IMPACT OF MICROWAVE PULSES OF ULTRASHORT DURATION ON A PERSONAL COMPUTER

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Procedure of the tests for electromagnetic compatibility and strength (EMSS) of a personal computer (PC) to microwave ultrashort duration pulse (USP) and analysis of the results are described. 3D simulation of the MW USP interaction with the test objects considering the configuration of the test area and screening effect of metal components estimates the level of electromagnetic field inside the PC case. Numerically and experimentally is shown that the MW field penetrating into the metal PC case through technological holes can induce the USP potentials in the PC circuitry sufficient to create functional upsets and degradations.

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INTRODUCTION

Modern electromagnetic environment presents a variety of impulse electromagnetics, where the mw USP stand out as an efficient external impact factor (EIF) for electronic devices, in particular for the objects of digit and computing technology (DCT) [1]. Well-known sources of short-pulse electromagnetic fields (EMF) such as pulse processing facilities, electrostatic effects, switches, est., which are characterized by a wide-range frequency spectrum and therefore relatively small spectral power density, in the case of proximity to the object can affect the functioning of electronic devices [2]. To the contrary, the USP sources of narrowband radiation (especially RF and MW ranges), are characterized by greater directivity and power density of radiation, and able to produce dangerous levels of impulse voltages in the circuits of electronic devices at distances of tens to hundreds of meters. They are a potential threat to the objects of DCT: control means of technological processes, information and telecommunication networks, systems of data processing and computing. Thus, large spectral power density typical for the MW USPs, as well as high penetrating quality compared to other USP signals label them to be the most dangerous EIF.

In recent years, the EMSS tests of electronic equipment using the MW USP are entering into practice due to IEC recommendations [3]. At the same time, the complexity of the testing and measuring equipment significantly limits the ability to conduct and compare results of these tests, making a number of unique features in the results. This work describes the tests of standard PC affected by MW USP, and the analysis of functional upsets and failures occurring in the tested objects.

1. EXPERIMENTAL EQUIPMENT AND CONDITIONS OF THE TESTS

1.1. DESCRIPTION OF THE TEST STAND

The tests were curried on in the laboratory of relativistic microwave electronics of NSC KIPT NAS of Ukraine using the TS-1 test facility based on a high-current nanosecond electron accelerator "Astra" [4]. A relativistic magnetron created the MW USP radiation with the following characteristics:

• radiation frequency	3 GHz;
• pulse duration	10...30 ns;
• output power	100...500 MW.

The area for the location of the object under test (OUT) included several operation zones (Fig. 1) allowing to study the OUT at different levels of USP MW fields:

- zone *A* – the area between the MW source and the screen-absorber (SA) (E = 50...1500 kV/m);
- zone *B* – the area behind the SA (E = 15...100 kV/m);
- zone *C* – open space inside a shielded box (SB) located behind the SA (E = 0.01...2 kV/m).

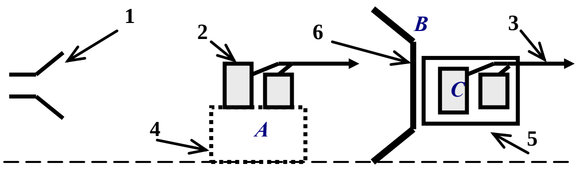


Fig. 1. Layout of the test facility TS-1 operation area: 1 – MW antenna; 2 – test object; 3 – channels for data transmission and power supply; 4 – dielectric seat; 5 – screened box; 6 – MW absorber

Closed EB was also used to placing the auxiliary equipment and components that were not subject to irradiation. The distribution of E-field intensity along the axis of the zone A is shown in Fig. 2.

