Moving Target FSR Shadow Detection Using GPS Signals

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Keywords: FS effect, FSR, GPS, detection and estimation.

Abstract: Forward Scatter GPS (FS-GPS) radio shadows obtained from different objects are investigated in this article. FS radio shadow is essential physical phenomenon, which can be used to extract some useful information about the objects that generate it. Registration of FS-GPS radio shadows from moving and stationary objects is performed using a small commercial GPS antenna and mobile and stationary receiver. Topology of the experiment meets the requirements for the appearance of the FS effect. The results presented in this article show that from FS-GPS radio shadows of different objects can be extracted information about the parameters of the object (size, speed and direction of movement, distance to the receiver). The information obtained can be used in various applications like those in classic radar, including radio barriers, security, classification and identification of moving and stationary objects.

1 INTRODUCTION

Forward Scattering Radar operates in the narrow area of the forward scattering effect where the bistatic angle is close to 1800, and the target moves near the transmitter-receiver baseline (Fig.1) [1].

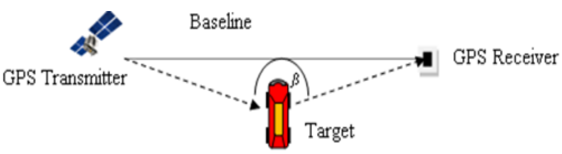

Figure 1: FSR topology.

In FSR, the Babinet principle is exploited to form the forward scatter signature of a target (see figure 2). The Babinet principle says "A plane absorbing screen of limited dimensions may be replaced by a complementary infinite plane screen with an aperture shaped exactly like the original screen (the complementary screen has openings where the original screen is closed and vice versa). The incident field diffracted at the aperture gives rise to the field coinciding with the shadow field of the original absorbing screen, (except for the sign)' (Fig.2).

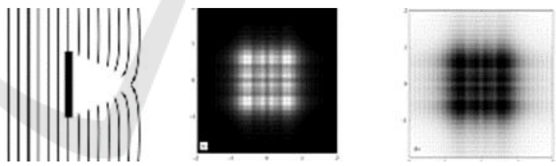

Figure 2: Babinet's principle applied to the FS case with the receiver positioned on the other side of the targets at β = 180°.

Due to the forward scattering effect, the Radar Cross Section (RCS) of targets extremely increases (by 2-3 orders) and mainly depends on the target's physical cross section and is independent of the target's surface shape and the absorbing coating on the surface. The use of GPS signals as a passive radar system is becoming increasingly popular as an alternative to radar systems. The idea to apply a GPS L1 receiver to FSR for air target detection is discussed in [2]. Some experimental results of a GPS L1 receiver concerning the detection of air targets are shown and discussed in [3]. A possible algorithm for

Kabakchie H., Garvanov I., Behar V., Daskalov P. and Rohling H.
Moving Target FSR Shadow Detection Using GPS Signals.
DOI: 10.5220/0005420900340040

Proceedings of the Third International Conference on Telecommunications and Remote Sensing (ICTRS 2014), pages 34-40
ISBN: 978-989-758-033-8

air target detection in a GPS L5-based FSR system is described in [4], and the detection probability characteristics are calculated in [5] in case of low-flying and poorly maneuverable air targets in the urban interference environment. GPS L1 FSR system is researched in [6, 7] for detection of FSR shadows from stationary ground objects. Target detection is indicated if the signal integrated from some satellites exceeds a predetermined threshold. In this paper a passive FSR system, similar to the GPS L1 FSR system, in which GPS satellites are exploited as non-cooperative transmitters, is studied. The aim of this study is to verify the possibility to detect FSR shadow of moving ground targets when GPS satellites are located at small elevation angles. The experimental scenarios include stationary or moving targets, stationary or moving GPS-FSR receivers that register different FS shadows. The paper investigates the possibility of extracting useful information from the radio shadow The obtained experimental results can be used to develop software applications to a GPS receiver that could measure traffic movement, target velocity and target classification.

2 FSR EXPERIMENT DESCRIPTION

The purpose of the experiments is to verify that with a small and omnidirectional commercial GPS antenna is possible to record differences in GPS FS shadows of moving and stationary targets depending on the size of the target and the target velocity, and also to verify whether the difference in the shadows allows classifying the objects (Fig.3).

