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Detection Area Analysis in the ELINT System

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Abstract:

This article proposes a comparative method of a possible analysis technique of the detection area, in the Electronic Intelligence (further ELINT) system, regarding the values of detection probability P_D, false alarm probability P_F and the change of output within ELINT source P_Z. By this analysis it is assumed that there is a monitoring of mobile ELINT sources, which are located on the margin of ELINT system radio horizon, whereby it is necessary to carry out the radio-locating of these sources in the main lappet of directivity pattern source axis and ELINT device.

Keywords:

Electronic Intelligence, reconnaissance system, Doppler effect, transmitter, power agility, probability detection

1. Introduction

Electronic Intelligence (ELINT) is one of the basic types of signal intelligence (SIGINT) which uses the principles of electromagnetic energy in the atmosphere propagation when operating. The aim of ELINT devices is to detect, locate, analyze, identify and pursue the sources of electronic signals in the detection area. This area is defined by directivity pattern external border and its size depends on more parameters of ELINT reconnaissance.

The source of electronic signals and ELINT devices create so-called ELINT Reconnaissance System. Its most important parameter is the shape and size of detection area, in which the ELINT device is able to detect the electronic signals

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sources with required index figures. Exactly these index figures are limited by parameters of the ELINT Reconnaissance System, as for example:

- maximum distance detection R of ELINT source,
- detection probability P_D,
- false alarm probability P_F,
- output of ELINT source P_Z.

The given parameters limit the practical use of ELINT devices. In real life there are cases when it is inevitable to review whether the given type is appropriate for detecting certain types of sources or the given reconnaissance information (from the point of incidence and given probabilities) suits the user.

The correct analysis of these cases is not easy and requires complex access to facts which in some cases seem incomparable. The base of solving given problem is to evaluate the change of range in the ELINT device, depending on the change of detection P_D, false alarm probability P_F, and the output of the ELINT source P_Z. When analyzing the problem given above, it is assumed that there is detection of ELINT sources in the axis main beam of directivity pattern source and ELINT device.

The configuration of the ELINT system is shown in Fig.1.

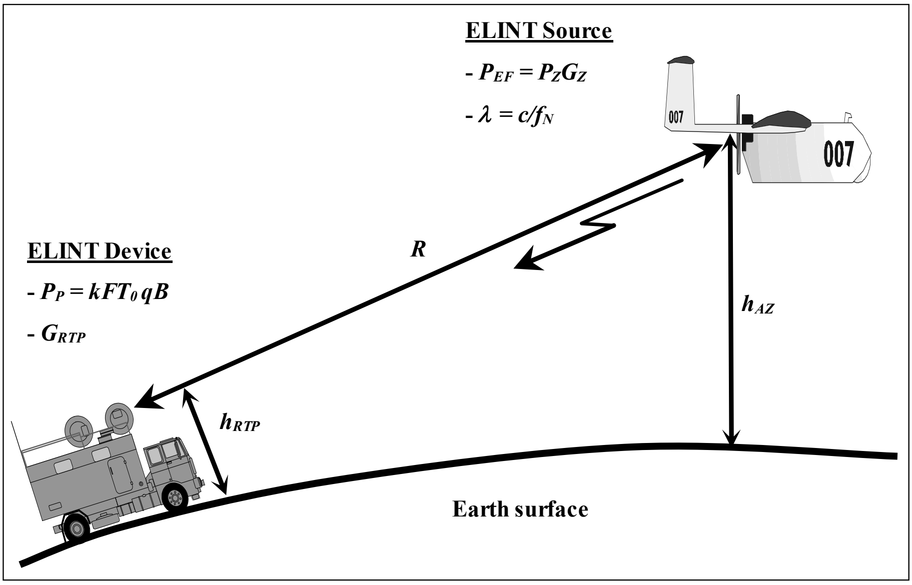

Fig. 1 ELINT system configuration

2. Distance of Detecting Sources in the ELINT System

The maximum distance of detecting ELINT sources belongs to the most important parameters of the ELINT device, whereby its value limits the maximum distance of ELINT device space detection. When counting the maximum range $R_{\max}$ [km] of ELINT device, we start from Radio horizon equation in the following form [1]:

