BIOSCIENCES BIOTECHNOLOGY RESEARCH ASIA, April 2015. Vol. **12**(1), 767-778

Methods of Assessing the Influence of Ultrashort Electromagnetic Pulses and Ultrahigh Frequency Radiation on Integrated Circuits

Anarbayev Alibek Yersainovich, Antontsev Alexandr Vitalievich and Shaikhin Agibai Kaliakovich

Kazakh National Technical University After K.I. Satpayev,
Republic of Kazakhstan, 050013, Almaty city, Satpayev street 22a, Russia.

DOI: http://dx.doi.org/10.13005/bbra/1722

(Received: 04 January 2015; accepted: 10 February 2015)

This paper describes the direct and indirect methods of assessing the influence of ultra-short electromagnetic pulses on integrated circuits. Stability of electronic equipment and its components under ultra-short electromagnetic pulses and ultrahigh frequency radiation has been experimentally assessed. Various dependencies of the indicator of some integrated circuits malfunction within the duration of ultra-short electromagnetic pulses and ultrahigh frequency energy have been assessed.

Key words: Radioelectronic system, Ultra-short electromagnetic pulse, Ultrahigh frequency radiation, Integrated circuit, performance index.

Currently, means of electromagnetic destruction of radioelectronic systems (RES) and devices are being actively developed, as well as means of destruction based on new physical principles, in particular. So, in recent years, new high-power generators that produce periodic and single Ultra-Short Electromagnetic Pulses (USEP EMI) have appeared. They feature new qualities absent in conventional jamming sources, namely, ultra-wide band and high amplitude. Their spectral density is distributed in the range between hundreds of MHz and GHz (Antinone and Ng, 1989; Baljuk *et al*., 2007).

The particularity of this type of radiation is comparability of the length of exposure to pulses with the duration of working pulses during processing of digital information. Therefore, under the influence of USEP EMI on computers and digital devices, signals are induced in their circuits, similar to the working ones, which lead to disruption of digital systems. One of the possible areas of application of such emitters is remote suppression of components of electronic warfare systems (EWS), in particular, of microprocessors and devices for data transmission, and processing systems built on their basis. Today they form the largest part of the elements used in radio communication systems, operate at progressively higher frequencies and lower voltages, and thus become more susceptible to USEP EMI (Baljuk *et al*., 2007; Williams 2003, Sakharov, 2006).

Besides, it should be noted that the following features of information communication components development are observed today:

a) Software takes up to 80% of implemented functions, and hardware takes approximately 20% of functions; implementation of VLSI makes it possible to implement almost any function, including those in mobile units;

b) There was a fairly sharp transition from

---

* To whom all correspondence should be addressed.

analog to digital transmission systems, and in the latter, transition from PDH to systems of synchronous digital hierarchy (SDH) and the use of broadband B-ISDN and ATM occurred;

c) Under the influence of development of basic technologies, telecommunications processes and systems are being developed towards increasing execution speed;

d) There is globalization of standards requirements in the information technology and in electromagnetic compatibility and units' resistance to intentional electromagnetic influence.

Therefore, USEP EMI is now a new serious threat to electronic systems. In addition, rapid development of microelectronics and active general introduction of various systems for processing, transmission and storage of information into operation of the state structures leads to active development of information infrastructures (II) (Sakharov, 2006).

Analysis of digital devices that are the basis of systems for data transmission and processing shows their high vulnerability to USEP EMI. The research of USEP EMI influence on electronic components of information infrastructures shows that it is necessary to conduct research and testing in their true location for adequate assessment of the real resistance of information infrastructure.

Solution to the problem of assessing USEP EMI influence assessment on II electronic systems using methods of mathematical modeling is not possible today, due to the lack of appropriate analytical tools. With that, analysis of numerical methods for solving such problems shows the impossibility to obtain reliable calculated results.

It should be noted that the methods for creating advanced information infrastructures protected from intentional exposure to USEP EMI, including fixed or spatially separated, are highly unexplored today due to their versatility and complexity. Currently, the most promising method of assessing vulnerability of electronic systems is the calculation-and-experimental method, which makes it possible to assess critical levels of influence on distributed systems that II belong to, with reasonable accuracy.

The potential importance of the issue of assessing II vulnerability is also shown by the development of a set of standards governing the requirements and the procedures of testing information processing systems of guarded design. Currently, GOST R 52863-2007 "Automated Systems of guarded design. Tests of resistance to intentional power electromagnetic influence" is in force (Antinone and Ng, 1989; Baljuk *et al*., 2007).

Currently, the following documents are being introduced and developed:

GOST R "Information Protection. Automated systems of guarded design. Organization and content of work for ensuring protection against intentional destructive electromagnetic and electrical influence. General provisions".

GOST R "Information Protection. Automated systems of guarded design. Means of protection from intentional destructive electromagnetic and electrical influence. General requirements".

GOST R "Information Protection. Automated systems of guarded design. Means of detecting intentional destructive electromagnetic and electrical influence. General requirements".

The main properties of the information processed in telecommunication systems are: availability, integrity and confidentiality. Availability of many input/output ports and switching channels ensures high degree of vulnerability of the devices that are part of TCS to the action of pulsed electromagnetic interference.

By its functional structure, Digital Electronic Equipment is characterized by the absence of regular antenna feed lines of the radio receiver. According to this fact, the research is mainly focused on working with objects that have various options of internal inter-unit and inter-element wiring and screening (Zee, 1984; Krasiuk and Dymovich, 1974).

