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Development of workspace and algorithms for testing SpaceWire onboard equipment

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For a long time, the foreign space industry has been using one of the most advanced and actively developing technologies for transmitting information on board a spacecraft – SpaceWire. This technology provides high-speed transmission of large amounts of information, the creation of a single high-speed data processing infrastructure for connecting sensors, data processing system elements and mass memory blocks. In Russia, SpaceWire is gradually being introduced and used on promising spacecraft. To verify the compliance of the onboard equipment of such vehicles with the requirements of the SpaceWire ECSS-E-ST-50-12C Rev standard.1 there is a need to develop the workplace described in this article. The workplace is designed so that SpaceWire onboard equipment can be connected to it and tests can be run that check certain parameters of information exchange regulated by the standard. The article presents the general structure of the workplace, as well as a description of each of its elements separately, together with a description of their functionality. The article also describes the developed testing algorithms. Among them, we can single out a check for compliance with the bit error coefficient to the required value, a check for support for the header removal method by SpaceWire switches, as well as a check for compliance with the requirements for the RMAP and STP-ISS transport protocols. The algorithms of these tests are presented in the form of flowcharts and a detailed text description. The tests themselves are implemented in the form of program code in the C language. As a confirmation of the correctness of the developed tests, practical testing of SpaceWire devices was carried out, among which two payload boards for the NORBY spacecraft can be distinguished, as well as an ultra-large integrated circuit 1931KH014 of a programmable switch for SpaceWire networks. A brief description of the testing devices used in the work is given in the form of a presentation of their functionality applicable to the testing workplace being developed.

Keywords: onboard equipment, spacecraft, test stands, testing algorithms, SpaceWire.

Разработка рабочего места и алгоритмов тестирования бортового оборудования SpaceWire

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В зарубежной космической отрасли на протяжении долгого времени используется одна из наиболее передовых и активно развивающихся технологий передачи информации на борту космического аппарата – SpaceWire. Данная технология обеспечивает высокоскоростную передачу больших объемов информации, создание единой инфраструктуры высокоскоростной обработки данных для соединения датчиков, элементов системы обработки данных и блоков массовой памяти. В России SpaceWire постепенно внедряется и используется на перспективных космических аппаратах. Для проверки соответствия бортовой аппаратуры таких аппаратов требованиям стандарта SpaceWire ECSS-E-ST-50-12C Rev.1 существует необходимость в разработке рабочего места, описанного в данной статье. Рабочее место предназначено для того, чтобы к нему можно было подключить бортовое оборудование SpaceWire и запустить тесты, проверяющие определенные параметры информационного обмена, регламентируемые стандартом. В статье представлена общая структура рабочего места, а также описание каждого из его элементов в отдельности вместе с изложением их функционала. Также в статье описаны разработанные алгоритмы тестирования. Среди них можно выделить проверку на соответствие коэффициенту битовых ошибок требуемому значению, проверку поддержки метода удаления заголовка коммутаторами SpaceWire, а также проверку на соответствие требованиям к транспортным протоколам RMAP и СТП-ИСС. Алгоритмы данных тестов представлены в виде блок-схем и подробного текстового описания. Сами тесты реализованы в виде программного кода на языке С. В качестве подтверждения корректности работы разработанных тестов было проведено практическое тестирование устройств SpaceWire, среди которых можно выделить две платы полезной нагрузки для космического аппарата «НОРБИ», а также сверхбольшую интегральную схему 1931КХ014 программируемого коммутатора для сетей SpaceWire. Приведено краткое описание используемых в работе устройств тестирования в виде изложения их функционала, применимого к разрабатываемому рабочему месту тестирования.

Ключевые слова: бортовая аппаратура, космические аппараты, стенды тестирования, алгоритмы тестирования, SpaceWire.

Introduction

Unification of the computer interfaces used for a long time has been a problem in the design of spacecraft (SC). For domestic spacecraft, the introduction of a multiplex information exchange channel (MIEC) based on the foreign standard MIL-STD-1553B has become significant in the unification of on-board interfaces. Based on it, two versions of domestic standards were released: GOST 26765.52–87 and GOST R 52070-2003 [1], which replaced it, which still serves as the foundation for the unification of spacecraft on-board interfaces. At the same time, there are still needs to increase the speed of transmission and processing of information, reduce energy consumption, mass and cost of space technology, which requires the introduction of new information transmission technologies based on the achievements of modern microelectronics.

