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RESEARCH OF THE CONDITIONS OF USING AN EXPERIMENTAL METHOD FOR CARRYING OUT QUALITY CONTROL AND QUANTITATIVE EVALUATION OF THE STABILITY OF RADIO ELECTRONIC MEANS TO THE IMPACT OF POWERFUL ELECTROMAGNETIC RADIATION

Об'єктом дослідження є функціонування радіоелектронного засобу (РЕЗ) при його опроміненні потужним електромагнітним впливом (ПЕМВ). Одним з найбільш проблемних питань є відсутність загальної методики кількісної оцінки стійкості РЕЗ до руйнівної дії напруженості поля ПЕМВ. Тому дане дослідження присвячено визначенню умов використання експериментальної методики проведення якісного контролю і кількісної оцінки стійкості РЕЗ до дії ПЕМВ.

У ході дослідження застосовувалась методика, що містить методи теоретичного узагальнення, аналізу та синтезу, метод представлення вузлів (частин) РЕЗ еквівалентними схемами, методом окремого аналізування стійкості його вузлів (частин, пристроїв). Сучасні РЕЗ складаються з багатьох різних за своїм функціональним призначенням пристроїв. Кожен із пристроїв містить велику кількість різноманітних зв'язків і елементів. Тому оцінка стійкості РЕЗ методом поблокового дослідження стійкості її вузлів (частин, пристроїв) дозволить оцінювати ступінь дії ПЕМВ на різні вузли та усю РЕЗ відокремленними параметрами. А саме, параметрами, які характеризують завадову обстановку, створювану самими вузлами РЕЗ, і параметрами, що характеризують ступінь сприйнятливості різних частин (вузлів) РЕЗ до впливу ПЕМВ.

Прикладний характер запропонованої методики є визначення умов використання різних методів випробувань, пов'язаних з визначенням стійкості РЕЗ до впливу ПЕМВ, що забезпечують такі переваги:

– більш високий ступінь вірогідності одержуваних результатів у більш короткі проміжки часу;

– використання нових більш завадостійких видів зв'язку між окремими частинами контрольно-вимірювальної апаратури (КВА) і досліджуваними РЕЗ при створенні вимірювальних стендів.

Результати проведеного дослідження дозволяють зрозуміти порядок, умови експериментальних випробовувань та вимоги до КВА. Це дозволить у наступних дослідженнях оцінити стійкість як окремого блоку, так і РЕЗ у цілому.

Ключові слова: *потужний електромагнітний вплив, радіотехнічний засіб, оцінка стійкості радіоелектронного засобу.*

1. Introduction

There are various approaches to the quality control and quantification of the stability of radio-electronic means (REM) to the effects of powerful electromagnetic influence (PEMI) [1]. One of the most common approaches is a rigorous mathematical method that implements a mathematical model of a radio electronic device in interaction with external and internal obstacles, and makes it possible to evaluate the operability of a radio electronic device in a given jamming situation [2–4]. However, it is very difficult to actually create such models that fully take into account all the links between the signals affecting the REM and its own characteristics. Therefore, in practice, as a rule, mathematical models of individual REM devices or its general simplified model are created. This allows to estimate the qualitative picture of the processes under study, but does not give a high probability of quantitative estimates [5–7]. The method of equivalent circuits can be applied for individual devices of electronic devices in assessing their stability. This method gives good results in the analysis of quite simple in its functional construction of the REM devices. When evaluating various types of high-frequency devices, such as antenna-feeder, radio receiving and radio transmitters, which are an indispensable part of most radio electronic devices, the spectral analysis method is successfully used. This method allows us to estimate the degree of influence of the PEMI on the operation of the high-frequency path.

Therefore, it is relevant to study the method of experimental assessment of the REM resistance to the impact of a electromagnetic radiation wave.

2. The object of research and its technological audit

The object of the research is the REM functioning when it is irradiated with PEMI.

One of the most problematic issues is the lack of a general methodology for quantifying the REM sustainability

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to the destructive effect of the intensity of the field of electromagnetic field. Therefore, it is proposed in the work to use an experimental method for estimating the level of stability of the modes of REM operation when it is irradiated with PEMI. This will allow to take into account the connections between individual REM devices and their structural, installation, technological and other features. This will also effectively formulate the conditions for applying an experimental approach to quantifying the REM stability, destructive effects of the field strength (electrical and (or) magnetic component) of the PEMI and determine the appropriate list of indicators of the REM electromagnetic resistance.

3. The aim and objectives of research

The aim of research is determination of the conditions for the use of an experimental methodology for conducting quality control and quantitative assessment of the REM resistance to the PEMI impact.

To achieve this aim it is necessary to perform the following tasks:

1. To determine the main parameters, which determines the REM stability and are subject to control when exposed to the electromagnetic radiation wave.
2. To determine the features of test methods related to the determination of the resistance of a radio electronic device before, during and after the PEMI impact.
3. To determine the list of tasks, which arise, depending on the stage of development of new REM, their structure and functional purpose in assessing the sustainability of the REM to PEMI.
4. To propose a scheme of the test bench and provide recommendations for conducting complex tests of REM for resistance to the impact of electromagnetic energy.

