Semantic modeling and structural synthesis of onboard electronics protection means as open information system

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Abstract. The article describes the component representation approach and semantic models of onboard electronics protection from ionizing radiation of various nature. Semantic models are constructed, the feature of which is the representation of electronic elements, protection modules, sources of impact in the form of blocks with interfaces. The rules of logical inference and algorithms for synthesizing the object properties of the semantic network, imitating the interface between the components of the protection system and the sources of radiation, are developed. The results of the algorithm are considered using the example of radiation-resistant microcircuits 1645RU5U, 1645RT2U and the calculation and experimental method for estimating the durability of on-board electronics.

1. Introduction
The design of on-board electronics (OE) used in space vehicles has always been and is being given a lot of attention, and first of all it concerns the reliability of space equipment. The electronic component base used has distinctive features that impose a number of limitations on design solutions [1]: a broad functional nomenclature (more than 1500 titles), low seriality (from 10 to 100 thousand units) throughout the life cycle of the product and, as a consequence, their high cost, as well as high requirements for reliability, resistance to ionizing radiation, extended temperature range (from -60 to 125°C), long periods of trouble-free operation (up to 15 years).

In addition, in the design process of the OE, it is necessary to solve the issues of providing constructive, electronic, information compatibility with other components of spacecraft. All this causes the urgency of research and development of specialized methods for component synthesis of OE, the purpose of which is to automate the process of searching for optimal configurations of the target technical system.

2. Formulation of the problem
The task consists in developing a component representation of the means for protecting the on-board electronics from ionizing radiation of various nature and creating their semantic models.

In [2], the technique of structurally-parametrical synthesis of open information systems (SOIS) is proposed, based on the concept of technical self-organization [3]. Its peculiarity is the component representation of information processes, software and hardware modules, program code, as well as constructive, electrical / optical, information constraints as elements of information systems with interfaces.
In the present work, this technique was applied to the structural synthesis of on-board electronics and its means of protection against ionizing radiation. In particular, each component of OE and ionizing radiation sources is complemented by interfaces through which it interfaces with protection components and radiation source components. Interfaces, as generalized properties of components, are synthesized on the basis of an analysis of the revealed elementary properties, such as levels of accumulated, absorbed, permissible dose of ionizing radiation.

3. Component representation and semantic modelling of protected on-board electronics

In space, on-board electronics is exposed to various factors that cause it to malfunction, including ionizing radiation, consisting of a stream of primary charged particles, such as electrons, protons and heavy charged particles, as well as consisting of secondary particles that arise due to nuclear reactions associated with primary charged particles.

In [3], a calculation and experimental method for estimating the stability of on-board electronics based on the calculation of the failure rate of microcircuits due to the action of charged particles in outer space and the frequency of possible catastrophic failures, as well as the dependence (projection) of the received dose of ionizing radiation on the orbit height and thickness protection for the year, is described (Figure 1).

![Figure 1. Projection of the accumulated dose from the height of the orbit and the thickness of protection for the year.](image)

According to the methodology of SOIS, this projection can be represented by blocks:
1. Ionizing radiation associated with the accumulation of the radiation dose for the year.
2. Elements of protection, reducing the level of transmitted radiation.
3. Microcircuits with known acceptable characteristics of receiving a dose of radiation, which does not affect its functioning.

The ionizing radiation unit includes built-in components describing two groups of orbits, each of which has the properties of minimum hmin and maximum hmax height, as well as minimum dmin and maximum dmax dose of accumulated radiation per year (Figure 2).

![Figure 2. Groups of orbits of ionizing radiation.](image)

For the lower group of orbits, $h \in [500, 900]$ km, $d \in [104, 106]$ rad, for the upper one: $h \in [900, 36000]$ km, $d \in [106, 107]$ rad. Each group of orbits includes the components of individual
disjoint orbits defined by the same parameters as the orbit group, and the number of orbits and their
details are selected on the basis of: set goals and objectives of OE, a set of components describing the
chips and protection means, functions of orbit segmentation over the ranges of accumulated radiation
dose.