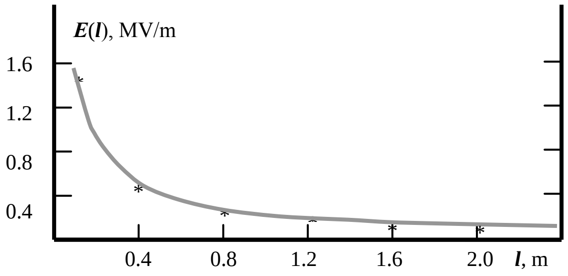


Fig. 2. Distribution of the E-field strength in the operating area of the TS-1

1.2. MICROWAVE FIELDS IN TEST AREA OF THE STAND TS-1

Checking the parameters of MW USP and the OUT response to this EIF was produced in all test zones. The distribution of the E-components of the affecting MW impulse in the test area was measured by means of calibrated sensors integrating vacuum and crystal MW detectors. The signals of the MW monitors and OUT response were transmitted by several noise-immune optical and electrical information channels and were recorded by analog and digital oscilloscopes in the frequency range of 200 MHz and 2.25 GHz, respectively.

1.3. TEST OBJECTS

Several typical PCs (2000...2002) were investigated on functional upsets and failures under different *E*-field levels of MW USP. In particular, the tested PC had several configurations:

Configuration A. Basic complete of PC: the system unit with the processor Pentium Intel/AMD (100...200 MHz), SVGA monitor, 101-key keyboard and mouse. The PC was fed off-line by a shielded power source.

Configuration B. PC in Configuration A with cables connected to the parallel input/output bus (COM port) simulating external circuits.

Configuration C. Several units of the PC (monitor, system unit, keyboard, mouse, power supply) exposed individually during the PC operation.

2. SIMULATION OF THE PC IRRADIATION BY MW IMPULSE

Irradiation of the PC by MW USP was investigated numerically using the package CST Microwave Studio [4]. Simulation gives the opportunity to determine the effectiveness of the MW USP penetration inside the TO, which was located in the screened metal case and estimate the level of electromagnetic field coupling to sensitive elements inside the PC case. The numerical experiment was carried out in two stages. At the beginning, it was calculated the MW field distribution in the test area, which contained a screen-absorber and metal box, and then the field penetration inside a shielded box, simulating the PC system unit through the slot in the front wall (Table 1).

Table 1

The characteristics of the MW USP source and object

TA dimensions	2.5×2.5×2.5 m
SA dimensions	1.5×1.5×0.05 m
SB dimensions	0.5×0.4×0.6 m
SA electrical parameters	ε=1.5, tg δ=0.7, μ=1
MW frequency	3 GHz
MW *E*-field amplitude	5.10^6 V/m
MW pulse width	15 ns
the coordinates (X,Y,Z) of points presented in Fig. 3 in meters	**1** (0, 0, 0.5), **2** (0, 0, -0.35), **3** (0, 0.3, -0.35)

2.1. MW FIELD DISTRIBUTION IN THE TEST AREA

A plane vertically polarized electromagnetic wave in the form of radiosignal with a 3 GHz carrier and 15 ns Gaussian envelope traveled down the test area (TA).

The TA was limited by flat walls of concrete (bottom, top and rear) and lead (left and right), Fig. 3,a. The screen-absorber and screened box behind the screen were located in the middle of the TA orthogonally to the wave propagation (Fig. 3,b). The SB presenting a technological volume was opened to the side opposite the direction of the wave.

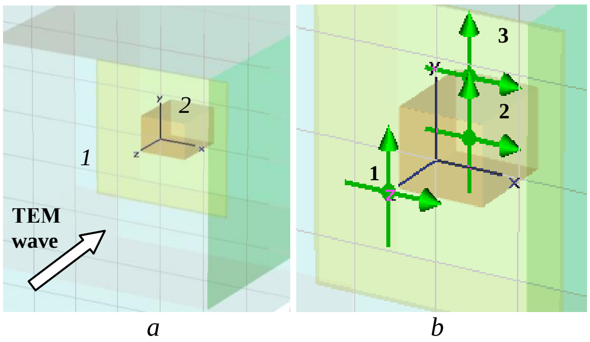


Fig. 3. The structure of test area with the locations of SA (a-1) and SB (a-2), and the points of the E-field measurement (b). The origin of coordinates corresponds to the SA center

The *E*-field distribution in the TA depended on the irradiation stage. A characteristic time separating these stages was about two propagation times of the wave in the TA (~16 ns).