A purposeful attempt to change this situation was made by the European Space Agency (ESA). The European Association for Standardization in the Field of Space Technology (European Cooperation for Space Standardization (ECSS)), working within the framework of the European Space Program, in 2003 adopted the first version of the SpaceWire standard – "Connections, nodes, routers and networks". In 20019, the current SpaceWire ECSS-E-ST-50-12C Rev standard was adopted.1, based on the standards IEEE 1355-1995, TIA/EIA-644 and IEEE Standard1596.3-1996 [2].

Workplace development

Hardware and software modeling technologies are becoming an integral part of scientific and technical activities in the modern world. Conducting experimental studies of complex technical systems, as a rule, is associated with economic and technological difficulties. In this regard, the role of specialized tools is increasing, allowing to model technical systems before their manufacture and further use the constructed models in the development and operation of equipment [3].

To date, SpaceWire technology is widely used in the space industry by all major space agencies and is used in many current ESA, NASA and JAXA space missions [4]. In this regard, the question arises about how to test equipment that supports this technology. Currently, no comprehensive solution to this problem has been identified in Russia. In this regard, the development of a stand for complex testing of SpaceWire onboard networks was started.

The stand is a complex that works out aspects related to the construction of the onboard network, as well as checks individual devices for compliance with the SpaceWire ECSS-E-ST-50-12C Rev standard.1, as well as the standards of the transport protocols RMAP ECSS-E-ST-50-52C [5] and STP-ISS [6]. It consists of several modules. The modular structure makes it possible to further reconfigure the stand depending on the task being solved. The first module of this stand (workplace) is described in this article.

The on-board equipment testing workplace is tasked with working out aspects at the device level. The equipment of the module should provide data transfer between two devices, implementing a simple network. Therefore, the module can use two units of on-board equipment to be tested. One of these test objects can be replaced by a simulator.

Data transmission is controlled by an external software and computing module (SCM-1), which is a personal computer (PC) with special software (SS-1). This SS-1 is a program written in the C programming language. This program allows you to test the compliance of the bit error rate (BER) with the required value, check the support of the header removal method by switches, support for mechanisms regulated by the RMAP and STP-ISS transport protocols. The module will have a tester "Type-1", which allows you to perform checks corresponding to the specifics of the module. For the tests considered, such a tester is the 4Links Diagnostic SpaceWire Interface. This device allows you to transmit, receive and process data packets, manage connection parameters, record information about past operations [7].

As technological equipment, the module uses a router designed to connect the 4Links Diagnostic SpaceWire Interface with test objects, and so that in the future this module can be connected to other modules of the stand being implemented with the subsequent organization of various network topologies.

The structure of the workplace unit (WP) for testing on-board equipment (OE) is shown in fig. 1.

