PROBLEMY MECHATRONIKI
UZBROJENIE, LOTNICTWO, INŻYNIERIA BEZPIECZEŃSTWA

ISSN 2081-5891 **8, 3 (29), 2017, 43-56**

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

Problems with Integrating the IKZ-02P IFF Interrogator with the JODEK-SP Air Defence Gun and Rocket Artillery System

Paweł DOBRZYŃSKI*, Adam KOŁAKOWSKI,
Waldemar ŚMIETAŃSKI

Military University of Technology, Faculty of Mechatronics and Aerospace
2 gen. S. Kaliskiego Street, 00-908 Warsaw, Poland
**Corresponding author's e-mail address:pawel.dobrzynski@wat.edu.pl*

Received by the editorial staff on 21 November 2014.
The reviewed and verified version was received on 17May 2017.

DOI 10.5604/01.3001.0010.4109

Abstract. The objective of integrating the IKZ-02P identification friend-or-foe interrogator with the ZUR-23-2SP air defence gun and rocket artillery system (henceforth "ADGRAS"), codename "JODEK-SP", was to provide the latter with a novel functionality consisting of locking out the ADGRAS every time the IFF interrogation returned "friend" for aircraft operating in the operating range of the ADGRAS deployed to effect anti-aircraft defence at air bases. This paper presents the conclusions from an analysis of interface cooperation of the IKZ-02P IFF interrogator system and the JODEK-SP ADGRAS, complete with results of an experimental verification applied to validate the solutions applied to integrate both systems.
Keywords: anti-aircraft defence, radio-electronic detection, fire control systems

1. INTRODUCTION

A short-range interrogator of an IFF system (where IFF stands for "identification friend-or-foe" in the NATO nomenclature) enables the identification of the allegiance (nationality) of airborne and surface vessels.

The application of a short-range IFF interrogator with the ZUR-23-2SP ADGRAS (air defence gun and rocket artillery system) required the design engineers who attempted the integration to solve several technical problems, including:

- ensuring the capacity of automatic lockout of the ADGRAS weapon subsystems forced by the IFF interrogator: the gun subsystem (by interlocking the effect of actuating the electric fire triggers), and the rocket missile subsystem (by interlocking the missile launch mechanism);
- ensuring the IFF performance in all operating modes of the ADGRAS (e.g. the FAULT mode, in which the ADGRAS on-board computer is inoperative; the REMOTE mode, in which the ADGRAS operation is controlled by a remote firing computer, abbr. KOZ);
- enable the override of the ADGRAS weapon lockout, e.g. for the purposes of self-defence, if an enemy intercepts and uses the IFF "friend" codes;
- decoding and transmission of the information received by the IFF interrogator to the ADGRAS onboard computer (via a digital interface) or safety controller (a transistor key);
- forcing the IFF interrogation of tracked objects over a serial connection (RS 422) or a digital input (of an I/O module).

Integration of the IKZ-02P IFF interrogator, manufactured by BUMAR-Elektronika S.A. (Poland) with the effector, JODEK-SP ADGRAS, was one of the essential requirements for the ADGRAS platform, given that its intended use will include the defence of domestic (Polish) and NATO air bases located at a great distance apart. Hence, under the R&D work No. O R00 0136 12 titled *PILICA short-range air base defence anti-aircraft gun and rocket artillery system*, co-financed by the National Centre for Research and Development in Poland, the effects of integrating the IKZ-02P with the JODEK-SP ADGRAS Technology Demonstrator (TD) was carried out. The results of the R&D work are presented herein.

2. IKZ-02P IFF INTERROGATOR

The IFF system operated by NATO forces (Mark XA and Mark XII) meets the current NATO standards. It is a dual-use (commercial and military alike) solution operating on the principle of a secondary radar. Unlike primary radar, secondary radars do not receive a radar echo from the target, just its reply.

A secondary radar system comprises two active devices: an interrogator and a transponder (also known as a beacon).

The interrogator transmits an interrogation signal over a single carrier frequency towards a target equipped with a transponder. The transponder of the target receives and decodes the interrogation, to which it responds with a reply code on a different carrier frequency. The reply is received, processed and decoded by the interrogator, followed by a suitable representation of the reply. Hence, the reply can either be indicated visually (the form of which depends on the technical capabilities of the interrogator), aurally (by sound), or relayed via a serial connection to a command centre.