In turn, each group of orbits of ionizing radiation can be represented by two or more orbits.
Let us consider an orbit with a width of 3556 km, on which it is possible to determine the
interaction with the component of the onboard electronics protection through an interface that includes
two main parameters, one of which is given by a linear function, and the second - by the density of the
protective layer characterizing the degree of distortion of the dose range of accumulated radiation
(Figure 4) - the upper part of Figure 3. The protection component is characterized by having at least
one pair of input and output interfaces with the same composition of properties, but different ranges of
values and is a component of conjugation of the microcircuit and the orbit of ionizing radiation, and
corrects the range of values of interface parameters that determine the accumulated radiation dose for
the year.

I, II, III, IV, V – numbers of dedicated components of the onboard electronics protection

Figure 3. The investigated orbit of ionizing radiation.

Based on the results of calculation [4], for the chosen orbit, five protection components were
identified, marked in Figure 4 by Roman numerals, each of which, in turn, is determined by intervals
of the values of the density of the protective impurity. They can be divided conditionally into three
classes: A) not having any influence on the range of values of the accumulated dose of radiation, B)
lowering the dose to a fixed range of values, B) lowering the dose to several fixed ranges of values,
depending on the height and density of the absorbing impurity. For the class B orbit, coefficients a, b
determining the analytical expression for the linear dependence of the height on the absorbing density
are calculated empirically and dividing the region of the absorbed radiation dose into two subregions.
For example, for protection component IV, coefficients a and b are determined by two points

\[ P(0.87, 36000), \ Q \in (1, 32444). \]

4. Generalized algorithm of conjugation of components of onboard electronics with sources of
ionizing radiation.

In Figure 4 shows the organization of information interaction between the components of the orbit of
ionizing radiation with the protection components through their interfaces.

In determining the behavior of protection components, the individual elementary properties and
properties of the orbit of ionizing radiation transmitted through the input interface are separately
identified. In determining the behavior of protection components, the individual elementary properties
and properties of the orbit of ionizing radiation transmitted through the input interface are separately
identified. In addition, the components of the onboard electronics are additionally introduced: a) with
external protection implemented by the protection component b) with built-in protection. The
component of the ionizing radiation orbit has two interfaces for interaction with integrated circuits
indirectly through the protection components and for interaction with on-board electronics directly.

So, the components of the orbits of ionizing radiation (IR) have a range of given radiation dose per
year \( d_{min}^{IR}, d_{max}^{IR} \), and a range of heights \( h_{min}^{IR}, h_{max}^{IR} \). OE components have an acceptable range of
radiation doses accumulated per year \( d_{min}^{OE}, d_{max}^{OE} \) as well as a range of heights \( h_{min}^{OE}, h_{max}^{OE} \), on which
they are supposed to be used.
Figure 4. Interface organization of the information interaction of the orbit radiation ionizing components with protection components.

Let us distinguish three types of compatibility between the components of the system:

- \((IR, OE)\), compatibility of components of ionizing radiation orbits with components of on-board electronics;
- \((P, OE)\), compatibility of protection components with components of on-board electronics;
- \((IR, P)\), compatibility of components of the orbit of ionizing radiation with protection components.

Further, let us assume that the compatibility \((IR, P)\) is performed on the entire set of components, and also the constructive compatibility \((P, OE)\) is provided. Other types of compatibility can be described by the rules system:

\[
\begin{align*}
\left(\frac{d_{min}^{OE}}{d_{max}^{IR}} \leq d_{min}^{IR}\right) \cap \left(\frac{d_{max}^{OE}}{d_{max}^{IR}} > d_{max}^{IR}\right) & \to (IR, OE); \quad (1) \\
not\left(\frac{h_{min}}{h_{max}^{IR}} \leq \frac{h_{min}^{IR}}{h_{max}^{RI}}\right) \cap \left(\frac{h_{max}}{h_{max}^{IR}} > \frac{h_{max}^{IR}}{h_{max}^{RI}}\right) \cap & (P, OE) \\
\left(\frac{d_{min}^{OE}}{d_{max}^{IR}} \leq d_{min}^{IR}\right) \cap \left(\frac{d_{max}^{OE}}{d_{max}^{IR}} > d_{max}^{IR}\right) & \to (P, OE) \text{ is a OE}. \quad (3)
\end{align*}
\]