4. Research of existing solutions of the problem

Affecting the PEMI effect on REM systems can be due both to the direct effect of pulsed electromagnetic fields on electrical and radio circuits, and to guidance in connecting lines and current and voltage circuits [7–9]. The sensitivity of the communication system equipment to the PEMI action largely depends on its position relative to the direction of the electric and magnetic field vectors, the geometric dimensions of the electrical networks and circuits, their configuration, interconnections, and the ratings of electrical loads. And also, it is necessary to take into account: the value of capacitive and inductive connections with the elements of the design of the communication system and the environment, the quality of shielding and the method of grounding, the presence of filters and surge arresters. The problem of assessing electromagnetic stability, as one of the indicators of electromagnetic compatibility at the global level, is carried out by numerous international organizations under the auspices of the UN. The most widely conducted work is the International Electrotechnical Commission (IEC) and its International Special Committee on Radio Interference (CISPR), as well as the European Committee for Electrotechnical Standardization (CENELEC) [10]. In Ukraine, there are standards [10, 11] that allow to define approaches to the determination of resistance to lightning strike at REM and the requirements for compatibility of household appliances. The rest of the research is aimed at consideration of individual cases of electromagnetic effects with a known structure on individual systems, the structure of which is also known.

In particular, the authors of [6, 9] propose the construction of the protection of telecommunications objects from broadband electromagnetic effects. The authors of work [2] estimate the state of telecommunication taking into account the action of broadband radiation. The study of the factors of threats to the violation of the electromagnetic integrity of telecommunications systems using electromagnetic weapons is presented in [12].

The author of [13] explores the factors of electromagnetic weapons, which is being developed by the United States for use in combat. The author notes that electromagnetic weapons systems are the first weapon systems that can simultaneously protect against enemy attacks with radio-technical means, and at the same time unexpectedly strike the hostile systems behind the battlefield with an electromagnetic pulse. Experimental data on the stability of some military radio systems are provided.

According to the author of the work [14], electromagnetic damage and protection from it of a military and civilian REM is an important task of modern armies. In order to adequately assess the level of electromagnetic stability of the REM, it is necessary to investigate the influence of various factors affecting the electromagnetic energy, since it is diverse and requires research on the stages of REM development.

The author of [15] develops a technology to ensure the lack of stability of computing equipment at the design and placement stage inside the house. This allows to conduct a full prediction of noise immunity and reduce interference with broadband electromagnetic effects. At the design stage, technologies have been developed to ensure that the computer equipment is in the inventory state.

The authors of [16, 17] conduct studies of the level of favorableness of specific samples (systems) of radio engineering and electronics to a destructive electromagnetic effect with known parameters. The authors present the results of experiments on the external effects of the electromagnetic field on the receiver through the antenna-feeder path (AFP), and it is concluded that two thirds of the energy strikes, penetrates through the AFP.

Thus, the results of the analysis allow us to conclude about the desirability of a general study of the conditions for using an experimental technique for conducting high-quality electromagnetic control of the RTM and the need to determine the parameters for quantifying the RTM resistance to powerful electromagnetic effects.

5. Methods of research

To solve the set objectives, the following methods are used: theoretical generalization, analysis and synthesis, the method of representing nodes (parts) of REM equivalent circuits, the method of a separate analysis of the stability of nodes (parts, devices).

5.1. The main parameters that determine the REM stability and are subject to control when exposed to the PEMI. Depending on the stage of the REM development, their structural scheme, functional purpose and operating conditions, the experimental assessment of the REM stability may include measurements:

– parameters of external PEMI, affecting the REM;
– interference parameters in the internal circuits and communication lines of the REM, as well as between the REM and control and measuring equipment (CME);
– parameters of individual parts of the radio electronic system before and after exposure to the electromagnetic radiation spectrum;
– parameters of radio-electronic devices in general before and after the PEMI impact;
– REM parameters in general when exposed to the PEMI.

Modern REMs consist of such different in their functional purpose devices as antenna-feeder, receiving and transmitting, digital computing, controlling and synchronizing. Each of the listed devices contains a large number of various connections and radio electronic elements (REE), therefore the assessment of the REM stability is a very complex technical task.

The parameters defining the REM stability should be considered those PEMI characteristics and the REM parameters, significantly affect the quality of their functioning (compliance of the REM technical characteristics with the specified requirements). They can be divided into the parameters characterizing the interfering environment created by the REM, and the parameters characterizing the degree of susceptibility of various parts of the REM to the impact of electromagnetic radiation.

Let's consider the main REM parameters that characterize the degree of their susceptibility to the PEMI effects. REM susceptibility is understood to be the degree of the REM's response to the impact of a electromagnetic radiation signal, with or without the main signal, via an antenna, a screen, power supply circuits, grounding, control and switching. The degree of REM susceptibility to the impact of the electromagnetic radiation wave is mainly determined by the receiving devices and digital information processing devices. The main paths of the PEMI impact on the REM are shown in Fig. 1, 2.

The reception channel of the useful signal (Fig. 2, *d*) is characterized by:

– sensitivity $P_{c\cdot min}$;
– frequency selectivity (bandwidth, squareness coefficient of amplitude-frequency characteristic (AFC));
– instability of the local oscillator frequency of the receiver;
– internal noise input receiver;
– non-linear characteristics of amplifiers and mixers used in the receiver, which is the reason for the expansion of the spectrum of the received signal.

An important characteristic that makes it possible to judge the susceptibility of a radio-electronic device by the receiving channel of a useful signal is the ratio:

$$U_s/(U_n+U_i),$$

where U_s, U_n, U_i – respectively, the voltage of the useful signal, noise and interference at the input of the receiver. For normal reception of a useful signal with a power of P_s, the condition $P_s > P_{s.min.}$ should be satisfied.