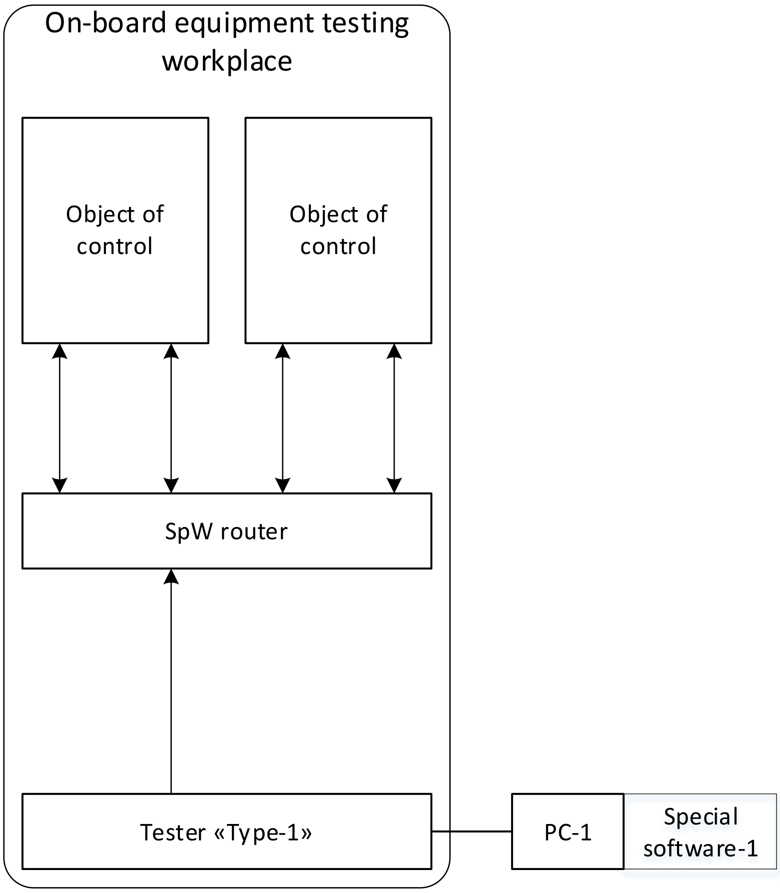

Fig. 1. Structure of the on-board equipment testing workplace unit

Рис. 1. Структура блока рабочего места тестирования бортовой аппаратуры

Testing algorithms

Testing algorithms have been developed for the WP on-board equipment, some of which are implemented in the form of SS-1. Further, each of them is described in more detail:

1. One of the tests at the symbolic level is to check for compliance with BER equal to 10-12 for a speed of 100 Mbit/s [8]. Therefore, the following testing algorithm was developed.

Before starting testing, it is necessary to connect the first port of the node under test to the first port of the testing device.

At the initial stage, a link is installed between the receiver and the transmitter. After a successful connection, an array of data is formed from a predetermined number of packets of a certain length, and then they are sent. After the packet arrives at the receiver, it is compared bitwise with the expected packet (the expected packets are written in the receiver code in advance). There is an increase in the variable that is the counter of distorted bits. When the last packet is transmitted, BER is calculated as the ratio of the distorted received bits to their total number. This number is compared with the required one, and according to this result, a message is displayed about whether the equipment meets the BER requirements or not. The flow chart of this testing algorithm is shown in Fig. 2.

2. At the network level, as one of the tests, the support of SpaceWire switches for the header deletion method is checked. When implementing this method, packet headers, including the destination node address, are discarded when passing through the switch port.

Before starting testing, it is necessary to connect the first port of the switching unit under test to the first port of the testing device. For the remaining ports to transfer the switch, use loopback cables [9].