$$R_{\max} = 4{,}123\left(\sqrt{h_{RTP}} + \sqrt{h_{AZ}}\right) \quad (1)$$

where:

h_{RTP} is the height of ELINT device antenna [m],
h_{AZ} is the height of ELINT source antenna system [m].
Theoretical distance of detection R ELINT source is given by the Beacon Equation in the following form [2]:

$$R = \sqrt{\frac{P_Z G_Z G_{RTP} \lambda^2}{(4\pi)^2 k T_0 F q B L}}, \qquad (2)$$

where:
P_Z is the output of ELINT source [W],
G_Z is the antenna gain of ELINT source,
G_{RTP} is the antenna gain of ELINT device,
λ is the wavelength [m],
q is the power signal to noise ratio on the output of ELINT device receiver,
F is the ELINT device receiver noise figure,
k is the Boltzmann constant $1{,}38.10^{-23}$ [J/K],
T_0 is the absolute temperature [K],
B is the receiver bandwidth of ELINT device [Hz],
R is the distance of locating ELINT source [m],
L is the loss when processing and transmitting the pulse electronic signal.
From the Beacon Equation it is obvious that the distance of detecting ELINT source changes not only with the change of its output P_Z, but also with the change of power signal to noise ratio q on the output of ELINT device receiver [3].

The least favourable conditions for detecting signals in the ELINT system are for the distances of ELINT sources, which are moving on or in the close proximity to the margin of radio horizon. In terms of propagation of electromagnetic waves it is actually a diffraction area.

3. The Influence of Source Probability Detection on Range on the ELINT System

The level of power P_Z transmitted by the ELINT source in the direction of ELINT device or the power signal to noise ratio on the output of ELINT device receiver q define the probability detection of ELINT source P_D and the false alarm probability P_F [3].

The given detection probabilities of the ELINT source depend on the distance of detection R, as well as on its power P_Z.

Even if the ELINT device will be stationary and the ELINT source will be moving in proximity to the margin of radio horizon, it is possible to characterise the ELINT system as non-stationary transmission system.

Due to the movement of the ELINT source, the Doppler effect will occur in received signals, whereby their phase will change. The signal at the input of the ELINT receiver will be the combination of more elements which spread due to reflections off of its surroundings and onto the antenna system from various directions. This fact will become evident in the random changes of the received signals amplitude. From the above mentioned reasons it is possible to consider such system to be a transmission channel with Rayleigh distribution amplitude and balanced distribution of received signal phase [4, 5].

For such a defined system, it is possible to formulate the target detection probability P_D by the power signal-to-noise ratio at the receiver output q and false alarm probability of the target P_F in this formula [6]:

$$P_D = P_F^{\frac{1}{1+q}} \tag{3}$$

3.1. Influence of Source Detection Probability on the Range in the ELINT System

The detection probability of sources P_D expresses the percentage of periodically repeated signals transmitted by the ELINT source which will be correctly detected by ELINT device.

Let us assume that ELINT device monitors two sources. For ELINT Reconnaissance System when detecting the first source let the following parameters mean:

- detection probability $P_{D1,}$
- false alarm probability $P_{F1,}$
- ELINT source output $P_{Z1.}$

When detecting the second source in the same ELINT system, then these parameters mean:

- detection probability P_{D2},
- false alarm probability P_{F2},
- ELINT source output P_{Z2}.

According to [6] it is possible to express the ratio of detecting distance R_2 / R_1 by the following formula:

$$\frac{R_2}{R_1} = \sqrt{\frac{P_{Z2}}{P_{Z1}} \cdot \frac{\frac{\ln P_{F1}}{\ln P_{D1}} - 1}{\frac{\ln P_{F2}}{\ln P_{D2}} - 1}}. \tag{4}$$

From the formula (4), provided that $P_{F1} = P_{F2} = P_F$ and $P_{Z1} = P_{Z2}$, it is possible to set the formula for detection distance R_2 of the second ELINT source this way:

$$R_2 = R_1 \sqrt{\frac{\frac{\ln P_F}{\ln P_{D1}} - 1}{\frac{\ln P_F}{\ln P_{D2}} - 1}}. \tag{5}$$

According to the formula (5) the calculations and simulations of dependability $R_2 = f(R_1)$ in the ELINT system were made. The influence of probability P_{D2} in range 0.5÷0.95 for the detection distance R within the detection area of ELINT system for discrete values of correct detection probability P_{D1} = (0.5; 0.6; 0.7; 0.8; 0.9 and 0.95) was assessed. The example of the above described simulations for $P_{D1} = 0.9$ is given in Fig. 2 [7].