The specified value of the specified relation is one of the most frequently used in practice criteria that allow one to quantify the REM susceptibility to the impact of electromagnetic radiation through a channel of a useful signal.

REM susceptibility to the PEMI impact is also largely influenced by the AFP characteristics of the receiving path, namely:

– width of the main lobe of the radiation pattern (RP);
– levels of AFP RP side lobes;
– coefficient of the directed action;
– effective antenna area S_{ef};
– polarization parameters of the antenna [3, 7, 9].

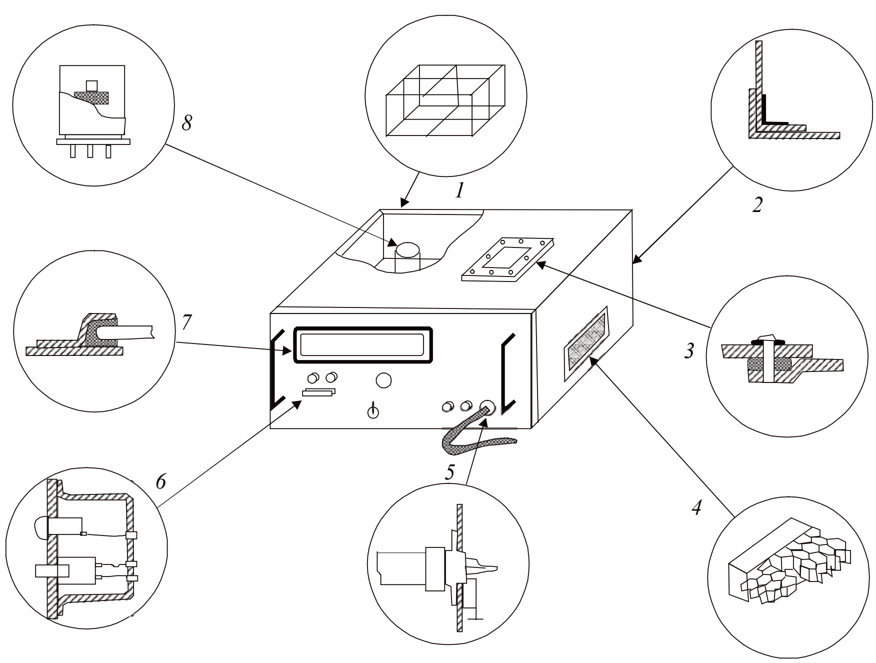

Fig. 1. Ways of penetration of powerful electromagnetic effects inside a REM separate unit and methods of blocking such penetration: 1 – welded frame of the REM box; 2 – continuity of the REM box; 3 – electromagnetic sealing gaskets; 4 – ventilation and cutting openings; 5 – cables and detachable contact connections; 6 – additional partial shielding; 7 – leading transparent materials; 8 – local shielding

