Digital Television Broadcast -Based Passive Radar Research and Development

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***Abstract*—Nowadays passive radars are gaining ground and become more popular. Now, that the so far insurmountable technological limitations begin to disappear, beside the theoretical researches the investigation of realizations with the recently available hardware technologies are becoming more important. This paper presents a feasibility experiment of such a passive radar that uses DVB-T (Digital Video Broadcast - Terrestrial) signal to detect airplanes. In this paper the he principle operation of the passive radar systems has confirmed both with simulations and measurements.**

***Index Terms*—DTV based passive radar, passive air surveillance, passive radar experiment**

I. Introduction

Passive radars are able to detect and track targets with using non-cooperate transmitters of opportunity. In recent years a number of scientific papers address the operation of passive radars [5]. Several of these papers study in depth the capabilities of the illuminating sources [7],[5]. Among the so far investigated sources of illumination the DVB-T signal has outstanding correlation properties, therefore it could be suitable to utilize as a reference source [3],[4],[6],[7],[8]. However, only a small number of papers presents measurement results with factually realizes systems. The main purpose of this paper is to confirm with practical techniques the so far theoretically investigated methods. The operation of the detection procedure has verified with both simulation techniques and real measurements.

II. Principle of operation

In this section a simplified model of the passive radars will be presented. Figure (1) illustrates the operation of the passive radar. Signals emitted from the transmitter tower can reach the receiver antenna of the radar on a number of different paths (also including the direct path). In order to build up the simplest model, it is sufficient to take into account only two paths. One of them is the direct path signal from transmitter tower to the radar and the other is the signal which reflects from the airplane.

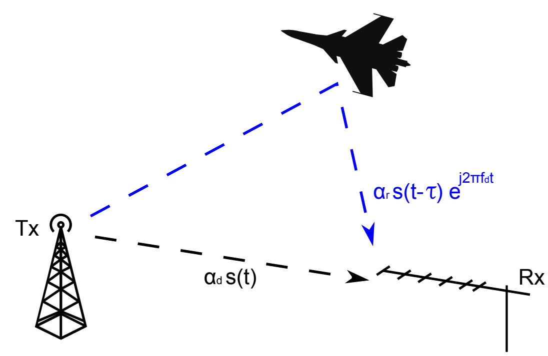

Fig. 1. Passive radar main signal paths

Signals that propagate in different paths are suppressed independently. Let us denote the attenuation of the direct path with α_d, and the loss of the reflected wave path with α_r. Beside the propagation losses the different signals arrive with different time lags to the receiver, because of their finite propagation speed. The time difference between the lag of direct path signal and the reflected signal is denoted by $\tau = t_r - t_d$. The signal reflected from a moving target will also suffer the effect of Doppler shift which depends upon the speed and geometric position of the airplane. It is denoted by f_d. Thus, the received signal is composed of two components traveling separate paths.

Based on these the received signal $r(t)$ can be written as:

$$r(t) = \alpha_d \; s(t) + \alpha_r \; s(t-\tau) \; e^{j2\pi f_d t} \tag{1}$$

In other words, the received signal is composed of two signals, the direct path signal, and the time delayed and Doppler shifted copy of the same signal. Thus, the detection is performed by searching the τ time delayed and f_d Doppler shifted copy of the direct path signal or also know as reference signal in the received signal. Practically it can be done with correlation calculation. By calculating the autocorrelation function of the received signal, we get correlation peaks with maximum signal to noise ratio where the received signal is identical to itself time delayed version as close as possible. In order to maximize the enhancement in the correlation function, the direct path signal needs to be corrected with the same f_d Doppler frequency. Since the exact speed and therefore the Doppler frequency of the target are not known priori at the receiver side, the reference signal must be shifted with all the possible Doppler frequencies.

Afterwards, the detection of the airplane can be performed with the calculation of the following two-dimensional Doppler-delay cross-correlation function:

$$\chi(\tau, f_d) = \int_{-\infty}^{\infty} r(t) \; r^*(t-\tau) \; e^{j2\pi f_d t} dt \tag{2}$$

III. Ambiguity function analysis of the DVB-T signal

Since we are using correlation computing in the signal processing algorithms, the investigation of the correlation properties of the used illuminator sources is essential. In order to analyze the potential opportunities of the used illuminator signal, the ambiguity function of the signal must be examined. The calculation procedure of the ambiguity function is identical in this case to the calculation method of the Doppler-delay correlation function (2) used for detecting targets given in section (II).

