
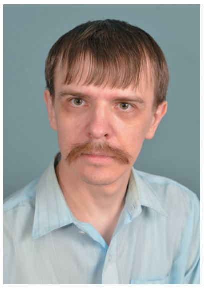

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MECHANISMS AND PROBABILITIES OF FUNCTIONAL FAILURES OF MICROELECTRONIC ELEMENT BASE UNDER ELECTROMAGNETIC PULSE INTERFERENCE

The paper considers computational and experimental methods for defining the probability of functional failures for the electronic component base under electromagnetic pulse interference. The analysis of the properties of the pulse interference random process and the physical mechanisms of interference influence on electronic node elements is carried out. The ways of failure probability calculation based on the concept of the probabilistic interference nature are elaborated. It is shown that the analysis of interference influence enables to prove the choice of pulse equivalence conditions, which is vital for electromagnetic compatibility.

Keywords: *safety systems, functional failure, pulse interference, mechanisms of influence, failure probability, pulse equivalence.*

At present, microelectronic and microprocessor safety systems are widely applied in the sector of energy, transport, chemical and petrochemical industries. The purpose of these systems is to minimize and prevent the consequences of technological process malfunctions, therefore they are critical information systems (CIS) which are subject to very high requirements of functional safety.

One of the reasons for functional safety reduction is functional failures under the pulse electromagnetic interference influence on the element base. Data distortions occur at the lowest level of the structural hierarchy – in integrated microcircuits – with extension to the higher levels of a microelectronic and microprocessor system. The analysis of the functional safety of a safety system as a whole, consequently, begins with the consideration of this problem in relation to the devices of the lowest level of the structural hierarchy. Thus, there is a necessity in computational and experimental methods for defining the probability of functional failures in the element base [1].

To develop such methods, we should consider the properties of pulse interference. In general, the interference is a random process which can be represented by [2, 3] (Fig. 1)

$$s(t) = \sum_{k=-\infty}^{\infty} a_k s_k \left(t - kT - t_0, \alpha_1, \alpha_2, \alpha_3 \ldots\right), \tag{1}$$

where $s(t)$ is a random function, k is an enumerative variable, a_k is a random amplitude of a pulse, V; s_k is a function of a pulse form, t is time, s; T is the longest time for pulse repetition, s; t_0 is random time of pulse occurrence, s, $0 \le t_0 \le T$; α_1, α_2, α_3 are parameters of a pulse form, 1/s.

As every pulse in (1) can cause a failure in the element base, it is logical to consider separate process implementations (1) – in other words, separate pulses.

There are two possible mechanisms of pulse influence on the element base. Pulses of sufficient energy may cause a failure in the element base due to overheat of *p-n* transits, which

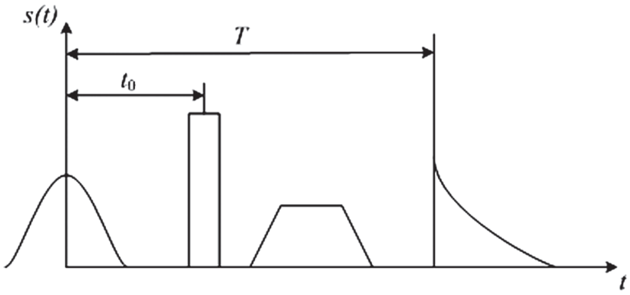

Fig 1. Random flow of pulse interference

leads to reduction of the wanted signal level [4, 5]. Pulses with no such energy can have the voltage-time area which is sufficient for the false switching of the element base [6, 7]. Consequently, a random process (1) shall be characterized by the laws of energy distribution, voltage-time area and other pulse parameters. It is confirmed by results [8], where the flows of pulse interference are proposed to be described by distributions of the interval among pulses and by pulse duration time, as well as by the probability of pulse occurrence, whose parameter exceeds a certain level and by average frequency of movement of such pulses.

It is known [9, 10] that the energy required for a failure of a certain type of the element base is of low dispersion degree, and thus it can be considered as energy constant. Immunity of the element base to dynamic interference is described by the characteristic of dynamic immunity which is expressed by a hyperbolic curve [6, 7] (Fig. 2). In the coordinates of U, τ formula of this curve is

$$U\tau = const = nS, \tag{2}$$

where U is an amplitude of a pulse, V; τ is pulse duration, s; n is a numerical coefficient, S voltage-time area of a pulse, V·s.