Decoding the reply code requires that the code which is used by the transponder and the interrogator that decodes the reply must be the same. If the code is identical at both ends of the exchange, the replying target is qualified as a "friend"; otherwise, it is a "foe". Fig. 1 shows a simplified principle of encoding the IFF transmissions. The interrogator directional antenna is physically interfaced with the interrogator. The interrogator outputs VHF interrogation signals via its IFF antenna and receives VHF reply signals. The signals in the context of IFF systems are also called 'squawks'. Each time it receives and decodes an interrogation, the transponder produces its reply via an omnidirectional antenna.

The IFF system is commercial and military; it supports the following interrogation types, or Modes. Each Mode is differentiated by the number of possible code combinations and the information volume returned in the reply. The Modes are as follows:

- Mode 1: Military aircraft mission; 32 possible reply codes.
- Mode 2: Military aircraft personal identification; 4096 possible reply codes.
- Mode 3: Military / civilian ATC; 4096 possible reply codes.
- Mode A: Civilian; number of possible reply codes as in Mode 3.
- Mode B: Civilian; 4096 possible reply codes. This Mode is used in the United Kingdom only.
- Mode C: Military / civilian; for altitude reporting.
- Mode 4 (SM, secure mode): Strictly military use; ensures a high level of IFF confidence. Unlike the preceding Modes on the list, where actual encoding is used for the replies only (and the interrogation signal is encoded only to be differentiated from the possible interrogation Modes), Mode 4 uses a full enciphering (encryption) of the interrogations. The high confidence level of IFF is achieved by applying encryption codes with algorithms that have time-variable (pulse-to-pulse) parameters.

The short-range interrogator contemplated herein uses Modes 1, 2, 3/A and 4 only. The interrogating ground station must generate interrogation signals that are appropriate for the information requested from the target's transponder; hence, at least two interrogation types (Modes) must be transmitted with two interrogation formats towards the target aircraft to prompt the right reply of the transponder.

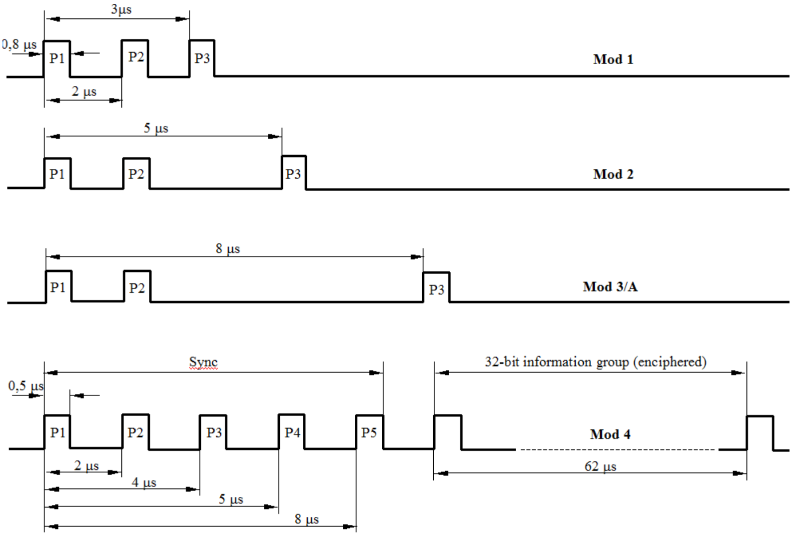

Fig. 1. Time trends of an interrogation signal in various interrogation modes [1]

Each interrogation signal contains a number of pulse pairs. Each pulse pair is generated in sync with the probing pulse transmitted by the primary radar. Each pulse width is 1 μs (some references specify 0.8 μs) and fixed; the interval between the pulses in each pair is variable and depends on the interrogation Mode. The following list shows the time intervals between the first pulse (P1) and the second (P3) impulse in a pair, with the corresponding interrogation Modes.

- 3 μs → Mode 1 (Military aircraft mission);
- 5 μs → Mode 2 (Military aircraft personal identification);
- 8 μs → Mode 3/A (Military / civilian ATC);
- 21 μs → Mode C (Military / civilian altitude reporting).

The time trends in Fig.1 show that the interrogation signal is made from three successive pulses designated P1, P2, and P3. The interrogations in each Mode are differentiated by the location of P3 relative to P1 and P2. P2 is always 2 μs from the leading edge of P1.

