

LANGMUIR PROBES' SECONDARY POWER SUPPLY
SYSTEM FOR THE "OBSTANOVKA" EXPERIMENT
AND PLASMA-WAVE COMPLEX ABOARD THE RUSSIAN
SEGMENT OF THE INTERNATIONAL SPACE STATION

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Abstract

The Plasma-wave complex is scientific instrumentation for plasma and wave parameters measurements in the vicinity of the International Space Station, and is implemented in the "Obstanovka" experiment aboard the Russian segment.

The Langmuir probes instruments, developed at the Space Research and Technology Institute of the Bulgarian Academy of Sciences, measured the following parameters: electron temperature, electron and ion concentration, plasma and the International Space Station's surface potential. One of the results is that sharp jumps in the surface potential are detected when crossing the terminator and the Equatorial anomaly.

The Langmuir probes operate outside the Russian "Zvezda" module. Families of voltage-ampere characteristics of the Langmuir probe are measured – when the voltage changes in a certain range, the value of the current flowing is recorded.

There are block and functional diagrams of the instrument Langmuir probes and its secondary power supply system, designed to supply the measuring probe, the analogue and digital circuit boards.

Key words: secondary power supply system, Langmuir probe, International Space Station

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Introduction. Plasma-wave complex (PWC) from “Obstanovka” experiment measures electromagnetic fields and plasma waves of natural and technogenic origin in the ionospheric plasma and electromagnetic parameters of space weather outboard the International Space Station (ISS). The total mass of PWC is 55 kg. The average power consumption is 60 W [1].

Developers of PWC are from Bulgaria, UK, Hungary, Poland, Ukraine, and Sweden. The instruments for storing, processing and transmitting of telemetric information (BHTI), DACU-1 and DACU-2, which collect, store and transmit data on board the ISS, were manufactured by the Vigner Science Centre of the Hungarian Academy of Sciences.

The DFM-1 magnetometer was manufactured by the Institute for Space Research, Russian Academy of Sciences (IKI-RAS). The digital spectral analyzer ASP-3 was manufactured by BL-Electronics from Hungary [1].

Langmuir probes, potential probes and material samples (LP-1, LP-2, DP-1, DP-2, DP-PM) [2] were manufactured at the Space Research and Technology Institute of the Bulgarian Academy of Sciences (SRTI-BAS) for “Obstanovka-1” experiment [3–10,16].

Correlation electron spectrometer CORES was manufactured at the University of Sussex, United Kingdom.

Radiofrequency analyzer RFA was manufactured by the Polish Space Research Centre of the Polish Academy of Sciences.

Combined wave probes KVZ-1, KVZ-2 and magnetometer DFM-2 were manufactured in the Lviv Centre of the Space Research Institute of the National Academy of Sciences of Ukraine/GSAU [1,11].

The PWC complex is structurally divided into three main parts in accordance with the three workplaces: two plasma-wave complexes PVK-1, PVK-2 and a unit BHTI. The information from the BHTI is fed to the onboard ISS RS telemetry systems: TM IUS (Ethernet) and TM BITS. For long-term storage, the BHTI has hard disk drive – replaced and returned to the Earth twice a year. To ensure the operating temperature of the secondary converters KVD-1 and KVD-2 units they are equipped with non-hermetic automated temperature control systems. PWC integration, climatic, vibration, thermo, vacuum and electromagnetic compatibility tests were carried out at IKI-RAS [1,13]. Each instrument included in the PWC had its own test equipment, allowing autonomous verification of the instrument’s performance and conformity with its technical description. Controlling the power supply to the PWC and the transmission of command and information data was provided by the on-board instrumentation. In particular, power was supplied from the PWC on-board power switching system BSK5E5-32 via seven feeders. The installation of the PWC has two stages:

- assembly of the electrical circuit inside the ISS-BHTI connection;
- installation and connection of PWC equipment on the external surface of the ISS during the cosmonauts’ exit on April 19, 2013 [1].

On April 23, 2013 the first activation of the scientific equipment of the PWC was carried out. Power was supplied to the PWC by the Ethernet codeword commands corresponding to each device. The fact of power supply to the PWC devices was controlled by the signals “power is supplied” via the DACU-BHTI via the BITS-2-12 telemetry system with analog parameters ATM-1-ATM-5. The power consumed by PWC was no more than 110 W.