Figure 3: Experimental equipment

The paper discusses three experimental scenarios. In the first two scenarios the objects are stationary (bridge and building) and GPS receiver moves while in the third scenario - the object moves and GPS receiver is stationary. In all scenarios the condition for the occurrence of FS-GPS effect are guaranteed. In the registration of shadows from buildings and vehicles are selected satellites located low on the horizon. In a study of radio shadow from the trestle are selected satellites located high above the horizon, so that the baseline "receiver-satellite" is always perpendicular to the plane of the object (building, station, and car). The purpose of these experiments is to check whether the type of the registrated FS shadows depends not only on the dimensions of the object, but also the speed of the GPS receiver or the object. The dependence of the type of FS shadow on the size and speed of the marine targets using coastal FSR radars is established in [1]. During the first scenario the GPS recording system is mounted at a car. In this study we verify the possibility of detection of ground targets by using a GPS L1-based FSR system when GPS satellites are located at small elevation angles (Fig.4).

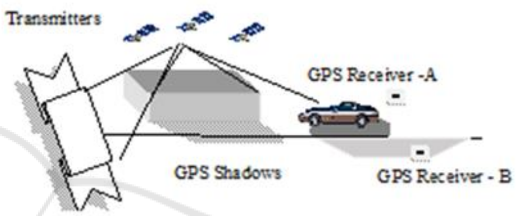

Figure 4: GPS-FSR topology (GPS receiver – A is moving, GPS receiver – B is stationary)

During the experiment, the car with the GPS receiver moves parallel to the building and records the GPS signal in order to registrate the FS shadow from the beginning to the end of the building. The idea of this experiment is to verify whether the energy of the signal from the satellite and the proposed from us the signal processing trough accumulation of the navigation message from GPS within several hundred milliseconds is sufficient to form the FS shadow of a stationary object with large dimensions, which can be registered with the experimental equipment. During the second experiment the car with mounted GPS receiver moves with velocity of 60-70 km. under the large bridge (Fig.4). The third scenario includes a moving targets and stationary-based GPS-FSR system that records FS shadow of cars moving on the road (Fig.4). The car with the GPS receiver is positioned from the one side of the road and records the signal from GPS. For recording are selected such visible satellites, which are located at low elevation angles and form a baseline (between satellite and receiver) perpendicular to the road, in order to form the FS effect. During the experiment are recorded the satellite signals when cars move on the road. Cars passing on the road have different dimensions (cars, buses, trucks, etc.).

3 SIGNAL PROCESSING

The general block-scheme of a possible algorithm for FSR shadow detection using several (M) visible satellites is shown in Fig 4 [1, 8]. According to this block-scheme, several visible GPS satellites are acquired and tracked over the complete duration of recorded signals. We consider the case when the acquisition and tracking algorithms of a GPS receiver are implemented in MATLAB. The absolute values of the Ip component at the output of the Code&Carrier tracking block are then integrated during N milliseconds. These integrated output signals from M satellites are additionally summed in order to improve SNR before detection. Target detection is indicated if the signal integrated from M satellites exceeds a predetermined threshold H. In such a system, the signal integrated at the output of the Code&Carrier tracking block (message bits) of a GPS receiver can be used for detection of the FSR shadow created by moving targets.

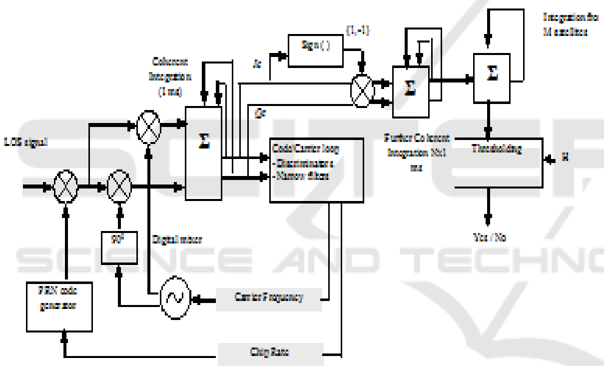

Figure 5: Signal processing used for target detection in a passive FSR using GPS signals from *M* satellites

In this paper we propose to additionally integrate the output signals from M visible satellites in order to improve the SNR before detection. Target detection is indicated if the signal integrated from M satellites exceeds a predetermined threshold.

