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The Specific Radar Signature in Electronic Recognition System

Abstract. *In the electronic intelligence system (ELINT) in the process of identification radar signals are used both technical and tactical parameters. The detailed analysis of radar signal parameters was made in conjunction to radar applications. The paper describes the role of the specific radar parameters (signatures), mainly the different types of interpulse modulation and in which way they may be applied in the electronic recognition system. A few examples of measured signals with different types of interpulse modulation for radars about different applications are presented.* (***Specyficzna sygnatura radaru w systemie rozpoznania elektronicznego***).

Streszczenie. *W systemie rozpoznania elektronicznego (ELINT) wykorzystuje się zarówno parametry techniczne jak i taktyczne. W artykule dokonano analizy poszczególnych parametrów sygnału radarowego w powiązaniu z przeznaczeniem jego źródła emisji. Opisano metodę tworzenia specyficznej sygnatury (metryki) radaru dla parametrów mierzalnych oraz modulacji międzyimpulsowej oraz sposób ich wykorzystania w systemie rozpoznania. Poszczególne rodzaje modulacji międzyimpulsowej zilustrowano danymi pomiarowymi od radarów o różnym przeznaczeniu.* (***The Specific Radar Signature in Electronic Recognition System***).

Słowa kluczowe: radar, modulacja międzyimpulsowa, rozpoznanie elektroniczne.
Keywords: radar, interpulse modulation, electronic intelligence.

Introduction

The nature of electromagnetic environment has a significant influence on radar construction and its parameters [1]. Radar may be employed on the ground, in the air, on the sea and in space. Land-based radars have been typically applied to detection and location of aircraft and space targets. Naval radars may observe other ships or aircrafts and may also be used as a navigation aid to locate shorelines or buoys. An airborne radar may be used to detect other aircrafts, ships, land vehicles or in navigation.

Radars used by armed forces have mainly the following applications: airborne early warning, ballistic missile warning, air defence search and acquisition, missile control and guidance, fire control, identification systems (IFF), air and marine navigation (beacons – altimeters), aircraft landing, airborne interception and battlefield surveillance.

Measurement and analysis

The typical electronic recognition system, (Fig. 1), consists of the following subsystems:

1) Signal receiver: provides, with a very short acquisition time, long range detection of emitter radiations and measurement of its primary parameters.
2) Signal processor: allows, in a dense electromagnetic environment, a very accurate analysis of complex radar signals, input data sorting input data into the pulse trains with the aim of producing one pulse train for each received radar signal. This analysis allows to set up the signature of radar parameters in order to precisely identify and update the radar database [2, 3].
3) Signal recognition system: allows to extract and select the features of incoming data to the classifier, which successively compares the specific signal parameters (signatures) with a library of known emitter characteristics to determine possible identities of detected signals.

The radar parameters which can be directly measured by the electronic intelligence (ELINT) system are [1]:

- radio (carrier) frequency (RF),
- pulse width (PW) or pulse duration (PD),
- pulse repetition interval (PRI),
- scan pattern and rate,
- beam width and side lobe levels,
- angle of signal arrival (AoA),
- signal amplitude (A),
- polarization.

