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Analysis of radar signals by PSD methods

Lubos Rejfek*, Ladislav Beran, Pavel Chmelar, Nataliia Chmelarova, Viktor Pek, Ondrej Fiser

Department of Electrical Engineering, Faculty of Electrical Engineering and Informatics University of Pardubice, Pardubice, Czech Republic

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ABSTRACT

The article is targeted on an application of selected Power Spectral Density (PSD) methods to analyze the radar signals with frequency modulated pulses. First, simulated signals to test the power spectral density methods themselves are used. The second step was the test of the methods applied on real measurement. The primary aim of the work was to focus on the analysis of the long targets by parametric power spectral density methods. The involved methods are Periodogram, Multiple Signal Classification (MUSIC) method and Eigen value method.

1. Introduction

In principle, the radar with frequency modulated (FM) pulses is a combination of pulse radar with a frequency modulated continuous wave (FMCW) radar. Block scheme of this radar is given in the Fig. 1 (Piper, 1995). Transmitted signal and received signal by the PIN diodes are switched. The output signal obtained from the radar is the differential frequency of the transmitted signal and received signal. The principal of the radar signal simulator and timing diagram of this type of the radar are described in (Rejfek et al., 2014).

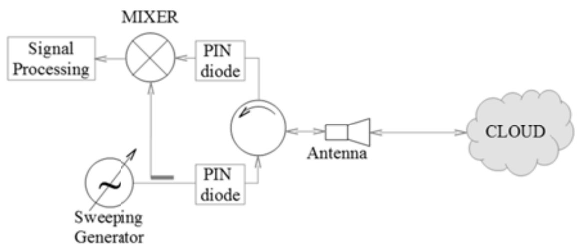

Fig. 1: Block scheme of radar with FM pulses (Piper, 1995)

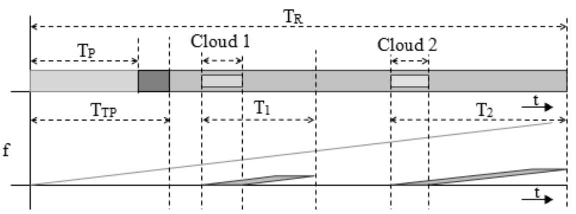

Fig. 2: Frequency sweeping of radar transmitter signal and representation of the received signals

An example of radar frequency sweeping is shown at the Fig. 2. Time interval T_P corresponds to the radar signal broadcasting. The time T_R is for entire cycle of measurement. The sweeping corresponds to one period of T_R. The "sweeping" line reflects the transmitted frequencies while trapezoids display received signals. Transmitted signal is continuously modulated and the differential frequency depends on the distance of the target. An example of the received signal is shown at the Fig. 3. The black line corresponds to the signal containing reflection from target and the gray line shows the background (signal without target). Time of the broadcasting is three microseconds and receiver is open for twenty-five microseconds. Difference of power spectrums forms the received signal in depended on the radar system distortions as well as on clutters. These power spectrums can be created by different methods (Fig. 3).

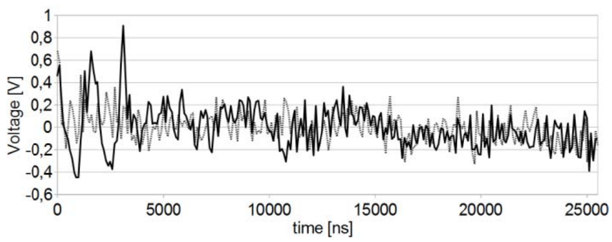

Fig. 3: An example of the received signal containing target reflection and an example of background signal (without the target component)

2. Test PSD methods

Power spectral density (PSD) methods for the radar signals analysis are used. The signal spectrum is a function of the distance from the particular

* Corresponding Author.
Email Address: lubos.rejfek@student.upce.cz

target Usually the PSD methods are divided into two groups. In the first group non-parametric methods (periodograms and others) are considered, in the second one contains parametric methods (Auto Regressive (AR) model, MUSIC and other). For the recent analysis the power spectrum calculated by the Fast Fourier Transformation (FFT) algorithm (non-parametric method), MUSIC method and Eigen vector decomposition method were selected. The above mentioned last two methods are parametric. An experimental condition to obtain parameter *p* according to (Smekal, 2009) is defined by following equation:

$$0.05 \cdot N \leq p \leq 0.2 \cdot N \tag{1}$$

N= Length of the signal (number of samples),
p= Parameter (parameter of the used filter)

2.1. Periodogram

Power spectrum density is calculated by equation (2) using the Fourier transformation. Modified periodograms (Bartlet, Welch and others) are based on this periodogram but are of smaller resolution. The FFT algorithm is used for periodogram:

$$P_{xx}(e^{j\omega}) = \frac{1}{N}\left|\sum_{n=0}^{N-1} x[n]\cdot e^{-j\omega n}\right|^2 \tag{2}$$

