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Experimental Assessment of the Resistance Parameters of a Radio Equipment to the Influence of Powerful Electromagnetic Radiation

Oleksandr Fyk
Doctor of Technical Sciences, Associate Professor, Professor of the Department of Military Communications and Informatization National Academy of the National Guard of Ukraine Kharkiv, Ukraine, e-mail: aifleks@ukr.net

Olena Novykova
Candidate of Technical Sciences, Associate Professor, Professor of the Department of Military Communications and Informatization National Academy of the National Guard of Ukraine Kharkiv, Ukraine, e-mail: nangu.nea@gmail.com

Roman Honchar
Candidate of Military Sciences, Senior Researcher, Senior Scientific Officer of the Research Center of Service and Combat Activity National Academy of the National Guard of Ukraine Kharkiv, Ukraine

Oleksandr Voronin
Senior Lecturer of the Department of Military Communications and Informatization National Academy of the National Guard of Ukraine Kharkiv, Ukraine

Oleh Nazarenko
Senior Lecturer of the Department of Tactics National Academy of the National Guard of Ukraine Kharkiv, Ukraine, e-mail: aifleks@ukr.net

Dmitriy Kucher
Doctor of Technical Sciences, Professor, Professor of the Armament Department Naval Institute of the National University "Odessa Maritime Academy" Odessa, Ukraine, e-mail: dmitr_bor_kucher@ukr.net

Abstract—
The existing approaches to quality control and quantitative assessment of the resistance of radio equipment to the influence of powerful electromagnetic radiation do not allow such an assessment to be fully carried out due to the low probability of quantitative assessments, the complexity of the functional construction of individual radio equipment, etc. Therefore, the most objective is the experimental method of assessing the resistance of a radio-technical device to the influence of powerful electromagnetic radiation, which allows taking into account the functional connections between individual devices of a radio-technical device and their features. The article describes the main parameters that determine the resistance of radio equipment to the influence of powerful electromagnetic radiation, the choice of methods for measuring the parameters of tested radio equipment before, after and during exposure to powerful electromagnetic radiation, as well as recommendations for conducting experimental studies of the stability of radio equipment with the available control and measurement equipment as part of the control and test stand.
The control and test stand must meet the following basic requirements: affect the operation of the tested radio electronic means; have a speed that is sufficient to register the expected change in the controlled signals of the radio electronic means and transient processes in their circuits; have the necessary multi-channel capability, which allows you to register the entire set of signals that characterize the operation of the radio electronic means; have high interference resistance.
Standard memory oscilloscopes, including loop ones, can be used as part of the control and test stend to measure and register low-frequency signals (parameters of the radio electronic means power sources, control signals, telemetry signals, code structures of transmitted signals, etc.). Methods of controlling the high-frequency parameters of the radio electronic means, determining their susceptibility to the influence of powerful electromagnetic radiation, should include measuring the sensitivity of the radio receiver as a function of the carrier frequency of the electromagnetic field by measuring the power or voltage of the signal at the input of the receiver, in which the ratio Uc / (Ush+Up) at the output of the receiver is not less than the given value.

Keywords- influence of powerful electromagnetic radiation, channel for reception of useful signal, malfunction of radio equipment, stability of radio equipment, susceptibility of radio equipment.

I. INTRODUCTION

Formulation of the problem. In order to carry out an experimental assessment of the resistance of a radio technicalmeans (RTM) to the influence of powerful electromagnetic radiation (PEMR), it is necessary to solve a number of serious problems, the main of which are: determination of the main parameters characterizing the resistance of the RTM to the influence of PEMR; the choice of methods for measuring the parameters of the tested RTM before, after and during the influence of powerful electromagnetic interference (PEMI); selection of methods for measuring the parameters of secondary (induced) interference in the internal circuits of the RTM, including in all communication lines between the RTM and the control and measuring equipment (CME).