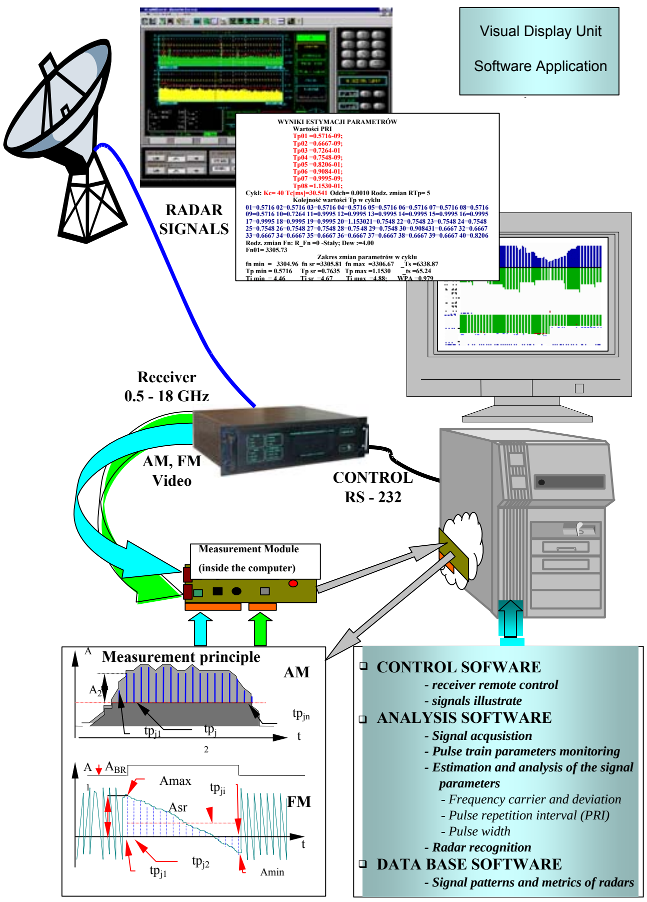

Fig.1. A structure of electronic recognition system

These parameters are passed on digitally to the processor in order to sort and divide them into pulse chains associated with the detectable radars. The processor derives secondary radar parameters such as PRI and PRI modulation (agility, stagger, dwell and switch, jitter). These parameters can be recorded as a radar ‘fingerprint’ [4].

Since each radar has limited parameter ranges (e.g. transmission within a limited frequency band) and often identifiable characteristics, it is assumed that radar signals with similar characteristics originate with the same platform.

At the last stage of radar signal processing, the classifier compares the measured signal’s parameters (signatures) with a library of stored radar types, which may have a high degree of inherent uncertainty arising from the methods of data gathering and processing [1, 4]. This operation permits to recognize specific type of previously identified radars, the number of such radars in use and initial identification of newly positioned radars and their function.

Applying knowledge-based techniques to radar identification

The nature of a platform that carries the radar and the environment in which it operates have a significant influence on its design. The most important parameters which correspond to the technical characteristics in a specific type of radar and permit to recognize its application are following: pulse width, carrier frequency, pulse repetition frequency, type of scan and beam width [5, 6, 7].

The characteristics generally associated with the long frequency radars, i.e. under 3 GHz are the following: easy to generate high powers, low atmospheric absorption, wide pulse width, low PRF, wide beam width, poor resolution in range and angle. High frequency radars have opposite characteristics.

Low frequencies are used mainly for long range surveillance, early warning and missile control, whereas high frequencies are more commonly used for short-range applications such as battle surveillance, aircraft landing and short-range missile control.

The radars with narrow pulses, i.e. pulse width less than 1 μs have the following characteristics: low minimum range, high resolution, low pulse energy, short range, wide band width receiver. Wide pulses have the opposite characteristics.

The range resolution is the minimum detectable difference in range between two targets. If two or more targets are located at a distance less than minimum range from each other, they are presented as a single target. The minimum range is the minimum distance from the radar that a target may be still appearing on the radar indicator.

Both range resolution and minimum range are given by

$$R_{\min} = \frac{c\,\tau_i}{2} \tag{1}$$

where: R_{min} - minimum range or range resolution, c - velocity of electromagnetic wave propagation, τ_i - pulse width.

The maximum range of a radar depends on the medium power emitted by the antenna. But the medium power depends on the pulse duration, therefore the larger is distance the radar can operate, the larger the pulse width needed.

Pulse repetition frequency (PRF) limits the maximum unambiguous range of a pulse radar. The maximum unambiguous range is the maximum distance that a target can be located from the radar in order to return a pulse echo to the receiver before the next pulse is transmitted. Therefore the pulse repetition time must be long enough to permit a pulse echo to get the receiver before the next pulse is emitted. Radars with a low PRF, i.e. less than 1000 Hz have the following characteristics: long range, high pulse energy, poor velocity measurement.

