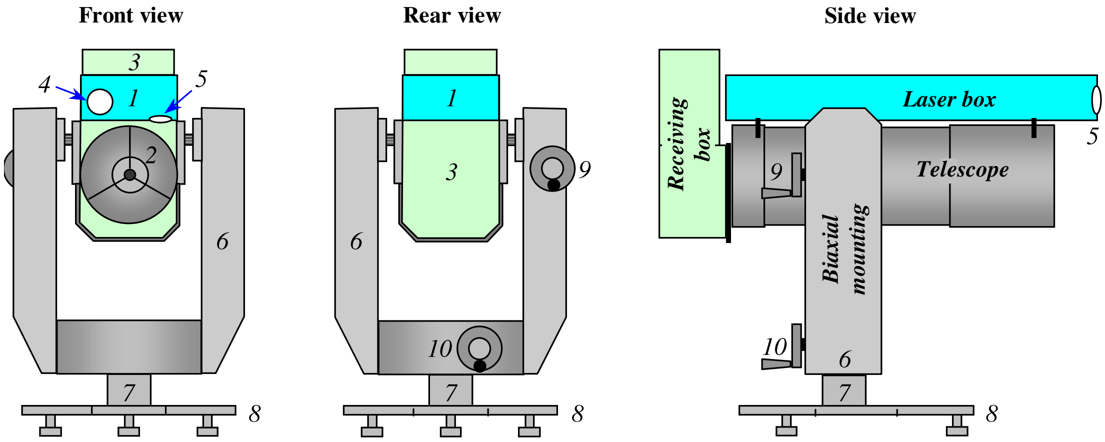
Schematic representation of TRD is shown in Fig. 3. Main units of TRD (the laser box *1*, receiving telescope *2* and two-channel photoreceiving box *3*) are installed at the biaxial mounting with a gear at elevation and azimuth angles.

Laser box is mounted at the top of the telescope with help of the bearers. Laser beams are transmitted in the atmosphere through the window *4*. Power cable and water-cooling pipes pass through the input window *5* of the laser box bottom.

Photoreceiving box is mounted at the rear end of the telescope.

Receiving telescope with the laser and receiving boxes is installed in the fork mounting *6* by means of two semi-axes that allows rotation of the telescope in vertical plane with help of the worm bearing by means of the knob *9*.

Biaxial mounting consists of the fork mounting *6*, support *7* and immovable base platform *8*. Inside of the support a bearing is installed providing its rotation in horizontal plane from -180° up to 180° interval of azimuth angles by means of the knob *10*.



1 – laser box
2 – telescope
3 – receiving box
4 – windows for output of laser beam
5 – window for input of the power cable and water pipes
6 – fork mounting
7 – support
8 – base platform
9 – knob for telescope turning in a vertical plane
10 – knob for telescope rotation in a horizontal plane

Fig. 3. **SMOKE ANALYZER:** Transmitting and receiving device.

B. Principle of operation

At SA operation the laser emits a series of pulses of radiation at 532 and 1064 nm wavelength. Laser beam is collimated and directed into the atmosphere.

Power supply provides pumping of laser active element and control of optical shutter (Q-switch) of the laser. Internally sealed water cycle cooling system is intended for cooling of the laser's flash lamp and active element.

Receiving telescope collects radiation, scattered by atmosphere in backward direction, and transmits it through a field of view diaphragm into photoreceiving box, where a beam splitter divides backscattered radiation between two optical channels – 1064 and 532 nm.

Then backscattering light signals enter photomultiplierPMT-100 and APD module, which transform light signals into electric (analog) signals and produce its amplification. High voltage and low voltage power supply units feed PMT and APD and their amplifiers.

Finally, PMT and APD module output electric signals are transmitted for two-channel analog-to-digital converter (ADC) installed in PCA slot of the personal computer. ADC converts analog electric signals of PMT and APD to digital code and transmits it into PC memory for saving and further processing.

V. MODULE DESCRIPTIONS

A. Laser block

The laser block is developed on the basis of commercial laser LS-2131.

Laser LS-2131 is a pulsed Nd:YAG laser working at a Q-switch mode of operation. It is intended for lasing of short pulses of infrared radiation at the fundamental frequency (1064 nm), which is partly transformed to the second harmonic (532 nm) by frequency doubler – KTP crystal.