Analysis of recent research and publications. There are different approaches to qualitative control and quantitative assessment of RTM resistance to the influence of PEMR. One of the most general approaches is a strict mathematical method that implements a mathematical model of the RTM in interaction with external and internal obstacles, which allows you to assess the performance of the RTM in a given interference situation [1]. However, it is very difficult to actually create such models that fully take into account all the connections between the signals affecting the RTM and its own characteristics. Therefore, in practice, as a rule, mathematical models of individual RTM devices or a general simplified model of RTM are created, which allows you to assess the qualitative picture of the studied processes, but, unfortunately, does not give a high probability of quantitative assessments. For individual RTM devices, the method of equivalent circuits can be used to assess their stability [2; 3]. This method gives good results in the analysis of RTM devices that are quite simple in terms of their functional construction. When evaluating various types of high-frequency devices, which are an integral part of most RTM (antenna-feeder, radio receiving and radio transmitting devices), the spectral method of analysis is used quite successfully [1]. This method makes it possible to assess the degree of influence of PEMI on the operation of the high-frequency path.

The most objective method of evaluating the resistance of the RTM to the influence of PEMR is the experimental method, which allows taking into account the functional connections between individual RTM devices, as well as their constructive, assembly, technological and other features.

The purpose of the article is to determine the list of parameters that determine the resistance of radio technicalmean to the influence of powerful electromagnetic radiation, to consider the methods of measuring the parameters of tested radio technicalmeans under the influence of powerful electromagnetic radiation, and also form recommendations for conducting experimental studies of the stability of radio technicalmeans with the existing control and measurement equipment as part of the control and test bench.

II. PRESENTING MAIN MATERIAL

A. The main parameters that determine the stability of the RTM and are subject to control under the influence of PEMR

Depending on the stage of RTM development, their structural scheme, functional purpose and operating conditions, experimental evaluation of RTM stability may include measurement of: parameters of external PEMR affecting RTM; interference parameters in the internal circuits and communication lines of the RTM, as well as between the RTM and the CME; parameters of individual parts of the RTM before and after exposure to PEMR; RTM parameters as a whole before and after exposure to PEMR; parameters of RTM as a whole during exposure to PEMR.

Modern RTM consist of such different functional purpose devices as antenna-feeder, receiving and transmitting, digital computing, control and synchronizing devices. Each of the listed devices contains a large number of various connections and electroradio-elements, so evaluating the stability of the RTM is a very difficult technical task.

The parameters that determine the stability of the RTM are those characteristics of PEMR and parameters of the RTM that significantly affect the quality of their functioning (compliance of the technical characteristics of the RTM with the specified requirements). They can be divided into:

1) parameters characterizing the malfunctioning interference environment created by the RTM themselves;
2) parameters characterizing the degree of susceptibility of different parts of the RTM to the influence of PEMR.

Let's consider the main parameters of the second group. RTM sensitivity means the degree of response of the RTM to the influence of PEMR together with the main signal and without it through the antenna, screen, power supply, grounding, control and switching circuits. The degree of susceptibility of the RTM to the influence of PEMR is mainly determined by the radio receiving device and digital information processing devices. The main ways of impact of PEMR on RTM are shown in Fig. 1-5.