This is clearly visible in the plots of Fig. 4, (points **2** and **3**). At early times, when the reflections from the walls of the operation area were not significant, there was slight (~2 times) *E*-field decrease for the wave that passed on the SA due to diffraction, and strong (up to 17 times) *E*-field decrease inside the open SB.

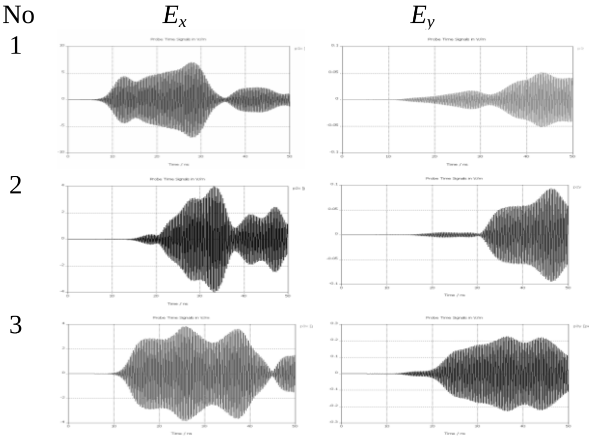


Fig. 4. Components of the electromagnetic field in fixed points of TA

At later times, when the TA walls repeatedly scattered the incoming wave, the field distribution was settled, and the resonances appeared, which could be seen in the horizontal and vertical cross-sections of the TA, Fig. 5. For the time ≥20 ns, the *E*-field strength around and inside the open SB was almost equal the field of the source.

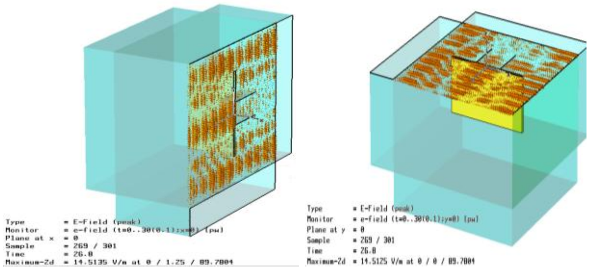
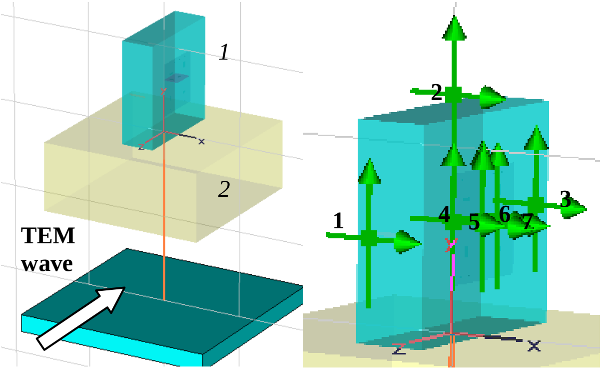


Fig. 5. Distribution of the E_X-component of the electromagnetic field in different cross-sections of TA

2.2. IRRADIATION OF THE PC

3D model of the PC consisted only of the system unit (SU) (1) placed on a 1 m height dielectric stand (2), Fig. 6,a. Two panels of absorbing material imitating the motherboard (located parallel to the wall) and video card (located on the motherboard orthogonal to the wall) were located inside the SU at the right wall (Table 2). The *E*-field components of electromagnetic wave were measured in the points **1-3** outside of the SU and points **4-7** inside its housing, Fig. 6,b.



a *b*

Fig. 6. (a) The TA with SU (1) and insulating stand (2), and (b) the points of the E – field measurement

