Quality assurance of electrical components for spacecraft on-board equipment

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Abstract. The paper considers the problems of ensuring high-level contractual requirements for single and complex reliability indicators of the spacecraft being designed. An original approach is proposed to ensure the quality of batches of electronic devices used to complete the on-board equipment of the spacecraft. The method of experimental quantitative estimation of coefficients taking into account changes in the operational intensity of failures from various factors, as well as the procedure for their reasonable assignment, is analysed.

1. Introduction

Currently, worldwide much attention is being paid to the development of space-based satellite communications and information retransmission. In the process of creation, there are promising space systems for satellite communication and retransmission with space vehicles that differ from analogues by a more complex structure, tougher requirements for indicators of efficiency and reliability, as well as by the cost of development.

The reality of modern world satellite construction is characterized by very tough competition for obtaining an order for the design and production of a spacecraft (SC), as the main element of the space complex. In order to win the tender and receive an order, the general contractor must provide a number of competitive advantages in the form of various operational, technical and economic characteristics of the future SC [1].

One of the advantages is the provision of high contractual requirements for single and complex reliability indicators of the SC being created and the attractive cost of its creation. The designer needs to start from a number of principles when planning work related to the problem of ensuring the reliability of SC at design stages. Such principles are as follows: the procedure for the formation of SC reliability requirements; productive methods of reliability guarantee.

Project-relating methods of ensuring reliability provide: application (selection) of electronic devices (ED) for the assembly of on-board equipment of SC (products of electronic and electrical engineering, the main among which are active elements, made in the form of discrete semiconductor devices and integrated circuits of varying complexity); the use of stable, wear-resistant and resistant to external influences of raw materials used in the design of SC and on-board systems [2]; application of optimal circuit solutions (design principles and project parameters of the SC, architecture, selected electrical and thermal modes of nodes and units of systems, structural design, protection from external influences, etc.), based on a special apparatus and modern methodology for carrying out project reliability analysis, as well as thermal, mechanical analysis and analysis of the resistance to space factors of the components of the SC being developed and modernized.

2. Approach for quality assurance of the electrical devices used for on-board equipment

The basic principle to ensure the quality of the electrical devices used for SC on-board equipment is the right choice of the devices and their characteristics for the future work.

Only electrical devices of the highest quality level are used in SC:

- ED of the domestic production with specific characteristics [3];
- ED of foreign production corresponding to the requirements of the European Space Agency or the USA Military Standards for use in space industry MIL-PRF-38535 (for integral circuits), MIL-PRF-38534 (for hybrid circuits), MIL-PRF-19500 (for semiconductor devices). All purchased items shall be checked in technology testing centres accredited by the government or non-state organizations having agreements of certificate mutual recognition [4].

Source [5] shows conditional accordance of the quality levels of integral and hybrid circuits, as well as of ED of domestic and foreign production. While producing SC on-board equipment an essential condition is decrease of ED heating and electrical loads in relation to permissible loads given in technical characteristics or specifications.

The used ED of the domestic production shall have the values of the minimum groundwork and necessary supply of the keeping quality duration based on the on-board equipment maintenance period and its production technological cycle. Standardization documents for ED should contain requirements for radiation persistence. In case these data are missing special tests are required.

The choice of the ED producer is carried out on the basis of the ED quality monitoring, at the same time the most important demand if radiation resistance.

EDs are purchased mainly by special quantities, which are produced basing on additional requirements. These requirements are defined on the basis of the background of ED work for each case and they can include additional demands for the raw materials, assembly parts, technology of production, equipment, quality control. Before installation all EDs are specially tested according to the worksheet of the input control.

In order to improve the quality of the applied EDs and reduce the intensity of failures by eliminating EDs with hidden defects from them, the on-board equipment intended for flight testing and operation in the spacecraft should be tested additionally in accordance with the "Supplementary program tests of electrical equipment in technology testing centres".

Criteria for acceptance of ED based on the results of the input control are established in the test program. EDs that do not meet the specified acceptance criteria from the results of additional tests are considered to be potentially unreliable and are not subject to installation into the flight equipment.