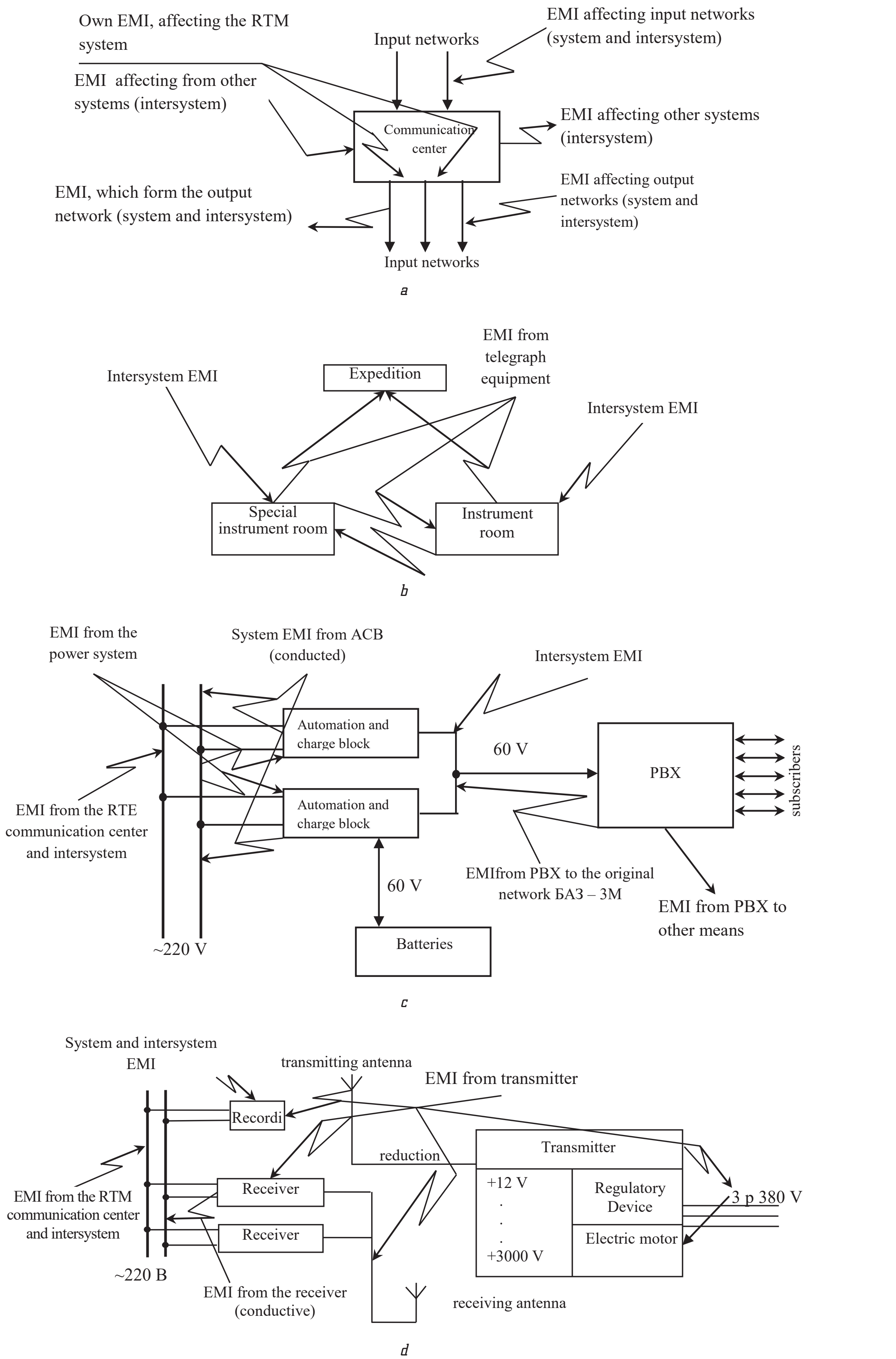

Fig. 2. Diagram of the influence of electromagnetic interference (EMI) at the communication center and its individual elements: *a* – the general scheme of the EMI influence; *b* – the scheme of EMI actions in the subsystem of the communication node-telegraph; *c* – the scheme of EMI actions in a subsystem of communication center of private branch exchange; *d* – functional diagram of the receiving-transmitting radio center and the EMI influence

In [7, 9], it was shown that PEMI affects the REM operation not only due to the passage of the useful signal by the receive channel. Its effect leads to induced currents and voltages in the circuits of grounding, control, etc. These paths of penetration, along with the previously listed, are also of great interest in assessing the stability and predicting the behavior of REM under the conditions of PEMI impact.

5.2. Methods of monitoring the REM parameters before, during and after the PEMI impact. At the initial stages of the REM development, the main aim of the tests is verification of the effectiveness of the adopted technical solutions, the choice of the optimal design options for the equipment, the assessment of the stability margin and electrical strength. At these stages, the measurement of crosstalk in the chains of individual devices under investigation takes an important place. At the next stages, control of the output REM parameters when exposed to the PEMI and checking their compliance with the specified requirements [10, 11] is becoming increasingly important.

The features of the test methods associated with the determination of the REM resistance to the impact of the electromagnetic wave are:

– a wide range of frequencies as useful signals and interference;
– REM test in the near zone of PEMI influence;
– measurement of the PEMI statistical parameters;
– measurement of pickups in different REM circuits when exposed to the electromagnetic radiation frequency;
– carrying out mathematical processing of measurement results in order to develop recommendations to improve the noise immunity of radio electronic facilities;
– search and implementation in the CME development of new design and technological solutions that provide a higher degree of reliability of the results obtained in shorter periods of time;
– development of new, more noise-resistant types of communication between the CME individual parts and the studied radio-electronic devices when creating measurement stands.

When choosing a method for monitoring the sustainability of a radioelectronic system, it is necessary to focus on such methods that would be implemented simply enough and would give satisfactory accuracy.

Depending on the stage of development of a radio electronic system, their structure and functional purpose, the following tasks may consistently arise in assessing the stability of radio electronic systems:

– determination of the characteristics of the electrical and magnetic components of the PEMI fields, affecting the REM;
– determination of voltages and currents given in the circuits of radio electronic means and on the interblock communication lines as a result of the action of the electromagnetic wave;
– determination of the change in the shape of the output signals and modes of operation of individual elements, circuits and devices of the electronic device during and after the PEMI impact;
– identification of elements, blocks, REM devices that are most critical to the impact of radiation energy.

6. Research results

The general scheme of the control and simulator for performing electromagnetic studies of the REM is shown in Fig. 3.

When choosing a specific measurement method at different stages of the REM development, data on the nature of specific violations of individual devices and equipment circuits (Table 1), of which the REM will be composed (or composed) when exposed to the PEMI will be useful.

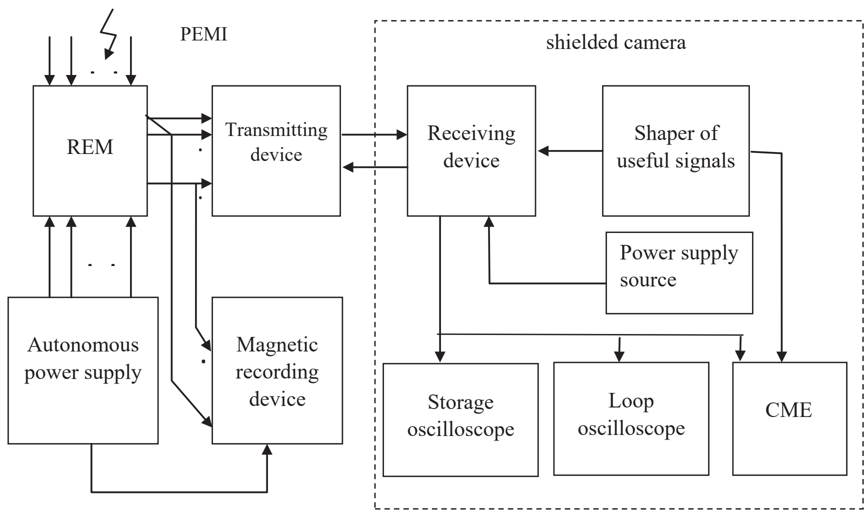

Fig. 3. Block diagram of a universal test and test bench for carrying out complex tests of radio-electronic means for resistance to the effects of powerful electromagnetic effects