N=Length of the signal (number of samples),
x=Measured signal

2.2. The music method

MUSIC algorithm in the following way could be described. The first step is an estimation of the auto-covariance matrix, the second step deals with calculation of the Eigen vector and Eigen values. Further the Eigen vectors for the lowest Eigen value were selected and the estimator was calculated. Equation for the MUSIC estimator computation in accordance with (Stoica and Moses, 1997) is defined by the formula (3). Calculation of the argument is the same as Discrete Fourier Transformation (DFT) of vector see (4). The FFT method is possible to use for faster calculation. This estimator represents the noise subspace. The estimator for signal subspace of MUSIC method is defined by other equation not included in this contribution.

$$P_{xx}(e^{j\omega}) = \left(\sum_{i=N-p}^{N}\left|s^H(e^{j\omega})\cdot \hat{v}_i\right|^2\right)^{-1} \tag{3}$$

$$DFT\{v_i\} = s^H(e^{j\omega})\cdot v_i \tag{4}$$

v = Eigen vector matrix,
S^H = Hermitan of the steering vector

2.3. Eigen value method

The Eigen value method is based on the MUSIC method. The difference against the MUSIC method is the way, in which the estimator was obtained. The Eigen vectors used here are divided by Eigen values. The estimator is defined according to (Mandic, 2012), see equation (5).

$$P_{xx}(e^{j\omega}) = \left(\sum_{i=N-p}^{N}\frac{\left|s^H(e^{j\omega})\cdot \hat{v}_i\right|^2}{|\lambda_i|}\right)^{-1} \tag{5}$$

λ = Eigen value

3. Signal processing

Selected methods involved in the test of the signal processing are the Periodogram, the MUSIC method and the Eigen value method. For the test the noise subspace is used. Spectra are recalculated from the frequency according to the distance, as it was described in (Mandlik and Brazda, 2015). Simulated signals are burdened by noise. Signal noise ratio is 10 dB. Generated signals into three groups are sorted. The first group is for one short target, the second group is for multiple short targets and the third group is for one long target. Examples of extreme parameters for parametric method according to the equation (1) are listed in the Table 1. Selected lengths of the sequences are 128, 256 and 660 samples. Results are tested by the parametric methods for minimal number of parameters on one hand and maximum number of parameters on the second hand. The length of the simulated signals consist 660 samples.

Table 1: Parameters *p* for different lengths of signals

N	*pmin*	*pmax*
128	6.4	25.6
256	12.8	51.2
660	33	132

3.1. Simulated signal with short target

The simulated signal with one short target with the length of 150 m was created for distance of one kilometer. As the first method for the test we choose the Periodogram. Graph of the Periodogram is given in the Fig. 4. We can see one target with signal noise ratio of 10 dB.

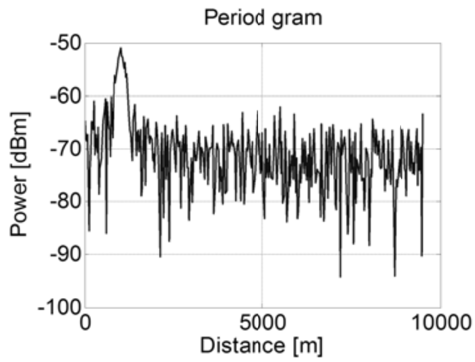

Fig. 4: Short target analyzed by the Periodogram

The second method is the MUSIC method. Graphs of the MUSIC method are shown in the Fig. 5. The black curve is for minimal parameter *p* and the gray curve is for maximal parameter *p.* The curves show that the value of the maximal parameter *p* generates a few false targets in this case.

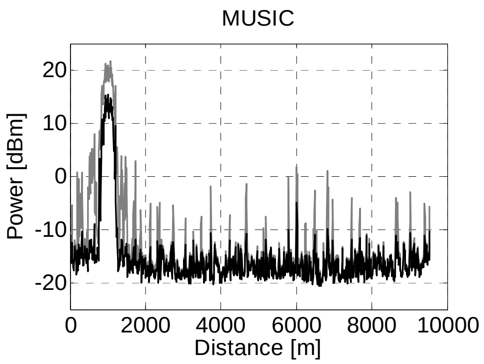

Fig. 5: Short target analyzed by the MUSIC method for parametr *p* (*pmax* and *pmin*)

The third tested method is the Eigen value algorithm. Results for this method at the Fig. 6 are shown. The black curve is for the minimum value of the parameter and the gray curve is for the maximum one. The black curve is without false targets, while the gray curve has a few false targets.