During the course of calculations the maximum Doppler frequency has chosen to $500\,\mathrm{Hz}$ according to the speed of an average target. (UHF band transmitter, maximum $300-400\,\frac{\mathrm{km}}{\mathrm{h}}$

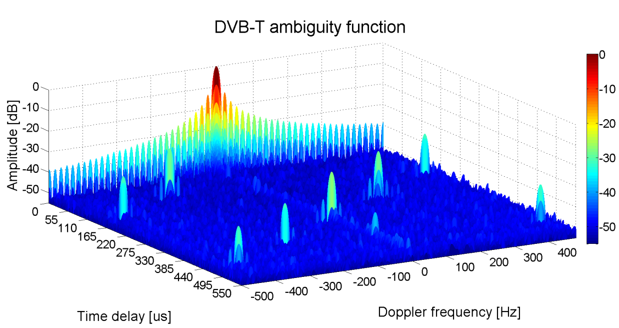

Fig. 2. DVB-T signal ambiguity function

target speed). The used coherent time processing interval for the evaluated function is approximately $60\,\mathrm{ms}$. It was chosen to ensure sufficient Doppler resolution. The digital video broadcasting terrestrial signal is sufficiently randomized due to the used (Orthogonal frequency-division multiplexing) OFDM modulation technique, and the used channel and source coding. The OFDM modulation has nearly 'white' spectrum because it transfers the data on closely spaced phase-shift keying or quadrature amplitude modulated carriers. The ambiguity function of the DVB-T signal can be seen in Figure (2).

According to the figure, the ambiguity function of the DVB-T signal provides approximately $50\,\mathrm{dB}$ dynamic range. This dynamic range (as the next section will show) is high enough to identify the correlation peaks arising from target reflections. Unfortunately some unwanted deterministic peaks are also generated due to the guard interval and the pilots. In some cases, these ambiguities can make it difficult to detect targets, hence it is advisable to eliminate these unwanted peaks [3],[6],[4],[8].

IV. Simulations of detection procedures

In this section a DVB-T signal based passive radar feasibility experiment will be presented.

The concept of operation has been verified first with simulations. We have chosen the Budapest Ferenc Liszt International Airport as the location of our experiment, because there the power of the reflected signal is relatively from the closely flying planes. Using the simulator program we have examined the detectability of a taking of airplane. During the simulation process we created the signal that could be measure at the output of the receiver antenna. After we have created the simulation signal we performed the passive radar detection algorithms. The block diagram of the simulator program is illustrated in figure (3). In the first stage the geometrical parameters of the target are calculated based on its actual coordinates, velocity and acceleration. In the knowledge of distances and angles the parameters $(\alpha, \tau, f_{Doppler})$ of the different signal paths are calculated using the following equations:

With equation bellow the received power level of the reference signal can be calculated.

$$P_{reference} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 L^2} \tag{3}$$

Using the bistatic radar equation the power level of the signal reflected from target can be determined.

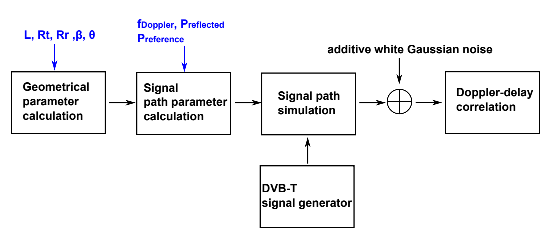

Fig. 3. Block diagram of the simulator program

$$P_{reflected} = \frac{P_t G_t \sigma G_r \lambda^2}{(4\pi)^3 {R_t}^2 {R_r}^2} \tag{4}$$

The Doppler-shift of the reflected signal can be estimated using equation (5).

$$f_{Doppler} = \frac{2v}{\lambda} cos\left(\theta\right) cos\left(\frac{\beta}{2}\right) \tag{5}$$

The meanings and the simulation values of the parameters referenced in the equations above (3, 4, 5) are the followings:

- $P_t \rightarrow 100\,\mathrm{kW}$- transmitting power of the broadcast station (Széchenyi hill)
- $G_t \rightarrow 0\,\mathrm{dBi}$- gain of the transmitter antenna
- R_t- distance between the transmitter and the target
- R_r- distance between the radar and the target
- $\sigma_b \rightarrow 100\,\mathrm{m}^2$- bistatic radar cross section
- $L \rightarrow 26\,\mathrm{km}$ - distance between the transmitter and the radar
- $G_r \rightarrow 0/15\,\mathrm{dB}$- gain of the receiver antenna
- $\lambda = 0.5\,\mathrm{m}$-wavelength of the utilized DVB-T signal
- θ, β are geometrical parameters arising from the locations of the transmitter, the target and the radar

[1],[2]

In the final step we create the signals traveling on the different paths using the previously calculated parameters and a DVB-T signal generator. The mathematical form of the produced simulation signal can be described as follows:

$$r(t) = \sum_{i=1}^{N} \alpha_i s(t - \tau_i) e^{j2\pi f_{d i} t} + n(t) \tag{6}$$

, where i denotes the number of the actually processed signal path, α the attenuation, τ the time delay and f_d the Doppler-frequency of the signal path. Additive white Gaussian noise is denoted by $n(t)$. The simulated signal is composed from 10^6 sample. (sampling frequency is $9\,\mathrm{MHz}$).

Running the simulation repeatedly for several consecutive snapshots we got the results presented in figure (4). In the figure the trace of the taking off airplane can be clearly observed. It has to be noted that this simulation is assumes isotrop antenna at the receiver side. It is also clearly visible that the correlation peak of the target disappears around $800\,\mathrm{m}$. After this distance the reference signal which travels on the direct path masks the week target echoes coming from higher distances. Actually the correlation peak of the reflected signal is under the dynamic range of the reference signal.

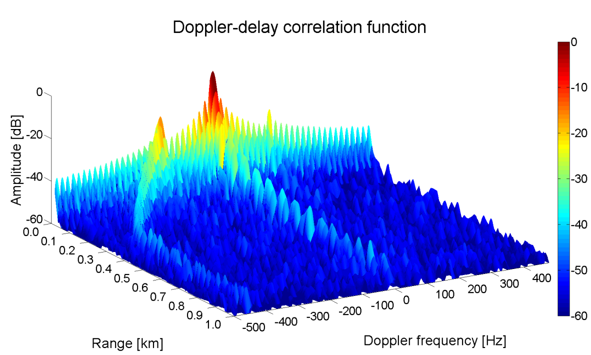

Fig. 4. Trace of the taking of airplane at the Doppler-delay correlation function using isotrop receiver antenna

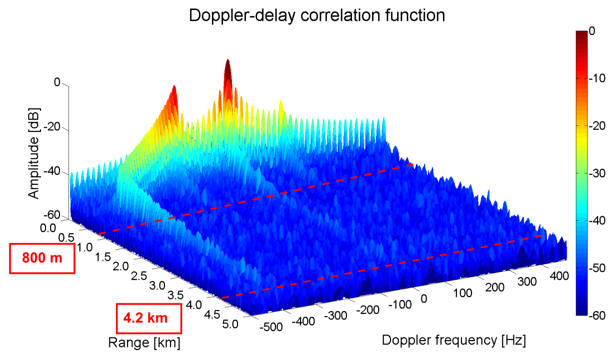

Fig. 5. Trace of the taking of airplane at the Doppler-delay correlation function using directional Yagi antenna

In order to increase the range of the radar we need to increase the isolation between the reference and the reflected signals. In the most easiest way this can be accomplished with using directional antenna.

The next presented simulation assumes a Yagi antenna at the receiver side with $15\,\mathrm{dB}$ front to back ratio. The calculated Doppler-delay correlation functions of this simulation can be seen in figure (5).

From the results it can be seen that the detection range has increased to $4.2\,\mathrm{km}$ from $800\,\mathrm{m}$. This detection range can be high enough to demonstrate the basic operation the passive radar.

It also has to be noted that the simulations presented above do not take into consideration the variation of the bistatic radar cross section of the target and the error of the antenna main beam positioning.

V. Airfield measurements

A. Measurement setup

In order to install the measurement setup simply we used general purpose hardware elements. Such as the (National Instruments) NI 2920 universal software radio (USRP) which is used to receive and acquire the radio frequency signals. The schematic build-up of the measurement is illustrated on figure (6). The software radio receives the signal that comes from the Yagi antenna which is designed for this measurement. This Yagi antenna has exactly the same front to back ratio that has been used in the previously discussed simulation. After that the USRP samples the analog down mixed-signal it transfers the data to a PC through gigabit Ethernet. On the PC side a Labview program acquires the samples and performs the Doppler-delay correlation process.