Table 1

Typical disturbances in radio electronic means when exposed to powerful electromagnetic effects

REM class (REM part)	Nature of violations	Note
Linear circuits: amplifiers of sinusoidal signals, video amplifiers, amplifiers of direct current	Distortion of the output signals, the appearance of spurious signals, self-excitation	Minimum obstacle energy causes high gain amplifier to fail $JW_n=(1...10^5)10^{-20}$ J
Pulse and logic circuits (keys, triggers, multivibrators, blocking generators, limit devices, etc.)	Distortion of the output signals, loss of information in the memory nodes	The minimum energy of the obstacle, causes failures in logic circuits, $W_n=(1...10)10^{-9}$ J
Generators of sinusoidal signals, signal generators of special shape	Frequency failure, short-term waveform distortion, loss of information	Most resistant to the effects of PEMI generators with quartz frequency stabilization
Antenna-feeder devices (AFD)	The interference appearance of the AFD load	Linear antennas are most vulnerable to the PEMI effects; possible: irreversible failure of the microwave diodes
Power sources	Short-term change in output voltage	–

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The monitoring of the REM resistance to the impact of a prime electric wave, as a rule, consists of two main stages. At the first stage, the REM parameters, which affect their electromagnetic compatibility, the REM effect of the PEMI, are monitored, and then the same measurements are made after the PEMI impact. In this case, the CME is not directly influenced by the PEMI, which allows the use of traditional measurement techniques and standard instrumentation. The second stage of control is an assessment of the REM sustainability under the PEMI impact. This type of control is more objective, although its implementation is associated with a number of serious difficulties.

According to the results of the carried out tests, the nature of the violations of the REM performance when exposed to the electromagnetic radiation characteristics with specified characteristics is judged. In this case, the impairment of the operability of a electronic device may be either irreversible or reverse, and is associated either with the failure of its individual elements or with the appearance of unacceptable spurious signals in their circuits. There are various criteria for evaluating the REM operability under the PEMI impact, including energy and temporary [4, 5, 12]. Energy criteria are based on determining the minimum energy of an obstacle at which a REM fails, while temporary ones are based on determining the minimum recovery time of an EF after a failure in operation as a result of the electromagnetic radiation wave.

Energy criteria are based on determining the minimum energy of an obstacle at which a REM fails, while temporary ones are based on determining the minimum recovery time of an REM after a failure in operation as a result of the PEMI influence.

A number of additional solid technical requirements are imposed on the instrumentation used to control the stability of the REM when exposed to the electromagnetic radiation wave. One of the ways to meet these requirements is to deduce a number of controlled signals from the PEMI influence. In general, this can be accomplished using transmitting and receiving devices, as well as a communication line.

The transmitting device used to output information from the PEMI influence zone is intended to convert the monitored parameter of the REM under investigation into a signal convenient for its transmission over the communication line to the CME. Because the transmitting device must be located in the zone of PEMI influence and directly connected to the REM, it places particularly high demands on noise immunity, effects on the tested equipment, overall dimensions, consumption, and the like.

The receiving device converts the transmitted signal to a form suitable for measurement and recording in the CME. Since the receiving device in this case is located at a certain distance from the zone of PEMI influence, less stringent requirements are imposed on it [8, 9].

As communication lines, wires, cables, waveguides are used, as well as the medium between receiving and transmitting devices. Audio, radio and optical signals can be transmitted via communication lines. The general structural diagram of the universal test bench, designed to test the REM for resistance before, during and after PEMI exposure, is shown in Fig. 1 [5, 8, 9].

Test bench (Fig. 3) must meet the following basic requirements:

– affect the work of the REM subjects;
– to have a sufficient speed to register the expected change in the monitored REM signals and transients in their circuits;
– have the necessary multi-channel, which allows to register the entire set of signals characterizing the operation of the radio electronic system;
– have high noise immunity.

CME removal and the individual measuring means from the PEMI influence by means of the transmitting and receiving devices makes it possible to exclude or substantially reduce the PEMI influence on the CME main part. And, therefore, to use in its composition standard measuring devices used in REM periodic inspections. Nevertheless, some of the requirements proposed for a test bench, for example, speed and noise immunity, can be mutually exclusive, which makes the development of such a bench a rather complicated task at high levels of field strength of the field electromagnetic field.

To measure and record low-frequency signals: the parameters of the sources of REM; control signals; telemetry signals; code structures of transmitted signals, etc. As part of the test bench, standard storage oscilloscopes can be used, including loop ones. Loop oscilloscopes belong to inertial devices, they practically do not respond to short-term impulse noise, which reduces the requirements for their protection.

To control the signals in the high-frequency paths of the REM when exposed to the electromagnetic radiation wave, as well as the transients occurring in the equipment circuits in most cases use spectral methods that can be divided into direct and indirect. Direct spectral measurement methods are based on the use of spectrum analyzers, which are used to determine the frequency bandwidth of the radiation frequencies at a given power level in decibels. Indirect methods are based on the existing dependence of the width of the working frequency band of the measured radiation on various indirect REM parameters, such as:

– the rate of decrease of the band-by-band spectra;
– time of establishment of manipulation signals;
– frequency deviation.

That is, parameters that can be measured directly with higher accuracy than the band of frequencies occupied by the obstacle.

