DVB-T Based Passive Radar

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***Abstract*—A Passive radar system is able to operate fully independent of illuminators of opportunity. In most cases these illuminator sources are traditional telecommunication or broadcast signals. During the design of a passive radar we are trying to exploit the opportunities of an already existing system, thus we need to face such problems that could be simply eliminated during the design of a traditional active radar. The properties of the used source of illumination essentially determines the overall performance of the system. The Digital Video Broadcasting - Terrestrial (DVB-T) signal has beneficial properties from our viewpoint, therefore it offers a great opportunity to develop an effectively operating system. 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 a DVB-T based passive radar using simplified models.**

Keywords*—*passive radar, PCL experiment, air surveillance, DVB-T

I. Introduction

Passive radars are able to detect and track targets with using non-cooperate transmitters of opportunity. A traditional active radar operates in such a way that it emits well specified radar signals, and those reflects from targets. These target reflections are then received and processed. In contrast to active systems passive radars do not emit anything, but they uses the signals from other sources in their environment to detect targets. Since these radars do not need to contain dedicated transmitter units, therefore the cost of operation and production is significantly lower. Owing to its beneficial properties 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. The main purpose of this paper is to confirm with measurements the so far theoretically investigated methods.

II. Theory of Operation

In this section a simplified model of the passive radar will be presented. Based on this model, the fundamentals of the detection can be understood. 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.

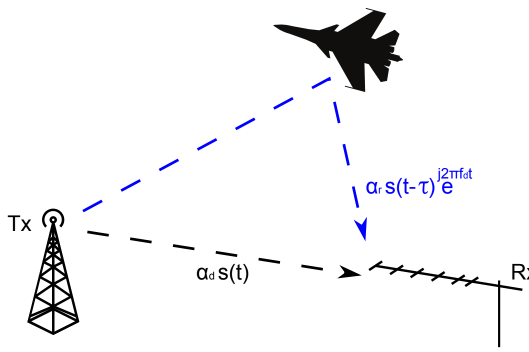

Fig. 1. Passive radar main signal paths

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 auto-correlation 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 get maximum 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.
During the detection, the first step is to generate the Doppler shifted versions of the receiver signal, and then calculate the cross-correlation functions between these auxiliary signals and the original received signal. From the number of calculated correlation function we can compose a two-dimensional function, which maximums denote those Doppler frequencies and time values where the received signal that contains the reflected signal matches with the signal transmitted by the broadcast tower.
Afterwards, the detection of the airplane can be performed with the calculation of the following two-dimensional Doppler-delay cross-correlation function:

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

The cross-correlation calculation acts as if the signal would pass through a matched filter. Based on this principle the Doppler-delay correlation function represents such an output of a matched filter bank, where the filter bank is composed of the reference signal and its Doppler shifted copies. In the following section the efficiency of the matched filter bank will be examined depending on the used reference signal.

III. Ambiguity Function Analysis

Since we are using cross-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).
If the used illuminator signal well correlates with the time and Doppler shifted copy of itself, it means that during the detection the reflected signals can not be identified with a high degree of certainty. In other words, the matched filter bank made from the illuminator signal can not be operate effectively because there is not enough high dynamic range between the outputs of the matched filter bank.
The ambiguity functions presented in the next two subsections are calculated using MATLAB. During the course of calculations the maximum Doppler frequency has chosen to 500 Hz according to the speed of an average target. The used coherent time processing interval for these evaluated functions is approximately 60 ms.

A. Analog TV signal

Figure (2) shows the ambiguity function of the analog TV signal used in Hungary. The ambiguity function of the analog TV signal not nearly provides high enough dynamic range to detect reflections.

In general, it can be said that a signal has advantageous correlation properties if the structure of the signal is noise-like with broadband smooth spectrum. The more we disturb the spectrum's smoothness, the more ambiguities will arise in the ambiguity function [3]. The analog TV signal does not meet these conditions due to the way its transfer the image information, and its built in sync signals.

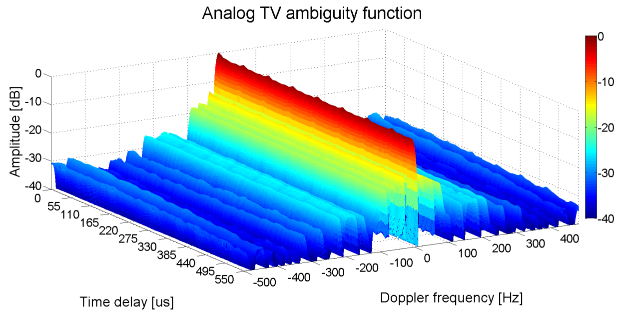

Fig. 2. Ambiguity function of the Analog TV signal

B. DVB-T signal

However, 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 (3).