Typical objects built on the basis of digital radio-electronic equipment are:

a) Technical means of protection;
b) Automated access control systems;
c) Video surveillance systems;
d) Computer equipment in headquarters, command centers, organs of government, radiation hazardous objects, etc;
e) Dispatcher equipment in airports;
f) Fire alarm systems;

g) Automated telephone exchange equipment, etc.

Practical methods

Researching items of electronic equipment for resistance to UHF influence makes sense from the standpoint of obtaining reference data, makes it possible for developers of equipment to compare various elements, and choose the most persistent of them for designing Radio-Electronic Equipment (REE), or to make a decision about the need for additional measures to improve equipment resistance in general (redundancy, additional shielding of the least stable elements and units, etc.). Obviously, in this case, the frequency ranges in which the tests should be performed can be remarkably narrowed, moreover, it is perfectly acceptable to use impact modes with large values of microwave pulse duration and repetition frequency for testing resistance elements and units of REE, as compared to those specified in the regulations (Gadetsky *et al*., 1999). With regard to the required values of energy parameters of influence (energy flux density (EFD) or the electric field intensity), the only requirement for them is to ensure that the EFD of UHF pulses are sufficient to cause incapacitation of tested elements and units.

Information about the influence on the object can be obtained either experimentally from electromagnetic fields with the required parameters influencing the object, or by calculation with the use of the methods of mathematical modeling. Currently, a vast majority of information about pulsed EMI interaction with electronic equipment is obtained in course of experimental studies.

It is known (Dolbnya *et al*., 2006) that there are two fundamentally different approaches to studying the resistance to electromagnetic interference that differ in the way of delivering radiation energy to the object:

a) The direct method, where the influence is accomplished by placing the object of study in an electromagnetic field with known amplitude and frequency characteristics;
b) The indirect method where the influence is accomplished by injecting UHF pulses with time-related and spectral characteristics corresponding to the electromagnetic radiation affecting the object, into particular circuits of the tested product.

Both methods have both advantages and disadvantages. In particular, the direct method ensures maximum correspondence of influencing parameters to the requirements of guidelines that normalize the influence within these electromagnetic field parameters. However, this method cannot always be realized, and hence cannot ensure studying the entire nomenclature of electronic equipment components and assemblies. Furthermore, results of direct test will substantially depend on individual characteristics of the object (length and configuration of the PCB tracks and wire cables), which leads to decreasing reliability of received information.

The main advantage of the indirect method is selectivity of action, which increases data reliability (as the tested element or unit of REE is directly exposed to the effect). Moreover, indirect tests require UHF units with less power, compared to the test units used for the direct method. Also, the indirect method allows adapting the results of experimental studies for use in calculation and

Table 1. Summary of results of studying parameters of pulse signals, resulting in impaired functioning of ICs of various series

Parameters of influence	Series of ICs		
	K1554 (150 MHz, CMOS, U_{pow} = 5 ... 9 V	K1533 (30 MHz, STTL, U_{pow} = 5 ... 9 V	K1554 (3 MHz, CMOS, U_{pow} = 5 ... 12 V
	U, V	U, V	U, V
UHF (3 GHz, 1 μs)	30…100	10…63	42…173
UHF (0.8 GHz, 2 μs)	13…23	4…13	13…39
UHF (0.5 GHz, 1 μs)	9.2	4…6	7.3 ... 9.2
UHF (0.3 GHz, 1 μs)	3.3	1.6 ... 2.2	3.3
SHI (0.1 ... 1.7 GHz; 30 ... 60 ns)	100…800	7…400	235…800

experimental techniques with a high degree of reliability. At the same time, in some cases, the indirect method provides substantially worse adequacy, as compared to the direct one. This is due to the impossibility of simultaneous impact on all circuit of the element (unit) of equipment, and to absence of methods that would relate the free space parameters of electromagnetic field, as stated in guiding documents to the parameters of the UHF pulse in the incoming feeder (Goncharov *et al*., 2007; Belokon *et al*., 2008).

In accordance with the general method of research (Berdyshev *et al*., 2000) and private methodological programs, the experimental evaluation of REE elements and units resistance was performed using the direct method.

In course of the study of integrated circuits stability, exceedance of the limits set in the specifications by the main parameters of the IC, should be used as criteria of stability (Floring, 1988; Yushkov *et al*., 2001).

It should be understood that the criterion defined this way, and the levels (parameters) of stability corresponding to it, will in no case characterize resistance of the electronic unit that contains the chip. Implementation of the defined criterion in this case will only mean that some of IC parameters have exceeded the limits set out in the specifications, i.e. a failure may (or may not) occur in the electronic unit.

It is logical to choose the following IC parameters as parameters that would indicate a failure if they exceed the limits set in the specifications:

a) IC output voltage, which must not be less than the minimum output high level voltage (when the output circuit is in the state of logical one) or more than the maximum low output voltage (if the output circuit is a logic zero);

b) Signal propagation delay upon activation (deactivation), i.e., the interval between the input and output pulses when the voltage at the output of the chip transfers from logical one voltage to logical zero voltage (or vice versa), measured at each 0.5, or at specified values of voltage, which should not exceed the value set in the Specifications;

c) Reading access time, i.e., the interval between the moment when the read signal is sent to IC input and the moment when information signals are received at IC output, which shall not exceed the values indicated in the specifications;

d) Information recording time, i.e., the minimum control signals match time at the inputs of the IC, ensuring information recording, which should not exceed the values specified in the specifications (Chumerin

