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SYSTEM TECHNICAL SOLUTION OF ELECTROMAGNETIC ADAPTATION

Abstract. In military radiolocation systems, electromagnetic compatibility includes the provision of joint operation of the elements that make up various military devices, the creation of joint working conditions for devices as elements of different systems, and inter-system activities. **The object of the research** is military radar equipment. The article describes the main schematic and technical solutions for electromagnetic compatibility in military radar equipment. In addition to the selection scheme, a method for synchronizing the operation of several radar stations that are very close to each other or operate at the same repetition frequency is studied. **The subject of the research** is the analysis of the electromagnetic compatibility system. The issues of joint selection, practical application, and reduction in the number of electromagnetic compatibility components are analyzed, and various simplifying assumptions are put forward. The essence of what is presented is diverse and depends on the specific situation. Thus, among the measures based on the use of spatial factors, the dispersion of the main radiation directions of radio-electronic devices in space, various methods of limiting radiation at certain volume angles, reception of signals from different directions, and the use of differences in the polarization structure, etc., were identified. **The purpose of the research** is to analyze the electromagnetic compatibility system in military radar devices. In accordance with this goal, the scientific research work sets forth the following tasks: analysis of the electromagnetic compatibility system in military radar devices; selection, provision, or, if necessary, modification of the system's operating principle; consideration of the planning and distribution of the radio frequency source among the elements included in the analyzed system; practical application of the approach based on the joint selection of electromagnetic compatibility, reduction in their number, and introduction of various simplifying assumptions, etc.; analysis of the general problem of solving the problem of parameters. To solve the tasks set, the following **research methods** are used: theoretical, mathematical, and comparative analysis. **As a result of the research**, a time synchronization device is proposed to ensure electromagnetic compatibility and obtain an unobstructed working zone on the indicator screen, depending on the dispersion of radar stations in the area. The use of a time synchronization device will solve system-technical problems, effectively combat mutual interference, ensure the quality of the operator's work, and increase the probability of correct detection.

Keywords: system engineering solution; selector; synchronizer; regulatory device; electromagnetic adaptation.

Introduction

A system is a technical collection of devices that have a certain relationship with each other in the performance of a given technical function. A collection of radio-electronic means placed in a limited area or a certain object can be a system in terms of ensuring their electromagnetic compatibility (EMU). The feature of the operation of such a system is the possibility of unwanted connections between its elements and with other systems [1–3]. Ensuring the joint operation of the elements that make up the various units of the vehicles whose main goal is to solve the general issue belongs to the intra-system measures of the EMU, and the creation of joint working conditions of the units as elements of different systems belongs to the inter-system measures of the EMU. Both of these measures are combined under the name of system technical measures. In any case, system technical measures are carried out in one of the following directions [4–6].

– selection of the sensitivity of radio receiver receptors and radio transmitter radiation as the analyzed element of the system, ensuring or, if necessary, changing the working principle of the system;

– planning, distribution or, if necessary, redistribution of the radio frequency source among the elements included in the analyzed system.

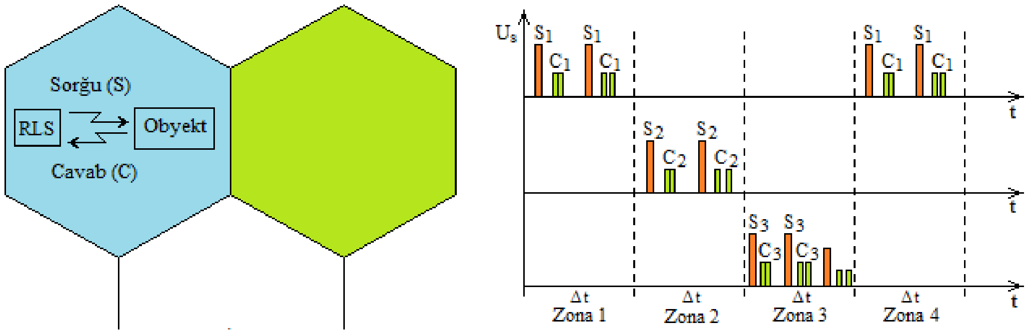
As a result, the practical application of the approach based on the joint selection of parameters becomes convenient with the reduction of their number and the introduction of various simplifying assumptions. Their nature is different and depends on the specific situation. Thus, the order of measures based on the use of spatial factors, the scattering of the main radiation directions of radio-electronic devices in space, different methods of limiting radiation at certain angles, reception of signals from different directions, the use of differences in the polarization structure, etc. have been revealed.