The scan rate varies from 3 to 30 rotations per minute. Usually low rotation speeds are used for long range radars, since scan rate must be low enough in comparison with PRF in order to permit each scan.

Type of scan pattern (circular, sector, conical, helical, spiral, raster, etc.) is related to the application of radar. For example, a circular scan is used by the majority of surveillance radars. Scan rate may be switchable together with PW and PRF in order to change the range. Sector scan is used for limited surveillance, target acquisition, terrain following, mortar location, ground control approach and height finder. Conical scan is used for tracking of low speed targets, tracking meteorology balloons, missile guidance and fire control.

The beam width affects the degree of the angular resolution of a radar. Angular resolution is the ability of a radar to discriminate between two targets at the same range but at a different azimuth and/or elevation. Narrow beams are more easily produced at higher frequencies, while at the lower frequencies larger reflectors are needed to get the same gain.

Signal polarization can give additional information on radar function and facilities. For example, circular polarization is used by command missile guidance systems which have to communicate with a rolling missile.

Radar parameters in the database

Radar signature in the database is described by many parameters which may be in different form, i.e. values of measured parameters, statistics parameters (means, variances), signal characteristics, pictures of platforms and antennas, text describing the specific radar solution, application and so on [3, 4].

At the output of ELINT receiver (Fig. 1) a vector of measured radar signal parameters $\mathbf{x}_i$ is calculated. In further part this vector consisting from N parameters will be denoted as

$$\mathbf{x}_i = \left(x_{i1}, x_{i2}, ..., x_{iN}\right) \tag{2}$$

where: index i - number of vector parameters, k – parameter number, x_{ik} – value of parameter k of vector i, ($i = 1, 2, ..., M$, $k = 1, 2, ..., N$), M – total number of vectors measured for all radars.

The vectors $\mathbf{x}_i$ measured for the same radar will form one class j, ($j = 1, 2, ..., L$), where L denotes total number of classes. In practice it is impossible to get enough information allowing for a very precise description of the radar parameters which would be in full accordance with real electromagnetic environment.

On the basis of multiple signal parameters measurements a radar signature (metrics) W_j representing appropriate radar (class) j in the database is formed as follow [2, 3]

$$W_j = \left\langle \left(\bar{x}_{j1}, \sigma_{j1}\right), ..., \left(\bar{x}_{jk}, \sigma_{jk}\right), ..., \left(\bar{x}_{jN}, \sigma_{jN}\right) \right\rangle \tag{3}$$

where: $\bar{x}_{jk}$ - the mean value of parameter k of class j, σ_{jk} - dispersion of parameter k of class j,

$$\bar{x}_{jk} = \frac{1}{n_j} \sum_{i=1}^{n_j} x_{ijk} \tag{4}$$

x_{ijk} - value of parameter k of vector i for class j, n_j - total number of measured vectors for class j.

In accordance with the statistical approach the radar signature in the data base for the class j is formed in the following way

$$\left\langle \bar{x}_{jk} - u_\alpha \sigma_{jk}, \ \bar{x}_{jk} + u_\alpha \sigma_{jk} \right\rangle \tag{5}$$

where the value u_α for established level of probability α is determined from the table of normal distribution.

Additionally, taking for consideration variance σ_{jk}^2 calculated on the base of the measured values of parameter k for each class j, a radar metrics in data base is determined in the following way:

$$\left\langle \bar{x}_{jk} - \frac{u_\alpha \sigma_{jk}}{\sqrt{n_j}} - \sqrt{\frac{n\sigma_{jk}^2}{C_2}} ;\ \bar{x}_{jk} + \frac{u_\alpha \sigma_{jk}}{\sqrt{n_j}} + \sqrt{\frac{n\sigma_{jk}^2}{C_2}} \right\rangle \tag{6}$$

or

$$\left\langle \bar{x}_{jk} - \frac{u_\alpha \sigma_{jk}}{\sqrt{n_j}} - \sqrt{\frac{n\sigma_{jk}^2}{C_1}} ;\ \bar{x}_{jk} + \frac{u_\alpha \sigma_{jk}}{\sqrt{n_j}} + \sqrt{\frac{n\sigma_{jk}^2}{C_1}} \right\rangle \tag{7}$$

where the values C_2 and C_1 for established level of probability α are determined from the Table of χ^2 distribution for n_j-1 degrees of freedom.