From analysis of the above mentioned simulations it is obvious that if condition $P_{D1} > P_{D2}$ applies, then $R_2 > R_1$. If condition $P_{D1} < P_{D2}$ applies, then $R_2 < R_1$.

3.2. Influence of Source False Alarm Probability on the Range in the ELINT System.

False alarm probability P_F expresses how many per cent of randomly repeated noise peaks at the input of ELINT device receiver will be incorrectly detected by this device as a useful signal.

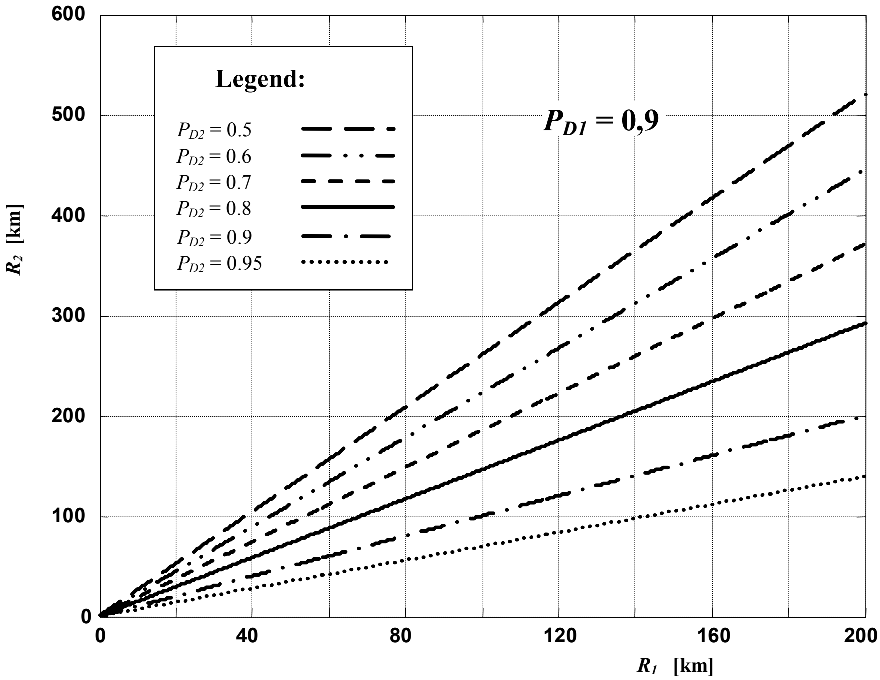

Fig. 2 Graph of dependency $R_2 = f(R_1)$ from P_{D2} for P_{D1} = 0.9

For the analysis of ELINT source false alarm probability influence on the change of ELINT device range according to formula (3) and on the assumption that $P_{D1} = P_{D2} = P_D$ and $P_{Z1} = P_{Z2}$, it is possible to state the formula for range detection R_2 of the second ELINT source this way:

$$R_2 = R_1 \sqrt{\frac{\frac{\ln P_{F1}}{\ln P_D} - 1}{\frac{\ln P_{F2}}{\ln P_D} - 1}}. \tag{6}$$

According to the formula (6) the calculations and simulation of dependency $R_2 = f(R_1)$ in the ELINT system have been made.

The influence of probability P_{F2} in the range $10^{-6} \div 10^{-9}$ for the detection range R within the area of ELINT system detection for the discrete values of false detection probability $P_{F1} = (10^{-9}$; 10^{-8}; 10^{-7} and $10^{-6})$ has been analysed. An example of above mentioned simulations results for $P_{F1} = 10^{-6}$ is given in Fig. 3 [7].