Materials and methods. *Langmuir probes for PWC.* Two cylindrical Langmuir probes [12] (LP-1 and LP-2) designed and manufactured at first stage in the Space and Solar-Terrestrial Research Institute at the Bulgarian Academy of Sciences, monitor the surface charging and the noises and disturbances in the surrounding plasma induced by the ISS and by the experiments conducted aboard it [5]. The main task of two identical LP-1 and LP-2 is to measure in two points the thermal plasma – near surface and 1.5 m from the surface of the Russian sector of ISS [5].

In ionospheric measurements for the spherical probe the errors are above 10% and strongly depend on the plasma parameters and on the voltage applied to the probe. The spherical probe is practically unusable for measuring the electron concentration, and the ion concentration data are unreliable for lighter ions at higher temperatures.

LP-1 and LP-2 measured the following parameters [5]:

- electron temperature $T_e = 1000 \div 6000$ K (derived from the slope of the volt-ampere curve in electron retardation region);
- electron concentration $N_e = 10^9 \div 10^{13} \text{ m}^{-3}$;
- ion concentration $N_i = 10^9 \div 10^{13} \text{ m}^{-3}$;
- current plasma and ISS potential $U_s = \pm 100$ V (the potential of the “ground” point of the ISS relative to the plasma).

The zero of the voltage generator is connected to be the satellite body and all voltages are applied with respect to this “zero”. The satellite also charges electrostatically and reaches some potential which is due to both the surrounding plasma and the solar electromagnetic radiation [5]. LP-1 and LP-2 are designed to measure plasma parameters in the frequency range $0.1 \div 100$ Hz [1].

LP-1 (1) consists of (see Fig. 1): a measuring mono-block LP-PP-1 (2) and an electronic block LP-VP-1 (6). Each LP-PP-1 is situated on a boom and consists of a sensor (3) and a multirange current meter (I/U-C) (4). The sensor (3) is a cylindrical electrostatic probe consisting of a measurement electrode (ME) for electron or ion collection (depending on the voltage applied), a guard electrode (GE) and a connecting rod (CR). LP-PP-1 is designed with three scales for positive currents and three for negative currents: $\pm 5 \cdot 10^{-5}$ A; $\pm 5 \cdot 10^{-7}$ A and $\pm 5 \cdot 10^{-9}$ A. The selection of the scale is controlled by a microprocessor. Circuit (4) converts the current from ME into voltage and sends it to module LP-VP-1 (6), mounted in the Data Acquisition and Control Units DACU-1 (5). Module (6) consists of: Controlled Voltage Generator (CVG) (7); Two-polarity Current Measurement

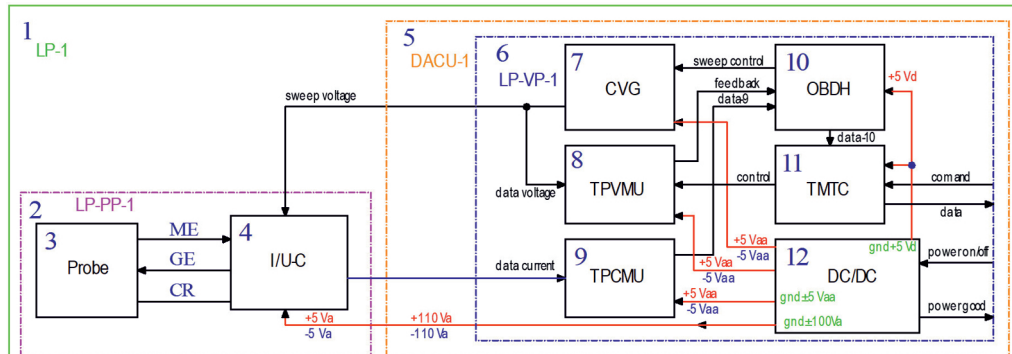


Fig. 1. LP-1 and secondary power supply system for LP-1

Unit (TPCMU) (8); Two-polarity Voltage Measurement Unit (TPVMU) (9); microcontroller for controlling and optimizing the measurement process included in On-Board Data Handling Unit (OBDH) (10); data processing and Telemetric Command (TMTC) (11) and power supply (DC/DC) (12). Circuit (7) generates sweep voltage ± 100 V applied to the ME. Maximum 20 s is the time for tracing ± 100 V. The sweep voltage generated by (7) is controlled by the OBDH (10). Circuit (8) measures the ME voltage, controls input value for potential checking and is a feedback for the software control of this potential. Two units (8) and (9) contain identical 16-bit ADC's, each of them interfacing with the microcontroller on its own SPI bus. TMTC is responsible for the interface between each of the LP devices and DACU [6].