The measured vector $\mathbf{x}_i$ is classified to this class ω_j from the set of known classes L if this formulae is fulfilled

$$\mathbf{x}_i \in \omega_j \Leftrightarrow \bigwedge_k x_{jk\,\min} \le x_{ik} \le x_{jk\,\max} \tag{8}$$

where: $x_{jk\,\min}$, $x_{jk\,\max}$ - appropriately the lower and upper limit of parameter k for class j.

The interpulse modulation

The modern ELINT systems may measure modulations of PRI and RF with a very high precision. If the variations occur on pulse or from pulse to pulse or from pulse group to pulse group, they are considered fast. If they occur from scan to scan or over longer periods, they are considered slow. PRI is the interval from start of one pulse to the start of the next pulse. These are radars with: PRI stable, PRI sliding, PRI dwell and switch, PRI stagger, PRI jitter [3, 7].

At the figures 2÷16 are illustrated the PRI's values (vertical axle) in versus successively intercepted pulses (horizontal axle) for radars of different applications and located on the different platforms.

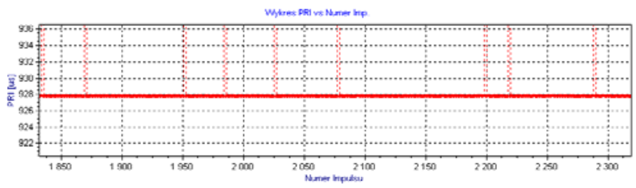

Fig.2. PRI stable – naval surface serch radar

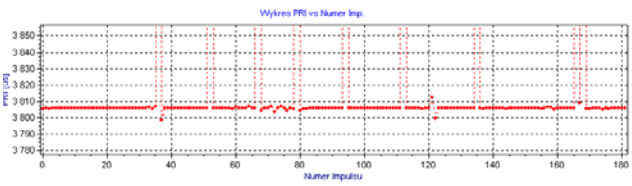

Fig.3. PRI stable – land-based search radar

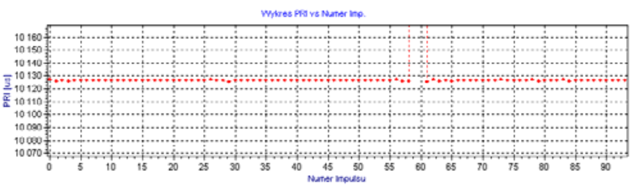

Fig.4. PRI stable – airborne meteorological radar

PRI sliding means a pulse train which continuously changes in a monotonically increasing or decreasing manner. Sliding occurs between a minimum and maximum set of PRI values known as the PRI limits.

Sweep time is the time required for one complete cycle between two extreme intervals. The PRI shortest/longest are the smallest/longest intervals within one sliding cycle. The slide shows the two basic forms of sliding: linear (Fig.5) and non-linear (Fig.6).

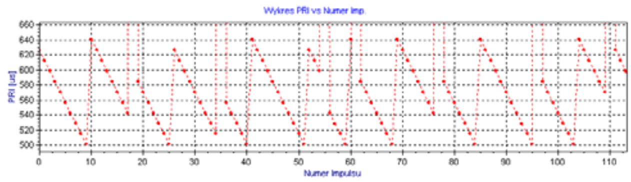

Fig.5. PRI sliding linear – naval search radar

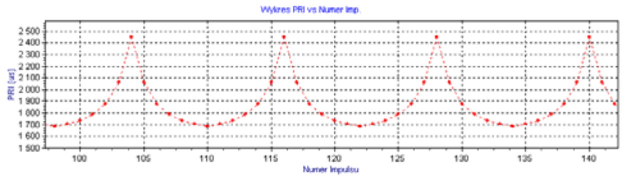

Fig.6. PRI sliding non-linear – land-based altimeter

The term PRI dwell, or rather PRI switching is used to categorize two types of interpulse modulation: multiple PRI, dwell and switch.