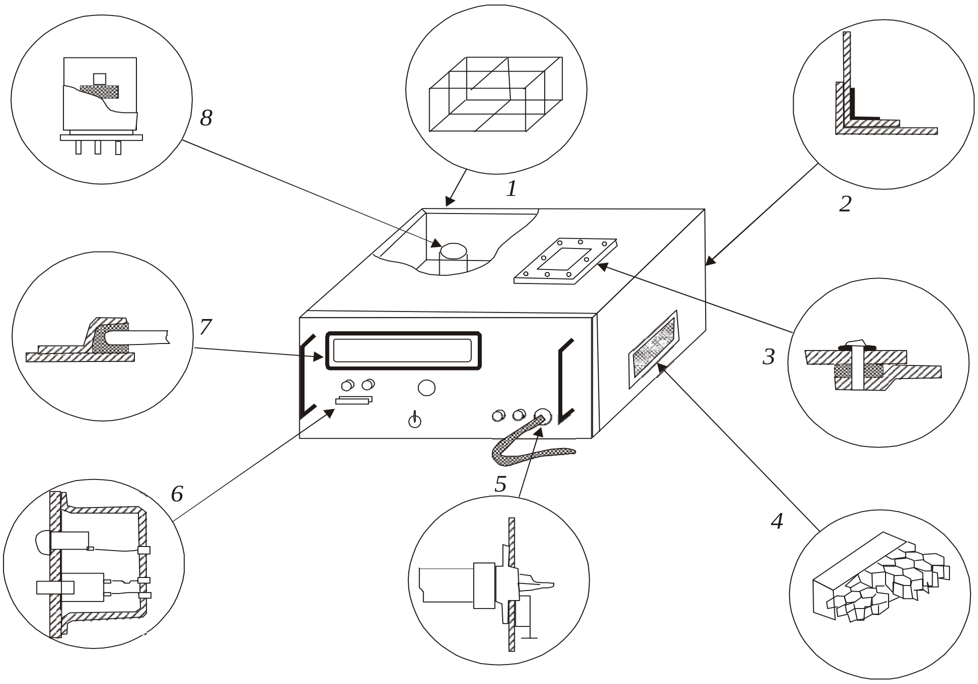


Figure 1. Implementation of some methods to increase the resistance of RTM resistance to the influence of PEMR:

1 - Welded body frame RTM; 2 - Continuity of the body RTM; 3 - Electromagnetic sealing gaskets; 4 - Ventilation and notched holes; 5 - Cables and removable contact connections; 6 - Additional partial shielding; 7 - Conductive transparent materials; 8 - Local shielding

The channel for receiving a useful signal is characterized:

– sensitivity $P_{c.min}$;
– frequency selectivity (frequency bandwidth, squareness factor AFR);
– instability of the local oscillator frequency of the receiver; internal noises of the input cascades of the receiver;
– nonlinearity of the characteristics used in the receiver of amplifiers and mixers, which is the reason for the broadening of the spectrum of the received signal.

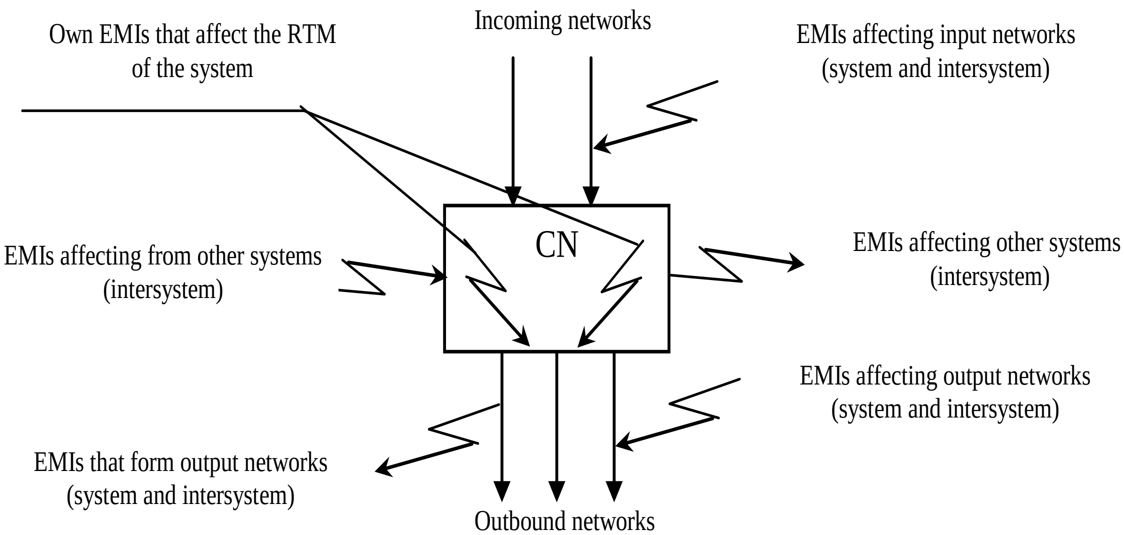


Figure 2. Scheme of electromagnetic interference (EMI) per communication node (CN)

