Electrical component base testing in process of spacecraft configuration

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Abstract. In current conditions and according to the quality level of Electronic Component Base of domestic production and due to the purchase of significant amount of electronic component base of foreign production - additional screening testing, diagnostic non-destructive testing with selective destructive analysis in professional testing centers are necessary. Costs of their performance are insignificant compared to possible losses of material (and not just material) while using spacecraft with bad quality of electrical component base. The authors show the need for additional testing of electronic component base applied in on-board equipment of spacecraft.

1. Introduction
Up-to-date development of rocket-space technology (RST) sets to the hardware engineers rigid requirements — improvement of overall-mass characteristics, increase of functional capabilities of equipment and enhancement of active shelf life (ASL) [1]. Electronic Component Base (ECB) which is used in on-board equipment of spacecraft must offer following specific conditions [2]:

- Variety of functional tasks performed by spacecraft lead to necessity of usage of wide range of part types of ECB at extremely small quantitative needs.
- Wide range of functional part type of ECB requires in the process of manufacturing applications of different techniques and some of them are unique and they are not exist in Russia.
- Rigid requirements to ASL with a total absence of reparability result in extra rigid reliability requirements and resistance to disturbing factors of space.

Due to very low size of consumption of ECB and until recently time wide accessibility of ECB of FP of military grade (for use in military systems) and SPACE grade (radiation hardness for use in aggressive space environment) related to absence in Russian Federation of specialized production of ECB for use in rocket-space technology (RST).

Since in the Russian Federation there is no specialized production of ECB for use in RST, the tasks of configuration of on-board equipment are solved by using ECB of FP and configuration of ECB of DP of on-board equipment through specialized technical testing centers with conducting an operation of complete incoming inspection (CII) of ECB, additional screening tests (AST), diagnostic non-destructive testing (DNDT) using selective destructive physical analysis (DPA).
2. Quality of electronic component base
On their functionality and grades the ECB of foreign and domestic production have following classification, according to the figure 1 [3]:

![Figure 1. Classification of Electronic component base.](image)

Table 1 shows selection requirements on quality level of ECB of foreign production for use by design engineers of on-board equipment according to ASL of spacecraft. In line, which corresponds to the quality level, sign “+” means that applying of ECB of foreign production with such quality level – approved, sign ”-“ means that applying of ECB of foreign production with such quality level – not approved.

| Quality level  | ASL over 5 years | ASL from 2 to 5 years | ASL up to 2 years |
|----------------|------------------|-----------------------|------------------|
| Space          | +                | +                     | +                |
| Military       | +                | +                     | +                |
| HiRel SCD      | +                | +                     | +                |
| HiRel MFR      | -                | +                     | +                |
| Industrial     | -                | +                     | +                |

When selecting the ECB products of FP for use in on-board equipment of spacecraft guide to the following requirements:

- Quality level of ECB of FP should confirm to the requirements specify in table 1.
- Level of radiation hardness ECB product of FP must ensure performance capability of spacecraft during target ASL, for all types of radiation effects to which the ECB product of FP is sensitive, depending on the functional purpose, manufacturing technology and type of semiconductor.
• It is preferable to choose qualified ECB products of FP in sealed housings included in the list of qualified ECB products of FP (QPL, QML, EPPL, etc.).
• Non-metallic housing parts of the ECB products of FP must be resistant to vacuum and thermal effects, the weight loss and the content of volatile condensable substances are determined in accordance with GOST R 50109.
• The tin content in the coating of the terminals of the ECB product of FP should not exceed 96%.
• When exposed to vacuum and heat the coating of the terminals should not form burrs ("whiskers").

3. Electrical component base of foreign production
The procedure for selecting and using the ECB of FP is determined by the stage of the shelf life of spacecraft, we will pay special attention on the production phase, at which the configuration procedure of ECB of FP of spacecraft is developed. In process of configuration of spacecraft on-board equipment, depending on the quality level of the purchased ECB of FP, the following tasks are solved [4]:

• demonstrate the conformity of the ECB products of FP to the requirements of the technical specifications for the manufactured spacecraft and the requirements to the applied documents;
• demonstrate the conformity of resistance to influencing factors specified in the model of external influencing factors;
• determine the possibility of using the ECB product of FP in the spacecraft by conducting incoming inspection, diagnostic tests, life-cycle tests and screening tests, if necessary.

Since foreign standards that establish requirements for electronic component base of FP for space applications, according to which it is produced and applied in foreign countries they are significantly differ from the regulatory documents that are valid in Russia, the process of selection, approval of the use of ECB of FP for creation of space equipment of DP and confirmation of its compliance - certification of ECB of FP in the system of compulsory certification of space technology with the issuance of a certificate, in current conditions is a very risky and expensive procedure [5].

The use by designers of ECB of the INDUSTRIAL grade (for industrial use) is associated with the need to conduct expensive certification tests, since the design of the ECB of this quality level does not guarantee radiation hardness and the probability of failure of these products during operation is much higher than of military- and SPACE grade.

4. Tests of the electronic component base
As for the ECB of DP, since serial domestic products of dual and special use from the "List of electronic component base permitted for use in the development, modernization, production and operation of weapons, military and special equipment" today do not meet to high requirements of designers of spacecraft on-board equipment to the level of quality and reliability and the development and production of electronic components within the framework of targeted programs of import substitution are associated with the need to attract multibillion budgetary financing and large time costs from the date of approval of the program - from 2 to 3 years [6], the main way of providing on-board equipment for electronic components of domestic production is the configuration through specialized technical testing centers.

In fact, the task of the test centers is selecting the required number of ECB elements that meet the rigid requirements of the space industry from the batches of ECB of general military (non-specialized) application. The solution to this task is a complex organizational and high-tech process that provides a configuration of ECB of DP of spacecraft on-board equipment with the required quality and reliability level.