Multiple PRI is basically an option on most radar systems, meaning the operator manually switches PRI, most often by selecting another pulse length and by doing so also changing PRI as pulse length and PRI are related to maintain the same duty cycle (Fig.8÷10).

Dwell and switch indicates that the radar is capable of transmitting a programmed sequence of PRI values. This type of PRI modulation may be used in a pulse Doppler tracking radar to resolve range and speed ambiguities or to eliminate blind ranges and speeds.

The parameters describing PRI dwell and switch are following: dwell number, PRI value, time to switch, number of pulses, total dwell time calculated by adding up the dwell times and switch times of all PRIs, dwell sequence.

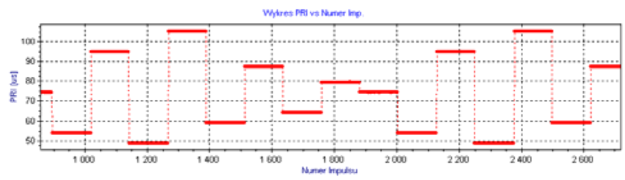

Fig.7. PRI dwell and switch (9-dwell, zero time to switch) – multi-function fighter-plane radar

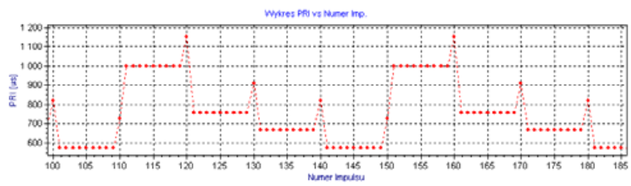

Fig.8. PRI dwell and switch (4-dwell, non-zero time to switch) – naval surface serch radar

The staggered PRI pulse train is a train of pulses in which two or more interpulse intervals are changed in a fixed sequence. The sequence is described by the number of 'positions' or intervals used in making up the sequence and the number of different intervals used.

The 'elements' represent the number of discrete PRI's used, while the 'positions' indicate the number of intervals used in the PRI pattern/sequence. Within a sequence the discrete interval(s) may be used more than once. The simplest form of PRI stagger is a two-element, two-position stagger.

The following parameters are used to PRI stagger:

- regular – element/position ratio is the same and differences between PRIs are equal (Fig.9);
- irregular – element/position ratio is the same, but PRI spacing is unequal (Fig.10);
- complex – element/position ratio is unequal, one or more PRIs are fired more than once in the sequence (Fig. 11).

Fig.9. PRI stagger regular (3-element, 3-position) – land-based search radar

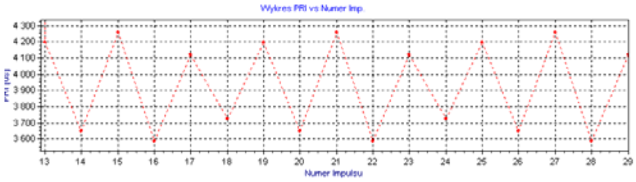

Fig.10. PRI stagger irregular (6-element, 6-position) – land-based search radar

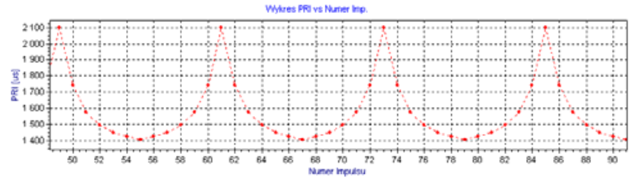

Fig.11. PRI stagger complex (7-element, 12-position) – air and surface search radar

A parameter PRI is considered to be a jittered if the variations from the mean PRI occur in a random or pseudo-random fashion. PRI jitter variations can occur between minimum and maximum PRI limits or can be variations from a mean value using discrete values. In the first case variations are termed ‘continuous jitter’ (Fig.12), in the second case as ‘discrete’ jitter (Fig.13).