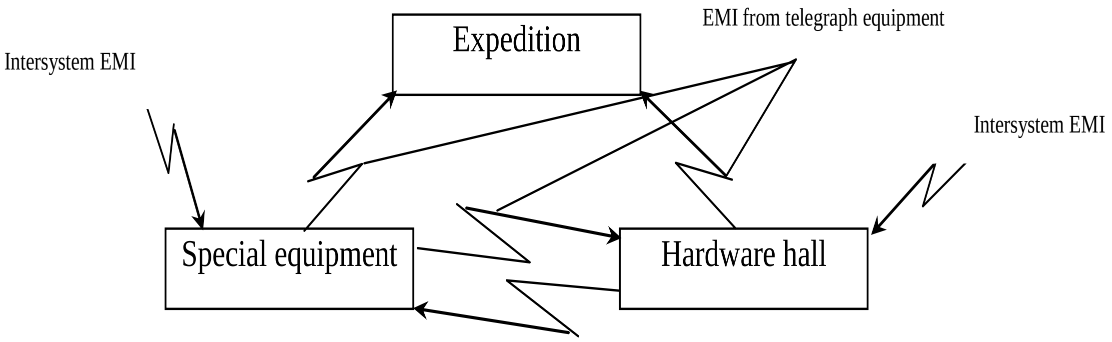
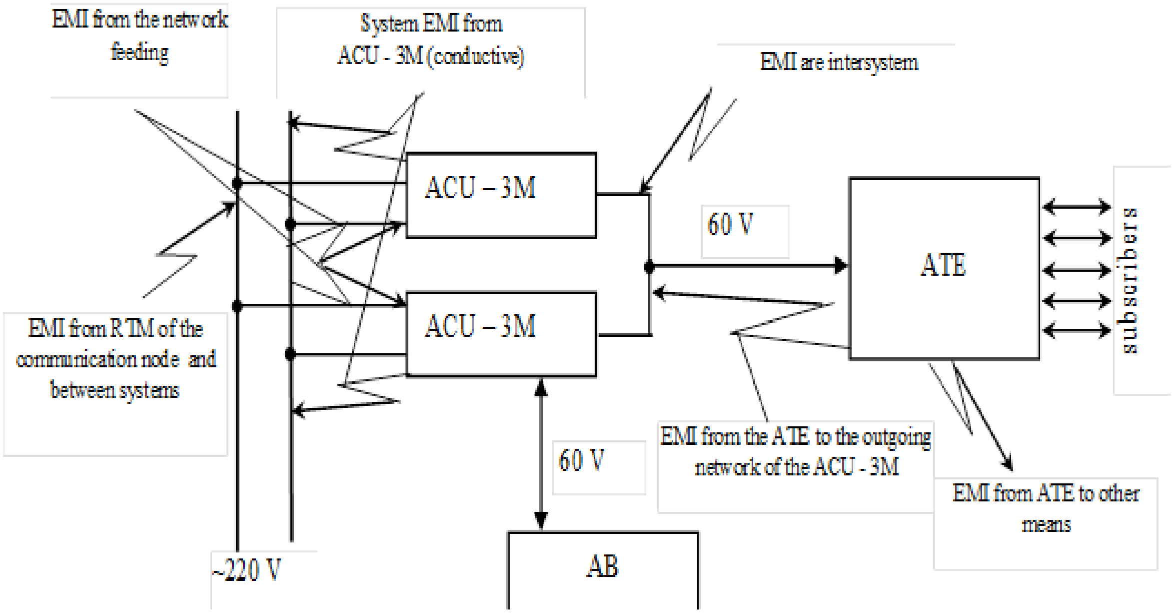


Figure3. Scheme of interference on the telegraph as a separate subsystem of the communication node



Source: developed by the authors

Figure 4. Functional diagram of the automatic telephone exchange (ATE) operation with electromagnetic interference: ACU – automatic and charging unit; AB – accumulator battery