From the analysis of the simulations it is obvious that if inequality $P_{F1} > P_{F2}$ applies, then $R_2 < R_1$. If $P_{F1} < P_{F2}$ applies, then $R_2 > R_1$.

4. The Influence of ELINT Source Power Change on Range in the ELINT System

The ELINT source power P_Z is given by the used transmitter, by which every ELINT source is equipped with. Let us assume that the ELINT device monitors two sources. The power of these sources is P_{Z1} and P_{Z2}. The other possibility is that it monitors the source with so-called power agility (the change of power from P_{Z1} to P_{Z2} and viceversa). Then according to the formula (4), it is possible to state the ratio of transmitting outputs P_{Z1} / P_{Z2} by the following formula:

$$\frac{P_{Z1}}{P_{Z2}} = \frac{R_1^{\ 2}}{R_2^{\ 2}} \frac{\dfrac{\ln P_{F1}}{\ln P_{D1}} - 1}{\dfrac{\ln P_{F2}}{\ln P_{D2}} - 1}. \tag{7}$$

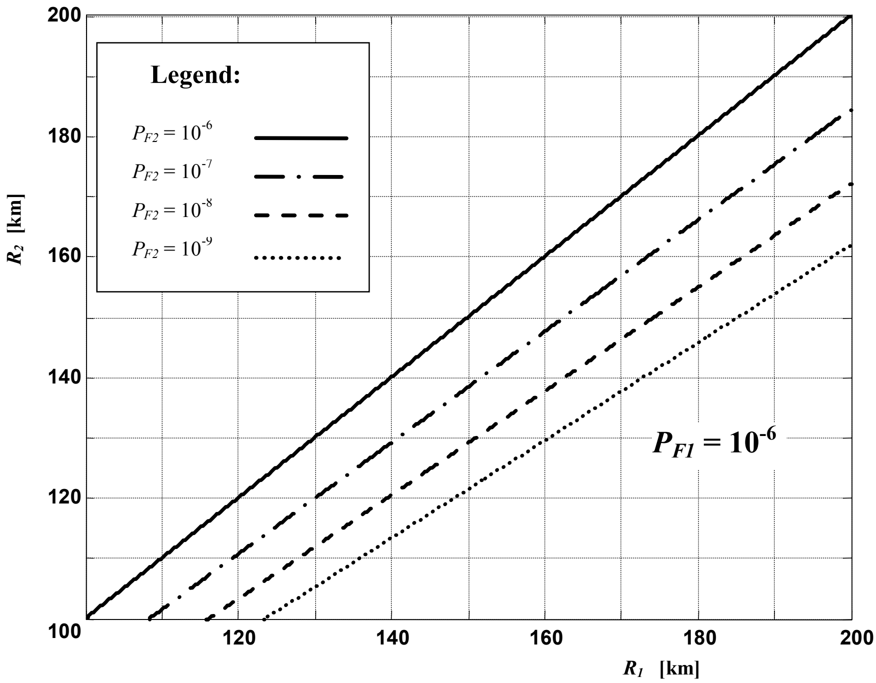

Fig. 3 Graph of dependency $R_2 = f(R_1)$ on P_{F2} for $P_{F1} = 10^{-6}$

From the formula (7) provided that $P_{D1} = P_{D2}$ and $P_{F1} = P_{F2}$, it is possible to state the dependence of change in ELINT sources transmitting powers P_{Z1} or P_{Z2} on the ELINT device range R with this formula:

$$R_2 = R_1 \sqrt{\frac{P_{Z2}}{P_{Z1}} \frac{\dfrac{\ln P_F}{\ln P_D} - 1}{\dfrac{\ln P_F}{\ln P_D} - 1}}. \tag{8}$$

According to the formula (8), the calculations and simulation of dependency $R_2 = f(R_1)$ in the ELINT system have been made. The influence of probability P_{Z1} in the range 0.5 kW to 20 kW for the detection range R within the area of ELINT system detection for the discrete values of detection P_{Z2} = (0.5; 1.0; 1.5; 2.0; ...; 9.5; 10.0) kW and (10; 11; 12; ...; 19; 20) kW has been analysed. An example of the above described simulations for P_{Z1} = 10 kW a P_{Z2} in the range 7.5 kW to 10 kW is given in Fig. 4 [7]. From the analysis of the above mentioned simulations it is obvious that if condition $P_{Z1} > P_{Z2}$ is fulfilled, then $R_2 < R_1$. On the assumption if $P_{Z1} < P_{Z2}$, then $R_2 > R_1$.