It is used by the compensation system of the transmission (interrogation) antenna lobes, which is explained further below. Hence, the characteristic property of each Mode is the time spacing between P1 and P3, which when decoded by the transponder, identifies the

Mode of each interrogation received and determines the reply type. The Modes 1, 2, and 3/A are SIF Modes (Selective Identification Facility).

Mode 4 has a different interrogation signal nature altogether, as shown in Fig. 1. P1, P2, P3, P4, and P5 are a group of sync pulses in Mode 4; P5 provides compensation for the antenna side lobes when transmitting, not unlike P2 in SIF modes.

The sync is followed by the proper interrogation in the form of an enciphered information group that may have a maximum of 32 pulses.

Aside from reply (code) decoding and the transmission of interrogations in the SIF Modes, the IFF system enables the transmission of special signals from the transponder which are decoded and represented by the interrogator. Special signals are replied to by a transponder once it receives an interrogation in any Mode. There are certain reply codes reserved for these special signals. The special beacon reply codes are as follows:

- Civilian aircraft emergency (code 7700);
- Civilian aircraft hijacking (code 7500);
- Civilian aircraft radio failure (lost communications) (code 7600);
- Military aircraft emergency (squawk T4, which is a series of four pulses, or frames);
- Military aircraft identification (squawk I/P);
- Aircraft special position identification code.

Special signals are not decoded by the short-range interrogator. A Mode 4 reply is called a 'triplet' that occupies one of the sixteen time points relative to the interrogation pulse. This point varies at random and is specified (encoded) differently for each interrogation. A Mode 4 reply is verified to be true if, for the respective interrogation package, the reply package contains a specific number of replies at correct time points. In non-war time situations, Mode 4 sees sporadic use (e.g. during drill and training or combat duty), and the IFF system works in SIF Modes with different variants of their interleave or sequential usage. This is specifically regulated by the applicable IFF system combat usage manuals.

Note that Mode 3/A enables civilian air traffic control by military radar posts, and military aircraft traffic by civilian air traffic control centres.

To ensure electromagnetic compatibility with other systems and eliminate false interrogations and replies, a major component of every IFF system is the so-called interrogator antenna side lobe compensation. The IFF system contemplated herein features side lobe attenuation systems during the transmission (interrogation) and reception of replies.

The compensation is performed by applying an auxiliary (compensating) antenna with characteristics that cover the azimuthal side lobes of the main characteristic. The auxiliary antenna works by the so-called differential characteristic.

3. LOCATION AND ROLE OF THE INTERROGATOR WITHIN THE JODEK-SP ADGRAS

As stated above, the IKZ-02P IFF interrogator is one of several microprocessor devices included in the JODEK-SP ADGRAS (Fig. 2).

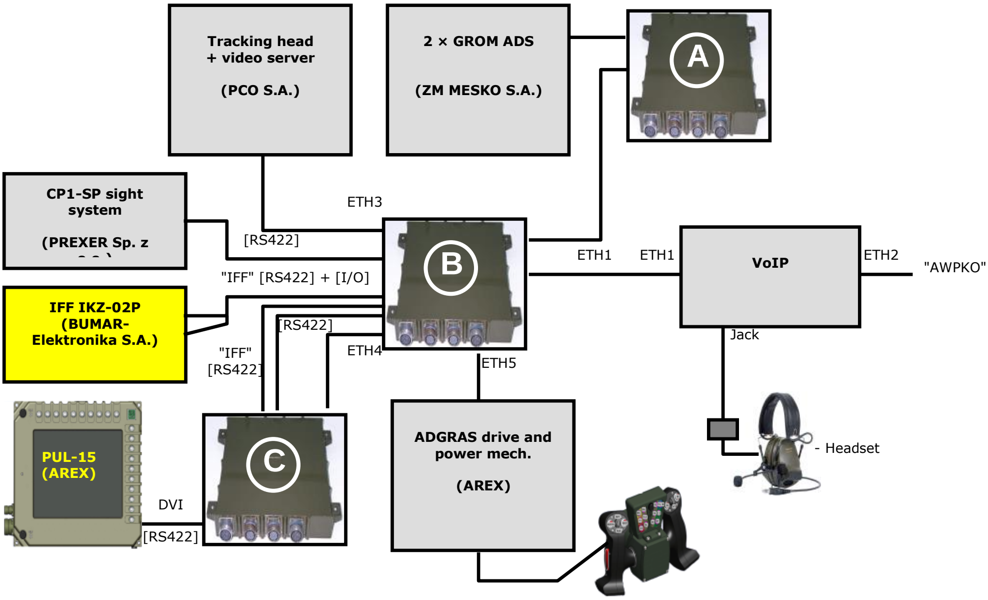

Fig. 2. Block diagram of the JODEK-SP ADGRAS (proprietary work):
(A) MSJ missile launch subsystem; (B) safety controller; (C) on-board computer

