The Experimental Study of Possibility for Radar Target Detection in FSR Using L1-Based Non-Cooperative Transmitter

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Abstract: *The Forward Scatter Radar (FSR) system is a special case of bistatic radar. In such bistatic FSR, the receive and transmit antennas are fixed and directed at each other, so the target detection takes place when the baseline is crossed. This type of radar provides a countermeasure to stealth technology because in the area of the forward scatter effect the targets' RCS depends only on the size and the shape of their silhouette. Passive radars use transmitters of opportunity as signal source, and therefore they are very attractive due to their inherit low cost. The advantage of considering Global Navigation Satellite System (GNSS) satellites as transmitters of opportunity is the high availability that these satellites offer. Anywhere on earth, around eight Global Positioning System (GPS) satellites are continuously in view. This provides an optimum scenario for implementation of a GNSS-FSR system. In this paper, some experimental results of a GPS-FSR system, where the signal at the output of the Carrier&Code tracking block is coherently integrated, are described and analyzed.*

1. Introduction

Forward Scattering Radar (FSR) is a specific type of bistatic radars that operate in the narrow area of the forward scattering effect where the bistatic angle is close to 180^0, and the target moves near the transmitter-receiver baseline [1-6, 11, 12]. In FSR, the Babinet principle is exploited to form the forward scatter signature of a target. According to this principle, the drastic enhancement in scattering is created due to the forward scattering effect. This type of radar provides a countermeasure to 'stealth' technology. 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. However, FSR has some fundamental limitations, which are the absence of range resolution and operation within very narrow angles ($\pm 10^0$) [1, 2]. In this paper a passive Forward Scatter Radar (FSR) system, in which GPS satellites are exploited as non-cooperative transmitters, is studied (Fig. 1). The civil L1 signal is transmitted by satellites at 1572.42 MHz and contains the coarse acquisition (C/A) code, which is unique for each satellite. The C/A code modulated signal is a BPSK signal with a chip rate of 1.023 MHz and the repetition interval of 1ms. The L1 signal frequency bandwidth is 2.046 MHz.

The idea to apply a GPS L1 receiver to FSR for air target detection is discussed in [7]. Some experimental results of a GPS L1 receiver concerning the detection of air targets are shown and discussed in [8]. A possible algorithm for air target detection in a GPS L5-based FSR system is described in [9], and the detection probability characteristics are calculated in [10] for the case when low-flying and poorly maneuverable (for example, helicopters) air targets are detected on the background of a white Gaussian noise, or in the urban interference environment or a Stand-off-Jammer (SOJ).

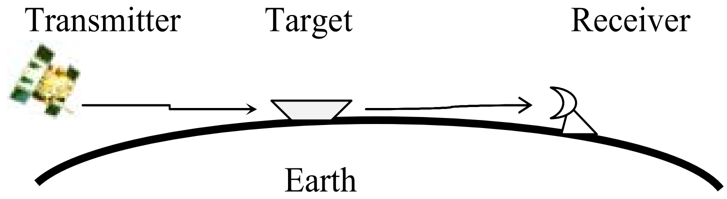

Figure 1. FSR topology

The aim of this study is to 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. 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 targets. In this paper, a possible algorithm for detection of ground targets at the output of the Code&Carrier tracking block of a GPS receiver is described and the results are obtained by processing the experimental records made by means of a GPS receiver.

2. Power budget

We consider the case when the target is located close to the "visible satellite-GPS receiver" baseline. The signal-to-noise ratio at the RF front-end output of the GPS receiver is [14]:

$$SNR = \frac{P_{rec}}{N_r} = \frac{P_t G_r \sigma}{4\pi R_{tg}^2 N_r} \tag{1}$$

According to [3-6], the forward scatter RCS σ of a target depends only on the physical cross section of the target (A_{tg}) and can be calculated approximately as:

$$\sigma = \frac{4\pi A_{tg}^2}{\lambda^2} = \frac{4\pi (hl)^2}{\lambda^2} \tag{2}$$

In (2), A_{tg} is the target physical cross section, and the parameters h and l are geometrical dimensions of a target. In order to obtain the SNR expression at the input of a CFAR detector in FSR, we replace the parameter σ in (1) by its expression (2).