Power supply block – technological model. During the tests of the technological instruments, significant aperiodic disturbances were found in one of the voltages generated by technological power supply block (PSB-T) which could not be stabilized. Figure 2 shows the circuit diagram of the technological PSB-T [4]. For stabilization of eight output voltages two controllers (U1, U2), two transformers (Tr1, Tr2) and two feedback connections (U3, U4) are used.

Power supply block – fly model. For the instruments LP-1 and LP-2 (Fig. 3) a secondary power supply system for fly models (SPS-LP-F) is designed, (d), (e). For the instruments LP-1; LP-2; DP-1 and DP-2 in board network (BN) circuit breakers type BSK5E5-32 are used [2, 13]. To ensure the requirements of BSK5E5-32 and [13], a circuit of electronic fuse and current limitation (EF-CL), (a), (b) was designed and implemented in space instruments LP, DP and AMEW [2, 14, 15].

The function of EF-CL is soft start for primary and secondary circuits in normal condition and self-shutdown in irregular condition. In (d), (e) we can see appearance and the functional diagram of SPS-LP-F. The appearances for modules LP-VP and LP-PP are shown in Fig. 3 (c). Let us discuss (e): to improve the power supply parameters [17] four controllers Ctr1-4 (7, 18, 29, 36);

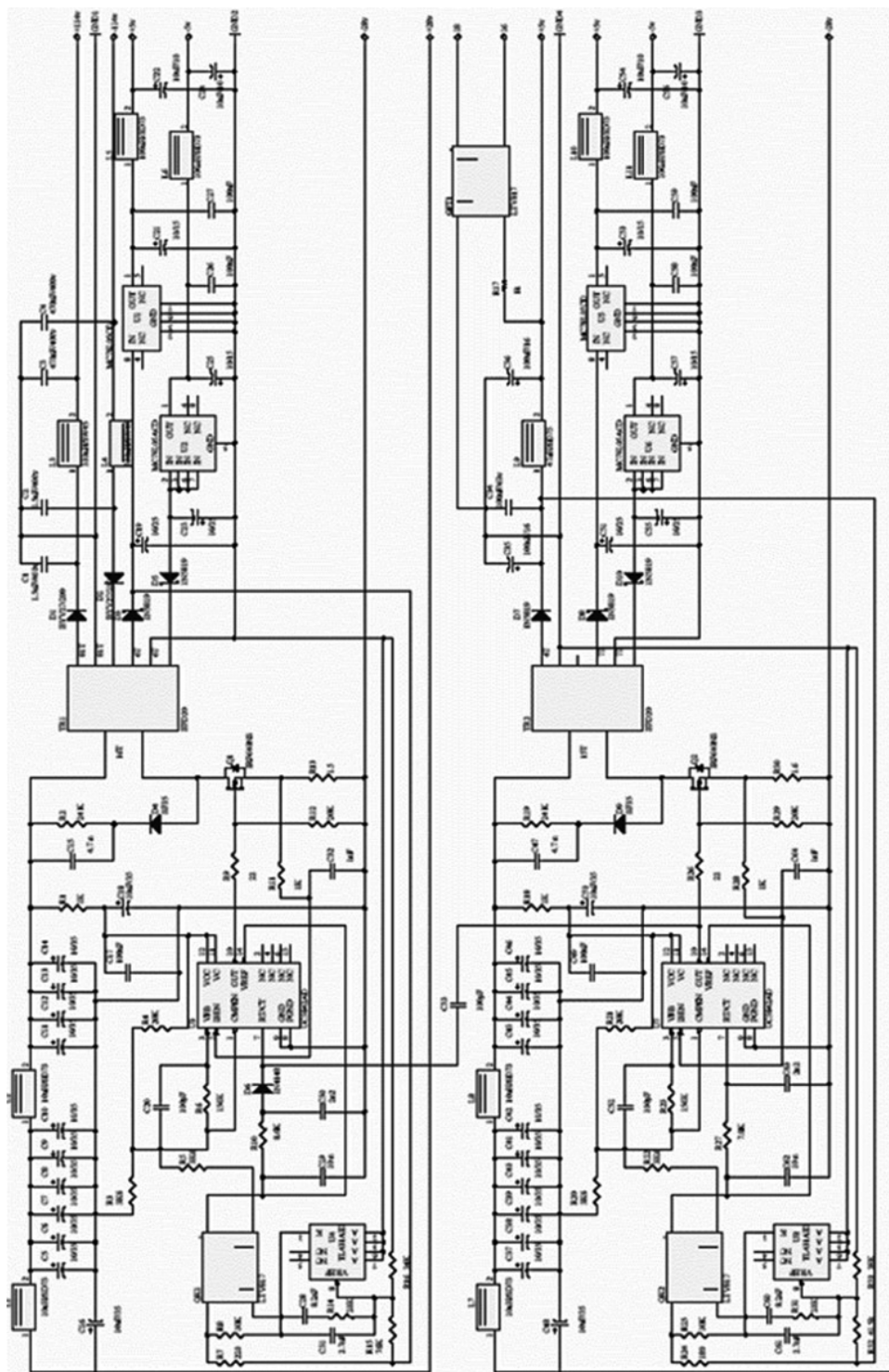


Fig. 2. Power supply block for Langmuir probe – technological model [4]