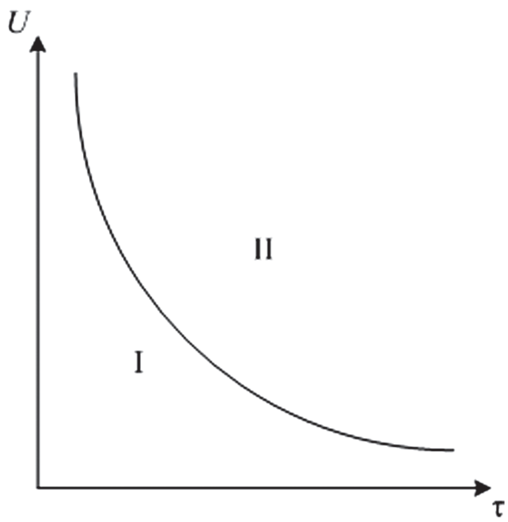

Fig. 2. Typical characteristic of dynamic immunity.
I – permissible interference area,
II – area of intolerable interference

As per formula (2), for the points of the characteristic

$$S = \frac{U\tau}{n} = const. \tag{3}$$

According to [7] the average characteristic of dynamic immunity is true for the whole range of microelectronic devices. Therefore, the S value in (3), the excess of which causes false switching, also has a negligible low dispersion, thus it also could be accepted as the constant one.

Accordingly, the energy and voltage-time area simultaneously characterize both – the interference levels and the level of the element base immunity. And if a value of the interference level using one of the Y_i parameters exceeds the immunity level X_i ($Y_i - X_i > 0$), the device failure occurs. Since, according to the above, the immunity levels X_i are constant for this element base, the probability of failure of the element base P_f can be determined as the probability of excess of the interference level over the immunity level [11, 12, 13] (Fig. 3)

$$P_f = \int_{X_i}^{\infty} f(Y_i)\,dY_i, \tag{4}$$

where $f(Y_i)$ represents the density of distribution of the interference level.

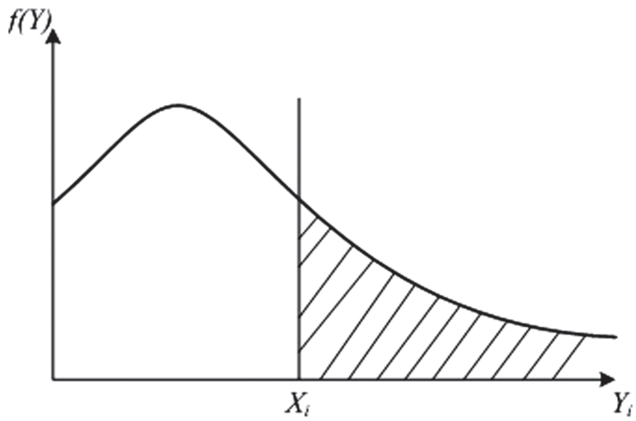

Fig.3. Calculation of the probability of an electronic device failure

Then in accordance with (4) it is possible to find the probabilities of element base failures caused by different influences:

$$p_1 = \int_{W_{thr}}^{\infty} f(W)\,dW,$$

$$p_{2act} = \int_{0}^{W_{thr}} f(W)\,dW \cdot \int_{S_{thr,act}}^{\infty} f(S)\,dS, \tag{5}$$

$$p_{2deact} = \int_{0}^{W_{thr}} f(W)\,dW \cdot \int_{S_{thr,deact}}^{\infty} f(S)\,dS$$

where p_1 is the probability of the failure by the pulse of high energy; W is the interference energy, J; $f(W)$ is the density of distribution of the interference energy; W_{thr} is the threshold value of the interference energy for this element base, J; p_{2act} is probability of false activation; S is voltage-time area of interference, V·s; $f(S)$ is the density of distribution of voltage-time area of interference; $S_{thr,act}$ is the threshold value of voltage-time area of activating interference, V·s; p_{2deact} is the probability of false deactivation; $S_{thr,deact}$ is the threshold value of voltage-time area of deactivating interference, V·s.