Table 2

The MW source and object characteristics

PC case dimensions (X,Y,Z)	0.2×0.6×0.6 m
slot dimensions (X,Y)	0.1×0.01 m
motherbord dimensions (X,Y,Z)	0.001×0.3×0.3 m
motherbord material electrical characteristics	ε=5, tgδ=0.03, μ=1
dielectric stand dimensions (X,Y,Z)	1×1×0.4 m
MW signal frequency	3 GHz
MW *E*-field amplitude	1 V/m
MW pulse width	10 nsc
the coordinates (X,Y,Z) of points shown in Fig. 7 in meters; the origin is in the middle of the base of the PC case	**1**(0, 0.3, 0.4) **2**(0, 0.64, 0) **3**(0, 0.3, -0.4) 4(0, 0.3, 0) **5**(0.09, 0.3, 0) **6**(0.045, 0.3, -0.07) **7**(0.09, 0.3, -0.07)

The dynamics of the *E*-field components was calculated for the case when the SU was not grounded, and system and video cards were connected inside the unit with the case. Simulation of electromagnetic field near and inside the PC model showed the following:

(i) In the outer areas relative to the PC (Fig. 7, points **1-3**) a single pulse was visible, whose structure had small variation compared to the original. The decrease of amplitude of the incident electromagnetic field was most significant near the PC housing only. This decrease of the *E*-field at a distance less than one half of the wavelength over the PC housing (point **2**) was as high as 3. At point **3**, located outside the housing, the field strength decreased and greater reached 4.

(ii) Inside the PC (Fig. 7, points **4-7**) it was seen the following:

- The *E*-field amplitude decrease compared to the original level because of the shielding effect was 7 times in the area of the slot of the housing, and from 30 to 80 times in the center.
- Strong changes in the structure of the MW USP compared to the original. There were changes associated with resonances at the characteristic frequencies of the SU housing and formation of the interference structure. The duration of the signal was substantially increased up to 8...10 times the length of the original signal.
- There was small increase of the *E*-field near the center of the system board of the PC in comparison with points far from it surface. For example, the ratio of the *E*-field maximums on the surface of the system board (points **5** and **7**) and in the SU housing (point **4**), reached 3.2 and 2.0, respectively. Obviously, it was also associated with the dimensional resonance, and natural amplitude decrease near the side walls of the housing.