4 EXPERIMENTAL RESULTS

Experiment 1. The receiver GNSS_SRR records the signals received from the satellite when moving along straight path behind a large building. The scenario topology is shown in Fig.6. Straight line shows the path of the GPS receiver mounted on the car. Dashed line indicates the direction of the necessary baseline "receiver-satellite" in which there is a condition for the occurrence of FS effect. That line is shown in Fig. 6 and Fig.7. With this line we choose the most suitable experimental satellite. Satellites that are visible during this experiment are shown in Fig.7.

Figure 6: Experiment 1

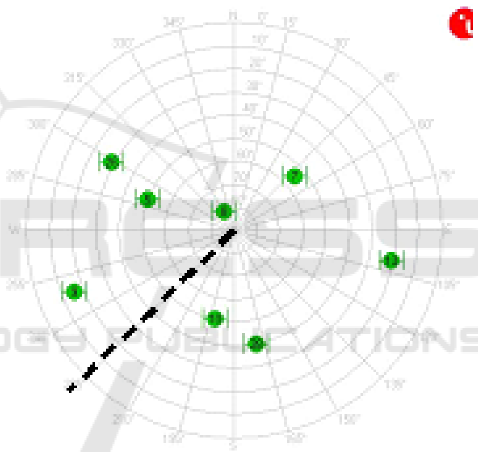

Figure 7: Satellite constellation

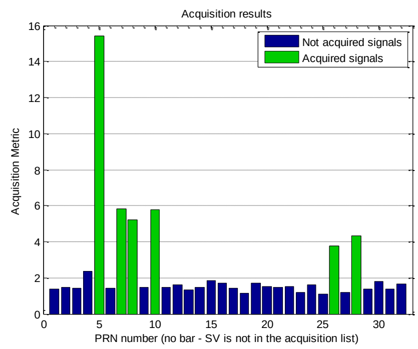

Figure 8: Acquisition results (Experiment 1)

The intensity of the signals from all visible satellites is shown in Fig.8. From Fig. 7 and Fig.8 follows that the most suitable for this experiment is satellite 9 because it is very close to the direction of the baseline where can be occur the FS effect, and is located the lowest elevation angles. The coherent integration of the I_P component power is made during 200ms, and results of integration are shown in Fig.9.

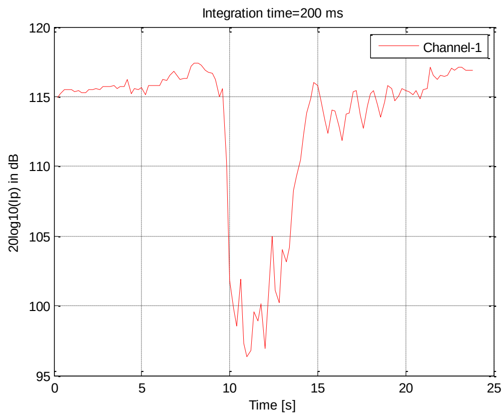

Figure 9: Integrated power of the message (200ms)

In the paper [6] it has been found that the interval of integration of the message is better to be 200ms because this interval of integration allows you to keep the shape of the shadow and to remove random fluctuations. It can be seen that the shadow due to the target (large building) can be exploited for detection of the target (large building).

Experiment 2. The car with GPS receiver moves with a constant velocity of 60 km/h under the small bridge (Fig. 10). The output of C/A code acquisition performance is shown in Fig. 11. It can be seen that during this experiment seven satellites are visible, three of which with numbers 12, 29 and 25 have the strongest signals. The signals from these satellites will be used for detection of the FS shadow created be a bridge.

Figure 10: Experiment 2

These satellites are located at the high elevation angles and should be meet the requirements for the occurrence of the FS effect. Navigation messages at the output of the Code&Carrier loop received from the satellites 12, 25 and 28 are shown in Figs. 12-14.