Use of the time factor

The time factor mainly leads to shortening, blanking of radiation time, time distribution, synchronization, and time regulation of the operation of radio-electronic devices [7]. The shortening of the irradiation time related to technical and organizational measures allows to improve the joint working conditions of the means. In practice, in order to shorten the radiation time, special radio devices working on the duty radio channel are used.

The blanking method is based on the termination of signal reception during the influence of strong impulse obstacles. This allows to protect the input cascade from overload and the receiver from non-linear phenomena and is more effective for pulse signal radio receivers.

The time distribution of pulse radios operating together in a certain area is more effective. Let's look at the implementation of this type of synchronization using the "Time-zone-system" method [8, 9]. Suppose there is a group of mobile radar stations (RADAR) in the area (Fig. 1).



a b

Fig. 1. Synchronization using the "time-zone-system" method: a – realization scheme; b – timing diagram

To remove the obstacle, the space area is divided into several zones, however, certain time intervals are allocated for working with each of them. Any RADAR within the given zone limits uses the time slot that corresponds to it. Since the RADAR in the neighboring zone is in a different time slot, the interference from it is eliminated. Time distribution in such systems is carried out with the help of highly stable special synchronizing channels.

The composition of events of a limited nature in a certain time area is determined by the time regulation. According to the established operating rules, if EMC is not provided by other means, then the work of some means is stopped for a certain period of time. As all possibilities have been exhausted, the application of the time regulation is a last resort. There are a number of similar measures of prohibitive nature, in which the work of secondary means is stopped for a certain period of time during the operation of more important means [10, 11].

Co-synchronization of pulse RADARs is related to matching the repetition periods and initial phases of the pulses emitted by them and can be implemented in different variants [12, 13]. If the radio transmitters of nearby RADARs radiate at the same time, then strong mutual interference signals will enter at the time when the receiving devices are closed, thereby eliminating their damage. Time synchronization is used for this purpose. In hard synchronization, the "controlling" station is defined as the pulse repetition frequency, the starting phase, and the "controlled ones" operating at or at a subharmonic of that repetition frequency. The synchronizing signals of vehicles placed in a limited area can be transmitted by cable line, and in other options, by special radio channels [14].

Sometimes it is possible to achieve time synchronization without a hard-wired "controller". The device included in each vehicle must solve: reception of neighboring RADAR signals of the same type, their separation by amplitude and duration; choosing dances with a larger repetition period among them. Suppression of signals with a different repetition frequency as a result of matching the time synchronization of the whole group with blanking allows to significantly weaken the unwanted mutual interference of RADARs in the group.

Time regulation device

In RADAR receivers, the pulse radio interference selection scheme is widely used due to the repetition period and also due to the fixed repetition frequency, where pulse modulation methods are used. The overlap of two or more streams of pulses is the basis of selection. In the overlapping scheme, one pulse is input directly, and the second is input through the delay line. The delay time of the delay line is equal to T_s, $2T_s$, ..., nT_s, where T_s is the repetition period of the useful signal, n is the sequence number of the delayed pulse stream. When the repetition period of the input pulses is equal to T_s, there is a signal at the output of the overlapping circuit.

In most cases, chaotic barrier pulses have such a combined effect on the selection circuit that some of these barriers pass to the output of the overlapping circuit. This reduces the effectiveness of the selection scheme. The number of this barrier pulses is proportional to the density of pulses in the radio barrier.

One of the effective countermeasures against asynchronous radio interference pulses generated in several RADARs operating simultaneously with a repetition period close to each other is joint synchronization of the RADARs [15]. This method can be used if the application of the selection scheme due to the recurrence period is ineffective.