$$SNR = \frac{P_t G_r (hl)^2}{\lambda^2 R_{tg}^2 N_r} \tag{3}$$

At the output of the Code& Tracking loops the signal-to-noise ratio is given by:

$$SNR = \frac{P_t G_r (hl)^2}{\lambda^2 R_{tg}^2 N_r} G_{SP} \tag{4}$$

where G_{SP} is the processing gain of the cross-correlator. After coherent integration of the message bits the SNR can be calculated as:

$$SNR = \frac{P_t G_r (hl)^2}{\lambda^2 R_{tg}^2 N_r} G_{SP} M \tag{5}$$

where M is the number of integrated bits of a message. For example, in [8], the SNR has been calculated at the cross-correlator output for the case of a GPS L5 signal and a small target (h=1m and l=1m). The SNR values have been calculated as a function of the distance to the target R_{tg}. The SNR values obtained are plotted in Fig.2, where parameters of the GPS L5 signal are: carrier frequency – f_0=1176MHz (λ=0.2551m); frequency bandwidth – ΔF=20.46MHz, the GPS L5 signal power near the Earth's surface – P_t=-154dBW.

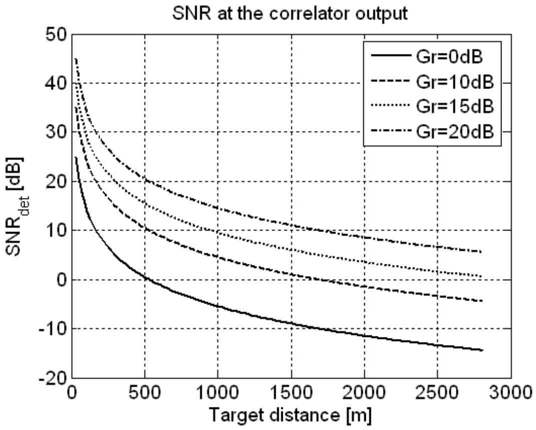

Figure 2. SNR at the correlator output integrated within 20msec

3. Signal processing

The general block-scheme of a possible algorithm for detection of targets when they are located close to the "visible satellite-GPS receiver" is shown in Fig 3.

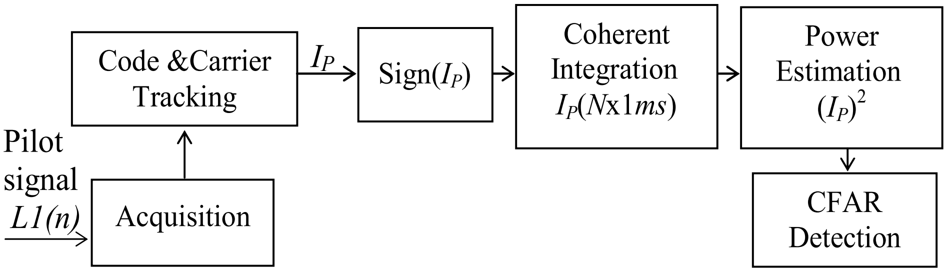

Figure3. FSR signal processing

According to this block-scheme, a visible GPS satellite is acquired and tracked over the complete duration of recorded signals. The tracking Code&Carrier loops operate with 1-ms integration time. This means that with every millisecond, a correlation value is obtained, whose magnitude is directly proportional to the satellite signal power being tracked (noise neglected). We consider the case when the acquisition and tracking algorithms of a GPS receiver are implemented in MATLAB. The tracking loops ensure that the prompt correlator is synchronized with the incoming pseudorandom (PRN) code. Moreover, they also synchronize the receiver's local oscillators, both in terms of frequency and phase with the satellite signal carrier. In this way, the correlation magnitude remains in the real part (I_P component), and just the sign changes caused by the navigation bits would remain, which are also wiped out. The absolute values of the Ip component at the output of the Code&Carrier tracking block are then integrated during N milliseconds. The power of the integrated signal is further used for detection of targets by means of the CFAR thresholding.

4. Experimental results

The aim of this experiment is verify the possibility for detection of stationary ground targets using FSR that exploits GPS satellites at low elevation angles as transmitters. In this experimental study, the GPS L1-based recording system consists of two different GPS receivers. The first GPS receiver (Antaris AEK-4R) will be used to determine the location of the satellites while the other software GPS receiver (GNSS_SRR) will be used to record and store GPS signals from different targets.