3. Increasing the reliability characteristics of flight EDs according to the results of the additional tests

An analysis of contractual requirements for modern SC reliability reshows that the requirements for the indicator of the longevity of a spacecraft with a long active life are constantly growing. The growth of requirements for indicators of longevity and reliability of spacecraft means a directive tightening of the requirements for the normal indices of the reliability of on-board spacecraft systems at the end of the required active life.

At the same time, the reference values of the basic failure rates of the main nomenclature of Russian EDs used for design calculations of equipment reliability for the past 10 years have grown insignificantly for a number of reasons, in connection with which the designers of on-board equipment systems have difficulty in confirming the required non-failure in the design phase [6].

One of the methods for ensuring the required faultlessness is the improvement of the applied methods of reserving on-board equipment (the method of reserve switching, the redundancy ratio, the reserve switching scheme, the reserve characteristic, the reserve fixing, the uniformity of reservation). However, the possibilities of ensuring the required reliability due to, for example, increasing the reserve multiplicity, as a rule, are limited. With redundancy by substitution, this method does lead to an increase in the probability of fail-free operation, but leads to a significant increase in the total mass of the SC, which contradicts the restrictions imposed on SC mass and cost.

The use of any other excess methods than structural, i.e. functional (redundancy of a serial chain of devices with one universal and other methods) is also used rarely because of the technical reasons. Thus, for the purposes of project confirmation of the required SC fail-free operation, additional principles are often needed to ensure the normalized reliability of the equipment being designed.

One of the principles is the use of highly-reliable EDs of the domestic production tested additionally in technology testing centres. This makes it possible to use an additional reduction factor for the base failure rates of EDs along with the normative ones. The model has the form

$$\lambda_э = \lambda_б' \times K_r \times K_{TTC} \times \prod_{i=1}^{n} K_i \,,$$

where: $\lambda_э$ – is the value of the ED operational failure intensity, used to calculate the equipment reliability; $\lambda'_б$ – is the source (basic) failure intensity of ED group, reduced to the conditions of the nominal electrical load at the ambient temperature of 25°C; K_r – is the standard regime ratio taking into consideration the change of $\lambda'_б$ depending on the electrical load and (or) the ambient temperature; K_i –are standard ratios that take account of changes of operational failure intensity depending on various factors: acceptance factor, operation factor, quality factor of the equipment development and production, ionizing radiation ratio; n – is the number of factors (ratios) taken into account; K_{TTC} – is the ratio which is additional to standard ones, which takes the account of the amount of the additional ED tests in technology testing centres before installation into the flight equipment as well as the increase of the ED reliability.

In accordance with the amount of additional tests K_{TTC} consists of the following types of tests and corresponding ratios:

- destructive physical analysis – K_{DPA};
- classification according to stricter standards – k_{ss};
- evaluation of ratio drifting – k_d.

Furthermore, taking into consideration independence of each component, KTTC is defined by the following equation

$$K_{TTC} = k_{DPA} \times k_{SS} \times k_d \,,$$

Paper [7] suggests the methods of k_{DPA}, k_{ss}, k_d ratios classification by stricter standards, which is developed on the basis of the ED tests analysis. Quantitative values of the expected ratios decreases are as a rule appointed for specific SC on the basis of the expert evaluation taking into account standard recommendation on quantitative values of the decreasing ratios, collected ED failure analysis during all kinds of tests and with the account of ratio results of the additional tests.

4. Conclusion

Thus, it is necessary as early as possible to solve all kinds of scientific and technical problems of improvement and development of theoretical and methodological theory, which will provide required SC reliability. Furthermore, it is essential to consider the uncertainty of the project decisions and analogue operational results. The authors of the paper suggested the procedure of developing KDI ratios together with the customer. The ratio takes the account of ED additional tests (input control, plant inspection, plant tests as a part of on-board equipment additional tests), which was used for some

SC [3]. Analysis showed that it became possible to reduce the base average ED group failure by more than three times and to assure the required reliability of SC on-board equipment.

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