Synchronization of the operation of several RADARs operating at leading frequencies close to each other is the most effective method of protection against asynchronous interference pulses. In this way, asynchronous barriers are converted into synchronous ones, in some cases they are completely suppressed, thereby ensuring the electromagnetic compatibility of RADARs. This method is more effective in RADAR with a low frequency of recurrence [16]. In addition, the less the repetition frequency differs in different RADARs, the higher the consistency of the synchronizer's work. There can be three types of joint synchronization: synchronization from a controlling RADAR; sequential (periodic) synchronization of RADARs; combination synchronization method.

As an example, let's look in detail at the method of synchronization from a controlling RADAR (Fig. 2). Here, the sensed pulses from one RADAR (controlling RADAR) are transmitted to other RADARs (controlled RADAR) by cable or special radio communication line. Let's number the RADARs located freely scattered in the area from zero to N. Without violating generality, RADAR0 can be considered as the controlling one, and the remaining RADARs as the controlled ones. Since the processes are similar for all managed RADARs, let's clarify the essence of synchronization in its application to RADAR0 and RADAR4.

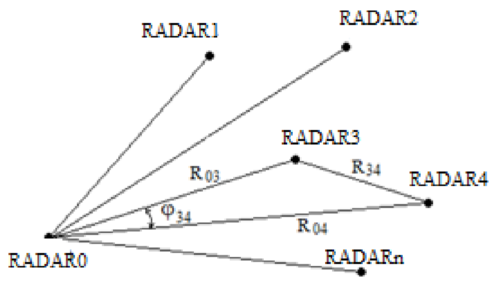


Fig. 2. Arbitrary arrangement of managed RADARs synchronized from one managed RADAR

Suppose that a dedicated radio communication line is used to transmit the synchronizing pulses to the controlled RADAR4. Each probe pulse of RADAR0 is a synchronizing pulse for RADAR4 (Fig. 3,a), transmitted over the radio communication line, reaches RADAR4 after the time $t_4 = R_{04}/c$ from its generation (Figure 3,c) and activates the synchronizer, i.e., the regulator which sets the sensing period of the controlled RADAR4 to the sensing period of the controlling RADAR0, there by synchronizing them [1, 17, 18].

In the designated mode, the synchronization process takes a certain amount of time. After that time, RADAR4 probe pulses are radiated in the target direction (Fig. 3, c). At the same time, together with synchro pulses, from the main or side lobes of the antenna's directional diagram, pulses from the control RADAR0 enter the input of the receiver of RADAR4 and form a synchronous barrier with a repetition period Ts (Fig. 3, d) [1]. The synchronous barrier pulse precedes the corresponding sensing pulse of RADAR4 by time $t_0=t_a$ (Fig. 3, c, d) and falls into the opening period of the distance preceding this pulse.