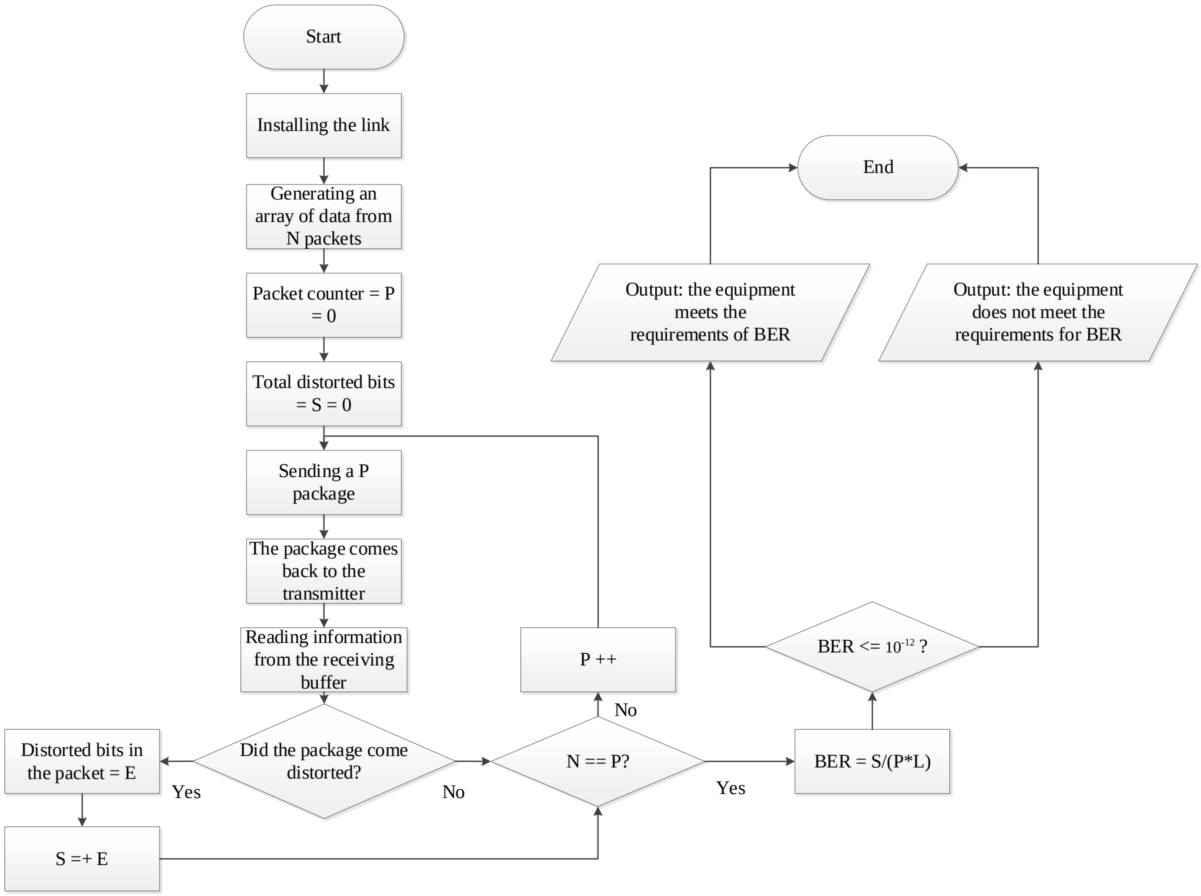

Fig. 2. Flowchart of the bit error rate testing algorithm

Рис. 2. Блок-схема алгоритма тестирования коэффициента битовых ошибок

A connection is being established. After that, a fixed data packet is formed with the indication of the path address, which points to all the ports of the switch involved without repetition. Next, the packet is sent to the switch, from which, after passing through all the ports, it should come back. Depending on whether the packet came back or not, the corresponding message is displayed. A flowchart of the algorithm for testing the method of removing the switch header is shown in Fig. 3.

This test is the first test for the network layer of the SpaceWire ECSS-E-ST-50-12C Rev.1 standard. On its basis, the verification of the path and logical addressing is being developed. When using path addressing, the destination address is defined as a sequence of router output port numbers that are used to orient the packet in the network [10]. In logical addressing, each destination node has a unique number or logical address associated with it [11]. It is also planned to develop an algorithm for testing the principle of "worm routing" [12].

3. At the transport level, test algorithms have been developed to verify the support of the tested equipment for the specified mechanisms of the STP-ISS protocol:

– sending three types of messages (control command , regular, urgent);

– receiving a maximum size packet;

– receiving/sending a confirmation packet.

As an example, it is proposed to consider sending a message and receiving a confirmation packet by the device under test. These algorithms can be implemented in a single test.