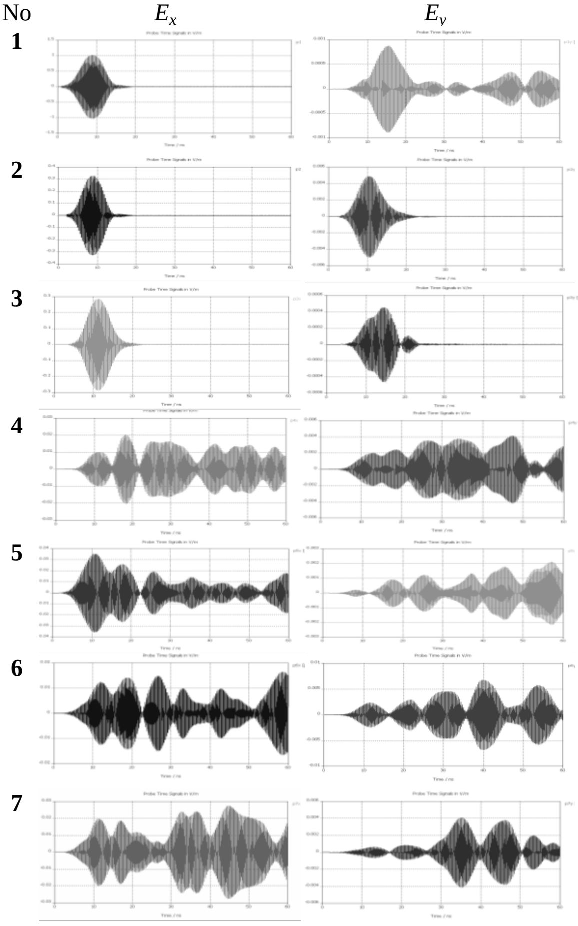


*Fig. 7. The E_X and E_Y field components at fixed points (**1-7**)*

Numerical experiments demonstrated high penetration ability of MW impulse inside the SU metal body via the technological window imitated the floppy-disk entrance. Thus, considering real electromagnetic field outside the SU reaching in the test zone **A** E_{OUT} = 100...500 kV/m, and also the *E*-field decrease due to the screening effect of the housing, the expected field value inside the SU can be E_{IN} = 1...6 kV/m. And also taking into account partial screening by the SB and remote positions of the OUT (zone **C**) one can count on the impact field in the SU E_{IN} = 20...50 V/m. As can be seen, the magnitude of the field impacting sensitive circuits within the PC is sufficient to cause not only functional upsets but degradations of the circuitry.

3. TESTS OF THE PC AND COMPONENTS

3.1. TEST RESULTS

Tests of the PC and components to impact of MW USP was carried out in single-pulse mode (t_P = 10...30 ns) and the E-field amplitude in the test area of 0.01...300 kV/m. The test procedure included: the comparison of initial and final characteristics of the TO, classification of failures, determination of the sensitivity levels. While carrying on the tests, the following PC response signals, which gave good enough evidence of the PC functioning, were recorded:

- clock bus signal;
- power supply voltage output;
- serial data input/output (COM port) signal.

General response features to MW USP impact.

Under all conditions of EMCS tests of the PC and components, starting with the E-field of 1...3 kV/m, it was observed formation of an intense SU response. The most sensitive components of the PC were: the keyboard, mouse, and system unit. The MW USP impact on any of the PC component or the PC complete resulted in appearance of disturbances on the PCI and COM buses, and at the +5 V and +/-12 V output of the power supply (Fig. 8). The result of each functional upset was self-rebooting of the PC. In some cases, there were "hangs" of the PC, which demanded forced rebooting. Perturbations in the busses strongly depended on the PC type, PC configuration, position and shielding of cables in the TA. The OUT response amplitudes corresponded to the intensity of the impact.

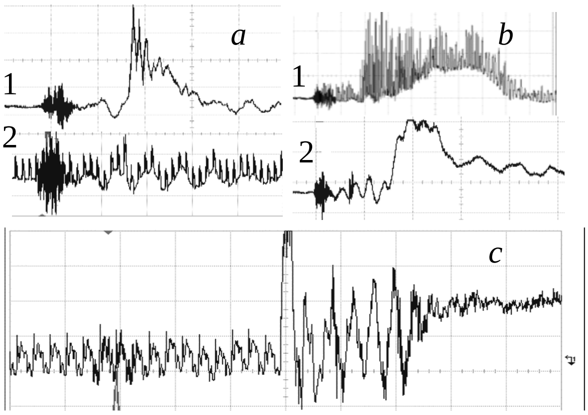


Fig. 8. The response signals of various buses at exposure of PC and components: (a) PC is in SB, zone A (E=1 kV/m); 1 – RTS bus, pin 7, 200 ns/div; 2 – Clock bus, 200 ns/div; (b) mouse is outside SB, zone B (E=50 kV/m); 1 – RTS bus, pin 7, 200 ns/div; 2 – TX bus, pin 3, 500 ns/div; (c) monitor is outside SB, zone B (E=80 kV/m), Clock bus, 100 ns/div. The MW USP marker is seen before each response impulse of the TO

For example, the tests of the PC system unit indicated its extremely high sensitivity to the affect of the MW impulse compared to other PC components. The SU response study was only possible when the unit was disposed in the screened box with closed lid ($E \approx$ 1 kV/m). It was noted earlier that the 3D model gave a 30-60-fold attenuation of the external MW impulse, corresponding to the E-field amplitude in the system unit, E_{IN} = 15...30 V/m.