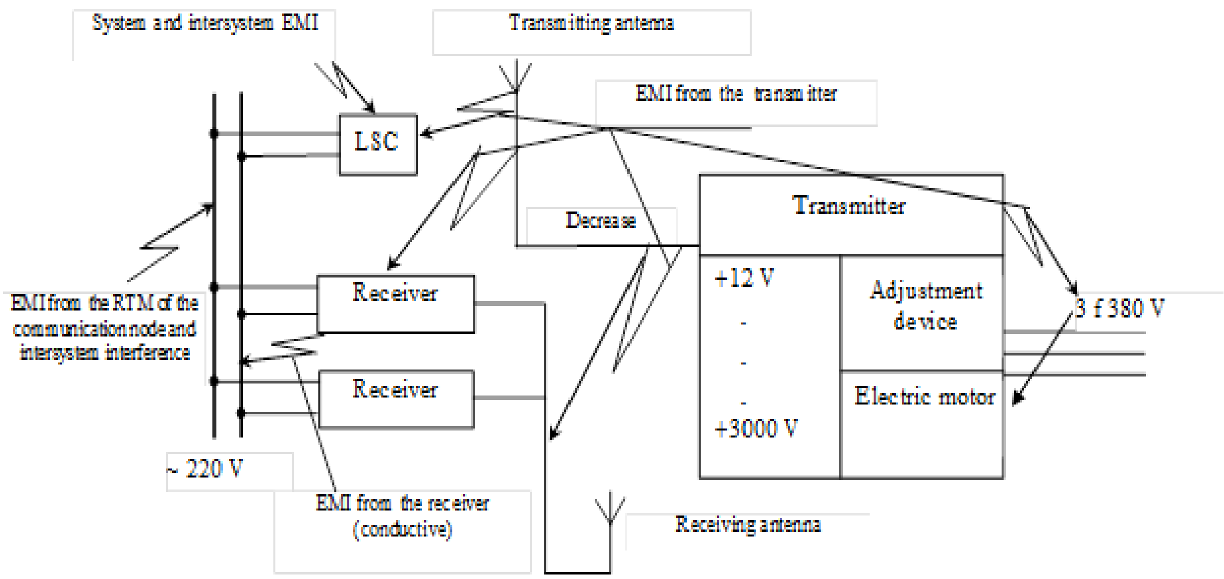


Figure 5. Functional diagram of the reception-transmission radio center and electromagnetic interference: LSC – loudspeaker communication

TABLE I. TYPICAL VIOLATIONS IN RTM DEVICES UNDER THE INFLUENCE OF PEMR TABLE TYPE STYLES

RTM class (component part of RTM)	**Nature of violations**	**Note**
Linear circuits (amplifiers of sinusoidal signals, video amplifiers, DC amplifiers)	Twisting output waveforms, appearance of false signals, self-excitation	The minimum interference energy that causes a high-gain amplifier to fail, W=(1...105)·10^{-20} Joule
Pulse and logic circuits (keys, triggers, multivibrators, blocking generators, boundary devices, etc.)	Twisting output waveforms, loss of information in memory nodes	The minimum interference energy that causes failures in logic circuits, W=(1...10)·10^{-9} Joule
Generators of sinusoidal signals, generators of signals of a special form	Sbiy frequency, short-hour twisting of the form of a signal, loss of information	The most resistant to the effects of PEMR generators with quartz frequency stabilization
Antenna-feeder devices	Appearance of obstacles in the AFD load	Linear antennas are most vulnerable to the influence of PEMR; irreversible failures of diodes are possible
Power sources	Short-term change in output voltage	

An important characteristic that allows you to judge the receptivity of the RTM by the channel of reception of the useful signal is the ratio $U_c / (U_ш + U_n)$, where U_c, $U_ш$, U_n – the voltage of the useful signal, noise and interference at the receiver input, respectively. For normal reception of a useful signal with power P_c the condition $P_c > P_{c\ min}$ must be satisfied. The specified value of the indicated ratio is one of the most frequently used criteria in practice, which allows to quantitatively assess the susceptibility of the RTM to the influence of PEMR on the channel of the useful signal.

The characteristics of the antenna-feeder device (AFD) of the receiving path also affect the susceptibility of the RTM to the influence of PEMR to a large extent, namely: width of the main petal of the directional diagram; the levels of the lateral petals of the AFD directional diagram; coefficient of directed action; effective antenna area $S_{eф}$; antenna polarization parameters [4; 5]. In works [1-5] it is shown that PEMR affects the operation of the RTM not only due to the passage of the useful signal through the reception channel. Its influence leads to the appearance of the indicated currents and voltages in the grounding, control, etc. circuits. These routes of penetration, along with the previously listed ones, are also of great interest in assessing the stability and predicting the behavior of RTM under the influence of PEMR.

B. Methods of control of RTM parameters before, during and after exposure to PEMR

At the initial stages of RTM development, the main purpose of the tests is to check the effectiveness of the adopted technical solutions, to choose the optimal options for the design of the equipment, and to evaluate the reserve in terms of stability and electrical strength. At these stages, an important place is occupied by the measurement of currents in the circuits of the individual devices under study. At the next stages, the control of the initial parameters of the RTM under the influence of PEMR becomes more and more important [9; 10; 11] and checking their compliance with specified requirements [13; 14; 15].