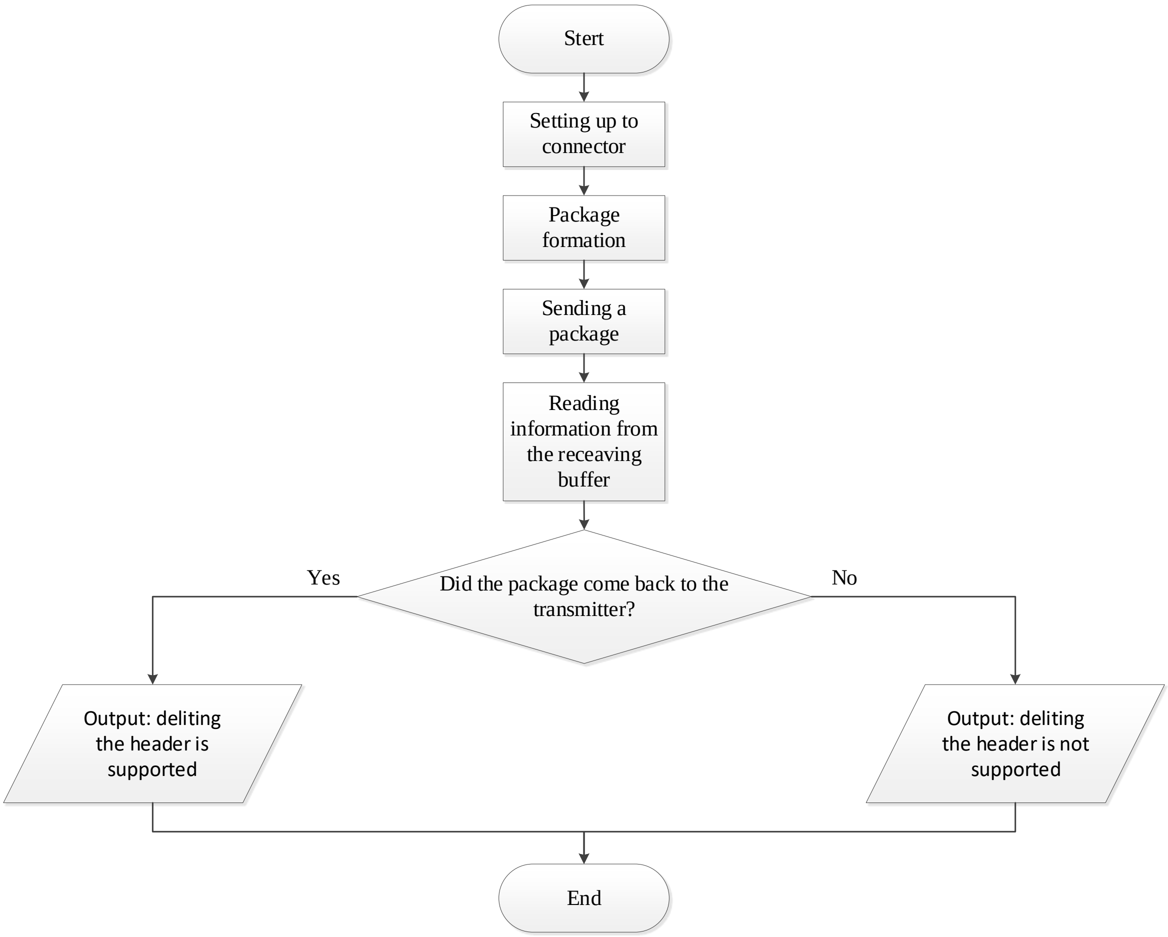

Fig. 3. Flowchart of the algorithm for testing the header removal method

Рис. 3. Блок-схема алгоритма тестирования метода удаления заголовка

The control device by means of software organizes the transfer of information between two nodes, one of which will be the equipment under test. In one case, this equipment will be a transmitter, in the other - a receiver. This can be implemented, since nodes can operate in full-duplex mode [13]. In this article, as an example, we consider the case in which the device under test is a transmitter.

At the initial stage, a connection is established between the transmitter and receiver. Next, a message is displayed about the selection of the test that the user wants to run - sending a control command (CC), an urgent message or a regular message. The user makes the appropriate choice. One of the testing blocks will be discussed in detail later. After passing one of these tests, a message is displayed with a suggestion to complete the entire test. The user can continue testing by selecting the "no" option, in which case he will be sent to the command test selection stage. Otherwise, testing ends. The flowchart of this testing algorithm is shown in fig. 4.

Algorithm 1 (CC) is considered as an example. The flowchart for the CC and information packages will be identical. The control device on the transmitter generates a fixed CC packet (with the response bit set to 1). The transfer starts. In parallel, a watchdog timer is started on the receiver. The receiver is waiting for a packet. The CC must be transmitted to the receiver. If the transmission of packets does not occur, then the watchdog timer expires on the receiver. When the timer expires, a message is displayed on the screen stating that the equipment does not support the transmission of CC packets. The test is being completed. If the CC is received by the receiver, a confirmation packet is generated and sent. If the confirmation packet is received by the transmitter, the corresponding message about the successful completion of the test is displayed. Otherwise, a failure message is displayed. After that, the test is completed. The flowchart of the test for sending the CC and receiving the confirmation packet according to the STP-ISS transport protocol is shown in fig. 5.