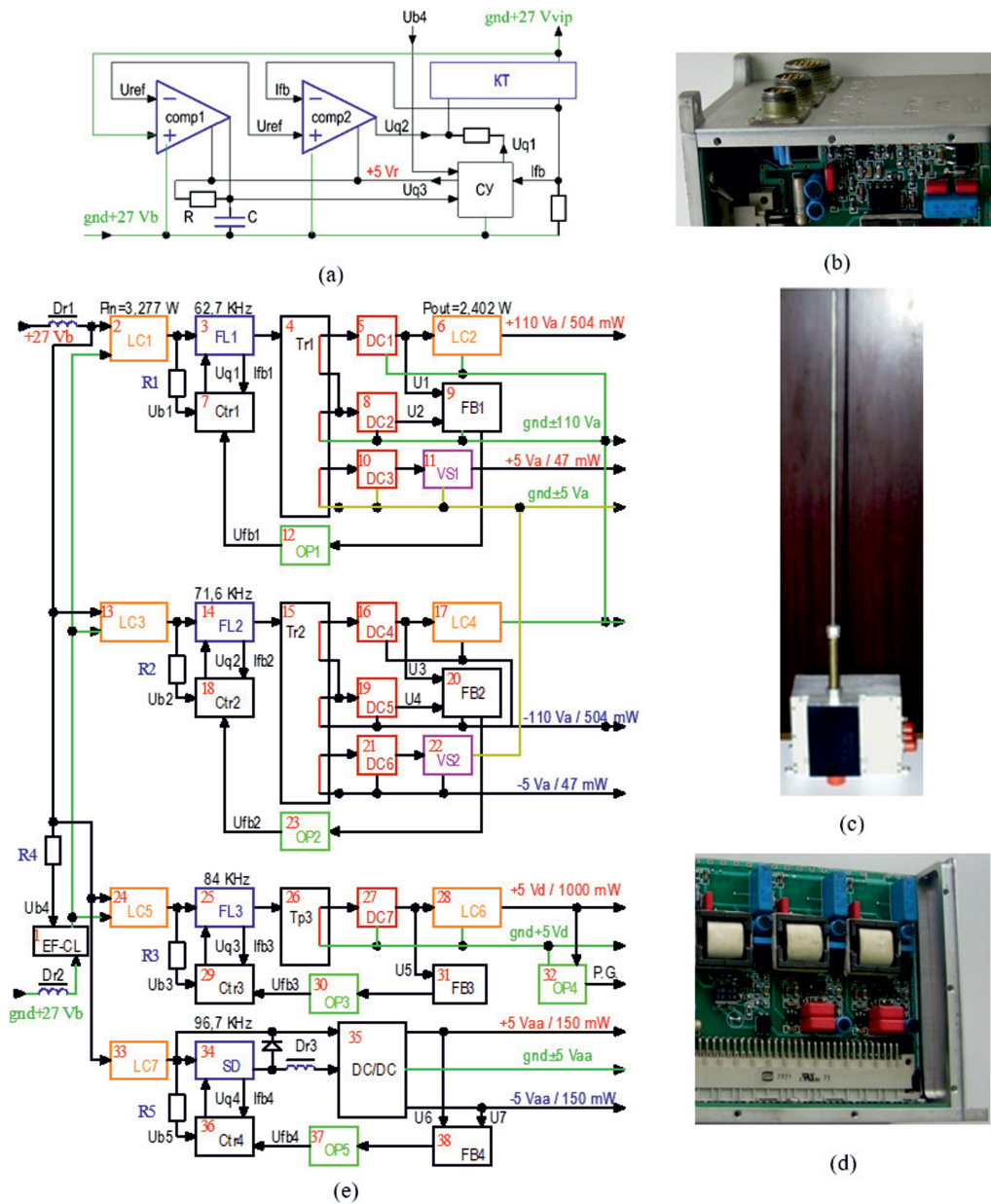


Fig. 3. The Langmuir probes instruments – Fly models LP-1 and LP-2. (a) Functional diagram of circuit for electronic fuse and current limitation EF-CL. (b) Appearance of EF-CL. (c) Appearances of Langmuir probes measuring mono-block LP-PP and electronic block LP-VP. (d) Appearance of secondary power system for Langmuir probe SPS-LP-F. (e) Functional diagram of SPS-LP-F

three Tr1-3 transformers (4, 15, 26); dedicated DC/DC converter TSM 0505D (35), and four stabilizing feedback loops FB1-4 (9, 20, 31, 38) are used. To meet

T a b l e 1

Parameters of SPS-LP-F-1,2,3,4 for instruments LP-1 and LP-2

SPS-LP-F-1,2,3,4	U _{bn} [V]	17	19	23	29	34	36
F-1, P _{out} = 2.402 W	efficiency [%]	64.52	64.50	64.47	60.25	55.90	53.99
F-1, P _{out} = 2.402 W	P _{bn} [W]	3.723	3.724	3.726	3.987	4.297	4.449
F-2, P _{out} = 2.402 W	efficiency [%]	63.65	64.35	63.92	60.02	55.63	53.81
F-2, P _{out} = 2.402 W	P _{bn} [W]	3.774	3.733	3.758	4.002	4.318	4.464