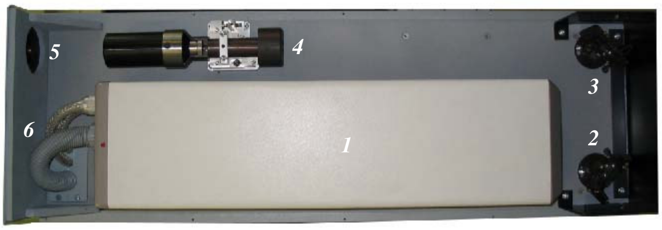
See laser's main specifications in the Section III.

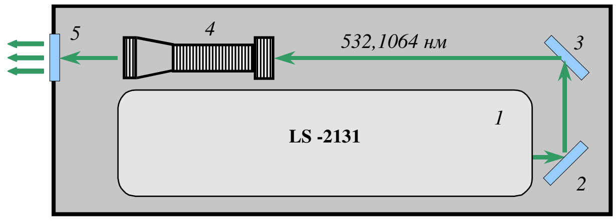
Main details and optical layout of the laser block are shown in Fig. 4.

Optical layout. Laser head emits radiation at wavelengths 1064 and 532 nm, which are reflected by turning mirrors *2* & *3* and directed to the beam expander *4*. Then laser beam comes to the open atmosphere through the window *5* at the laser box front panel.

Achromatic beam expander is the telescope system assigned for increasing of cross section of laser beam and accordingly decreasing the angle of divergence of laser radiation.

Design. The box of the laser block is made of aluminum alloy. Its dimensions are 800×300×130 mm. The internal surface of the box is covered with a light absorbing paint. The laser box is mounted rigidly at the top of the telescope with help of the special bearers. Flexible sleeve *6* with the power cord line and signal cable from the power supply along with the water hoses from the cooling system are lugged through the bottom window and attached to the laser *1*.





1 – laser LS-2131
2, 3 – turning mirrors
4 – beam expander
5 – protective glass plate
6 – sleeve with the power cord line and water hoses

Fig. 4. **Laser block**: Main details and optical layout.

B. Receiving telescope

The telescope provides collection of radiation scattered by the atmosphere with following transfer it into a photo-receiver. It represents a mirror type Quasi-Cassegrain objective consisting of large and small spherical mirrors, and a protective glass.

See telescope's main specifications in the Section III.

Main details and optical layout of the telescope are shown in Fig. 5.

1 – protective glass
2 – main mirror
3 – secondary mirror
4 – field of view diaphragm

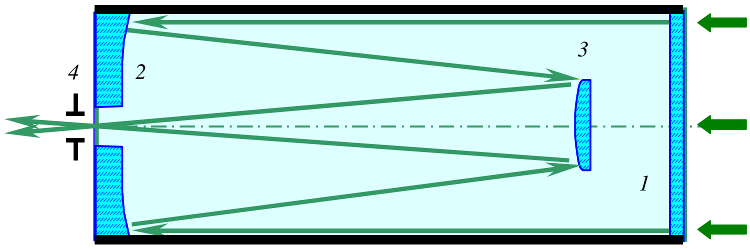


Fig. 5. **Receiving telescope:** Main details and optical layout.

Optical layout. Backscattered radiation passes through the protective glass *1* and falls onto the main concave spherical mirror *2*. The secondary convex spherical mirror *3* serves to increase the focal length of the telescope without enlarging of its geometric sizes. A light beam is reflected by the secondary mirror into the main mirror's hole intended for passing of the beam to the receiving box. Field of view diaphragm *4* is placed in the focal plane of the telescope.

Design. The case of the telescope is made of steel. The internal surface of the case is covered with a light absorbing paint. Pivots mounted at the telescope case allow connecting it with the fork mounting of the alt-azimuth turning device.