Each test with opened lid produced malfunctioning of one of the SU components registered as strong qualitative change of the PCI bus and COM signals. The check of the SU operation after the exposure revealed disorders in the implementation of the PC booting process. The proceeding of the test was possible only when the motherboard was replaced. Thus, the minimum MW USP E-field level affecting the SU can be considered as of ~1 kV/m.

Table 3 shows the critical values of the E-field, which led to functional upset of the PC (E_{CF}) or to complete failure (degradation) of the PC components (E_{CD}).

Disturbances on the PC buses.

(i) The response of different PC buses to the EIF was much different, especially at low-level external signal. It was already evident at $E \approx 1$ kV/m. The width of the response signal t_{RESP} = 0.2...1 µs, and reached 5...25 t_P.

(ii) The response of the PC circuits at low levels of MW USP had a tendency to show regular or chaotic oscillations.

Functional upsets.

(i) The most sensitive PC components to failure were: system unit, keyboard and mouse. The threshold level of functional upset in the mode of single MW USP was E_{CF} > 1...7 kV/m (Table 3).

(ii) A waveform analysis of PC response witnessed that each of the MW pulses (even of small amplitude) caused an upset or breaking a software execution, loss of illumination or image on the monitor screen. In almost all cases, opening of the actuator port and CD carriage occurred. The result of each of the failure was the "hang-up" of the PC, which demanded rebooting.

(iii) Functional upsets were usually accompanied by response of different PC buses, which lasted much longer than t_P. As a rule, at $E \approx 5$ kV/m the response width was of 1.5...4 µs (up to 200 t_P). For example, this ratio for the Clock buss always greatly exceeded 10.

(iv) More often, the character of the response was a kind of chaotic (or regular, turning into a chaotic) oscillations at relatively low frequencies (~5...15 MHz). The amplitude of the PC response to impact of the MW USP was at maximum after 75...150 ns after the signal-response beginning.

(v) The increase of the EIF strength (E >7 kV/m) additionally initiated a low frequency (less than 3...5 MHz) relaxations. Because they cover several cycles of a clock signal, the result was "hung-up" of the PC.

Failures

(i) Further increase in the EIF level as a rule led to the failure of the most sensitive OUT (system unit, keyboard, and mouse).

(ii) The highest probability of failures occurred in excess of E-field amplitude E_{CD} = 100...160 kV/m for the system block, and of 80...200 kV/m regarding another PC component (Table 3).

(iii) Degradation of the PC components had no direct correlation with exceeding the critical values of *E*-field. This was evidenced by random failures of the OUT after 10...25 tests even when the *E*-field amplitude was much below the observed critical level.

Table 3

The threshold levels of functional upsets and failures of PC and components (h is the height of the cables above the metal table)

TO	TO component	Upset level, E_{CF}, kV/m	Failure level, E_{CD}, kV/m
PC components (PC*)	Keyboard	2...7	100...160
	Mouse	2...7	180...200
	System unit	≥ 1...3	100...160
	Monitor	≥ 15	140...160
PC* with net mock-up	Net mock-up	5...6	-
PC*	Full complete	1...3, *h*=0.1 m 10, *h*=0 m	100...160 *h*=0 m
PC power supply	Power supply	30	120...160

*standard configuration.

3.2. ANALYSIS OF THE TEST RESULTS

The test results demonsrated high sensitivity of DCT objects to MW USP. The EIF impact was accompanied by a wide range of phenomena: functional upsets, partial degradation or complete failure of the most sensitive components of the PC.

The MW radiation (the wavelength λ = 0.1 m was about the characteristic lengths of the PC components) produced dimensional resonances for most of the components (keyboard, monitor, cables, etc.), which, because of this, were natural antennas. At the same time, high spectral power density of the MW USP up to 300 W/m^2 Hz and the pulse energy of 0.2...0.4 J were the reason of multiple high-level electric voltages excited in the irradiated structures, sufficient for producing the upsets or degradations in digital devices.