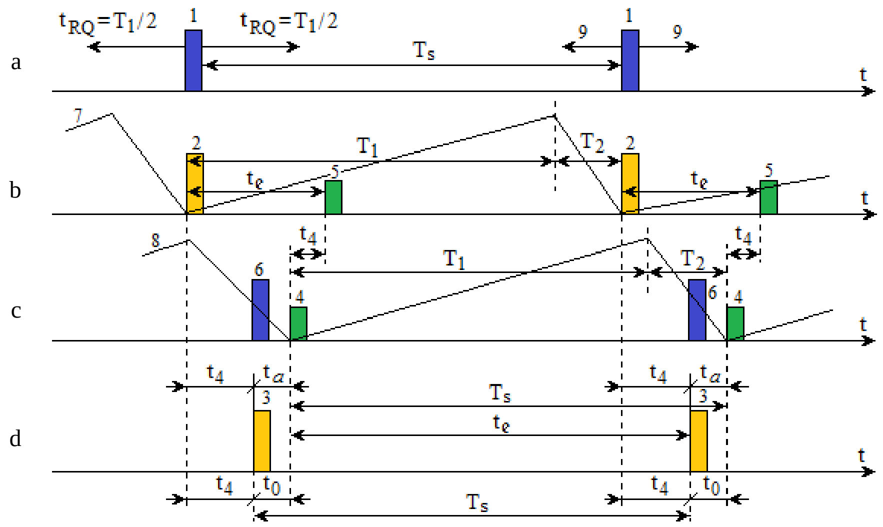


Fig. 3. Time dependences of the synchronization of the work of RADARs:
1 – synchro pulses; 2 – pulses sensed by the RADAR from the controller; 3 – pulses sensed by the controlling RADAR at the input of the controlled RADAR; 4 – pulses sensed by controlled RADAR; 5 –pulses sensed by the controlled RADAR at the input of the RADAR from the controller; 6 – synchronous pulses at the input of the controlled RADAR; 7 – the voltage of remote opening of the RADAR from the controller; 8 – voltage of remote opening of controlled RADAR; 9 – regulation device time interval

The delay of the opening cycle of the sensing pulse, which we are looking at, relative to the barrier pulse, determines the distance to the synchronous barrier ring in the circular sight indicator (Fig. 4) [3]:

$$t_\ell = T_s - t_0 = T_s - t_a. \quad (1)$$

If we denote the distance corresponding to T_s by $D = cT_s/2$ and the distance corresponding to the synchronization delay by $\Delta D = ct_a/2$ then the distance from the controller to the synchronous obstacle ring created by the indicator of $RADAR_0$, $RADAR_4$ is equal to will be (Fig. 4):

$$D_{40} = ct_\ell/2 = D - \Delta D. \quad (2)$$

Let's assume that the direct path time of distance opening is equal to T_1, and the reverse path time is equal to T_2, then $T_s = T_1 + T_2$. In the $t_a > T_2$ condition, barrier pulses fall on the straight path of opening, barrier rings are observed at the outer edge of the indicator, and its main observation area is unobstructed. In the case of $t_a \le T_2$, barrier impulses fall in the opposite direction of opening. Due to the fact that the indicator is closed during the reverse course, the obstacle is fully compressed. Under the condition $t_a \le T_2$, the indicator screen of $RADAR_4$ does not have obstacles caused by $RADAR_0$.

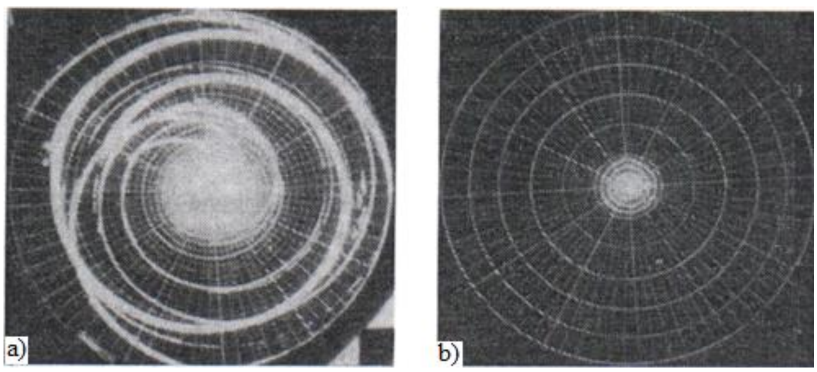


Fig. 4. The indicator screen of the control RADAR under the influence of radio jamming pulses: a – in the absence of synchronization; b – with synchronization

Now let's look at RADAR0 from the controller. At the input of its receiver, the sensing pulses of the controlled RADAR4 enter and also create a synchronous barrier (Fig. 3, b). The delay of the blocking pulses relative to the probing pulses of RADAR0 is constant and is equal to $t_\ell = 2t_4 + t_a$, and their propagation speed is the same. The distance to the obstacle ring on the indicator of $RADAR_0$ is equal to $D_{04} = R_{04} + \Delta D$.

Usually ta does not exceed 10...40 msec, so we can take ΔD = 4...6 km. For the distance $R_{o4} \leq$ 5...10 km, the rings from the obstacle are in the near zone of $RADAR_0$ or in the zone reflected from ground objects and practically do not prevent the detection of the target in the working range of the distance (Fig. 4). With an increase in the R_{o4} distance, the rings from obstacles move into the working zone of the indicator, which worsens the conditions for the operator to detect signals reflected from the target. Considering that the number of controlled $RADAR_s$ is equal to *N*, we will see that the number of rings from the obstacle is also equal to *N* in the indicator of the controlling $RADAR_0$. If we can change the t_{RQ} in a certain time interval due to the controlled RADAR pulses detected by the synchronizer, then we control whether the barrier rings are in the center or at the edge of the indicator (Fig. 3, a). It is known from practice that 15...25% of the pulse repetition period is spent on the opposite path of distance opening. The time variation of the proposed regulation device should be in the interval $t_{RQ} = \pm T_1/2$ (this is equal to 30...40% of T_s time).