The power and frequency of back-end emissions can be measured using measuring antennas, measuring receivers and other devices that convert the measured power to an amount convenient for recording and controlling the carrier center frequency of the received HF signal.

The control methods for HF parameters of radio electronic devices, which determine their susceptibility to the impact of electromagnetic radiation, should include the measurement of the sensitivity of a radio receiver. The sensitivity of the radio receiver is a function of the carrier frequency of the electromagnetic field and is determined by measuring the power or voltage of the signal at the receiver input and at the receiver output. In this measurement, it is controlled so that the ratio $U_s/(U_n+U_i)$ is not less than the passport value.

The frequency selectivity of a radio receiver can be measured by one- or one-signal-signaling method, blocking method, etc. obstacles create the same voltage at the output of the radio receiver.

Transients in various circuits of radio electronic means are most often controlled by amplitude-time methods using electronic oscilloscopes, which basically store them. In this case, as a rule, the following characteristics of the transition process are analyzed:

– the maximum value of the pulse U_{max};

– pulse front duration (rise time of the front from $0.3U_{max}$ to $0.9U_{max}$);

– the duration of the transition process at levels of $0.5U_{max}$ or $0.1U_{max}$.

The set of the listed data is sufficient to obtain the dependence of the current value of the transition process on time, which is later used to refine the mathematical model of the interaction between the REM and PEMI.

The accuracy of the evaluation of the above characteristics of the transition process is determined mainly by the type of used recording instrument. Table 2 shows the parameters of some types of Ukrainian storage oscilloscopes used in the composition of control and measuring stands.

Table 2

Specifications of some types of storage oscilloscopes

Type	Bandwidth, MHz	Write speed, km/s	Sweeping	Input parameters	Overall dimensions, mm; mass, kg	Note
38-7A (single beam)	0…20	1000	50 ns/div … 5 s/div	0.5 MOhm 55 pf	350×450×770 50	–
38-12 (single beam)	$5-10^{-6}$…0.1 0…10 0…50 0…$3.5-10^3$	4000	(0.1…5) μs/div (0.1…0.5) s/div	1 MOhm 30 pf	480×215×496 27	With interchangeable blocks
38-9A (single beam)	0…2	120	0.05 μs/cm … 0.6 s/cm	0.5 MOhm 45 pf	265×560×380 36	Vertical sensitivity 100 mV/cm … 10 V/cm
C8-15 (single beam, portable)	0…10	1000	0.05 μs/div … 0.5 s/div	1 MOhm 43 pf	180×300×480 16	Vertical sensitivity 2 mV/div … 5 V/div
38-18 (single beam)	0…10	250	0.05 μs/div … 1 s/div	–	330×177×500 16	Vertical sensitivity 1 mV/div … 5 V/div
38-2 (double beam)	0…7	500	0.05 μs/div … 25 s/div	0.5 MOhm 55 pf	670×1225×485 81	–
38-17 (double-beam)	0…1	540	0.2 μs/div … 25 s/div	1 MOhm 42 pf; with divider 1 MOhm 12 pf	300×180×480 16	Vertical sensitivity 1 mV/div … 5 V/div When playing 30 min, the save time is 5 days

The main parameters that determine the possibility of using a particular type of oscilloscope is the speed and probability of reproduction of the studied signal. These parameters depend on the frequency properties of the oscilloscope, as well as the accuracy of the reference, which depends on the parameters of the cathode ray tube and the input amplifiers.

7. SWOT analysis of research results

Strengths. The strength of research is the ability to assess the degree of PEMI impact on various nodes and the entire REMs by separate parameters. In particular, the parameters characterizing the jamming environment created by the REM nodes, and the parameters characterizing the degree of susceptibility of the various parts (nodes) of the REM to the effects of electromagnetic radiation.

Weaknesses. The weak point is that in the work there is no practical example of developing a specific PEMI-resistant REM (or a separate unit). However, the research results allow to understand the order, the conditions of the experimental tests and the requirements for CME. This will allow in subsequent studies to assess the stability of both a separate unit and the REM as a whole.

Opportunities. Formulated general conditions allow in further studies to study the resistance of a specific REM to the PEMI action both at the development stage and at the stages of its testing using test equipment, the requirements for which are also formulated in the work.

This technique will allow to reveal the electromagnetically-induced devices (nodes, blocks, elements) and make a decision to the REM developers on the construction of electromagnetic protection taking into account modern technologies. However, it should be noted that it is not yet possible to completely exclude the penetration of electromagnetic radiation into radio engineering systems, and especially through AFD.

Threats. Threats to the results of the research are that the calculation of these indicators should not use the same approaches and methods because of the different functional purpose and composition of the REMs. In addition, the approaches mentioned in the work to determine the methods for studying the PEMI on a radio electronic device should be checked for the accuracy of the methods specified in the references, including using the AWR, CST, HFFS, MMANA software and others.

The costs of such experimental tests should be considered at the stage of the REM development.

This will allow not only minimizing (up to 60 %) the impact on the radio-electronic means of electromagnetic energy, but also, if possible (limited technologies, the presence of antennas and other pathways of electromagnetic radiation in the radio electronic equipment, the development of electromagnetic weapons), prevent thermal electromagnetic damage of the radio electronic signaling system.

8. Conclusions

1. It is shown that the main parameters that determine the REM stability and are subject to control when PEMI impact are mainly determined by receiving devices and digital information processing devices.