Fig. 3. Layout of the IKZ-02P IFF interrogator system components on the JODEK-SP ADGRAS TD

The IFF interrogation designated “P” (which designates a version identical to the one used on the POPRAD mobile rocket missile system) was installed on the right-hand wall of the controller block console to enable operational access to the front panel, wiring harness connectors, and the memory module.

The IKZ-02P IFF interrogator was connected to the following wiring:

- power wiring;
- IFF interrogator to safety controller connecting cable;
- IFF antenna cable.

The IFF antenna was installed on the rocket missile launch platform via a bracket that can be set to the combat mode position or the transport mode position, as required.

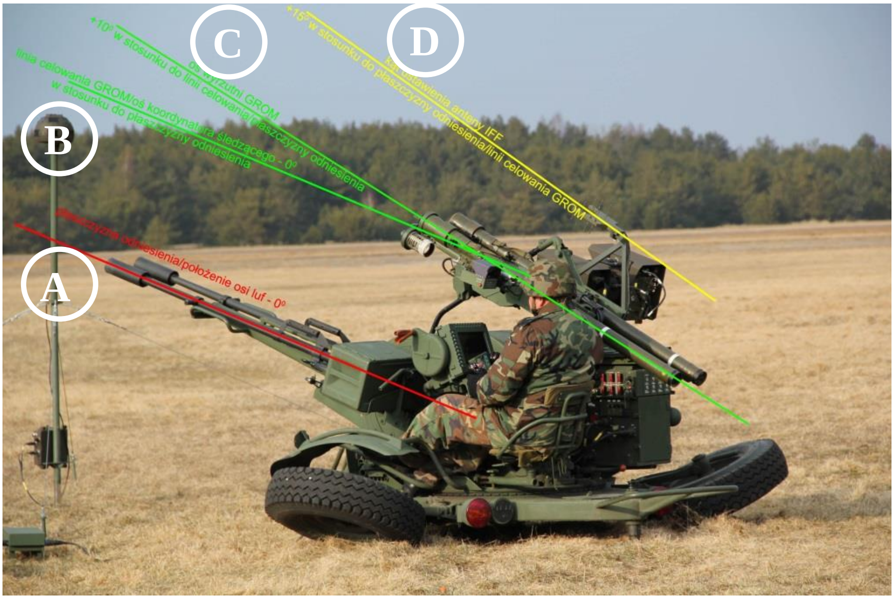

Fig. 4. Analysis of the IFF antenna elevation angle:
(A) Reference plane (AA cannon centreline); (B) GROM ADS tracking coordinator angle (0° to the reference plane); (C) GROM ADS launcher axis (+10° to the reference plane); (D) IFF antenna elevation angle (+15° to the reference plane)

The interim solution for the duration of this research featured a bolted fixture of this bracket that permitted repositioning as above by operating a winged head bolt. In this way the IFF antenna was installed on a bracket that permitted a reduction in the antenna’s elevation angle (folding) for transport.

The JODEK-SP ADGRAS safety controller featured an IFF lockout override switch on the operator’s side.

In its first version, the IFF antenna bracket elevation angle was chosen to accommodate a tripod-mounted IFF antenna; by this, the IFF antenna was elevated by 15° over its reference plane (the AA cannon centreline) / the GROM ADS line of sight.

The IFF antenna should be aligned with the GROM ADS line of sight (the reference plane) with a maximum deviation of ±5°. The initial orientation of the IFF antenna precluded any correct IFF interrogation by the IKZ-02P.

4. T-T COMPLIANCE VERIFICATION OF THE IKZ-02P IFF INTERROGATOR

Proper interfacing of the IKZ-02P IFF interrogator with the safety controller and the on-board computer of JODEK-SP was verified for the following operating modes of the ADGRAS: FAULT, MANUAL, and SEMI-AUTO, both for rocket missile and gun firing, by verifying that the IFF data was properly visualised on the ADGRAS operating display and relayed to a superior command level.