According to the figure, the ambiguity function of the DVB-T signal provides approximately 50 dB dynamic range. This dynamic range (as the next section will show) is high enough to identify the correlation peaks arising from target reflections. Although, the DVB-T signal has far higher dynamic range then analog TV has, but 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].

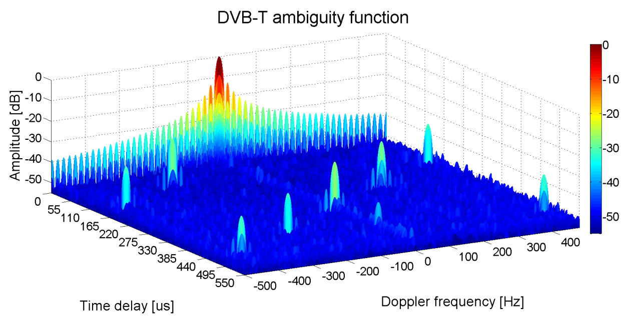

Fig. 3. Ambiguity function of the DVB-T signal

IV. Measurement Experiment

In this section a DVB-T based passive radar experimental measurement will be presented. The main goal of the measurement is to confirm in reality the above discussed DVB-T based passive radar's principle of operation.

A. Preliminary calculations

It is advisable to choose that location as the measurement site where the moving target passes close to the receiver antenna of the radar, because there the power of the reflected signal is relatively high. Because of the reasons above, the Budapest Ferenc Liszt International Airport was chosen as the measurement site. To prepare the measurement and to estimate the expected results based on the theory of detection, the expected power levels were calculated using the bistatic radar equation [1],[2].

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

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

, where

- $P_t \rightarrow 100\,\mathrm{kW}$- is the power of the transmitter at 'Széchenyi hill'
- $G_t \rightarrow 1$- gain of the transmitter antenna
- R_t- distance between the transmitter and the target
- R_r- distance between the receiver and the target
- $\sigma_b \rightarrow 100 m^2$- bistatic RCS (average airplane RCS)
- $L \rightarrow 26\,\mathrm{km}$ -baseline distance
- $G_r \rightarrow 9\,\mathrm{dBi}$ -gain of the receiver antenna
- $\lambda = 0.5\,\mathrm{m}$- wavelength

Currently at the utilized $610\,\mathrm{MHz}$ frequency there are operating three transmitter. These can be found at the 'Szécshenyi hill', at the 'Hármashatár hill' and one in the 'Száva street'. The measurement setup can be seen in Figure (4). Based on the calculations, the power level of the highest direct path signal is produced by the transmitter at 'Széchenyi hill'. This is approximately $-35\,\mathrm{dBm}$.

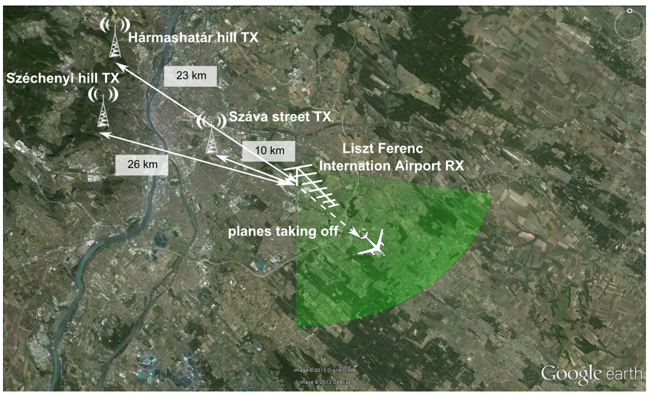

Fig. 4. Transmitter and receiver positions

In the knowledge of the DVB-T signal's dynamic range we know, that the minimum power level of the reflected signal can be $50\,\mathrm{dB}$ lower than the power level of the direct path signal in order to ensure successful detection.

The measurements has taken with an 8 element Yagi antenna that has $15\,\mathrm{dB}$ front-back ratio. By using this receiver antenna the power level difference between the direct path signal and the reflected signal can be further improved by $15\,\mathrm{dB}$. According to the previously discussed assumptions the minimum power level of reflected signal can be obtained. Thus we get, $P_{min} = -35\,\mathrm{dBm} - 50\,\mathrm{dB} - 15\,\mathrm{dB} = -100\,\mathrm{dBm}$.

By rearrange equation (3) the maximum distance can be calculated in the knowledge of the minimum detectable power level : [1],[2]

$$R_t R_r = \sqrt{\frac{P_t \sigma \lambda^2}{(4\pi)^3 P_{min}}} \tag{5}$$

Denotations are the same as in the equation above (3). Using formula (5) we get $4.3\,\mathrm{km}$ for the maximum estimated range. Therefore, according to the calculations the correlation peak arising from the reflected signal can be detected from this distance.