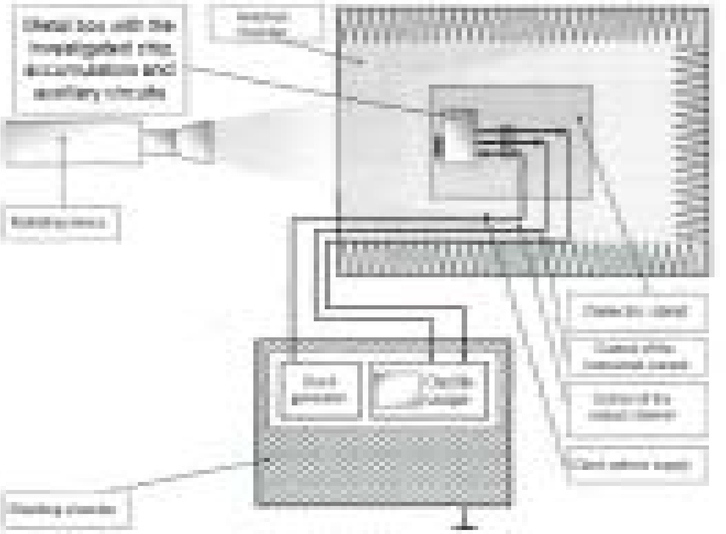

Fig. 1. Typical scheme of testing REE components and assemblies using the direct method

and Zelentsov, 2001).

Permissible ranges of values for each of these parameters are given in IC specifications. Therefore, the criterion of ICs stability under the influence of pulse electric signals should exceed at least one parameter outside the limits set above (Gromov *et al*., 2003; Steward *et al*., 1994).

In this case, the indicator of IC stability will be the level of IC operation without failures (OWOF) in certain time-related and spectral parameters of influence.

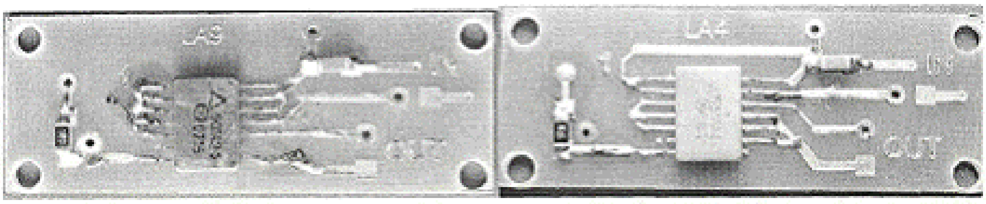

Fig. 2. Appearance of exposed circuit boards with 564LA9 and 1533LA4 chips on them

Figure 1 shows a typical research workflow with the use of direct method. It should be noted that in order to minimize the influence of UHF radiation on the operation of the auxiliary equipment, the following measures were taken:

a) Oscilloscopes, pulse generators, and computer equipment used were located at a considerable distance from UHF radiation spot in a shielded cabinet, which was achieved due to the use of a repeater between the studied integrated circuit (IC) and the oscilloscope;

b) Power was supplied to the studied integrated circuits from standalone chemical

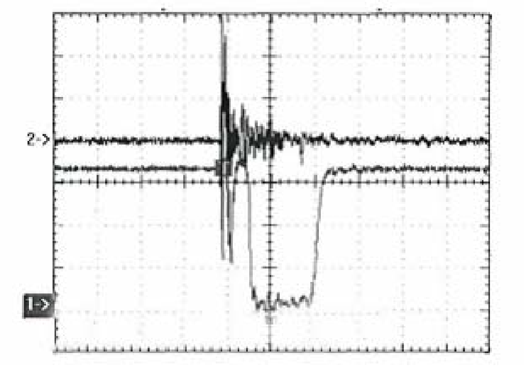

Fig. 3. 564LN2 IC reaction to influence

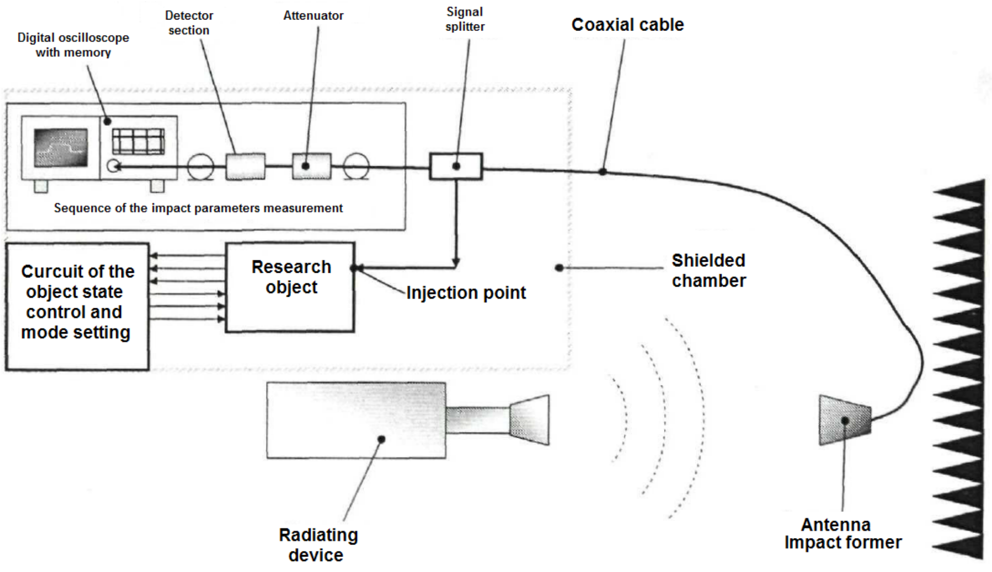

Fig. 4. Diagram of injecting UHF pulses using an antenna (spatial) attenuator

power sources (batteries);

c) The switching circuit, the repeater and the batteries were placed in a metal box with very high screening capacity.