Control of RTM resistance to the influence of PEMR, as a rule, consists of two main stages. On the first one, the parameters of the RTM that affect their

Features of test methods related to determining the resistance of RTM to the influence of PEMR are: a wide range of frequencies of both useful signals and interference; testing of RTM in the near zone of impact of PEMR; measurement of statistical parameters of PEMR; measurement of leads in different circuits of the RTM under the influence of PEMR; carrying out mathematical processing of the measurement results in order to develop recommendations that allow to increase the interference resistance of the RTM; search and implementation in the development of CME of new design and technological solutions that ensure a higher degree of probability of the obtained results in shorter periods of time; development of new, more interference-resistant types of communication between separate parts of the CME and the investigated RTM when creating measuring stands.

When choosing a method of controlling the stability of the RTM, it is necessary to focus on such methods, which would have a fairly simple implementation and at the same time gave sufficient accuracy.

Depending on the stage of development of RTM, their structure and functional purpose, the following tasks may consistently arise when assessing the stability of RTM: determination of the characteristics of the electric and magnetic components of the PEMR fields affecting the RTM; determination of induced voltages and currents in RTM circuits and on interblock communication lines as a result of PEMR action; determination of changes in the form of output signals and modes of operation of individual elements, circuits and devices of the RTM during and after the influence of PEMR on the RTM; identification of elements, blocks, devices of RTM, which are the most critical to the impact of PEMR.

When choosing a specific measurement method at various stages of development of RTM, generalized data on the nature of violations of individual devices and scheme of the equipment being studied under the influence of powerful impulse interference can be useful (table 1).

electromagnetic compatibility are monitored before exposure to PEMR on the RTM, and then the same measurements are carried out after exposure to PEMR.

In this case, the CME is not directly affected by the PEMR, which allows the use of traditional measurement methods and standard control and measurement devices. The second stage of control is the assessment of the stability of the RTM under the influence of PEMR. This type of control is more objective, although its implementation is associated with a number of serious difficulties.
According to the results of the tests, the nature of the malfunction of the RTM under the influence of PEMR with the specified characteristics is judged. At the same time, malfunctions of the RTM can be both reversible and irreversible, and associated either with the failure of its individual elements, or with the appearance of unacceptable false signals in their circuits.

There are different criteria for evaluating the efficiency of the RTM under the influence of PEMR: energy and time [12].
The energy criteria are based on the definition of the minimum energy of the obstacle at which the failure of the RTM occurs, and the time criteria are based on the definition of the minimum time for the recovery of the RTM after a failure in operation as a result of the impact of PEMR.
Recommendations for carrying out experimental studies of the stability of the RTM with the available CME as part of the control and test bench
A number of additional strict technical requirements are put forward to CME. CME is used to control the stability of RTM during exposure to PEMR.
One of the ways to meet these requirements is the output of a number of controlled signals from the zone of influence of the PEMR. In the general case, this can be done with the help of transmitting and receiving devices, as well as a communication line.
The transmission device, used to output information from the zone of influence of PEMR, is designed to convert the controlled parameter of the studied RTM into a signal convenient for its transmission over the communication line in the CME. Since the transmitting device must be located in the zone of influence of PEMR and directly connected to the RTM, it has particularly high requirements regarding interference resistance, influence on the tested equipment, overall dimensions, consumption, etc. [12, 16-19].
The receiving device converts the transmitted signal into a form convenient for measurement and registration in CME. Since the receiving device in this case is located at some distance from the zone of influence of PEMV, less strict requirements are put forward to it [12].
Wires, cables, waveguides, as well as the medium between the receiving and transmitting devices should be used as communication lines. Audio, optical and radio signals can be transmitted over communication lines. The general structural diagram of the universal control and test stand [1], intended for carrying out tests of RTM for resistance before, during and after exposure to PEMR, is shown in Fig. 6.