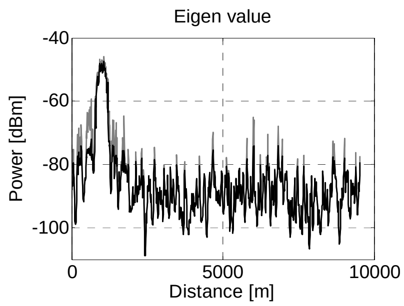

Fig. 6: Short target analyzed by the Eigen value method for *p* (p_{max} and p_{min})

3.2. Simulated signal with multiple targets

The results for three different targets are described in this section. Targets are in distance of 1 km, 2 km and 5 km. Lengths of the targets are 250 m, 300 m and 150 m. Signal noise ratio is 10 dB for the strongest target. Periodogram of this signal is shown in the Fig. 7. From Fig. 7 there is possible to detect all three targets.

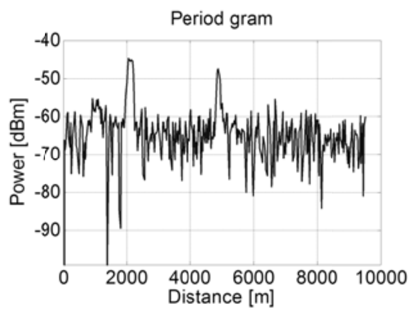

Fig. 7: Three targets analyzed by the Periodogram

The test of the MUSIC method applied on three targets is shown at Fig. 8. The Black curve is for minimum parameter *p* and the gray one is for maximum value of the parameter *p*. Loss of the first target is evident when the minimum parameter value is used.

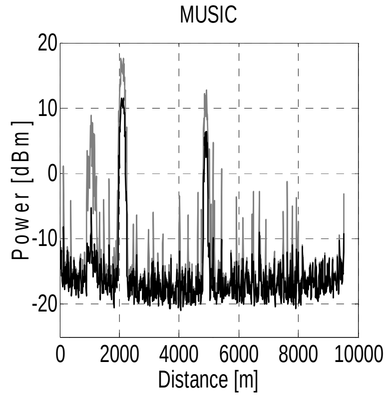

Fig. 8: Three targets analyzed by the MUSIC method for maximum and minimum parameter values (*pmax* and *pmin*)

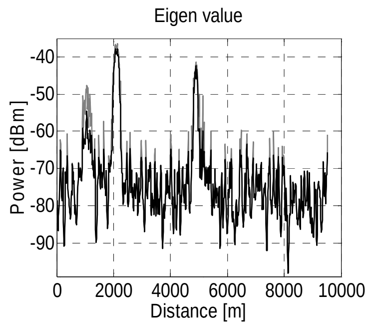

Fig. 9: Three targets analyzed by the Eigen value method for maximum and minimum parameter values (*pmax* and *pmin*)

The results for the Eigen value algorithm are shown at the Fig. 9. The minimum parameter (black curve) is usable for detection of all targets. Differences between the maximum and minimum parameters are very low.

3.3. Simulated signal with long target

In this case, the simulated target of length of 1.5 km was in distance of 1 km. The signal noise ratio was determined to be 10 dB. An example of periodogram of this signal is shown at the Fig. 10.

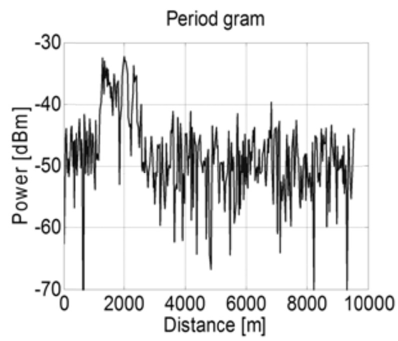

Fig. 10: Long target analyzed by the Periodogram

The results for the MUSIC method are given at the Fig. 11. There is evident that the minimum value of the parameter *p* is wrong choice for the target description.

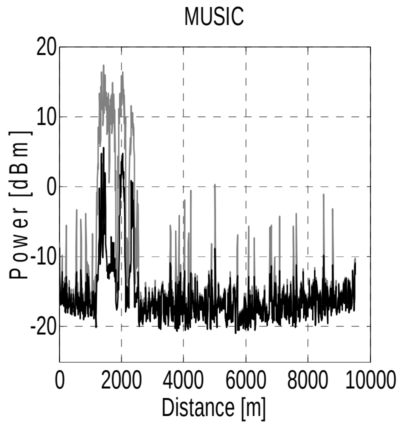

Fig. 11: The long target analyzed by the MUSIC method for maximum and minimum parameter values (*pmax* and *pmin*)

An example for the Eigen vector algorithm is shown at the Fig. 12. We found differences between minimum and maximum parameter *p* value to be insignificant. The target reliably by both values (maximum and minimum) of parameter *p* is described.