As to the tested ICs, as it was prescribed in (Goncharov *et al*., 2007; Gromov *et al*., 2003), radiation was applied to ICs engaged in standard mode and installed on PCBs with all necessary passive elements. Typical dimensions of the PCBs were 20x50 mm; their appearance is shown in figure 2. (Vasiliev *et al*., 1999; Shein *et al*., 1992; Bludov *et al*., 1994)

In order to verify the performance of the hardware, a series of preliminary experiments was performed in order to find the effects when the IC 564LN2 was exposed to UHF pulses with 3 GHz carrier frequency and the maximum energy flux density of 50 W/cm reached during the tests, as well as ultra-short electromagnetic pulses with duration 250 picoseconds and electric field intensity of 50 kV/m. (Vasiliev *et al*., 1999)

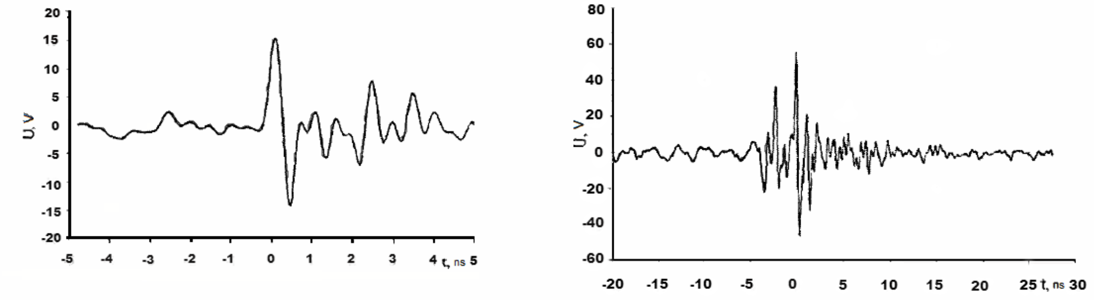

Fig. 5 . Waveform of pulse injected into the circuit (a), of pulse at the output of studied IC (b)

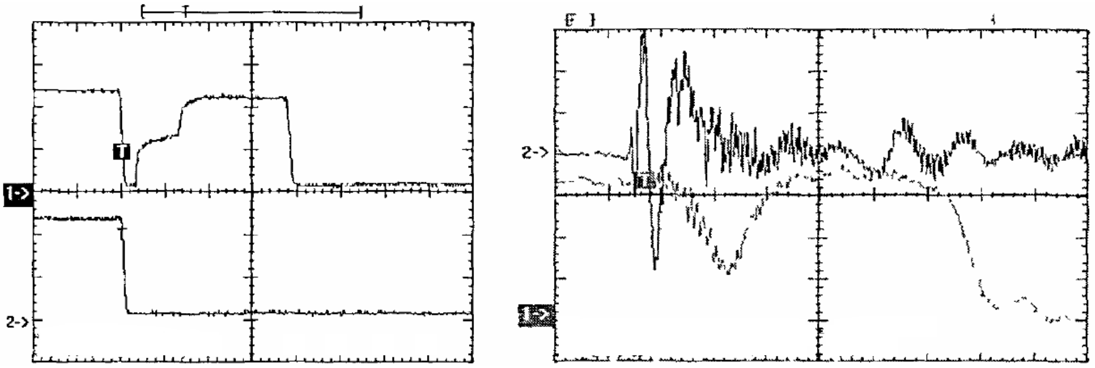

Fig. 6. Switching of K561LE5 IC (channel 1) when exposed to an interfering UHF pulse with duration of 1 µs (a) and 0.5 ns (b)

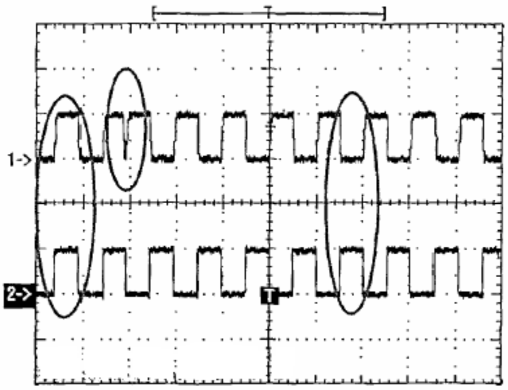

Fig. 7. Shape of signals from the reference output of the studies IC K561IE10 (channel 1) and the reference IC (Channel 2)

The recorded IC reaction to the influence is shown in Figure 3, which shows that even in the conditions of test equipment exposure to electromagnetic fields of maximum power, the switching circuit and the repeater ensure correct operation of tested IC, and instrumentation makes it possible to record signals from IC output with virtually no distortion (Dolbnya *et al*., 2000; Skorobogatov *et al*., 2001).

The “Zaliv 80/1” emitter of ultra-short electromagnetic pulses was used as a generator of electromagnetic radiation (Antinone and Ng, 1989; Baljuk *et al*., 2007; Williams 2003, Sakharov, 2006).