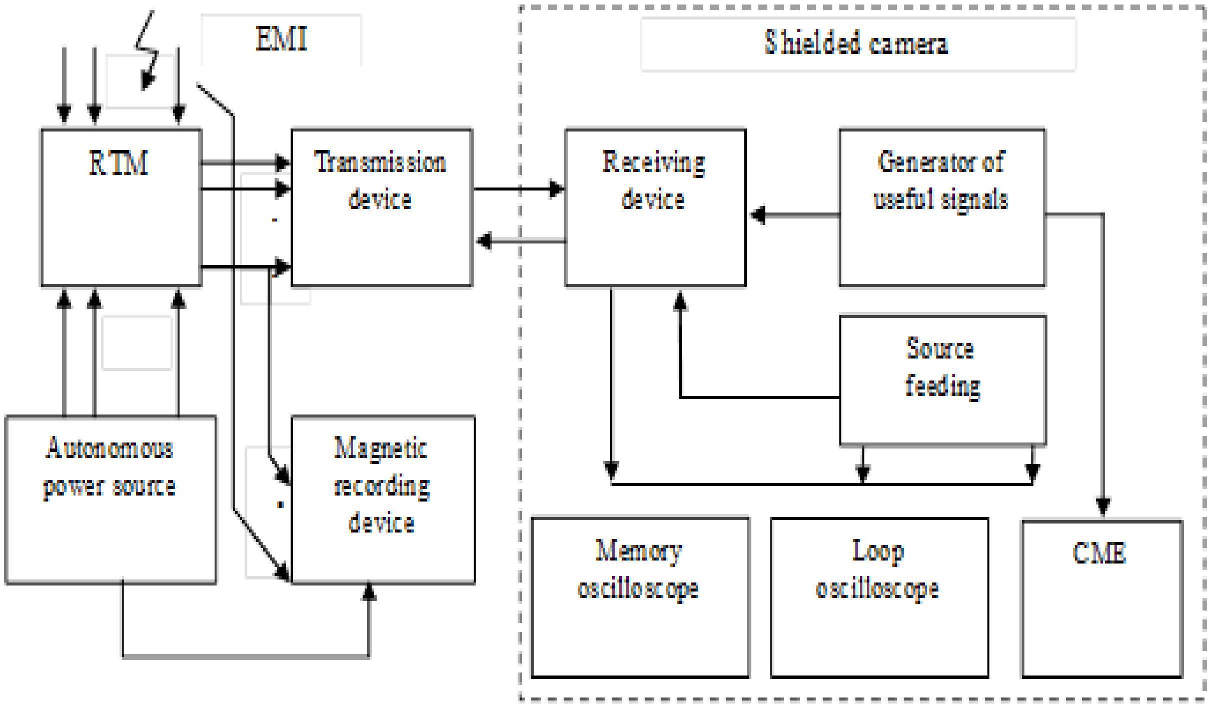


Figure 6. Structural diagram of a universal control and test bench for carrying out complex tests of RTM on resistance to the influence of PEMR

TABLE II. TECHNICAL CHARACTERISTICS OF SOME TYPES OF MEMORY OSCILLOSCOPES

Type	Frequency bandwidth, MHz	Recording speed, km/s	Screen sweep	Input parameters	Overall dimensions, mm; mass, kg	Note
38-7A	0 ... 20	1000	50 ns/ division	0,5 MOhm	350x450x770;	

(single beam)			... 5 s/ division	55 pF	50	
38-12 (single beam)	$5\text{-}10^{-6}$ ... 0,1 0 ... 10 0 ... 50 0 ... $3{,}5\text{-}10^{3}$	4000	(0,1...5) mks/ division ... (0,1...0,5) s/ division	1 MOhm 30 pF	480x215x496; 27	With interchangeable blocks
38-9A (single beam)	0 ... 2	120	0,05 mks/ sm ... 0,6 s/sm	0,5 MOhm 45 pF	265x560x380; 36	Vertical sensitivity 100 mV/sm ... 10 V/sm
C8-1S (single beam, portable)	0 ... 10	1000	0,05mks/division ... 0,5 s/ division	1 MOhm 43 pF	180x300x480; 16	Vertical sensitivity 2 mV/ division ... 5 V/ division
38-18 (single beam)	0 ... 10	250	0,05mks/division ... 1 s/ division		330x177x500; 16	Vertical sensitivity 1 mV/ division ... 5 V/ division
38-2 (two-beam)	0 ... 7	500	0,05 mks/division ... 25 s/division	0,5 MOhm 55 pF	670x1225x485; 81	
38-17 (two-beam)	0 ... 1	540	0,2 mks/division ... 25 s/division	1 MOhm 42 pF; with a divisor 1 MOм 12 pF	300x180x480; 16	Vertical sensitivity 1 mV/ division ... 5 V/ division, playback time 30 min, retention time 5 days