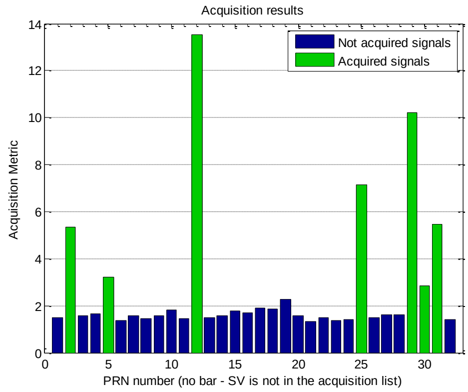

Figure 11: Acquisition results (Experiment 2)

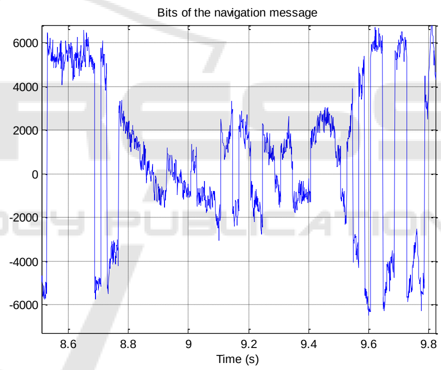

Figure 12: Navigation message of satellite 12

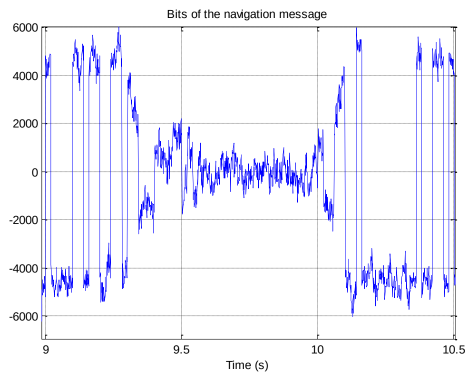

Figure 13: Navigation message of satellite 29

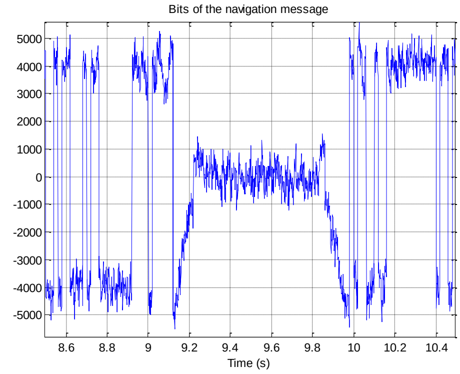

Figure 14: Navigation message of satellite 25

From figures 12-14, it is seen that during the passage of the vehicle under the bridge, the intensity of the information signal drastically reduces and forms a FS shadow with the certain geometry and form. The integrated messages from the three satellites obtained with a sliding window of 200 ms are shown in Fig. 15.

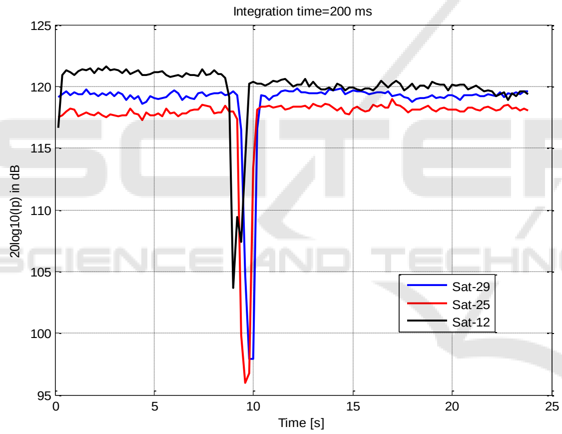

Figure 15: Integrated messages of satellites 12, 25 and 29

As seen from Fig. 15, the shape and size of the shadow depends on the direction (the position of the satellite) of the incoming signal from the satellites. The deepest shadow is obtained by satellite 25, which shows that this satellite creates the best conditions for the occurrence of the FS effect.

Experiment 3. The GPS receiver is positioned at the one side of the road (Fig. 16).The street has four lanes width of 4m, two in one direction. On the west of the receiver has a high building, so the GPS receiver only sees the GPS satellites from the east. During the experiment, several cars moves with a velocity about 10 - 20 km/h relative to the GPS receiver.

Figure 16: Experiment 3

The position of the visible satellites and the intensity of the incoming signals from them are shown in Fig. 17 and Fig.18. It can be seen that during this experiment six satellites are visible, two of which with numbers 16 and 32 create the best conditions for the occurrence of the FS effect. They are the most low on the horizon and the car crosses the baseline "satellite - receiver" at the angle of about 90 degrees. Satellites 1 and 30 are too low on the horizon, but in their case the vehicle crosses the baseline “”satellite-receiver”” at an angle other than 90 degrees.