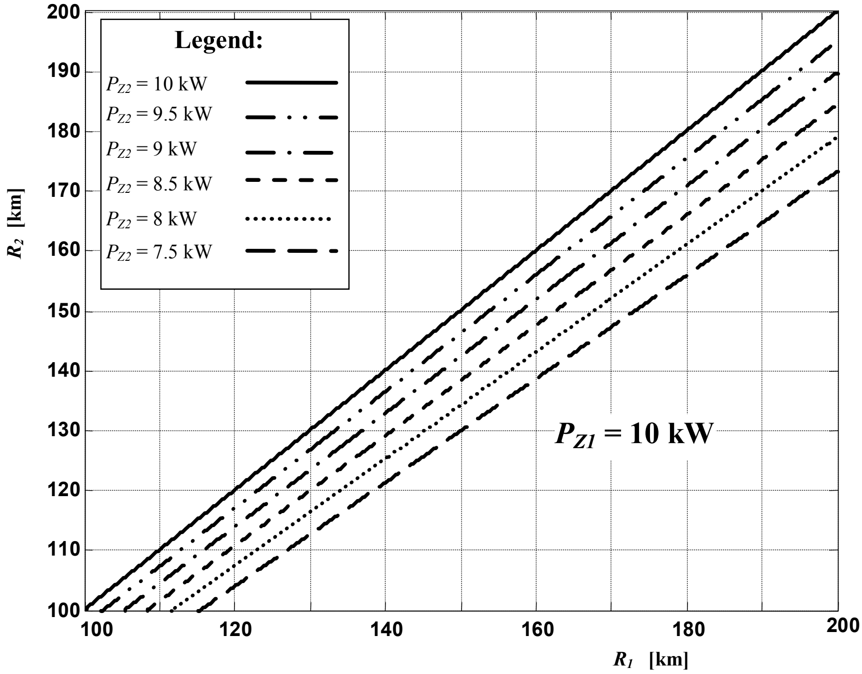

Fig. 4 Graph of dependency $R_2 = f(R_1)$ on P_{D2} for P_{Z1} = 0,9 and P_{Z2} for the chosen values 7.5 kW to 10 kW

5. The Range of the ELINT System when Changing Several Parameters at the Same Time

In the previous sections of this article there were several cases solved when congruent changes in range of the ELINT system (by changing one chosen parameter of this system P_D, P_F or P_Z) have been analysed. The rest of the given parameters were constant for this case. However, in practice there are cases, when more parameters of the ELINT system change at the same time. For example the P_Z change initiates for the expected detection range R corresponding P_D change. It is necessary to compensate for this change by adequate change P_F by means of threshold level detection change in the ELINT receiver.

It is possible to solve the analysis of simultaneous change of impact, for the range of ELINT system in the next part by proposed comparative evaluation method of detection area parameters of ELINT system [7]. The essence of this method is in comparing the ELINT system parameters P_{Z1}, P_{D1} and P_{F1} when detecting the signals from the first source with the ELINT system parameters P_{Z2}, P_{D2} and P_{F2} when detecting the signals from the second source. According to [7] the following formula for comparing the above given parameters of ELINT system is applied

$$\frac{R_2^2}{R_1^2} = \frac{P_{Z2}\dfrac{\ln P_{F1} - \ln P_{D1}}{\ln P_{D1}}}{P_{Z1}\dfrac{\ln P_{F2} - \ln P_{D2}}{\ln P_{D2}}}. \tag{9}$$

From the formula (9), after appropriate changes it is then possible to state a formula for the determination of the correct detection probability value P_{D2} depending upon the rest of ELINT system parameters valid for detection of both sources in the following way:

$$P_{D2} = \exp\left[\alpha\beta \frac{\ln P_{D1} \ln P_{F2}}{(\alpha\beta - 1)\ln P_{D1} + \ln P_{F1}}\right] \tag{10}$$

where:

$\alpha = P_{Z1}/P_{Z2}$ is the ELINT source output agility coefficient,

$\beta = R_2^2/R_1^2$ is coefficient of range variation in ELINT system.