In course of testing using the direct method, the level of object stability was taken as

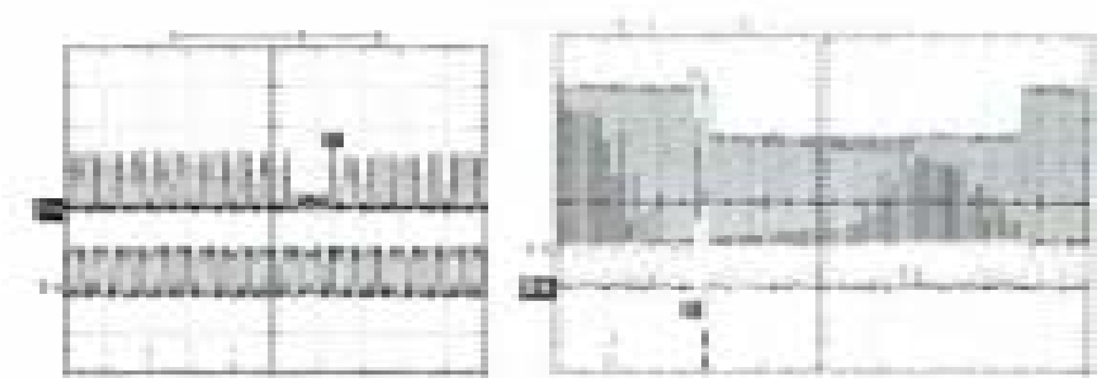

Fig. 8. Form of the output signal of tested IC KP1554LE1 (channel 1) and the output of the reference IC (channel 2) when exposed to UHF pulse of 400 ns (a) and 2 μs (b)

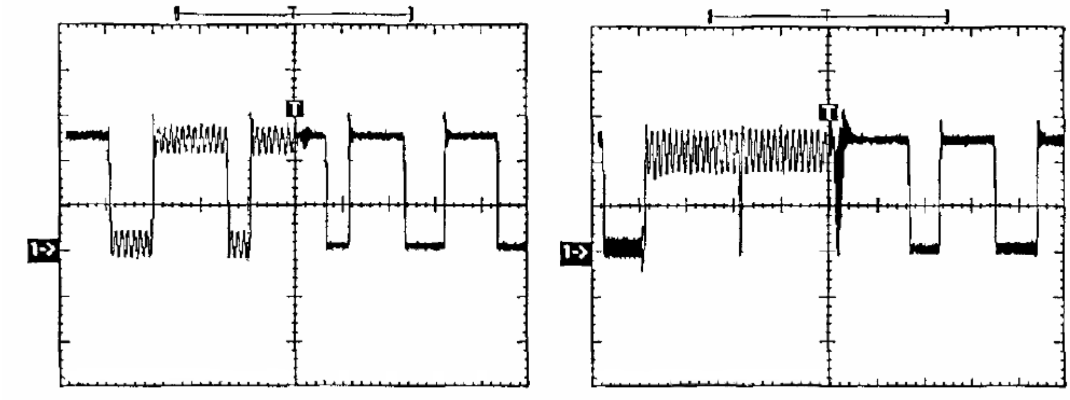

Fig. 9. Output voltage of IC K561LE5 when the logic input id exposed to an interfering pulse with carrier frequency of 0.5 GHz of duration 40 μs and power 1 W (a) and 1.5 W (b)

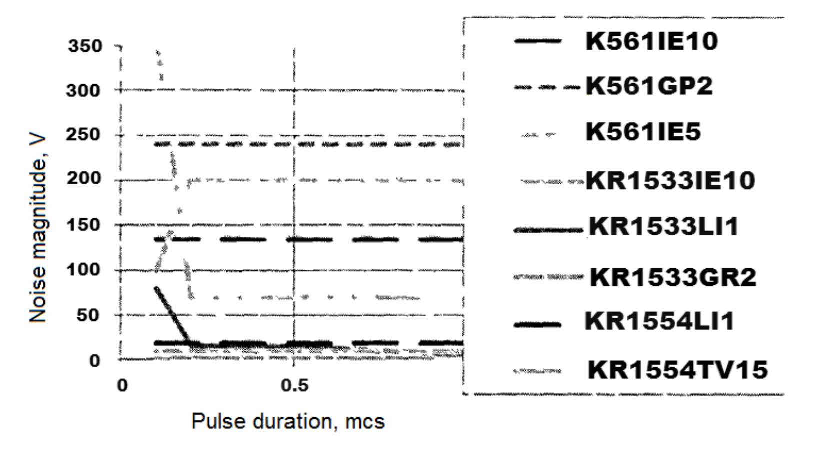

Fig. 10. Dependence of the 3 GHz interference pulse amplitude required for IC failure, on its duration

the maximum intensity of electric field value of ultra-short electromagnetic pulses recorded during the experiment that acts on the object studied, which still satisfies the criterion of object stability.

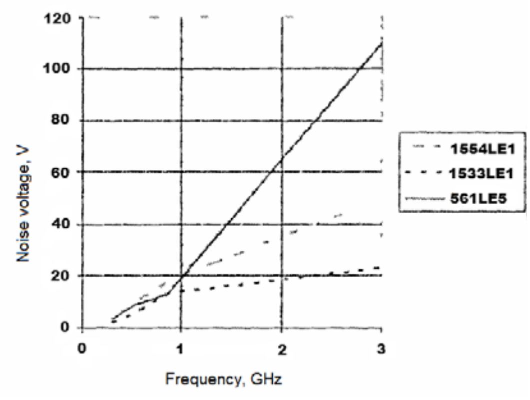

Fig. 11. Dependence of the indicator of logic elements malfunction on the carrier frequency of UHF pulses microsecond duration

The level of disruption of the studies object in this case was the minimum recorded during the experiment value of ultra-short electromagnetic pulses intensity of electric field that acts on the object studied, in which the criterion of object stability is not satisfied.