The experiments with the screened PC components demonstrated the possibility of effective electromagnetic protection and reducing the PC response tenfold. However, the objects of complex design that lacked a solid metal screen or contained long slots in the housing were a potentially poorly protected against microwave fields of USP. In this regard, it is important to specify another characteristic of the MW USP significant at coupling to complex objects – the polarization of the radiation. For the polarized electromagnetic wave the best conditions for penetration into the shielded housing with technological gaps (as in the system unit of a PC) can be realized. Therefore, high orientation sensitivity of an object appears.

In conclusion, it may also be noted that the PC component degradation was not necessarily geared to exceeding the critical value of the absorbed energy, but to the accumulation of irreversible changes in the component microstructures possible for a large number of exposures. This was evidenced by the random failures of OUT as a result of the 10...25 exposures, even if the amplitude of the electromagnetic field was much below the degradation critical level. Thus, it can be concluded that the impacts with a large repetition rate of MW USP are highly dangerous for the objects under test.

RESULTS

The response of the PC and its components was registered in almost all conditions of the tests on the MW USP impact. The response features (appeared at functional upsets and failures that caused full interruption of the PC operation) depended on hardness of the EIF, polarization of the MW radiation, degree of the shielding, and type of an object.

The results of the PC and components tests are in good agreement with the known characteristics of the electromagnetic strength of modern semiconductor elements to MW USP:

- threshold feature of the EIF affect;
- significantly greater width of the OUT response at it functional upset in comparison with the affecting MW USP;
- excitation of low-frequency relaxations in the response at high amplitudes of the EIF;
- for the case when the EIF amplitude excides the level of functional upsets, distributed thermal degradations in microstructures appear, that leads to their degradation and damage of the OUT overall.

The fundamental difference between responses of the PC and analogue instrumentation to an USP impact appears in the specifics of the PC functional upset. Even at small levels of the EIF a nonlinear response of the circuits with the width of several clock cycles "hold-ups" the PC. Obviously, the upset of the control program is received by the system as physical disorder. This needs resetting the PC, and results in losses of time, what in some cases can disrupt the task.

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ДЕЙСТВИЕ СВЧ-ИМПУЛЬСОВ СВЕРХКОРОТКОЙ ДЛИТЕЛЬНОСТИ НА ПЕРСОНАЛЬНЫЙ КОМПЬЮТЕР

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Описываются подготовка и анализ результатов тестов на электромагнитную совместимость и стойкость персонального компьютера к воздействию импульсных СВЧ-электромагнитных полей сверхкороткой длительности. Применено численное моделирование облучения тестируемых объектов с учетом конфигурации тестового пространства, позволяющее определить уровень воздействующих электромагнитных полей внутри корпуса ПК. С помощью расчетов и экспериментально показано, что импульсные СВЧ-поля достаточно легко проникают в металлические корпуса ПК через технологические отверстия. При этом, в областях чувствительных цепей ПК они могут возбуждать уровни воздействующих потенциалов сверхкороткой длительности, достаточные для создания функциональных сбоев и деградационных эффектов.

ВПЛИВ НВЧ-ІМПУЛЬСІВ НАДКОРОТКОЇ ТРИВАЛОСТІ НА ПЕРСОНАЛЬНИЙ КОМП’ЮТЕР

М.П. Гадецький, С.Ю. Карелін, І.І. Магда, І.М. Шаповал, В.О. Сошенко

Описуються підготовка та аналіз результатів тестів на електромагнітну сумісність та стійкість персонального комп’ютера до дії імпульсних НВЧ-електромагнітних полів надкороткої тривалості. Застосовано чисельне моделювання опромінення тестованих об’єктів з урахуванням конфігурації тестового простору, що дозволяє визначити рівень електромагнітних полів усередині корпусу ПК. За допомогою розрахунків та експериментально показано, що імпульсні НВЧ-поля досить легко проникають у металеві корпуси ПК через технологічні отвори. При цьому, поблизу чутливих ланцюгів ПК вони можуть збуджувати потенціали надкороткої тривалості з амплітудами, що достатні для створення функціональних збоїв та деградаційних ефектів.