Fig. 5. Overview of the T-47G tester
(left: control panel and power supply module; right: Tx/Rx antenna)

The IKZ-02P IFF interrogator was tested on the JODEK-SP ADGRAS TD with an IFF tester for Mark XII IFF equipment (operating in Modes 3/A and C).

The T-47G IFF tester, P/N T1-WS-5688-0105-2, is suitable for testing the following IFF equipment: IFF interrogators and transponders (beacons) operated in the NATO Mark XII system (Modes 1, 2, 3/A, C, and 4) and Mode S.

To ensure that the T-47G IFF tester manufactured by *Tel Instrument Electronics* was compatible with the IFF system installed on the technical platforms of the Polish Armed Forces, the T-47G IFF tester was equipped with a measurement kit, a tripod, and a 50-m extension power cord.

The measurement kit contained microwave loads, measurement connectors, a code generator, a direct tester connection cable line, and a 230 V/50 Hz power cord. Table 1 shows the basic technical specification of the T-47G tester.

Table 1. T-47G tester basic technical specification

Transmission

	VERIFICATION	
	BEACON	INTERROGATOR
Frequency	1030 MHz ±10 kHz	1090 MHz ±10k Hz
Output (from the antena)	7 dBm ± 1 dBm	-2 dBm ± 1 dBm
Output (Direct connect)	-42 dBm ± 1dBm	-42 dBm ± 1dBm
Modes tested	1, 2, 3/A, C, 4, S	1, 2, 3/A, C, 4
Primary beam width	15°÷60°	60°

Reception

Frequency	Range	1086.5-1093.5 MHz	1029.7-1030.3 MHz
	Measurement accuracy	± 200 kHz	± 200 kHz
Moc	Range	47-64 dBm	47-64 dBm
	Measurement accuracy	± 2 dBm (secure conn.) ± 3 dBm (antenna)	± 2 dBm (secure conn.) ± 3 dBm (Antena)
Sensitivity	Range	-50÷-87 dBm	-50÷-87 dBm
	Measurement accuracy	± 2 dBm (secure conn.) ± 3 dBm (antenna)	± 2 dBm (secure conn.) ± 3 dBm (Antena)
Ratio – replay number	Range	0-100%	
	Measurement accuracy	±1%	

During IFF interrogation testing, a functional test was carried out on the override switches of the IFF-forced firing lockout.

A verification was also carried out of an intentional override of the IFF-forced firing lockout by the safety controller upon a positive “friend” reply returned by the IFF interrogator.

5. ANALYSIS OF INTEGRATION PROBLEMS

The IFF interrogator worked properly in the tested ADGRAS operating modes. The target trace distance and status were properly indicated and visualised on the ADGRAS operating panel display. The safety controller locked out the ADGRAS weapons when the IFF interrogator returned a positive "friend" reply. The feasibility of unlocking the ADGRAS weapons with the safety controller at a positive "friend" reply returned by the IFF interrogator was positively verified. The IFF interrogation result visualisation performance was verified on a fixed target trace, an approaching target trace, and a departing target trace. During the verification process, the IFF interrogation status indicator systems performed correctly. The safety controller and on-board computer of the ADGRAS properly performed the positive "friend" identification indication (SIF) with the ADGRAS weapon lockout, no response indication, IFF interrogation distance indication, the IFF-forced weapon lockout, and other tested functionalities.

Fig. 6. Positive Mode 3/A "friend" reply to the IKZ-02P IFF interrogation – test distance to target trace: 10.8 nmi (200 hm) – incoming target trace

The JODEK-SP ADGRAS TD equipment was also tested with the accidental, actual entry of military and civilian aircraft into the air space of the Ustka Central Air Force Testing Grounds (Poland). Whenever the JODEK-SP ADGRAS TD with its IKZ-02P IFF interrogator had an aircraft with an IFF transponder in range, IFF interrogations were transmitted simultaneously from the IKZ-02P IFF interrogator and the T-47G tester, and the interrogation results for both systems were compared.

This helped to evaluate the compliance of the TD with the requirements for the transmission of the IFF interrogator status control signals (interrogation requests) and IFF interrogator responses (acknowledgements, identification results, and testing results).

However, the IFF interrogator electronic circuitry would freeze during testing (by operation halt). The condition was remedied by disconnecting the wiring from the IFF interrogator and resetting the IFF interrogator, however, the IFF interrogator only resumed correct operation for a short time before another freeze. Disconnecting the power supply from the IFF interrogator with its power controls did not restore the operation of the device to normal. Hence, it was not possible to verify proper IFF interrogation of the aircraft entering the operating range of the ADGRAS and compare the IFF interrogation results to those produced by the T-47G tester for the same airborne object type. Because of this, it was not possible to confirm the unitary results of the functional tests for the integration by the IFF interrogator with the ADGRAS on-board computer and safety controller.