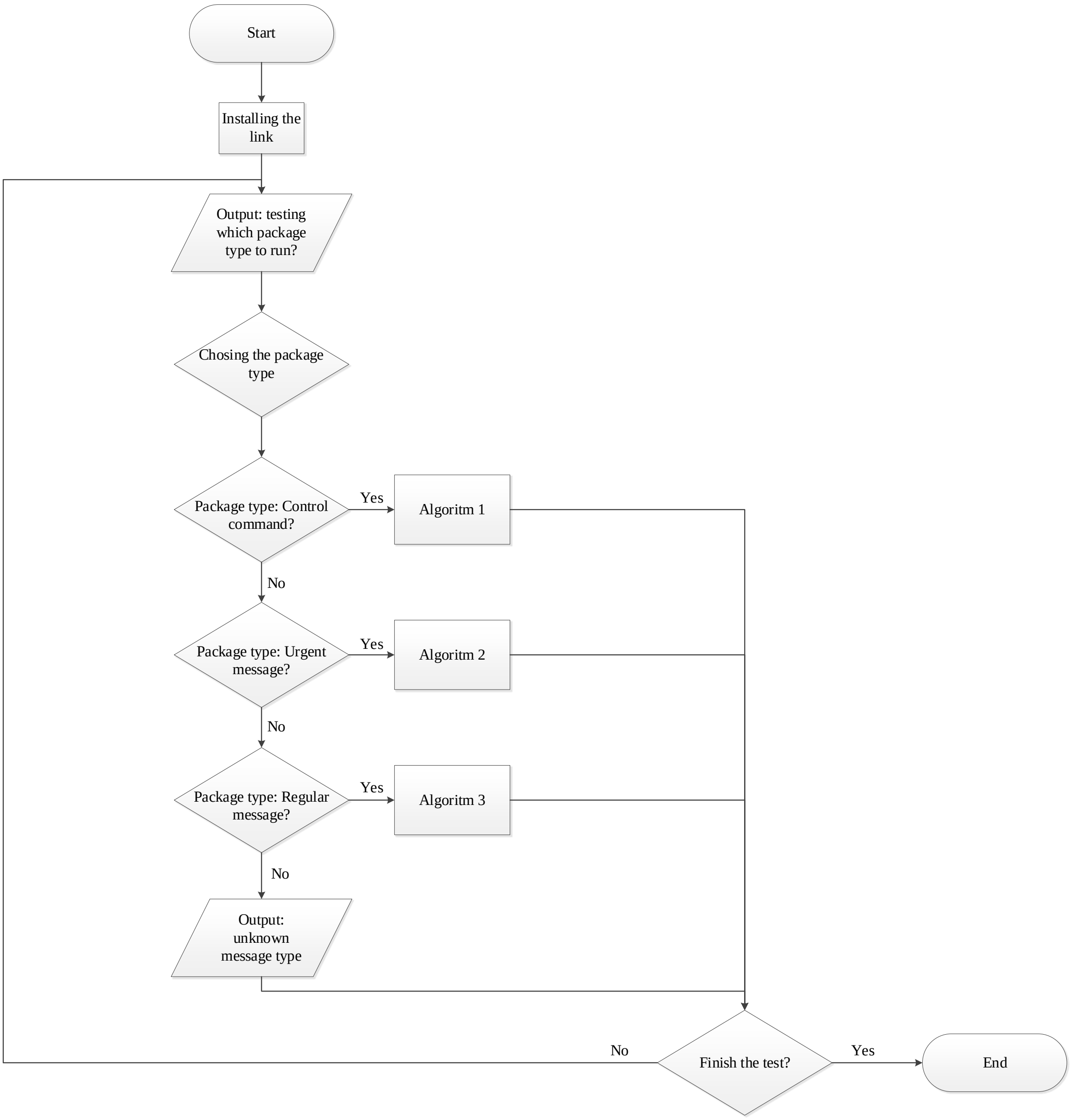

Fig. 4. Flowchart of the general algorithm for testing support
or the STP-ISS transport protocol

Рис. 4. Блок-схема общего алгоритма тестирования поддержки
STP-ISS transport protocol