For P_{F2} depending upon the rest of ELINT system parameters, valid for detection of both sources, it is possible to derive a new formula from (9) this way, for the determination of false detection probability

$$P_{F2} = \exp\left\{\frac{\ln P_{D2}\left[\ln P_{D1}(\alpha\beta - 1) + \ln P_{F1}\right]}{\alpha\beta \ln P_{D1}}\right\} \tag{11}$$

Between the individual parameters R, P_Z, P_D and P_F of each ELINT system a dependence exists in terms of formulas (10) and (11), which is under the given circumstances sufficient to compare the individual ELINT systems with one another.

According to the formulas (10) and (11) it was possible to perform the simulations for comparing the ranges of ELINT device to the ELINT source with the output agility depending upon the simultaneous changes of P_D and P_F. During simulations, the influence of the ELINT system's detection area parameters, to the probability P_{D2} and P_{F2}, was analysed. The example of performed simulations for P_{D2} results in the ELINT systems with the following parameters

- probability P_{D1} = 0.9,
- probability $P_{F1} = 10^{-7}$,
- ELINT source output P_{Z1} = 10 kW,
- probability $P_{F2} = 10^{-6}$, 10^{-8} , 10^{-9} and
- ELINT source output P_{Z2} = (4, 6, 8) kW

is shown in the Fig. 5.

An example of performed simulations for P_{F2} results in the ELINT systems with the following parameters

- probability P_{D1} = 0.85,
- probability $P_{F1} = 10^{-6}$,
- ELINT source output P_{Z1} = 15 kW,
- probability P_{D2} = 0.8, 0.75, 0.7 and
- ELINT source output P_{Z2} = (11, 9, 7, 5) kW,

is shown in Fig. 6.

For individual ELINT systems the influence P_D in range 0.5÷0.95, P_Z in range (0.5÷20) kW and P_F in range $10^{-6}÷10^{-9}$ depending upon the distance detection R = (200÷250) km has been analysed.

6. Conclusion

On the basis of the given results and from the calculations and simulations, it is possible to judge the possibilities of detecting sources in the ELINT system with sufficient credibility. When doing this, it is necessary to consider the distribution of amplitude, the phase of received signals, and to predict the agility of transmitted outputs by the ELINT sources.

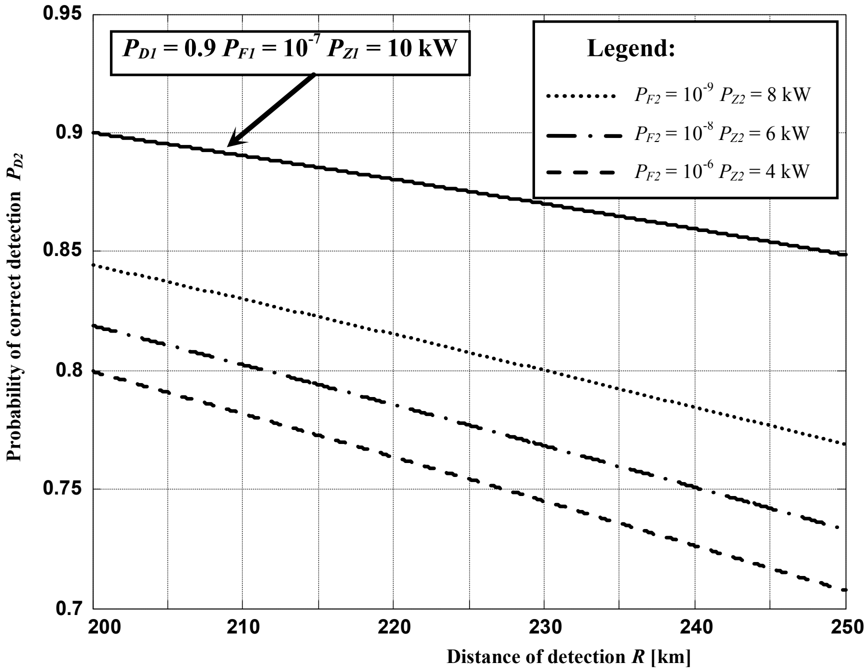

Fig. 5 An example of the simulation results for P_{D2} in the ELINT systems with the selected parameters P_Z, P_D and P_F