The main settings of the software radio were the following:

- operation frequency $\rightarrow f = 610\,\mathrm{MHz}$

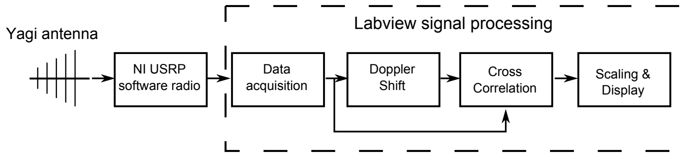

Fig. 6. Block diagram of the measurement setup

- IQ sampling rate $\rightarrow f_s = 9\,\text{MHz}$
- bit resolution $\rightarrow 16bit$
- acquired number of samples $\rightarrow 10^6$

B. Measurement results

After the samples were collected the Doppler-delay correlation function was calculated for some consecutive snapshot based on equation (2). The processed number of samples to calculate each snapshot was 10^6 sample, which is equivalent to $110\,\text{ms}$. That is the value of the coherent time processing interval. By merging the single snapshots we got the results shown in figures (7) and (8). It is seen in the figures that a correlation peak appears around the previously simulated Doppler-frequency $(300\,\text{Hz})$ and it moves away both in Doppler frequency and in time delay coordinates on the calculated correlation functions from snapshot to snapshot

Comparing the results it can be stated that the simulation and measurement results shows good agreement with the theory. The principle operation of the radar is proved to be correct.

The most important limitation factor of the radar range is the direct path interference which covered or masked the reflections came from higher distances.

VI. Conclusion

Nowadays passive radar researches are becoming more important due to its low operation costs and for its remarkable military importance. The spread of the radar can be attributed to the appearance of the newly available high performance computing systems.

A number of recently published scientific papers addresses the theory of operation and the usability of the illuminators of opportunity. Besides this relatively limited attention is payed to the investigation of realization with available technological devices. In this paper a feasibility experiment of a DVB-T based passive radar has been presented. We have managed to verify the basic operation of the passive radar both with simulations and with practical measurements.

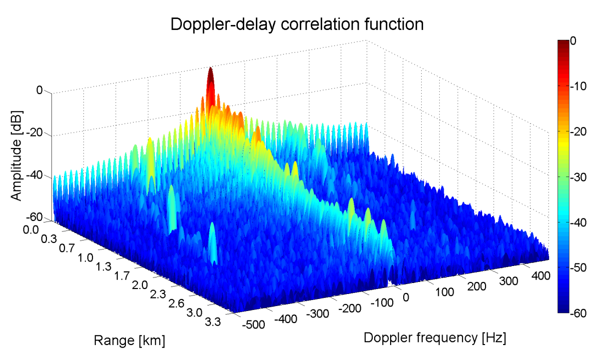

Fig. 7. Successfully detected airplane on the Doppler-delay correlation function - perspective view

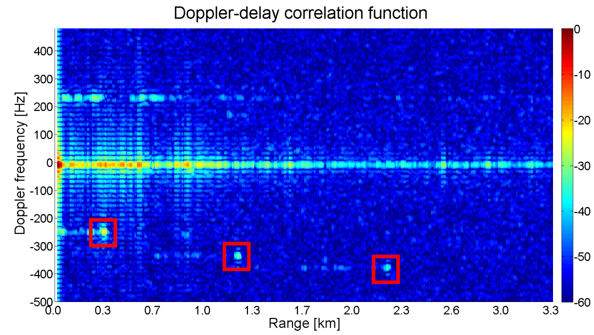

Fig. 8. Successfully detected airplane on the Doppler-delay correlation function - top view

The reference signal which travels on the direct path typically has reasonably high power relative to the reflected signals, hence the reference signal can mask the week target echoes. The importance of the isolation of the direct path signal and the reflected signal also has been confirmed. The separation of the direct path signal can be accomplished with using antenna array and applying digital beamforming methods. [9].

Acknowledgment

The research reported here was supported by the National Development Agency (NFÜ, Hungary) as part of the project Introduction of Cognitive Methods for UAV Collision Avoidance Using Millimeter Wave Radar, UWBSRR12, 2012-2015.

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