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Thus, the radio channel of the useful signal is characterized by:

– sensitivity P_{smin};
– frequency selectivity (bandwidth, squareness coefficient of the frequency response);
– instability of the local oscillator frequency of the receiver;
– internal noise input receiver;
– non-linear characteristics of amplifiers and mixers used in the receiver, is the reason for the expansion of the spectrum of the received signal.

In addition, the characteristic, which allows to judge the REM susceptibility by the receiving channel of the useful signal, is the ratio:

$$U_s/(U_n+U_i),$$

where U_s, U_n, U_i – respectively, the voltage of the useful signal, noise and interference at the input of the receiver. For normal reception of a useful signal with a power of P_s, the condition $P_s>P_{s.min.}$ should be satisfied. REM susceptibility to the PEMI impact is also largely influenced by the AFP characteristics of the receiving path, namely:

– width of the main lobe of the radiation pattern (RP);
– levels of AFP RP side lobes;
– coefficient of the directed action;
– effective antenna area S_{ef};
– polarization parameters of the antenna [3, 7, 9].

2. It is determined that the peculiarities of test methods related to the determination of the REM resistance before, during and after the PEMI impact include:

– a wide range of frequencies as useful signals and interference;
– REM test in the near zone of PEMI influence;
– measurement of the PEMI statistical parameters;
– measurement of pickups in different REM circuits when PEMI influences;
– carrying out mathematical processing of measurement results in order to develop recommendations to improve the REM noise immunity;
– search and implementation in the CME development new design and technological solutions that provide a higher degree of reliability of the results obtained in shorter periods of time;
– development of new, more noise-resistant types of communication between individual CME parts and the investigated REM when creating measurement stands.

3. As a result of the conducted research, the tasks that arise in assessing the REM sustainability are:

– determination of the characteristics of the electrical and magnetic component of the fields of the PEMI, affecting the REM;
– determination of voltages and currents given in the REM circuits and on the interblock communication lines as a result of the PEMI action;
– determination of the change in the shape of the output signals and modes of operation of individual elements, circuits and devices of the REM during and after the PEMI impact;
– identification of elements, blocks, REM devices that are most critical to the impact of radiation energy.

4. As a result of the research, it is proved that the proposed test bench for carrying out REM complex tests for the resistance to the PEMI effects in its composition should have CME with storage oscilloscopes, the characteristics of which are given in the work.

Recommendations are given for conducting experimental studies of the REM resistance to PEMI by existing CME as part of a test bench:

– the monitoring of the REM resistance to the PEMI impact consists of two main stages. At the first stage, the REM parameters, which affect their electromagnetic compatibility, the effect PEMI on the RES, are monitored, and then the same measurements are made after the PEMI impact. The second stage of control is an assessment of the REM sustainability under the PEMI impact. This method of control is more objective, although its implementation is associated with a number of serious difficulties;
– for control of signals in high-frequency REM paths under the PEMI influence, as well as transients occurring in the equipment circuits in most cases it is necessary to use spectral methods that can be divided into direct and indirect. Direct spectral measurement methods are based on the use of spectrum analyzers. Indirect methods are based on the existing dependence of the width of the working frequency band of the measured radiation on various indirect REM parameters, such as the rate of decrease of out-of-band spectra, the installation of manipulation signals, and the frequency deviation. That is, the measured parameters directly with higher accuracy than the band of frequencies occupied by the obstacle;
– a number of additional solid technical requirements should be presented to the instrumentation used to control the REM stability under the PEMI influence. One of the ways to meet these requirements is deduction of a system of controlled signals from the PEMI influence. In general, this can be accomplished by taking the transmitter and receiver, as well as the communication line, out of the experiment area.

References

1. Izmeritel'nyy kompleks dlya issledovaniya elektromagnitnoy obstanovki pri rasprostranenii sverkhkorotkikh elektromagnitnykh impul'sov v pomeshheniyakh zdaniya / Sakharov K. Yu. et. al. // Tekhnologii EMS. 2009. Issue 3 (30). P. 18–22.
2. White Donald R. J. A Handbook on Electromagnetic Interference and Compatibility. Gainesville: Don White Consultants, 1987. 870 p.
3. Barsukov V. S. Kompleksnaya zashhita ot elektromagnitnogo terrorizma // Sistemy bezopasnosti svyazi i telekommunikatsiy. 2000. Issue 32. P. 94–98.
4. Balyuk N. V., Kechiev L. N., Stepanov P. V. Moshhnyy elektromagnitnyy impul's: vozdeystvie na elektronnye sredstva i metody zashhity. Moscow: OOO «Gruppa IDT», 2007. 478 p.
5. Fyk A. I., Ol'khovikov S. V. Metodika otsenki sostoyaniya vkhodnykh tsepey radiopriyomnykh ustroytv pri vozdeystvii elektromagnitnogo impul'sa yadernogo vzryva // Systemy obrobky informatsii. 2005. Issue 5 (21). P. 170–178.
6. Larionenko A. V., Simakin S. V. Rezul'taty eksperimental'nykh issledovaniy vozdeystviya sverkhshirokopolosnykh elektromagnitnykh impul'sov na elementy telekommunikatsionnykh sistem // Tekhnologii EMS. 2009. Issue 3 (30). P. 33–37.
7. Kravchenko V. I., Bolotov E. A., Letunova N. I. Radioelektronnye sredstva i moshhnye elektromagnitnye pomekhi / ed. Kravchenko V. I. Moscow: Radio i svyaz', 1987. 256 p.
8. Bogdanov V. N., Zhukovskiy M. I., Safronov N. B. Sistema natsional'nykh standartov po zashhite informatsii ot prednamerennykh elektromagnitnykh vozdeystviy // Tekhnologii EMS. 2009. Issue 1 (28). P. 23–28.
9. Akbashev B. B., Balyuk N. V., Kechiev L. N. Zashhita ob'ektov telekommunikatsiy ot elektromagnitnykh vozdeystviy. Moscow: Grifon, 2014. 472 p.