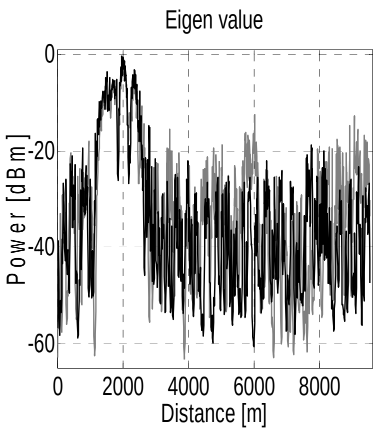

Fig. 12: The long target analyzed by the Eigen value method for maximum and minimum parameter values (*pmax* and *pmin*).

3.4. Application of methods to real measurement

The real data for the test by the 35.4 GHz radar measurement at the observatory Prochoice close to Prague was obtained. This radar is combines properties of the pulse radar and FMCW radar. Examples of signals obtained from this radar are shown at the Fig. 4. The 100 measurements were used to the tests. The values of the *p* parameter were *pmin* = 13 and *pmax* = 51.

The periodogram of real measurement is shown at the Fig. 13. The blind zone of this radar is approximately 200 meters. False targets in this range are caused by leakage of the signal through circulator and other system influences of the used radar. Targets within the distances of 500 m to 1.2 km are buildings in the village "Rozkos." Target between 1.5 km and 1.8 km corresponds to a small forest. Weak target at the distance above 3 km is the electrical substation Chodov.

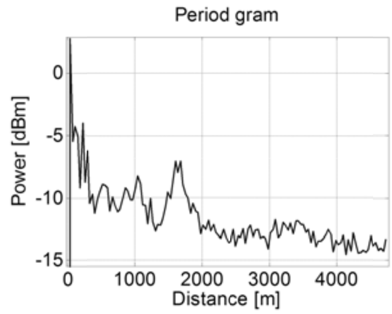

Fig. 13: Periodogram of the real measurement

The results of the MUSIC method applied on the real measurements are shown in the Fig. 14. It is obvious that weak targets, which correspond to the minimal parameter *p,* are lost in the noise.

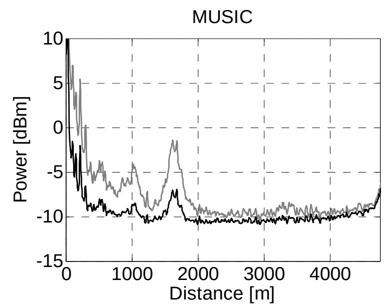

Fig. 14: Noise subspace of the MUSIC method of the real measurement

The real data analyzed by the Eigen vector method is shown at the Fig. 15. Differences between analyses for different parameters *p* insignificant and targets are easily detectable.

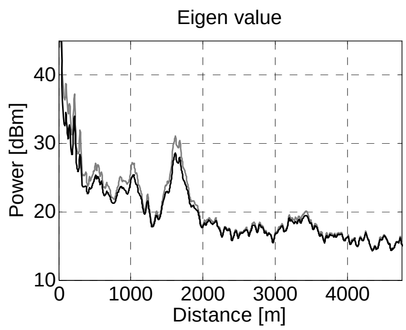

Fig. 15: Noise subspace of the Eigen value method of the real measurement

4. Conclusion

In the previous part tests of PSD methods on the radar signal were described. The PSD methods using three types of simulated targets as well as real measurement were tested. As the reference method the FFT was selected.

The first type of the simulated signal was signal with short target. Results for short target show that a parametric method generates false targets if maximum parameter *p* value was used. The best results were achieved by applying the Eigen value method. The second type of the simulated signal was signal with three targets. The targets in this case were not detected, when the Eigen value method was applied. The same problem appeared in the case when the minimum parameter *p* was chosen in the MUSIC method. The third type of the simulated signal was signal with long target. The evaluation of this type of target lead to the same results as it was described for the previous case.

Test of the parametric methods on the real signals showed that the Eigen value method is the best for this signal. Dependence on the parameter *p* is insignificant.

The Eigen value method shows the best results comparing with the other tested parametric methods. This method with minimal *p* parameter value could be used for processing of signals from pulse radar with frequency modulated pulses. In other cases utilization of the FFT for targets detections is possible. After the FFT the parametric method for target description in the analyzed signal can be used.

The results there are evident that the parametric methods of better resolution than non-parametric methods. Nevertheless, the parametric methods can generate false targets for the maximal parameter *p* value. The weak targets can be "loosed" using parametric methods with minimal *p*-value. The optimal algorithm for the processing of signal of the described radar is the target detection by the Periodogram. After this action parametric method can be used. The best results from the tested methods were observed by the Eigen value method.

Results from this study will be applied to the real radar system.

Acknowledgment

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