CONCLUSIONS

The test results obtained for the JODEK-SP ADGRAS TD and its cooperation with the IKZ-02P IFF interrogator were interpreted and the following conclusions were drawn with comments concerning the next stage of verification of both interfaced systems:

1. All wiring connected to the IFF interrogator installed in the ADGRAS requires optimization.
2. A rapidly removable enclosure panel is required to service the IFF interrogator and directly access its components.
3. The IFF antenna elevation angle with respect to the reference plane (the gun centreline or the gun cradle plane) / the GROM ADS line of sight must be changed from the tested +15° elevation.
4. The IFF antenna bracket position for transport by airlift must be revised; the tested IFF antenna bracket transport position was too high (the bracket fixture must enable the IFF antenna to be folded as mounted without the need to remove the bracket altogether for transport).
5. The IFF interrogator power supply stability must be re-verified to troubleshoot the problem of freezing the IKZ-02P electronic circuitry.
6. The IKZ-02P IFF interrogator connection wiring and the interfacing of the IFF interrogator with the ADGRAS security controller and on-board computer must be tested for all overvoltage that might cause the electronic circuitry to freeze.
7. The IFF interrogator must be verified again with the T-47G tester and aircraft with transponders operating in Mode 3/A, where the target compatibility requires Mode 4 (for Mark XII compliance).

8. A functional performance verification is required for the ADGRAS system interfaced with the IFF interrogator complete with a memory module (instead of a mockup module) and actual transponders (beacons) aboard actual military aircraft; the verification should be carried out at an Air Force Base.

REFERENCES

[1] Centrum Naukowo-Produkcyjne Elektroniki Profesjonalnej „RADWAR" S.A. 2008. „*Interrogator krótkiego zasięgu IKZ-02M. Opis techniczny i instrukcja eksploatacji*". Warszawa.

[2] Śmietański Waldemar. 2012. *Raport z realizacji projektu O R00 0136 12. Wykonanie programu symulatora interrogatora IKZ-02 do komunikacji z komputerem pokładowym PZRA JODEK-SP łączem szeregowym*. Opracowanie wewnętrzne WML WAT, Warszawa.

[3] Kołakowski Adam. 2012. *Raport z realizacji projektu O R00 0136 12. Wykonanie sprawozdania z badania integracji PZRA JODEK-SP z interrogatorem IFF IKZ-02P firmy RADWAR S.A. oraz badania układu chłodzenia rakiet GROM demonstratora technologii JODEK-SP*. Opracowanie wewnętrzne WML WAT, Warszawa.

[4] Dobrzyński Paweł. 2012. *Raport z realizacji projektu O R00 0136 12. Program badań poligonowych modelu funkcjonalnego przeciwlotniczego zestawu rakietowo-artyleryjskiego ZUR-23-2SP systemu PILICA krypt. JODEK-SP*. Opracowanie wewnętrzne WML WAT, Warszawa.

Problemy integracji interrogatora IFF IKZ-02P z przeciwlotniczym zestawem rakietowo-artyleryjskim JODEK-SP

Paweł DOBRZYŃSKI, Adam KOŁAKOWSKI,
Waldemar ŚMIETAŃSKI

Wojskowa Akademia Techniczna, Wydział Mechatroniki i Lotnictwa
ul. gen. S. Kaliskiego 2, 00-908 Warszawa

Streszczenie. Celem integracji interrogatora "swój-obcy" z przeciwlotniczym zestawem rakietowo-artyleryjskim ZU-23-2SP kryptonim JODEK-SP było uzyskanie nowej funkcjonalności, jaką jest automatyczne blokowanie systemu broni w wyniku interrogacji przynależności statków powietrznych realizujących zadania w strefie działania zestawu przeciwlotniczego będącego efektorem systemu osłony bazy lotniczej. Artykuł zawiera wnioski z analizy współpracy obydwu systemów, a także wyniki doświadczalnej weryfikacji, których zadaniem było sprawdzenie poprawności zastosowanych rozwiązań.
Słowa kluczowe: obrona przeciwlotnicza, rozpoznanie radioelektroniczne, systemy kierowania ogniem.