After the implementation into the legislation of the Russian Federation of the legal foundations of state regulation of relations related to the formation, features of placement, execution of the state defense order and state control (supervision) in the field of the state defense order, as well as the basic principles
and methods of state regulation of prices for goods, works, services under the state defense order, the approach to organizing the configuration processes of the spacecraft on-board equipment and their financial support has changed.

Today, the average term for configuration of spacecraft on-board equipment with ECB of DP has significantly increased and now it takes from eight to twelve months (including additional tests), from two to three of which are taken by the process of contracting with the Customer and the cooperation of ECB suppliers.

As regards the costs of additional tests of the ECB of the DP, it is necessary to consider the methodology of their implementation, which has the following (in general):

- All elements (without exception) of the tested batch of ECB pass incoming inspection and additional screening test [7, 8].
- From each ECB of certain classes (microcircuits, semiconductor devices, relays), test samples are formed for carrying out DPA with the distribution of the obtained DPA results [9] to the entire batch of ECB.

If necessary, the technical testing center (TTC) additionally provides testing of the ECB test sample for radiation hardness and other tests that require a special approach and configuration [1, 2, 10].

Taking into account the wide range of products, functional and technical features used by the designers of the element base of the spacecraft on-board equipment, as well as the requirements of the Customers for the operating modes, for each type of ECB, the volume and sequence of additional tests are determined, and in a result of this tests the ECB is divided into grades: suitable, potentially unreliable (meets the manufacturer's specifications, but does not meet the requirements of the rocket-space industry) and reject.

In future spacecraft, there will be a change in the parts range, an increase in the degree of integration and functional characteristics of ECB requiring additional work and the implementation of up-to-date method and types of screening tests using unique technical solutions that have not yet been implemented in Russian test centers, that will further lead to an increase in the cost of testing ECB and configuration.

5. Adjustment of additional tests

In addition to the implementation of new technical solutions that have not been implemented in technical testing centers, today, in order to minimize the risks of financial and temporary losses when configuration on-board equipment, monitoring and timely adjustment of existing technological processes for additional ECB tests are required.

The types and sequence of additional tests of ECB are determined by the programs of additional tests approved by the Customers and agreed in accordance with the established procedure by the corresponding centers of competence. As a rule, the period of additional tests in accordance with the programs does not exceed 2 months, however, the current state of the quality of modern electronic components developed by Russian manufacturers (as an analogue of foreign components) and used by the designers of ECB of the spacecraft on-board equipment can be increase up to one year or more [11, 12]. This is related to the fact of technological processes immaturity for the production of ECB and it’s adjustment requires significant time and financial resources.

Using the example of work on configuration of power modules of DP, we will consider the importance of timely adjustments by the testing center of technological processes for additional tests of ECB (table 2). For objective reasons, we do not indicate the type of power modules and the manufacturer.

Taking into account the special aspects of production technology, during additional tests at the phase of leakage control (paragraph 3.10), power modules in 80% of cases belonged to the grade of "rejects" and were sent to the manufacturer for rework. After rework, the power modules were returned to the test center and the additional testing process was started beginning with preparatory operations. Since the
defect was large, the test center decided to adjust the technology for conducting additional tests for this type of power modules by introducing an additional point of leakage control (now clause 3.1).

Table 2. Types and sequence of additional tests for power modules.

| Clause № | Type and sequence of additional tests |
|----------|---------------------------------------|
| 1        | Preparatory operations                 |
| 2        | Incoming inspection                    |
| 2.1      | Appearance inspection                  |
| 2.2      | Delivery of the batch to the Customer's representative |
| 3        | Screening tests and diagnostic non-destructive testing |
| 3.1      | Serialization                          |
| 3.2      | Aggravated parameter rules of technical conditions with recording of parameters |
| 3.3      | Contamination control                  |
| 3.4      | Aggravated parameter rules of technical conditions with recording of parameters |
| 3.5      | Thermal cycling                        |
| 3.6      | Aggravated parameter rules of technical conditions with recording of parameters |
| 3.7      | Thermal aging                          |
| 3.8      | Aggravated parameter rules of technical conditions with recording of parameters |
| 3.9      | Parameter drift calculation            |
| 3.10     | **Leakage control**                    |
| 3.11     | Aggravated parameter rules of technical conditions with recording of parameters |
| 4        | Final inspection                       |
| 4.1      | Appearance inspection                  |
| 5        | Final operations                       |
| 5.1      | Processing and analysis of results     |
| 5.2      | Marking                                |
| 5.3      | Drawing up of test results chart       |
| 5.4      | Delivery of the batch to the Customer's representative |
| 5.5      | Packing                                |
| 5.6      | Drawing up of an act of acceptance-transfer and results report |

Program adjustment indicated the ECB elements that do not meet the requirements of technical conditions at the first phase of additional tests. Common effect from the adjustment is about 4 million rubles as money equivalent and made it possible to significantly reduce the time of configuration, but even with the joint efforts of the test center and the manufacturer, they amounted to 14 months.

6. Conclusions
Since the configuration process is associated with significant time losses and financial costs, as well as the risk of a lack of a positive result even after carrying out a set of additional ECB tests, at each phase of configuration it is necessary to assess the probability of risks occurrence of additional time and financial losses associated with re-purchase (additional purchase of the missing quantity), and also to develop a comprehensive mechanism for end-to-end operational scheduling, controlling and adjusting the processes of configuration.

ECB in the process of additional tests can fail at various phases of their implementation, therefore, risk minimization is possible with a timely assessment of the expected probability of failures and adjusting, if necessary, the technological sequence and / or the volume of tests formed in accordance with the program of additional tests.

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