By using the following equation (6) the Doppler shift of the reflected signal can also be estimated [1],[2].

$$f_{Doppler} = \frac{2v}{\lambda} cos\left(\theta\right) cos\left(\frac{\beta}{2}\right) \tag{6}$$

, where θ and β are geometrical parameters of the measurement setup. Based on the average speed of the taking of airplanes ($v = 330\,\frac{\mathrm{km}}{\mathrm{h}}$) the expected Doppler frequency is $f_{Doppler} \simeq 300\,\mathrm{Hz}$.

To perform the calculations, the geometrical parameters were obtained with the use of the Google Earth program.

B. 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. In the present case it is an obvious choice, because it is not necessary to design and fabricate the receiver device to test the functionality of the passive radar's basic principle. The schematic build-up of the measurement is illustrated on figure (5). The software radio receives the signal that come from the Yagi antenna which is designed for this measurement. 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.

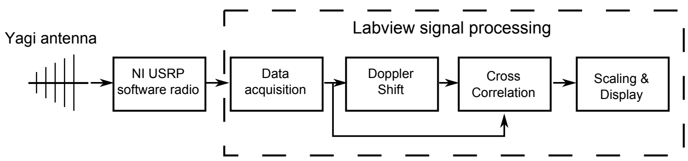

Fig. 5. Measurement setup

The main settings of the software radio were the following:

- operation frequency $\rightarrow f = 610\,\mathrm{MHz}$
- IQ sampling rate $\rightarrow f_s = 9\,\mathrm{MHz}$
- bit resolution $\rightarrow 16bit$
- acquired number of samples $\rightarrow 10^6$

V. 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 $110\,\mathrm{ms}$. That is the value of the coherent time processing interval. By merging the single snapshots we got the results show in figures (6) and (7). It is seen in the figures that a correlation peak appears around the previously estimated Doppler-frequency ($300\,\mathrm{Hz}$) and it moves away both in Doppler frequency and in time delay coordinates on the calculated correlation functions from snapshot to snapshot

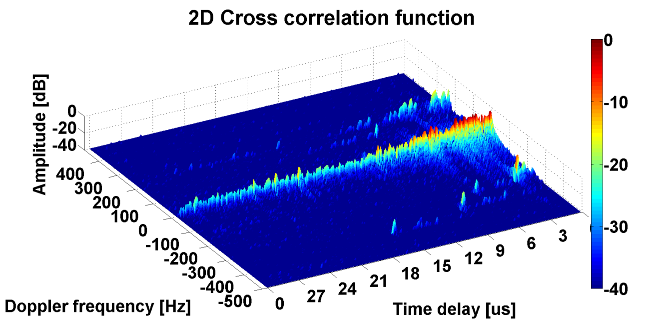

Fig. 6. Measurement result - 2D CCF perspective view

Transferring the indicated time delay values to bistatic range we get $3\,\mathrm{km}$ for $20\,\mu\mathrm{s}$. Comparing the measured and the previously estimated results it can be concluded that the principle theory of the passive radar proved to be correct.

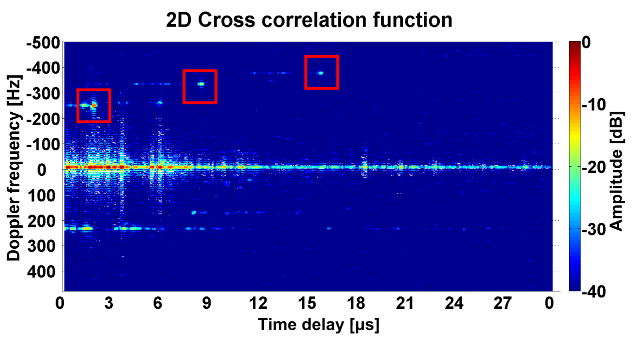

Fig. 7. Measurement result - 2D CCF top view

Having examined the obtained correlation functions at $0\,\mathrm{Hz}$ we find quite a lot of correlation peaks that are not related to structure of the DVB-T signal. Therefore the radar also received a number of reflected signals that came from the surrounding terrain objects. This effect can greatly destroy the enhancement of the useful correlation peaks. Nevertheless, the most important limitation factor is the direct path interference which covered or masked the reflections came from higher distances.

VI. Conclusion

In the first section the fundamental operation principles of passive radars and the basics of the signal processing methods were presented.

In the second section the properties of the illuminators off opportunity were analyzed. The analog TV signal and the DVB-T signal were examined in details. In the knowledge of the available dynamic ranges the DVB-T signal is proposed to utilize as the illuminator source.

In the third section a full value demonstration measurement were presented. According to the measurement results, it can be concluded that the target detection method of passive radars as it is studied previously is proved to be correct.

One of the major limitations in detection range for most passive radar systems is the masking due to the direct path interference. An obvious solution for this principal problem could be the application of phased array antenna systems [9].

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