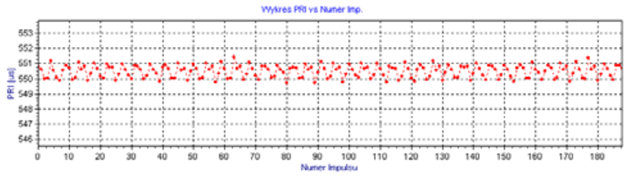

Fig.12. PRI continuous jitter – naval surface serch radar

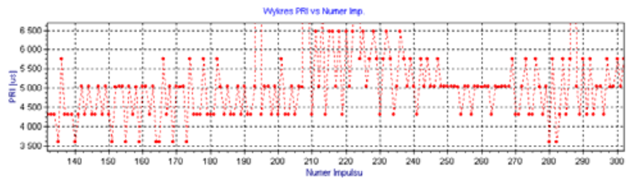

Fig.13. PRI discrete jitter – airborne searchl radar

The figures 14÷16 illustrate the value changes of pulse duration (PD) for radars with different applications.

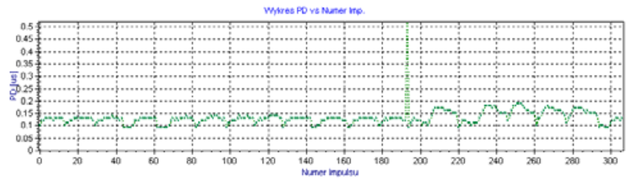

Fig.14. PD stable – naval navigation radar

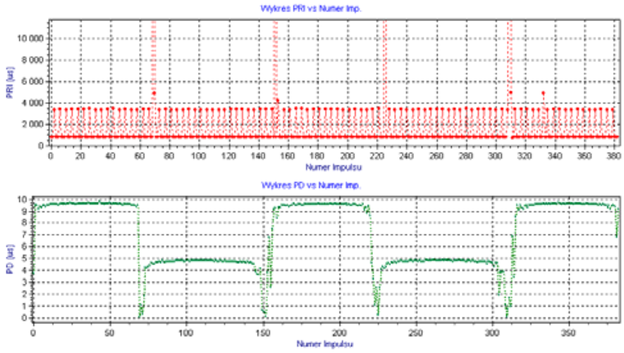

Fig.15. Changing PD values after each antena scan – aiborne surveillance radar

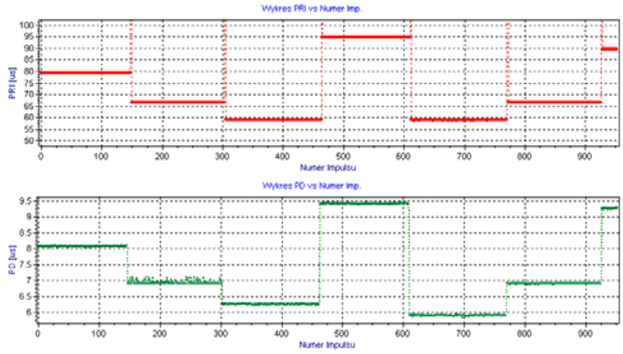

Fig.16. Synchronous changes values of PRI and PD – airborne warning radar

Conclusions

The data recording and analysis the measured results help us to extrapolate some facts in order to constructing the knowledge base and design the expert system in the last stage of radar recognition. The knowledge base employs a declarative, rule-based representation of facts about the radar domain [5, 7].

The capability of the electronic recognition system to correctly identify the detectable radar emissions in a dense electromagnetic environment is a key to their application in modern command, communication and control systems.

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