The formulas for the probabilities of false activation and deactivation consider the simultaneous fulfilment of two conditions: the energy of an interference pulse is less than the threshold level, and the voltage-time area is larger than the threshold value.

The advantage of this way of selection of interference parameters and immunity is that the formulas for probability calculation are significantly simplified in comparison to other parameters of a strongly marked random character, which are distributed by a certain law of a quite complicated mathematical form.

The failure probability can also be found on the basis of the notion of interference margin. The value of the interference margin is the difference of specified values of the immunity level and the interference level $u=X_i - Y_i$. Then the failure probability can be found under formula [11]

$$P_f = \int_{-\infty}^{0} f(u)du.$$

The determination of the laws of distribution density *f(Y), f(u)* is made either by acquisition of statistics of pulse interference flows at the site of the expected operation of the system [11], or by computational and experimental methods of the probability theory.

Pulses of high energy cause the failures of 1→0 type [4]. Pulses of changeover interference cause the failures of 1→0 and 0→1 types [7]. If to consider the pulses with different physical influences to be independent and incompatible events, the probabilities of functional failures can be calculated by formulas with consideration of (5)

$$P_{1\to 0} = p_1 + p_{2deact},\ P_{0\to 1} = p_{2act}.$$

Having these probabilities, it is possible to make the analysis of functional safety of microelectronic and microprocessor CIS using the methods described in [1].

It should be noted that the considered analysis of interference influence on microelectronic and microprocessor element base confirms the integral method of the search of the parameters of equivalent interference pulses proposed in [14, 15]. Equivalent pulses are the pulses which can similarly influence the functional safety of CIS equipment. The necessity to define the conditions of pulse equivalence is explained by the fact that in practice the flow (1) could contain the pulses of a different form. Switching interference can occur in the form of exponential, bi-exponential pulses, switching pulses, pulses in the form of a damped sinusoid. In case of commutation with a curve there occur pulse bursts in a form of a triangle or exponential curve. Ultra broadband nonrandom pulses which should not be ruled out under the current conditions can be bi-exponential, Gaussian or cosine-square pulses. For the tests, the rectangular pulses with the widest frequency spectrum are preferable [11]. Such diversity of pulse interference complicates the application of computational and experimental methods of the analysis of CIS functional safety and confirmation of the results of simulation by field tests. That is why there is a necessity in the methods for reduction of the scope of mathematical simulation and field tests with the aim of time and cost reduction. This could be achieved by the selection of such interference influences, the immunity to which would implicitly indicate the immunity to other types of interference. This approach can be implemented only in case of pulse equivalency [14, 16]. In the integral method the condition of pulse equivalence is the equation of the energies and voltage-time areas of two pulses

$$\begin{cases} W_1 = W_2 \\ S_1 = S_2 \end{cases}. \quad (6)$$

It is obvious that the equivalent pulses here have similar parameters specifying the consequences of pulse influence on the element base in terms of faultlessness of information processes in the system by the main physical means of influence. As it is shown in [14, 15], at the input delivery of circuits with lumped and distributed parameters of a rectangular pulse and its equivalent pulse whose parameters are calculated in accordance with (6), the sum of squared deviation of responses is the least in comparison to other known methods of definition of the conditions of pulse equivalence. It is also shown that the spectra of both pulses coincide with the accuracy which is sufficient for practical applications. Thus, the integral method for the definition of the conditions of pulse equivalence is the most appropriate for the analysis of electromagnetic compatibility and functional safety of CIS.

To sum up we can draw some conclusions.

Determination of the probability of failures of microprocessor and microelectronic element base of 1→0 and 0→1 type can be made by analysis of the features of electromagnetic interferences which are the flow of random events, and the mechanisms of interference influence on the element base.

Among the parameters of interference pulses we can mark out the parameters which simultaneously describe the immunity of the element base and enable to note the more simple formulas for calculation of the failure probability.

For appropriate simulation of the functional safety of CIS equipment it is necessary to perform the analysis of electromagnetic environment at the expected site of its operation in order to find the distribution of probability parameters of pulse interference and their time characteristic. It is explained by a significant influence of electromagnetic environment on the CIS functional safety.

The considered approach to the analysis of influence of pulse interference on microelectronic and microprocessor element base can become widely used for the development of modern safety critical systems in transport, energy and industrial sectors.

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