If we define the variable $X_{[\%]}$ as a value of percentage variation of ELINT system parameters P_Z, P_D a P_F , then it is possible to make analysis how the variations of these parameters influence the percentage change of range $R_{[\%]}$ in the system.

The percentage of variation of parameters $X_{[\%]}$ in the ELINT system is given by this formula:

$$X_{[\%]} = 100\left(\frac{P_{Z2}}{P_{Z1}} - 1\right) = 100\left(\frac{P_{D2}}{P_{D1}} - 1\right) = 100\left(\frac{P_{F2}}{P_{F1}} - 1\right) \tag{12}$$

and percentage variation of range $R_{[\%]}$ by the following formula

$$R_{[\%]} = 100\left(\frac{R_2}{R_1} - 1\right). \tag{13}$$

The graphic dependency of range variation $R_{[\%]}$ of the ELINT system on the percentage of variation of parameters $X_{[\%]}$, is presented in Fig. 7.

From the analysis and synthesis of the calculations and simultaneous results, it is possible to state that by partial change of some of the chosen ELINT system parameters (P_D, P_F and P_Z) there is a change in the area dimensions of ELINT device detection. Nonetheless, this change is most noticeable by the increase or decrease of detection probability P_D. Less noticeable differences, even if they are still very strong, are observable by the change of transmitted output P_Z. The false alarm probability P_F influences the area dimensions of ELINT device detection the least.

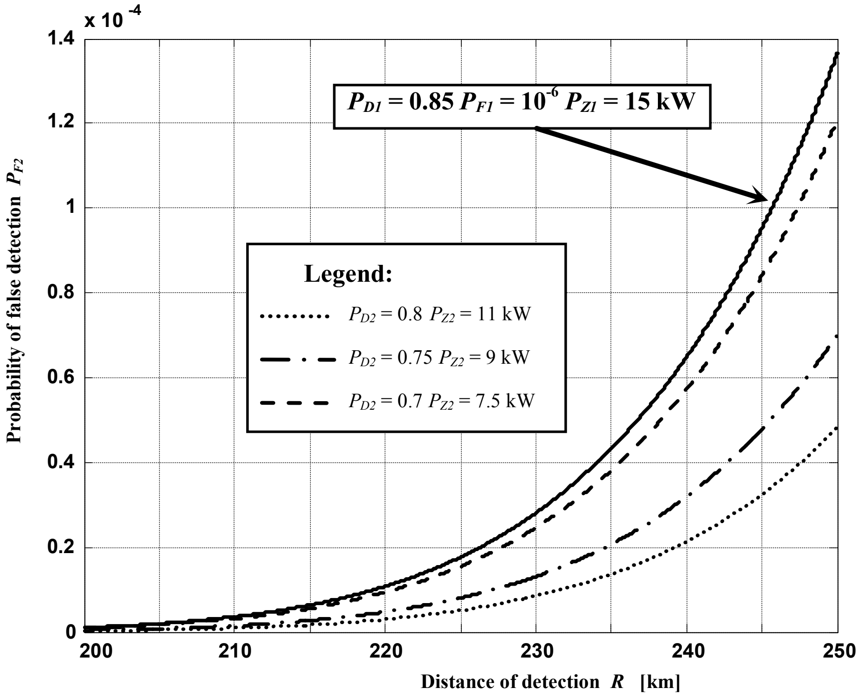

Fig. 6 An example of the simulation results for PF2 in the ELINT systems with the selected parameters PZ, PD and PF

The percentage variation of range $R_{[\%]}$ appears here only for the very big P_F changes. Within the original contributions of this article, the authors considered the vindication of mathematical apparatus and the proposal of a comparative method for analysis and synthesis of the ELINT device for range variation when monitoring the sources on the border of radio horizon in the ELINT system. At the same time, it is possible to consider the contributions of this article in defining the coefficient of source output agility α and the coefficient of range variation β for the ELINT system, as well as performing the simulations and acquired results when modelling ELINT systems with variation of selected parameters in the MATLAB software environment.