In implementing the indirect test method, the influence was executed directly on the outputs of the IC. A spatial (antenna) attenuator was used to deliver USEP EMI energy to the tested input of the object (Kornev, 2008; Grishnyaev and Kozlov, 1997). A typical experiment layout is shown in figure 4, where the same installation emitters were used as the emitters that were used in direct experiments

In the course of test of stability against narrow band influence, a broadband log-periodic antenna P6-68 was used for antenna (Grishnyaev and Weaver, 1997). Obviously, in this case, the time-dependent form of the UHF pulse extending

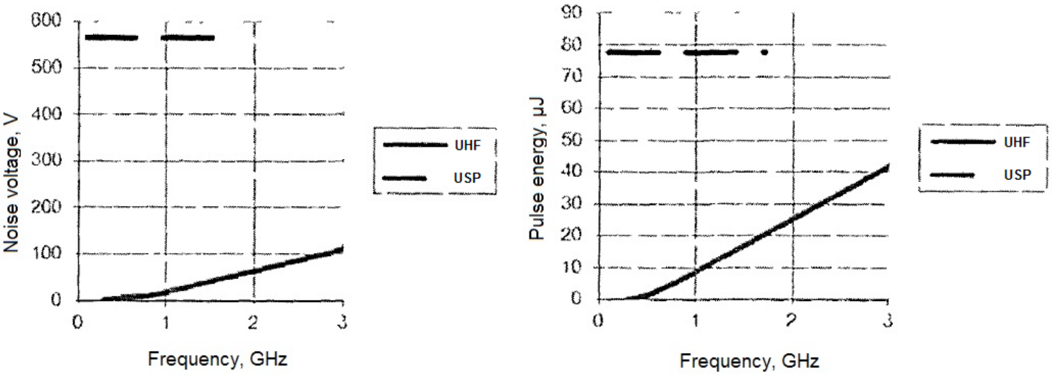

Fig. 12. Comparison of the amplitude (a) and energy (b) of UHF pulses with microsecond duration and ultra-short electric pulses causing disruption of K561LE5 ICs

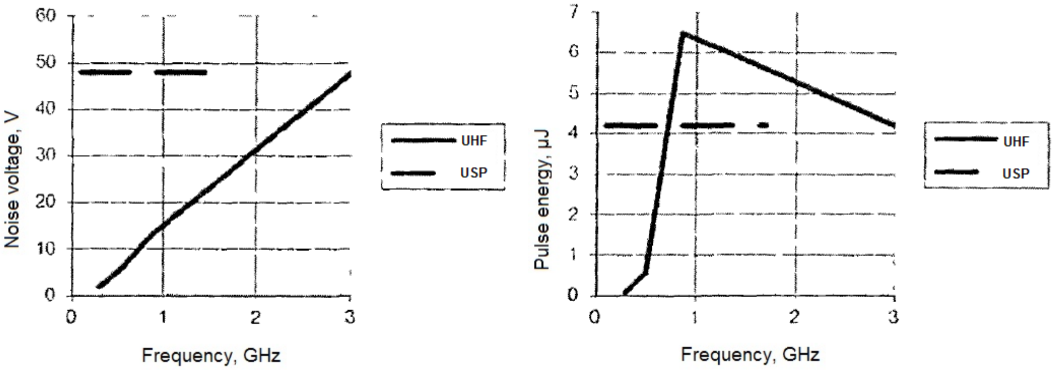

Fig. 13 . Comparison of the amplitude (a) and energy (b) of UHF pulses with microsecond duration and ultra-short electric pulses causing disruption of KR1533LE1 ICs

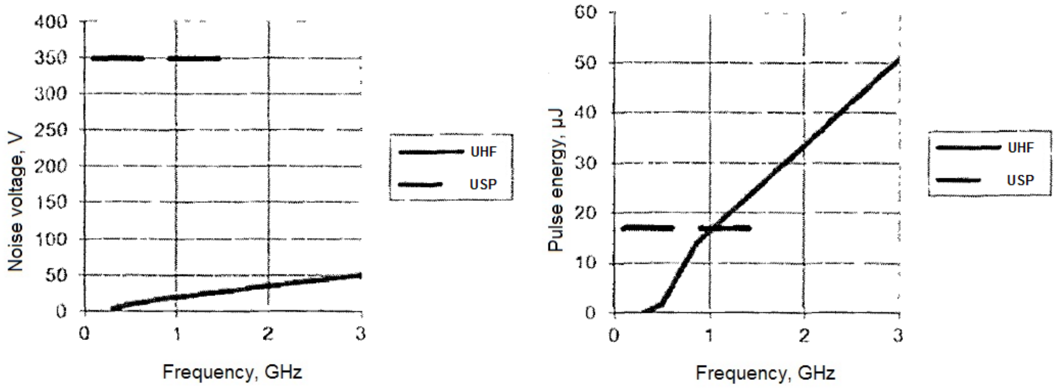

Fig. 14. Comparison of the amplitude (a) and energy (b) of UHF pulses with microsecond duration and ultra-short electric pulses causing disruption of KR1554LE1 ICs

in the space was transmitted to the input of the test object with virtually no distortion.

For tests of stability against ultra-wide band influence, the “Listva-R” horn transducer was used for antenna. Since the electromagnetic pulse on the antenna has ultra-wide range, in a fairly narrow-band receiving antenna feeder channel it will undergo significant distortion, as illustrated in Figure 5.

When testing by the indirect method, the object stability level was understood as the maximum recorded during the experiment value of voltage pulse amplitude acting on the input of the studied object, with which its stability criterion is satisfied.