10. DSTU EN 55014-1:2016 (EN 55014-1:2006; EN 55014-1:2006/A1:2009; EN 55014-1:2006/A2:2011, IDT). Elektromahnitna sumisnist. Vymohy do pobutovykh elektropryladiv, elektrychnykh instrumentiv ta analohichnoi aparatury. Chastyna 1. Emisiia zavad. Kyiv: DP «UkrNDNTs», 2017. 94 p.
11. DSTU3680-98 (HOST 30586-98). Sumisnist tekhnichnykh zasobiv elektromahnitna. Metody zakhystu. Kyiv: Derzhstandart Ukrainy, 1999. 10 p.
12. Walling E. M. High Power Microwaves: Strategic and Operational Implications for Warfare. Occasional Paper No. 11. Center for Strategy and Technology / Air War College / Air University / Maxwell Air Force Base. Alabama, 2000. 52 p. doi: http://doi.org/10.21236/ada425472
13. Geis J. P. Directed Energy Weapons on the Battlefield a New Vision for 2025. Occasional Paper No. 32 / Center for Strategy and Technology / Air War College / Air University / Maxwell Air Force Base. Alabama, 2003. 73 p. doi: http://doi.org/10.21236/ada463429
14. Gizatullin Z. M. Tekhnologiya prognozirovaniya i povysheniya elektromagnitnoy sovmestimosti tsifrovykh elektronnykh sredstv pri vneshnikh vysokochastotnykh impul'snykh elektromagnitnykh vozdeystviyakh // Tekhnologii EMS. 2010. Issue 3 (34). P. 22–29.
15. Camp M., Nitsch D., Sabath F. Susceptibility of Electronic Equipment to HEMP Threats // System Design and Assessment Notes. Notes 37. 2004. 17 p.
16. Baker G., Castillo J. P., Vance E. F. Potential for a unified topological approach to electromagnetic effects protection // IEEE Transactions on Electromagnetic Compatibility. 1992. Vol. 34, Issue 3. P. 267–274. doi: http://doi.org/10.1109/15.155839
17. Tesche F. Topological concepts for internal EMP interaction // IEEE Transactions on Antennas and Propagation. 1978. Vol. 26, Issue 1. P. 60–64. doi: http://doi.org/10.1109/tap.1978.1141785

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MATHEMATICAL MODELING OF CURTAIN GROUTING PARAMETERS FOR THE ROADWAYS FLOODING PREVENTION

Об'єктом дослідження є процес підтоплення дорожнього полотна в зоні впливу зрошувальних полів. Одним з найбільш проблемних місць є вплив таких техногенних факторів на рівень ґрунтових вод, як зрошувальні поля та автошлях, що переважають природні фактори. Надмірний вміст вологи знижує несучу здатність ґрунту, що призводить до прискореного руйнування і укорочення терміну служби дороги. У таких випадках для дороги з проблемами водовідведення потрібно більш частий ремонт і відновлення, ніж тій, на якій водовідведення функціонує нормально. Тому витрати на влаштування покриття необхідно порівнювати з витратами на підтримку водовідведення. Для збереження доріг та попередження їх підтоплення необхідний постійний контроль за станом рівнів ґрунтових вод (РГВ) та прогноз його змін.

В ході дослідження використовувалися математичні методи (аналітичне розв'язання диференціальних рівнянь фільтрації із залученням комп'ютерної програми Maple) для математичного моделювання параметрів протифільтраційної завіси. А також методи еколого-економічної оцінки та порівняльного аналізу для визначення вагомих факторів впливу на РГВ та впливу РГВ на довкілля.

Запропоновано інженерний захід для захисту дорожнього полотна від шкідливої дії ґрунтових вод, що передбачає встановлення протифільтраційної завіси вздовж автошляху. Проведене математичне моделювання параметрів протифільтраційних завіс, яке дозволить ефективно використовувати протифільтраційні завіси в боротьбі з підтопленням.

З рівняння руху рідкого середовища Полубарінової-Кочіної, було отримано рівняння Дюпюї, яке використано для рішення стаціонарної задачі визначення витрати води крізь протифільтраційну завісу. Далі було розв'язано стаціонарну задачу визначення витрати води крізь протифільтраційну завісу. Встановлено, що використання протифільтраційної завіси є ефективним навіть при таких параметрах: $K_ф \leq 0{,}7$ м/доб, при більшій довжині та меншому заглибленні самої завіси. Отримані розрахунки параметрів дозволять використовувати протифільтраційні завіси в різних галузях для захисту від підтоплення різноманітних господарських об'єктів.

Ключові слова: *підтоплення автошляхів, зрошувальні поля, коефіцієнт фільтрації, математична модель параметрів протифільтраційних завіс.*

1. Introduction

When constructing roads, special attention of project developers is paid to the traffic safety. The construction of roads and their maintenance in a satisfactory working condition takes a lot of effort, time and funding. In Ukraine, the problem of off-road is accepted to decide when traffic is no longer possible, especially with regard to inter-city traffic. Almost all regional roads become unsuitable for travel, especially those that lead to remote and mountain villages, where the road is the only thing that connects these settlements with the regional center. The road industry