F-3, P _{out} = 2.402 W	efficiency [%]	64.67	65.17	64.87	60.73	56.35	54.60
F-3, P _{out} = 2.402 W	P _{bn} [W]	3.714	3.686	3.703	3.955	4.263	4.399
F-4, P _{out} = 2.402 W	efficiency [%]	65.11	65.17	64.47	60.24	56.07	54.25
F-4, P _{out} = 2.402 W	P _{bn} [W]	3.689	3.686	3.726	3.987.5	4.284	4.428
F-1, P _{out} = 0 W	P _{bn} [mW]	595	661	726.8	1000.5	1302	1440
F-2, P _{out} = 0 W	P _{bn} [mW]	615.4	683	752.1	1029.5	1339	1476
F-3, P _{out} = 0 W	P _{bn} [mW]	603.5	646	742.9	1015	1315	1451
F-4, P _{out} = 0 W	P _{bn} [mW]	593.3	627	729.1	1003.4	1309	1450.8

the electromagnetic compatibility (EMC) requirements of [13] Dr1, Dr2 chokes and LC filters (2, 13, 24, 33) are used. The operating frequencies of Ctr1-4 are specially selected to avoid the combination of high-energy harmonics [18].

Results. Four identical flight models SPS-LP-F-1,2,3,4 were built for the ISS. Two of them LP-F-1,2 were operated in open space conditions outside the ISS from April 23, 2013 to May 9, 2015 without any functional problems.