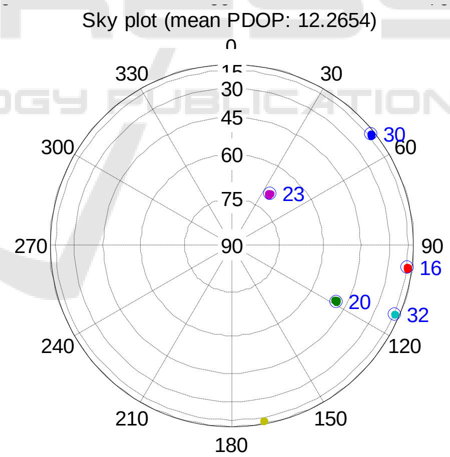

Figure 17: Satellite constellation

In the case of satellites 1 and 30, the conditions of the occurrence of FS effect are violated. Satellite 20 is located at the elevation angle close to 90 degrees, i.e. high above the horizon, which worsens the conditions of the occurrence of the FS effect. It is so because the direction of propagation of the waves from the satellite is not orthogonal with respect to the cross section of the vehicle. The same was observed for the satellite 23. The integrated signals from these satellites 16 and 32 are shown on Fig. 19 and 20.

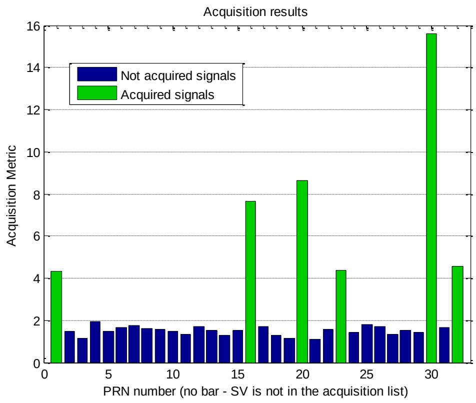

Figure 18: Acquisition results (Experiment 3)

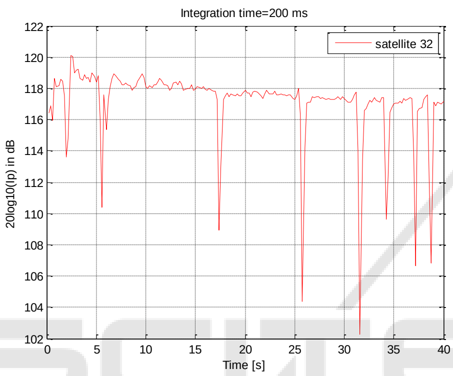

Figure 19: Integrated message from satellite 32

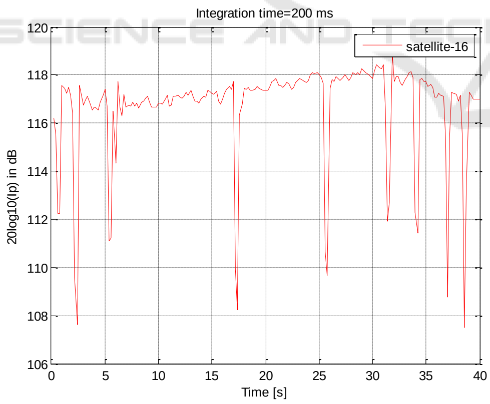

Figure 20: Integrated message from satellite 16

These figures show a series of FS shadows from different cars passing by the GPS receiver. As shown, the depth and shape of the shadow provides information about the size of the car, the speed and the direction of movementof the car, and the distance from the vehicle to the GPS receiver

.As can be seen that cars passing very close to the receiver have the deepest FS shadow (about 8-10 dB). A car passing at a distance of 4 meters from the GPS receiver creates the deepest FS shadow (about 8-10 dB). With increasing distance to 16 meters the depth of the FS shadow decreases by several dB (3-4 dB). The experimental results show that the size, the depth and the shape of the FS shadow could provide information about the car velocity and the intensity of the traffic. Using a predetermined multi-level threshold can be defined the distance to the vehicle from GPS receiver. It can be seen that the shape of the FS shadow (the first peak) can be used to determine the direction of the movement of the vehicle. In such a way it can be realized a selection and classification of vehicles.

The FS shadows obtained from 1 and 30 satellites are shown in Fig. 21 and Fig. 22.