Rule (1) determines the compatibility of the components of the IR with OE components that have internal mechanisms of protection against radiation effects at altitudes of the orbit. Rule (2) for each component of the IR forms pairs of compatible components P and OE, such that the OE component is not compatible with the corresponding component of the IR and at heights it is determined by the component of the IR, component P ensures the fulfillment of rule (1). The pairs \((P, OE)\) thus formed become components of OE, previously called components of the protected OE, as determined by rule (3), after which rule (1) is applied once again to complement set \((IR, OE)\).

Let us consider the algorithm for synthesizing the interfaces of the components of IR and OE, using which it becomes possible to apply SQL-like queries to the semantic model, complemented by rules (1-3).

**Step 1.** The descriptors of the elementary properties of the source components and the OE component are checked. Obviously, the intersection of descriptors contains the following elements: \(d_{min}, d_{max}, h_{min}, h_{max}\), where the domain of each element is the set of real numbers \(R\).

**Step 2.** Rule (1) is applied to ensure the synthesis of the object property "Compatible_Objects" between the components of the IR and OE components that will be applied at the heights of known orbits.

**Step 3.** Rule (2) is applied, which ensures the synthesis of the object property "Compatible_Objects" between components P and OE components.

**Step 4.** Rule (3) is applied, which ensures the synthesis of protected OE components, which are pairs \((P, OE)\). The protected OE component has new elementary properties \(d_{min}^{OE}, d_{max}^{OE}\).
Step 5. The rule (1) is applied to the protected components.

Step 6. The "Interface" classes are synthesized for (IR, OE), which bind them through the object properties "Has_An_Interface". The introduction of additional classes of interfaces allows the latter to extract knowledge about the possibility of using OE components in various orbits of ionizing radiation without recalculations of rules (1-3).

5. Synthesis of the conjugation system of the ionizing radiation orbit with the components of onboard electronics

Let us consider the operation of the algorithm within the framework of the SOIS technique when solving the problem of ensuring the radiation compatibility of OE with orbits of ionizing radiation using the example of 1645RU5U, 1645PT2U microcircuits [5]. Figure 5 shows a fragment of the semantic network describing the interaction of the 1645RU5U and 1645PT2U microcircuits with the IR component through the protection component IV.

![Semantic Network Diagram]

Figure 5. A synthesis scheme of the interface providing radiation compatibility of the IR orbit with integrated circuits.

To illustrate the solution, the semantic model and the calculation of the parameters of the protection component IV of class B are given. For protection component IV, ensuring the operation of the
1645PT2U in the selected orbit of the IR, the values of protection density values range are \([0.87,1]g/cm^2\) and \(a = -27353.85, b = 59797.85\).

As a result of a series of experiments, the synthesizing system has formed classes and properties of the semantic network, defining new objects (protected components) and compatibility interfaces of the IR component with OE components, one of which is represented by the 1645RU5U chip, and the second – by a protected component including the 1645PT2U microcircuit and protection component IV.

6. Conclusion
The paper suggests the adaptation of the methodology of structurally-parametric synthesis of open information systems to solving the problem of ensuring radiation compatibility of OE with orbits of ionizing radiation. At the same time, all OE elements and sources of ionizing effects were represented by components with interfaces defining the allowable ranges of accumulated radiation values at the entry / exit points of each component. The results of the algorithm work are considered by the example of radiation-resistant microcircuits 1645RU5U, 1645RT2U and the calculation and experimental method for evaluating the durability of on-board electronics.

References
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