Table 1 gives the parameters of SPS-LP-F-1,2,3,4 for device LP-1 and LP-2 at idle P_{out} = 0 W and at full load P_{out} = 2.402 W with resistor equivalent load. Input power in BN (P_{bn}) is different for U_{bn} = 17 ÷ 36 V, but for working range 28.5 ± 5.5 V efficiency changes only ~ 60 ± 5%. The technical documentation for SPS-LP-F-1,2,3,4 is compiled. The SPS-LP-F design fulfils the requirements of the ISS electric power system [19,20].

Discussion. Data on the electrical potential of the ISS recorded by the probe Langmuir LP-1 (ZL-1), indicate that when leaving the shadow, the ISS potential value increases from ~5 to ~ 20 V [11] (the floating potential of the station has become -20 V).

Conclusions. According to the specification, at a BN voltage of 28.5 V a minimum consumption of 0.3135 W must be ensured for each LP device in the off-state condition. For the flight samples, 3.3 times lower than the desired consumption was achieved (0.094 W). It was measured by the LP instrument that the surface potential off ISS fluctuates between 3 ÷ 25 V with respect to the ambient plasma.

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REFERENCES

- [¹] KLIMOV S. I., V. A. GRUSHIN, K. BALAJTHY, D. BACHVAROV, S. M. BELYAEV et al. (2021) Studying of space weather electromagnetic parameters of ionosphere in “Obstanovka 1-step” experiment on the Russian segment of the ISS, *Kosmicheskaya tekhnika i tekhnologii*, **1(32)/2021**, 20–41 (in Russian), DOI: 10.33950/spacetechn-2308-7625-2021-1-20-41.
- [²] GRAMATIKOV P., R. NEDKOV, G. STANEV (2019) Secondary power supply system for spacecraft potential monitor DP-1 and DP-2, “Obstanovka” Project, International Space Station, Aerospace Research in Bulgaria, **31**, 108–116, DOI: <https://doi.org/10.3897/arb.v31.e09>.
- [³] KIROV B., S. ASENOVSKI, D. BACHVAROV, A. BONEVA, V. GRUSHIN et al. (2016) Langmuir probe measurements aboard the International Space Station, *Geomagn. Aeron.*, **56**(8), 1082–1089, <https://doi.org/10.1134/S0016793216080120>.
- [⁴] KIROV B. (2010) Report on FA8655-08-1-3006 Langmuir probes for “Obstanovka” experiment aboard the Russian segment of the International Space Station, August 04, 8 pp, <https://apps.dtic.mil/sti/pdfs/ADA525750.pdf>.
- [⁵] KIROV B., S. ASENOVSKI, D. BACHVAROV, A. BONEVA, V. GRUSHIN et al. (2015) Langmuir probe measurements aboard the International Space Station. In: Proc. 19th Russian Conf. Sun Physics: Sun & Sun-Earth Physics – 2015, St. Petersburg, Pulkovo, 5–9 Oct, 205–208, <https://www.researchgate.net/profile/Stanislaw-Klimov/publication/292144186>.
- [⁶] KIROV B. (2011) An instrument for measuring the near-surface plasma temperature and concentration, and the surface charging of the international space station. In: Advances in Geosciences, Vol. 27: Solar Terrestrial (ST), 85–97, <https://pdfs.semanticscholar.org/0923/ed60fe70b12ce74f4ba57a654ef30eee77cd.pdf>.
- [⁷] GOUSHEVA M. N., P. S. ANGELOV, P. S. HRISTOV, B. B. KIROV, K. Y. GEORGIEVA (2003) The ionosphere plasma structural parameters investigation by a Langmuir cylindrical probe eliminating the spacecraft floating potential influence, Aerospace Research in Bulgaria, **18**, 65–69, http://journal.space.bas.bg/arhiv/n18/Articles/8_Gousheva.pdf.
- [⁸] BACHVAROV D., A. BONEVA, B. KIROV, Y. BONEVA, G. STANEV et al. (2014) Primary information preprocessing system for LP, DP devices-project “Obstanovka”. In: Proc. Int. Conf. on Big Data, Knowledge and Control Systems Engineering, Sofia, Bulgaria, 65–72 (in Bulgarian), <https://www.iict.bas.bg/acomin/events/8-10-October-2013/PrimaryinformationpreprocessingsystemforLP,DPdevices-project.pdf>
- [⁹] KLIMOV S. I., V. E. KOREPANOV, Y. V. LISSAKOV, O. V. LAPSHINOVA, K. SOROKIN et al. (2002) Obstanovka experiment onboard International Space Station for space weather research. In: Proc. Space Weather Workshop: Space Weather Applications Pilot Project, ESTEC, Noordwijk, The Netherlands, 1–13, https://swe.ssa.esa.int/TECEES/spweather/workshops/spw_w4/proceedings/PaperFinal.pdf
- [¹⁰] MERLINO R. L. (2007) Understanding Langmuir probe current-voltage characteristics, *Am. J. Phys.*, **75**(12), 1078–1085, <https://doi.org/10.1119/1.2772282>.
- [¹¹] KLIMOV S. I., V. A. GRUSHIN, L. D. BELIAKOVA, D. I. NOVIKOV, V. N. ANGAROV et al. (2012) Methodology of spatio-temporal measurements plasma-