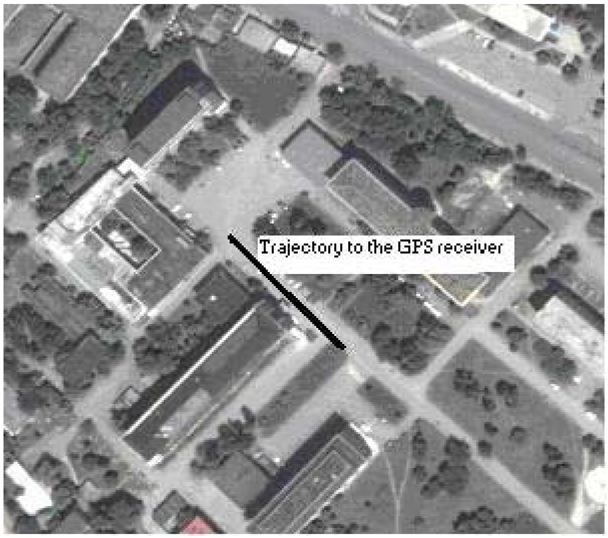

Fig.4. Experimental scenario

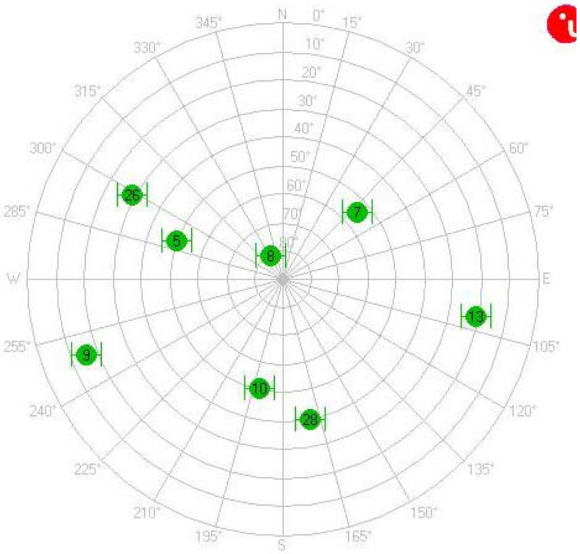

Fig. 5. Satellite constellations

Using the receiver AEK-4R, we can monitor the location of satellites (Fig. 5) and choice an appropriate satellite, the signal from which will be record by the GNSS_SRR signal recording system. For example, the satellite 28 from Fig.5 and Fig. 6, whose elevation is in the range of 40^0 is used for the experimental testing. During the experiment, the receiver GNSS_SRR records the signals received from the satellite 28 when moving along straight path behind a large building as shown in Fig.4. This large building is located close to the baseline between the satellite 28 and the GNSS_SRR signal recording system. The experimental records are further processed using MATLAB. All visible satellites acquired by the acquisition algorithm are shown in Fig.6. The Ip component at the output of the Code&Carrier tracking block of the sattelite 28 is shown in Fig.7. The coherent integration of the I_P component power is made during 1000, 200 and 20 ms, and results of integration are shown in Fig.8, Fig.9 and Fig.10. It can be seen that the shadow signal due to the target (large building) can be exploited for detection of the target (large building). It can be also seen that the integration time influences the CFAR detection, i.e. the longer time of integration the more stable CFAR detection.