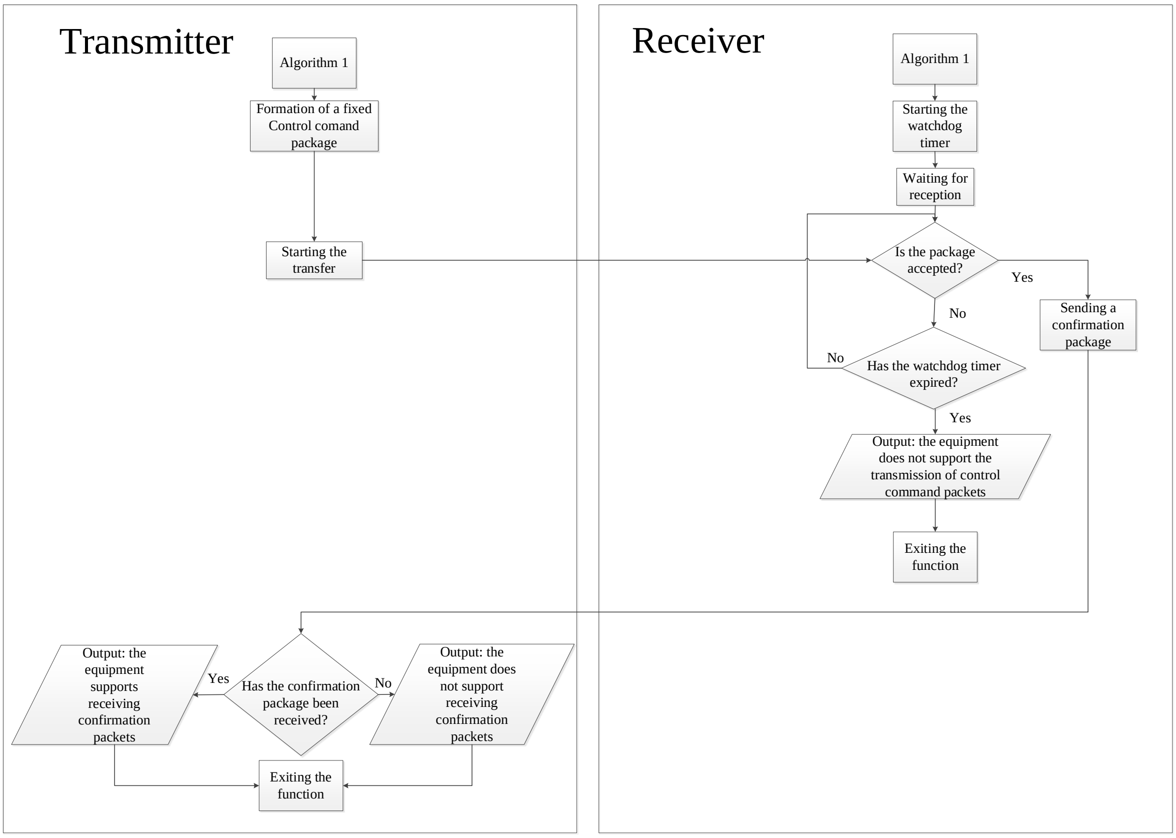

Fig. 5. Flowchart of the test of sending the control command and receiving the confirmation packet according to the STP-ISS transport protocol

Рис. 5. Блок-схема теста отправки КУ и получения пакета подтверждения согласно транспортному протоколу СТП-ИСС

Similar STP-ISS testing algorithms were developed for the RMAP transport protocol, but they were not implemented programmatically. In this regard, these tests are not submitted for review within the framework of this article.

Practical testing

The above tests were tested on real SpaceWire equipment. To test support for the header removal method, an ultra-large integrated circuit 1931KH014 of a programmable switch for SpaceWire networks was used [14]. So, during testing it was revealed that this switch supports this method.

To test equipment compliance with BER requirements (10-12 for 100 Mbps speed) two payload boards were used for the NORBY spacecraft [15]. For this equipment, BER has not exceeded the required limits.

Two payload boards for the NORBY spacecraft were also used to test on-board equipment support for the STP-ISS transport protocol. This equipment has successfully passed all the previously considered tests (sending three types of messages (CC, normal, urgent), receiving a maximum size packet, receiving/sending a confirmation packet).

Conclusion

During the work on this project, the general structure of the onboard equipment of testing workplace was developed and its functionality was presented. Several testing algorithms have been developed and subsequently implemented in the C programming language. The developed algorithms were tested on SpaceWire equipment. In the future, the following tasks will be solved:

– software implementation of testing algorithms to verify the compliance of equipment with the requirements of the RMAP transport protocol standard;

– development of testing algorithms to expand the functionality of the workplace;

– adding new modules of the test bench to simulate the onboard network of the spacecraft.

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