In this case, the level of abnormal operation of the studied object is understood as the minimum obtained in the experiment value of the amplitude of the voltage pulse acting on the input of the object, at which the object’s stability criterion ceases to be satisfied. The experiments showed relatively high sensitivity of tested ICs to the influence of both ultra-short electrical pulses and UHF pulses with microsecond duration. With that, the result of this experiment significantly depended on both parameters of affecting signals and the type of the IC studied.

In all cases, the effect of exposure was change in voltage at IC output, which, depending on the parameters of the injected signal and the type of the IC, may result in the following effects.

Changing the IC logical state for the time equal to or greater than the duration of the acting impulse. Increasing the duration of IC failure over the duration of the interference is most characteristic of effect of SHP signals; for some circuits increased VPR was also noted with increasing levels of affecting voltage (power). This effect is characteristic for the case when the duration of the disturbance signal is much shorter than the IC clock period. Figure 6 shows examples of switching K561LE5 IC under the action of the UHF pulse with the duration of 1 µs and ultra short pulse with duration 50 ns. It is worth noting that in the second case (Figure 6 b) IC switching occurred after the end of the ultra-short pulse duration.

Information distortion at IC output. This effect is typical for integrated circuits with complex logic (counters and RAM). An example of binary counter information distortion by an IC is shown in figure 7, which shows that before the influence, the output voltage of the tested IC changed synchronously with the reference one, as a result of the influence, the picture changed significantly, since the influencing ultra-short pulse was considered a useful signal by the IC.

Suppression of the output information signal of an IC for the duration of interference of the jamming pulse and further. This effect is typical for cases where prolonged exposure to interference exceeds the duration of the clock pulses (Figure 8).

Distortion of time-dependent parameters of the pulses at IC output. This effect was observed when the IC is exposed to long radio pulses with carrier frequency of 0.3 GHz and 0.5 GHz with the power insufficient for IC switching. In particular, Figure 9 (a) shows the output voltage oscillogram of IC K561LE5 in case of exposure of its logical input to interference frequency of 0.5 GHz with duration of 40 ms and power about 1 watt. It can be seen that as a result of the influence there is a significant increase in the interval during which IC output is in the state of logical one, and the IC is switched to the high state at the moment of clock pulse arrival. With further increase of the interference power up to 1.5 W, the IC is switched for the period not exceeding the duration of the acting pulse (Figure 9 (b))

IC catastrophic failure. It is distortion observed under sufficiently high levels and/or exposure time. It is especially characteristic when the ICs are influenced by UHF pulses with carrier frequency 0.3 to 1 GHz.

The presented results of experimental studies allowed determining dependence of IC malfunction on the duration of a voltage pulse (Figure 10). To build the dependency of IC error rate on the duration of a pulse we used the fact that in experiments on a PD-10t UHF installation (carrier frequency 3.06 GHz) all four modes of operation of this installation were used, ensuring pulses of various duration with maintaining all the other parameters constant.

After comparing the dependencies shown in figure 10, a conclusion can be made that the parameter that determines the effectiveness of the impact on studied circuits is the amplitude of pulses, and not their energy, and the level of IC failure virtually does not depend on the duration of the acting pulse, starting with the duration of 200 ns.

Experiments for studying the influence of UHF pulses with microsecond duration on the IC also made it possible to assess the dependence of malfunction of basic logic elements (2 OR-NOT) on interference pulses carrier frequency (figure 11). Figures 12-14 show comparison of malfunction parameters for cases of IC exposed to UHF pulses and SSP signals.

From the diagrams in figures 12-14, we can conclude that the maximum impact on ICs have radio pulses with microsecond duration and carrier frequencies up to 1 GHz.

RESULTS

Based on the results of the experiments, the following conclusions can be made:

a) IC stability to the influence of ultra-short electromagnetic pulses and microwave radiation does not have close relationship with its technology.
b) The parameter that determines effectiveness of influence on the studied ICs is the amplitude of pulses, and not their energy.
c) The level of IC failure is virtually independent of the pulse duration, starting with 200 ns duration.
d) In the studied frequency range, the values of malfunctions indicator are almost identical for logical elements of various IC series.
e) In the frequency range of up to 1 GHz, the influence of radio pulses on ICs is more efficient, as compared to exposure to super short pulses, even from the point of view of energy pulses.
f) While in analog devices failures of their elements are rigidly tied to the moment of influence and have quite determined impact on the object in general, in digital devices, the occurrence of failures is caused by a change in ICs logical state, and is usually random in nature and is characterized by a wide range of effects observed at the level of the object.

CONCLUSION

This work describes the experimental approach to the study of the influence of UHF radiation and USEP EMI on electronic equipment using the direct and the indirect method. This problem has traditionally been purely experimental due to the complexity of building an adequate mathematical model. In the future we plan to work in two main directions:

a) Obtaining and processing further experimental data with detailed study of effects appearing in REE and associated with exposure to interference;
b) Working in the area of mathematical USEP EMI modeling in order to build a mathematical model of USEP EMI influence on REE.