- wave processes in the ionosphere using the infrastructure of the Russian segment of the International Space Station. In: Proc. Jubilee Int. Congr. Science, Education, Technologies "40 Years Bulgaria – Space Country", Vol. 1, Varna, 81–88 (ISBN 978-954-577-36-6), https://www.researchgate.net/publication/310014463_Association_Scientific_and_Applied.
- [12] SHUN'KO E. V. (2009) Langmuir Probe in Theory and Practice, Boca Raton, USA, Universal Publ., 243 pp (ISBN 978-1-59942-935-9).
- [13] S. P. Korolev Space Rocket Corporation "Energia", Russian Segment of the International Space Station. User's Guide, 191 pp (in Russian), https://www.gastroscan.ru/literature/pdf/iss_rs_guide.pdf.
- [14] NEYCHEV S., S. KLIMOV, A. ANEV, N. BARUH, L. BELYAKOVA et al. (2014) Device for measurement of spacecraft potential of ISS – equipment and first results. In: Proc. 9th Sci. Conf. with Int. Part. "Space Ecology Safety", 15–23 (in Russian, ISSN 1313-3888), http://www.space.bas.bg/SES/archive/SES2013_DOKLADI/NEDKOV_PLENAREN.pdf.
- [15] GRAMATIKOV P. (2017) Secondary power supply system of space equipment "AMEF-WB". In: Proc. SES2017, Space Research Technology Institute, Bulgarian Academy of Sciences, 149–152 (in Bulgarian, ISSN 1313-3888), http://www.space.bas.bg/SES/archive/SES2017_DOKLADI/2_AerospaceTechnologies/7_Gramatikov.pdf.
- [16] SHKEVOV R. (2008) Method and device for protection of space complexes during active experiments, BG Patent No 65422/29.09.2008, Espacenet Document BG65422B1, 2008, Patent Office of the Republic of Bulgaria, https://worldwide.espacenet.com/publicationDetails/biblio?DB=EPDOC&II=0&ND=3&adjacent=true&locale=en_EP&FT=D&date=20050630&CC=BG&NR=108417A&KC=A.
- [17] BASSO C. P. (2014) Switch-Mode Power Supplies SPICE Simulations and Practical Designs, McGraw-Hill Education, 957 pp, ISBN 978-0-07-182473-6.
- [18] MANIKTALA S. (2014) Switching Power Supply Design and Optimization, McGraw-Hill Education, 537 pp, ISBN 978-0-07-179813-6.
- [19] GIETL E. B., E. W. GHOLDSTON, B. A. MANNERS, R. A. DELVENTHAL (2000) The electric power system of the International Space Station-a platform for power technology development. In: Proc. 2000 IEEE Aerospace Conf., Vol. 4, 47–54, DOI: 10.1109/AERO.2000.878364.
- [20] JANNETTE A. G., J. S. HOJNICKI, D. B. MCKISSOCK, J. FINCANNON, T. W. KERSLAKE et al. (2002) Validation of international space station electrical performance model via on-orbit telemetry. In: IECEC'02 2002 37th Intersociety Energy Conversion Engineering Conference, 2002, July, IEEE, 45–50, DOI: 10.1109/IECEC.2002.1391972.

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