The control and test stand must meet the following basic requirements: affect the operation of the tested RTM; have a speed that is sufficient to register the expected change in the controlled signals of the RTM and transient processes in their circuits; have the necessary multi-channel capability, which allows you to register the entire set of signals that characterize the operation of the RTM; have high interference resistance. Thus, the level of accuracy of registration of the expected change in the controlled signals of the RTM and transient processes in their circuits is determined mostly by the type of recording device used in the control and measuring stands. The parameters of some types of domestic storage oscilloscopes are listed in Table 2. The main parameters that determine the possibility of using one or another type of oscilloscope are the speed and probability of reproduction of the investigated signal, which depend on the frequency properties of the oscilloscope, as well as the accuracy of reading, which depends on the parameters of the electron beam tube and input amplifiers.

III. CONCLUSIONS

1. Removal of the CME and separate measuring devices from the zone of influence of PEMR with the help of transmitting and receiving devices makes it possible to exclude or significantly reduce the effect of PEMR on the main part of the CME and, therefore, to use standard measuring devices used in periodic checks of the RTM. Still, some of the requirements proposed for the test stand, for example, speed and immunity to interference, may turn out to be mutually exclusive, which at high levels of PEMR field strength makes the development of such a stand a rather difficult task.
2. To measure and register low-frequency signals (parameters of RTM power sources, control signals, telemetry signals, code structures of transmitted signals, etc.), standard memory oscilloscopes, including loop ones, can be used as part of the control and test bench. Loop oscilloscopes are classified as inertial devices, they practically do not react to short-term impulse disturbances, which allows to reduce the requirements for their protection. One of the ways to reduce biases when measuring and recording low-frequency parameters of the RTM is the use of magnetic recording devices located in the immediate vicinity of the RTM.
3. To control the signals in the high-frequency paths of the RTM during the influence of PEMR, as well as transient processes arising at the same time in equipment circuits in most cases, spectral methods are used. They can be divided into direct and indirect. Direct spectral measurement methods are based on the use of spectrum analyzers, with the help of which the width of the spectrum of radiation frequencies is determined at a given power level in decibels. Indirect measurement methods are based on the existing dependence of the width of the working frequency band of the measured radiation on various non-direct parameters of the RES, such as the rate of decrease of out-of-band spectra, the time of establishment of manipulated signals, frequency deviation, that is, parameters that can be measured directly with higher accuracy than the frequency band occupied by interference.
4. The power and frequency of interfering radiation can be measured using measuring antennas, measuring receivers and other devices that convert the measured power into a value that is convenient for registration and control the carrier center frequency of the received high-frequency signal [6-8].
5. Among the methods of controlling the high-frequency parameters of RTM, which determine their susceptibility to the influence of PEMR, it is worth including the measurement of the sensitivity of the radio receiver as a function of the carrier

frequency of the electromagnetic field by measuring the power or voltage of the signal at the input of the receiver, in which the ratio $U_c / (U_ш+U_n)$ at the output of the receiver is not less than the specified value.
The frequency selectivity of a radio receiver can be measured by a single or multi-signal method, a blocking method, etc. [8; 9]. The susceptibility of the RTM to PEMR, which spreads through power circuits, is quantitatively determined by the ratio of the level of interference in the power circuits to the level of interference at the receiver input, provided that those and other interferences create the same voltage at the output of the radio receiver.
6. Transient processes in various RES circuits are most often controlled by amplitude-time methods with the help of electronic oscilloscopes, mainly memory ones. At the same time, as a rule, the following characteristics of the transient process are analyzed: the maximum value of the impulse U_{max}; the duration of the pulse front (the rise time of the front from 0,3 U_{max} to 0,9 U_{max}); the duration of the transient process at the levels of 0,5 U_{max} or 0,1 U_{max}. The set of listed data is sufficient for obtaining the dependence of the current value of the transient process on time, which will be used further to refine the mathematical model of the interaction of the RTM with the PEMR.
7. The accuracy of the assessment of the above characteristics of the transient process is mostly determined by the type of oscilloscope used.

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