C. Two-channel photoreceiving box

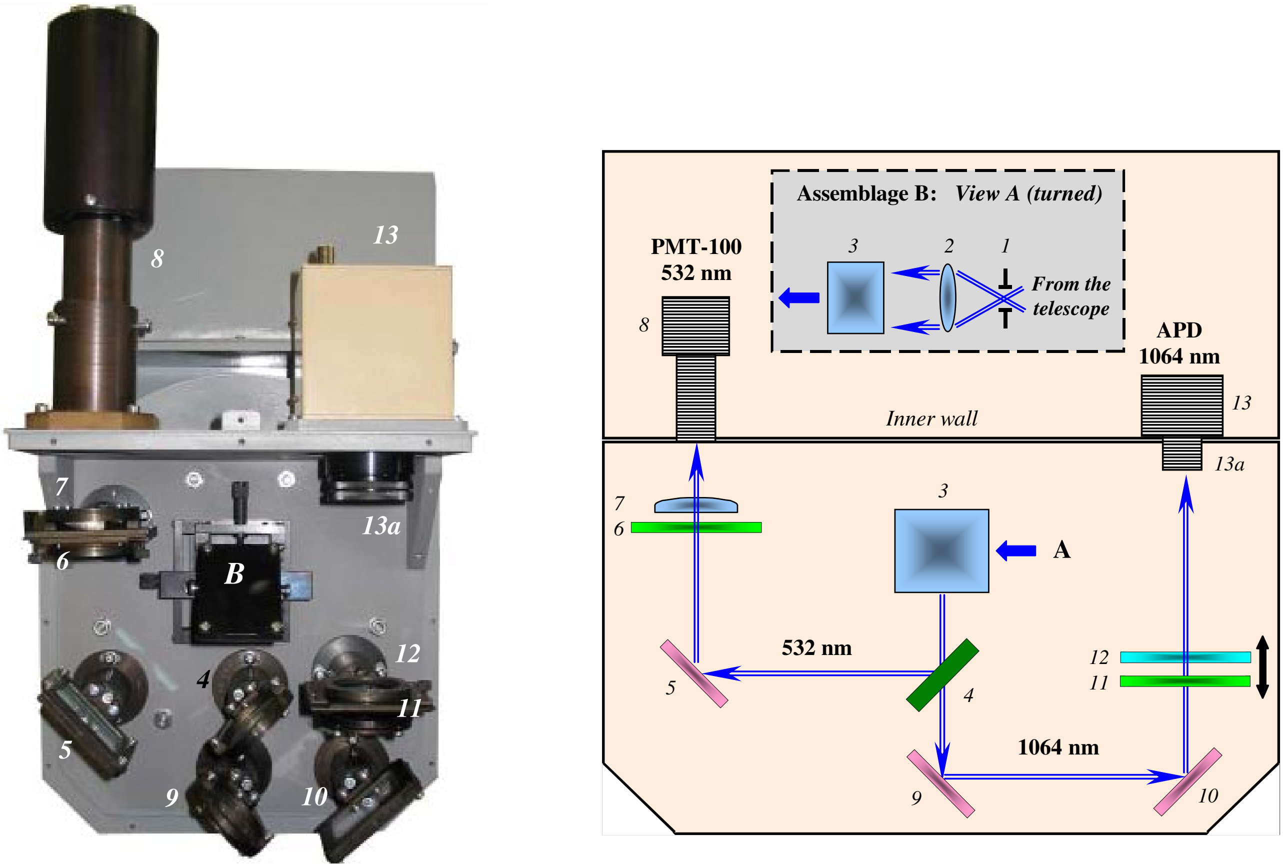
Photoreceiving box is intended for dividing backscattered radiation between two optical channels and registration of the light fluxes by PMT and APD module with subsequent transmission to Data Registration and Processing System.

See photoreceiving box's main specifications in the Section III.

For registration of the light fluxes are used two types of photodetectors:

- **channel 532 nm - photomultiplier PMT-100**, which is a detector of light signals in UV and visible spectral ranges. PMT-100 is mounted along with a wideband amplifier of the output signals.
- **channel 1064 nm - APD module**, assigned for detection of light signals in the near infrared wavelength range. APD module consists of objective lens, photoreceiver (avalanche photodiode of Perkin-Elmer), umformer (unit for high voltage feeding of the avalanche photodiode) and amplifier of the input signals. All these elements are mounted in common metal case.

Main details and optical layout of the photoreceiving box are shown in Fig. 6.



Assemblage B for passage of a beam from the telescope

1 – field of view diaphragm

2 – collimating lens

3 – turning mirror

4 – beam splitter

Channel 532 nm:

5 – dielectric mirror

6 – interference filter

7 – focusing lens

8 – PMT-100 with an amplifier

Channel 1064 nm:

9, 10 – dielectric mirrors

11 – interference filter

12 – neutral filter

13 – APD module

13a – objective lens of APD module

Fig. 6. **Photoreceiving box**: Main details and optical layout.