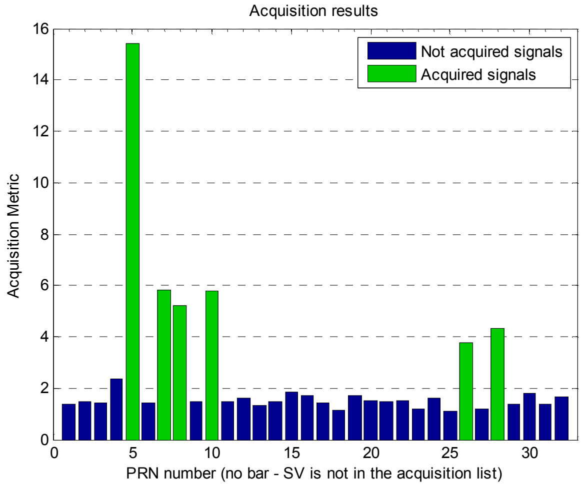

Fig. 6.Acquisition results

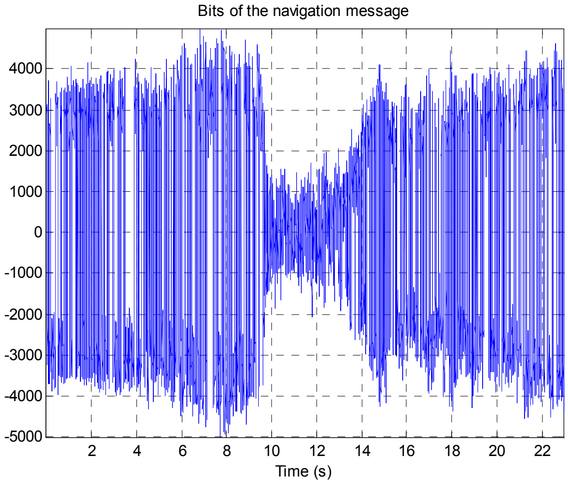

Fig 7. Navigation message of satellite 28

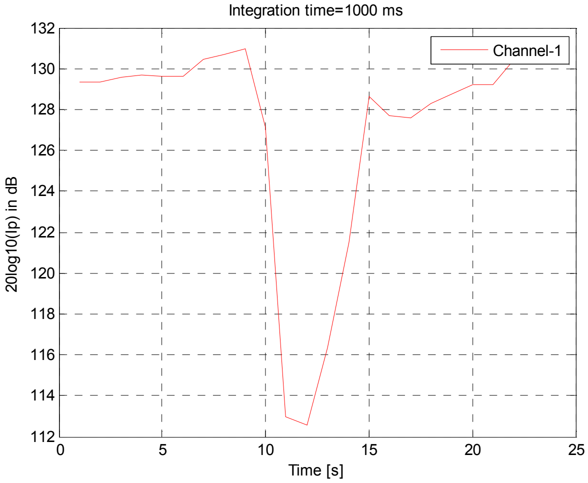

Fig.8. Integrated power (1000ms)

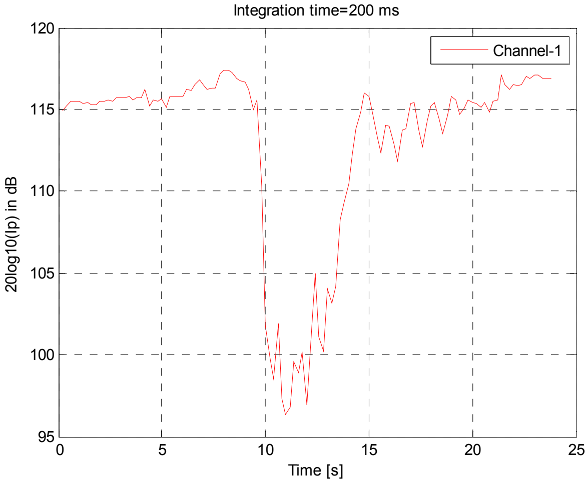

Fig. 9. Integrated power (200ms)

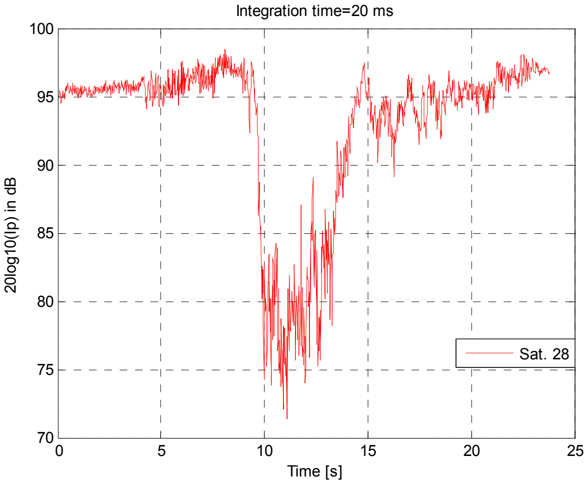

Fig. 10. Integrated power (1000ms)

4. Conclusions

The results obtained show that a bistatic FSR system with a GPS-L1 based non-cooperative transmitter can be used for detection of ground signals. Such a FSR system uses the integrated signal at the output of a Code&Carrier tracking block of a standard GPS receiver.

Acknowledgements

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