REFERENCES

1. Antinone R. and W.C. Ng, (high power microwave) testing of electronic components. Lawrence Livermore National Lab., CA (USA), 1989; 80.
2. Baljuk N.V., L.N. Kuchiev and P.V. Stepanov, Powerful electromagnetic pulse: influence on electronic equipment and methods of protection. Moscow: OOO “IDT Group”, 2007; 478.
3. Williams, T., EMC for product developers. Moscow: Publishing House of Technology, 2003; 540.
4. Sakharov, K.Y., Emitters of ultra-short electromagnetic pulses and methods of measuring their parameters. Moscow: MIEM, 2006; 159.
5. Zi, S., Physics of semiconductor devices, vol. 1. Moscow: Mir, 1984; 90-95.
6. Krasyuk, N.P. and N.D. Dimovic, Electrodynamics and radiowaves propagation. Textbook for radio-technical universities and faculties. Moscow: Vysshaya Shkola, 1974; 115.
7. Gadecki, N.P., K.A. Kravtsov and I.I. Magda, Functional failures of the personal computers under the influence of electromagnetic pulses with ultra-short duration. In the Proceedings of the 9th International Crimean Microwave Conference, 13-16 September 1999, Sevastopol, Crimea, Ukraine, 1999; 326-328.
8. Dolbnya, S.N. (Directorate for Development of Basic Military Technologies and Special Projects), A.N. Goncharov, A.N. Kornev, S.V. Panteleev, A.V. Pevnev, A.V. Fateev (12 Central Scientific-Research Institute of the Ministry of Defence), D.V. Gromov, S.A. Polevich (Experimental Scientific-Production Association Specialized Electronic Systems), Experimental studies of REE elements and units for stability against the effects of pulsed electromagnetic radiation. In the Proceedings of the All-Russian Conference “Durability 2006”.
9. Goncharo, A.N., A.N. Kornev, S.V. Panteleev, A.V. Pevnev and A.V. Fateev, Experimental studies of digital REE elements and units for stability against the effects of pulsed electromagnetic radiation, report at the conference in section No.2 of STC of Rosatom of Russia. RFNC of All-Union Electric Power Research Institute, Sarov, 2007; 56-62.
10. Belokon, I.N., A.P. Goncharov, S.N. Dolbnya, A.N. Kornev, S.V. Panteleev, A.V. Pevnev and A.V. Fateev, Patent of the Russian Federation “Method of remote neutralization of mines and explosive devices with electronic detonators during areas clean-up” of 05.06.2008 #2328845; 2008.
11. Berdyshev, A.V., V.F. Ivoilov, A.V. Isaikin *et al*, Experimental study of the influence of UHF pulses on electronic device containing integrated circuits. Radiotekhnika, 2000; **6**: 85-88.
12. Floring, ”.., The future battlefield: a blast of gigawatts? IEEE Spectrum, 1988; **25**(3): 50-54.
13. Yushkov, Y.G., P.Y. Chumerin, S.N. Artemenko *et al*, Experimental study of microwave pulses influence on PC operation. *Radio-engineering and Electronics*, 2001; **46**(8): 1020-1024.
14. Chumerin, P.Y. and D.V. Zelentsov, Studying the influence of the parameters of external electromagnetic influence pulses on PC performance. Scientific and Technical Collection. In the Proceedings of the Russian Scientific Conference “Radiation Stability of Electronic Systems - Durability-2001” (NIIP, Lytkarino, 5-7 June 2001), *Moscow: Pimes*, 2001; **4**: 25-27.
15. Gromov, D.V., V.V. Elesin, A.N. Goncharov *et al*, Operation of personal computers in the fields of radar radiation - Scientific and Technical Collection: In the Proceedings of the Russian Scientific Conference “Radiation Stability of Electronic Systems - Durability-2003” (NIIP, Lytkarino, 3-5 June 2003), Moscow: Pimes, 2003; **6**: 27-28.
16. Klyuchnik, A.V., D.E. Maslov and A.V. Solodov, Thermal damage to integrated circuits. Electronic Equipment. *Series UHF Electronics*, 1994; **1**(461): 46-48.
17. Vasiliev, K.B., A.V. Klyuchnik and A.V. Solodov, Statistics of digital integrated circuits failures caused by pulsed radio emission. In the Proceedings of 9th International Crimean Microwave Conference, 13-16 September 1999, Sevastopol, Crimea, Ukraine, 1999; 329-330.
18. Shein, A.G., E.V. Grigoriev and V.V. Starostenko, The influence of electromagnetic field orientation on exposed integrated circuits. *Electronic Equipment. Series Management of Quality*, 1992; **2**(149): 16-18.
19. Bludov, S.B., N.P. Godetsky, K.A. Kravtsov *et al*, Generation of high-power UHF pulses with ultra-short duration and their influence on integral electronics. *Plasma Physics*, 1994; 20(7-8): 712-717.
20. Dolbnya, S.N., A.N. Kornev and L.N. Sorokin, Assessing stability of low-noise amplifiers for “Liana” space systems against pulses of UHF radiation. In the Proceedings of the 26th Military and Scientific Conference: 2 central research institute of the ministry of defense. Tver, 2000; 43-45.
21. Skorobogatov, P.K., S.N. Dolbnya, A.N. Kornev

and L.N. Sorokin, Modeling damage of the input transition of an UHF amplifier using the method of electro-thermal analogies. Scientific and Technical Collection. In the Proceedings of the Russian Scientific Conference "Radiation Stability of Electronic Systems - Durability-2001" (NIIP, Lytkarino, 5-7 June 2001), Moscow: Pimes, 2001; **4**: 147-148.

22. Kornev, A.N., Experimental studies of computer equipment vulnerability to the influence of pulsed electromagnetic radiation. Report. In the Proceedings of the Conference in the Memory of Tikhonravov, 4 Central Research Institute of the Ministry of Defense, 2008.
23. Grishhyaev, N.N. and A.N. Kozlov, Assessment of the damaging effect of microwave radiation on electronic equipment containing antenna-feeder devices. *Defense Enginery*, 1997; **1-2**: 66-121.
24. Grishnyaev, N.N. and Y.V. Tkach, Studying stability of weapons and military equipment containing antenna-feeder devices against the influence of microwave radiation. *Defense Enginery*, 1997; **6-7**: 22-24.