Optical layout. The field of view diaphragm *1* combined with the collimating lens *2* and turning mirror *3* into one block *B* is located at entrance aperture plane of the photoreceiving box (on the telescope optical axis). Backscattered radiation passes from the telescope through the field of view diaphragm *1*. Collimating Fabri lens *2* installed after diaphragm transforms radiation collected by telescope into beam with small divergence. Then beam are turned by mirror *3* on 90º in direction of a beam splitter *4*, which reflects radiation at 532 nm and transmits radiation at 1064 nm, thereby dividing beam into two optical channels:

- **channel 532 nm** - turning dielectric mirror *5* directs radiation of 532 nm wavelength on a photocathode of the PMT-100 tube *8* through the interference filter *6* and focusing lens *7*;
- **channel 1064 nm** - radiation of 1064 nm wavelength is directed to the receiving area of APD module *13* by the turning dielectric mirrors *9* & *10* through the interference filter *11* and changeable neutral filter *12*.

Interference filters serve to separate backscattering signal from background sky radiation. The neutral filter is used for changing of intensity of light signal entering APD receiver.The image of main mirror is formed on PMT-100 and APD photocathodes by focusing lens *7* and objective lens *13a* of APD module. This will serve for homogeneous and stable illumination of cathode by backscattering light.

Design. Receiving box is rigidly mounted to the telescope's backside by screws. Case of the receiving box is made of aluminum alloy. Its dimensions are 600×260×160 mm. The internal surface of the case is covered with a light absorbing paint. All optical elements are installed on the mountings supplied by the adjustment screws. Case is divided by a wall into two blocks with the removable back walls – for attachment and adjusting optical elements and the photoreceivers. Besides on the optics block backwall there is a small window with a removable cover intended for change of the interference filter on neutral one and vice versa.

D. Power supply and cooling system

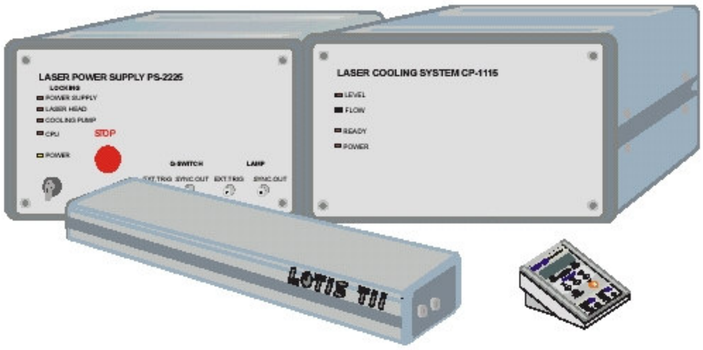


Fig. 7. Laser with its Power supply and Cooling system.

Laser feeding and cooling.

Power supply PS-2225 is used for supplying flash lamp, control of Q-switch and energy indication of the fundamental frequency. PS is delivered with a remote control with an interface cable - for a distant controlling of PS and laser operation (Fig. 7).

An internally sealed water cycle cooling system CP-1115 with water-to-air heat exchanger is utilized for cooling the flash lamp and active element of the laser.

Fig. 8. High voltage power supply of PMT.

Photodetector PMT-100 feeding.

High voltage power supply (Fig. 8) is intended for producing of stabilized and regulated high voltage for power supply of PMT-100 dynode system. Maximum output voltage is 2500 V. For convenience of control there is a remote control board.

Standard low voltage power supply of ±12 V serves for feeding of the PMT-100 amplifier.

Fig. 9. Low voltage power supply of APD.

Photodetector APD feeding.

Low voltage power supply (Fig. 9), which has the output voltages of +30 V, 200 mA and ±12 V, 100 mA, feeds the APD umformer and amplifier.

All elements of PSCS are installed inside a metal compartment (see Fig. 1) and connected to electrical network 220 V.

E. Data registration and processing system

ADC board. Two-channel analog-to-digital converter (ADC) is intended for transformation of analog lidar signal into digital form for storage and further processing at PC. Electronic board of ADC is inserted in PCA slot of the personal computer.

See specifications of ADC in Section III.

Software. Control of the process of measurement is fulfilled in the interactive regime by means of the “Program for control of measurements”. Then “Program of data processing” is used for measurement data analysis. Software is oriented at using of PC of IBM Pentium I types or analogs.