References

[1] BARTON, D. and LEONOV, S. *Radar Technology Encyclopedia.* Boston : Artech, 1997.

[2] PEEBLES Jr., PZ. *Radar Principles.* New York : Wiley, 1998.

[3] TKÁČ, J., OCHODNICKÝ, J. and ŠPIRKO, Š. Vyhodnotenie dosahov radaru s využitím digitálnej mapy. In *Zborník „Nové trendy v rozvoji letectva“.*Košice : Vojenská letecká akadémia, 2002, p. 41-47. ISBN 80-7166-034-5.

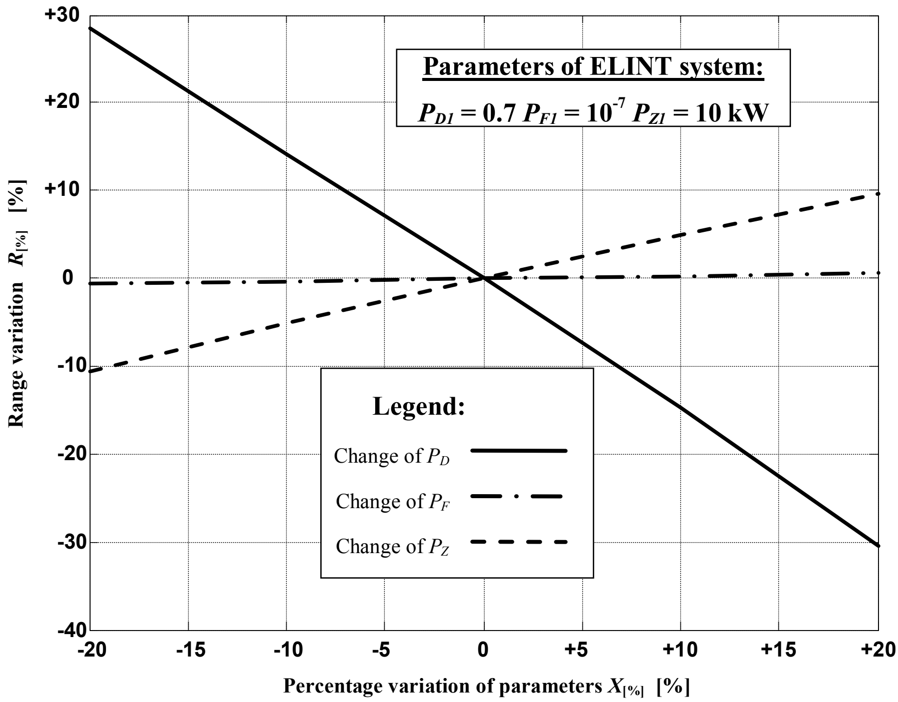

Fig. 7 The graphic dependency of range variation $R_{[\%]}$ of ELINT system on variation of parameters $X_{[\%]}$

[4] LEE, W. C. Y.: Mobile *Communications Design Fundamentals*. 2nd Edition, New York, Wiley & sons, 1993.

[5] STEELE, R. *Mobile Radio Communication*. London : Pentech, 1994. ISBN 0-7803-1102-7.

[6] ŠPIRKO, Š. and TKÁČ, J. The comparison of probability of target detection. In *Proceedings of 10th International Symposium on Mechatronics.* Trenčín : Trenčianska univerzita, 2007, p. 141-144. ISBN 978-80-8075-210-1.

[7] MATOUŠEK, Z. Analýza priestoru detekcie v rádiotechnickom prieskume. [Dizertačná práca], Liptovský Mikuláš : AOS, 2008. 125 p.

[8] PETZ, I. and NEČAS, P. Simulation techniques and modelling in training. In *Proceedings of International Conference on Military Technologies 2009 "ICMT'09"*. Brno : University of Defence Brno, 2009, p. 482-485, ISBN 978-80-7231-648-9.