Depending on the distance of the detected target, the operator creates an unobstructed working zone on the indicator screen by tuning the regulation device (Fig. 4, b). By adding the regulatory device to the selection scheme, the harmonization of the joint activity of a large number of $RADAR_s$ that make up the radio technical complex, and thus the EMC, will be ensured.

Conclusions

Obtaining accurate information about all targets under any conditions in the area of operation of radar systems is an important issue. But recently, the increase in the number of radio equipment that emits waves of different ranges has led to the concentration of radio frequency sources. Stations working on close frequencies interfere with each other. The solution to this problem is very urgent, especially in the military field. For this purpose, the issue of intra-system and inter-system electromagnetic adaptation has been investigated in the presented scientific article.

More attention has been paid to the use of the time factor in the provision of EMC. As an example, a problem is set and its solution is given. As a result, it is proposed to introduce a time regulation device that regulates the repetition frequency of different stations in the synchronizer device. Its application will solve system and technical problems and effectively fight mutual obstacles. A software version of this proposed device is also possible in the future.

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Системно-технічне рішення електромагнітної адаптації

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Анотація. У військових радіолокаційних системах електромагнітна сумісність включає забезпечення спільної роботи елементів, що входять до складу різних військових пристроїв, створення умов спільної роботи пристроїв як елементів різних систем, а також міжсистемну діяльність. **Об'єктом дослідження** є військова радіолокаційна техніка. У статті описано основні принципові та технічні рішення забезпечення електромагнітної сумісності радіолокаційної техніки військового призначення. Крім схеми вибору, досліджується метод синхронізації роботи кількох радіолокаційних станцій, які знаходяться дуже близько одна до одної або працюють на одній частоті повторення. **Предметом дослідження** є системи електромагнітної сумісності. Проаналізовано питання спільного вибору, практичного застосування та зменшення кількості компонентів електромагнітної сумісності, висунуто різні спрощувальні припущення. Суть представленого різноманітна і залежить від конкретної ситуації. Так, серед заходів, заснованих на використанні просторових факторів, були виділені розсіювання основних напрямків випромінювання радіоелектронних засобів у просторі, різні способи обмеження випромінювання під певними об'ємними кутами, прийом сигналів з різних напрямків, використання відмінностей поляризаційної структури та ін. **Метою дослідження** є аналіз системи електромагнітної сумісності радіолокаційних пристроїв військового призначення. Відповідно до цієї мети в науково-дослідній роботі ставляться наступні завдання: аналіз системи електромагнітної сумісності радіолокаційних пристроїв військового призначення; вибір, забезпечення або, за необхідності, модифікація принципу роботи системи; розгляд планування та розподілу джерела радіочастот між елементами, що входять до аналізованої системи; практичне застосування підходу, заснованого на спільному виборі електромагнітної сумісності, зменшенні їх кількості та введенні різноманітних спрощуючих припущень тощо; аналіз загальної задачі вирішення задачі параметрів. Для вирішення поставлених завдань використовуються такі **методи дослідження**: теоретичний, математичний та порівняльний аналіз. В **результаті проведених досліджень** запропоновано пристрій синхронізації часу для забезпечення електромагнітної сумісності та отримання безперешкодної робочої зони на екрані індикатора в залежності від розкиду радіолокаційних станцій на місцевості. Застосування пристрою синхронізації часу дозволить вирішити системно-технічні проблеми, ефективно боротися із взаємними перешкодами, забезпечити якість роботи оператора, збільшити вірогідність правильного виявлення.

Ключові слова: системне технічне рішення; селектор; синхронізатор; регулюючий пристрій; електромагнітна адаптація.