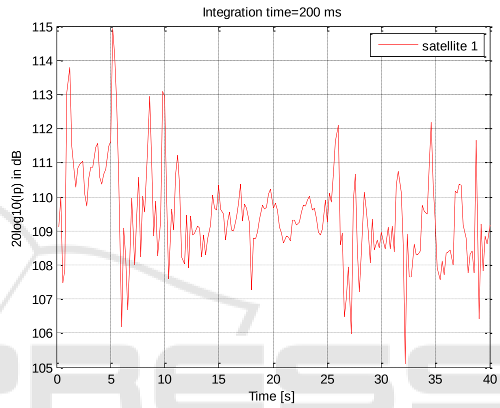

Figure 21: Integrated message from satellite 1

It can be seen that unlike the satellite 1, the signals from the satellite 30 form the relative deep FS shadow of passing cars. This shows that unlike the satellite 1, the satellite 30 does not fulfill the conditions for the occurrence of the FS effect.

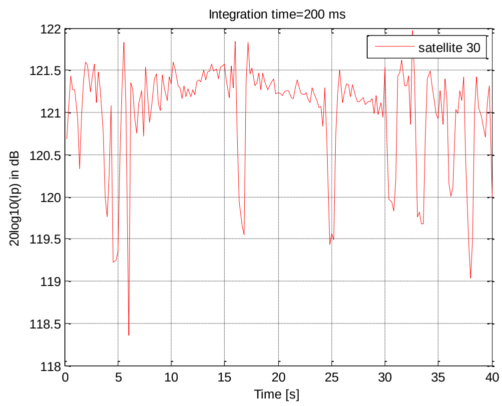

Figure 22: Integrated message from satellite 30

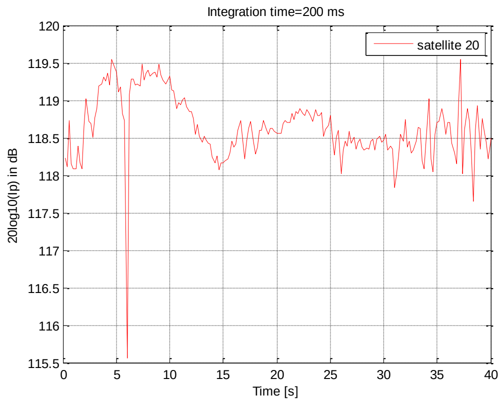

Figure 23: Integrated message from satellite 20

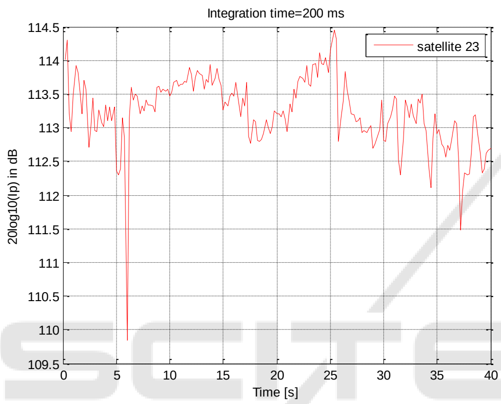

Figure 24: Integrated message from satellite 23

The integrated signals from satellites 20 and 23 are shown on Fig. 23 and 24. This satellites are high above the horizon ant the FS shadow is small. In this case the majority of the energy of the transmitted signal passes over the target and the signals from these satellites cannot be used for detection of the FS shadow created by cars.

5 CONCLUSIONS

Using a small commercial GPS antenna and GPS receiver it is made a number of experiments with moving and stationary objects and moving and stationary receiver. Topology of the experiment suggests the presence of the conditions of occurrence of FS effect. This means that the satellite receiver and a transmitter are located on the same line, which crosses the object. Experiments have shown that mobile and stationary object as well as mobile and stationary GPS receiver can registrate the occurrence of the FS radio shadow. Experiments have shown that the FS shadow can provide information about the parameters of the object (size, speed and direction of movement, distance to the receiver), from the width, shape and length of the received FS shadow.

The occurrence of FS shadow is essential physical phenomena, which can be used to extract some useful information about the objects that create it. The information obtained can be used in various applications like those in the classic radar, including radio barriers, security, classification and identification of moving and stationary objects.

ACKNOWLEDGEMENTS

This work is partly supported by the projects DDVU02/50/2010, MU-FS_05/2007 and NIP-01-2014.

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