Quad Channel DVB-T Based Passive Radar

Tamas Peto, Rudolf Seller
Department of Broadband Infocommunications and Electromagnetic Theory
Budapest University of Technology and Economics, Budapest, Hungary,
peto@hvt.bme.hu, seller@mht.bme.hu

***Abstract*—The detection performance of the passive radars systems is limited by the direct path interference. The application of digital beamforming antenna arrays in the surveillance channel has been proposed so far. The suppression can be accomplished with the proper beampattern synthesization. In this paper real measurement data utilising the spatial filtering techniques are presented. The detected target SINR is analyzed using different surveillance channel beam space processing techniques.**

***Index Terms*—Passive radar, beamforming, DPIS,PCL**

I. INTRODUCTION

Passive radars are representing a promising new direction of the radar technology. These specific radars are capable of detecting targets in a unique way, without emitting any electromagnetic illuminator signal. The basic operation has been widely investigated and verified with a most diverse illuminators of opportunity (IOP). The most common illuminator sources are the FM, DAB, DVB-T, GSM, UMTS signals. From among the potentially available IOPs the DVB-T (Digital Video Broadcast - Terrestrial) signal has outstanding features in terms of passive radar application [1],[2].

Research findings have shown that that proper separation of the different signal components has great impact on the performance of the detection. Namely the presence of the strong (DPI) direct path interference in the surveillance channel can mask the weak target echoes resulting in limited radar range [2].

This critical issue can be remedied by algorithms operating in the time, space or in the space-time domain. Time domain algorithms are focusing on getting to know the impulse response of the surveillance channel with analyzing the properties of the reference signal in the surveillance channel. This method could be very effective in an adaptive implementation [5], [6]. Additionally the spatial filtering techniques have also great importance as they are working in a different domain. Using antenna system at the receiver side along with adaptive beamforming techniques, the direct path interference can be effectively suppressed. The performance of this method has been analyzed with simulations so far with promising results [3],[4].

This paper addresses the verification of this method by presenting real measured data carried out with a special hardware unit designed for passive radar applications. The presented experimental results are particularly adressing the achieved imporvements. The improvement is quatified via the analysis of the signal-to-interference-plus-noise-ratio (SINR) of a detected target at the output of cross-correlation detector. The structure of the experimental hardware unit along with its design considerations are also discussed in detail. A simplified mathematical model of the received signals is reviewed in section II. The applied signal processing algorithms are expressed in section IV and finally the measurement scenario and the obtained results are presented in section V and VI.

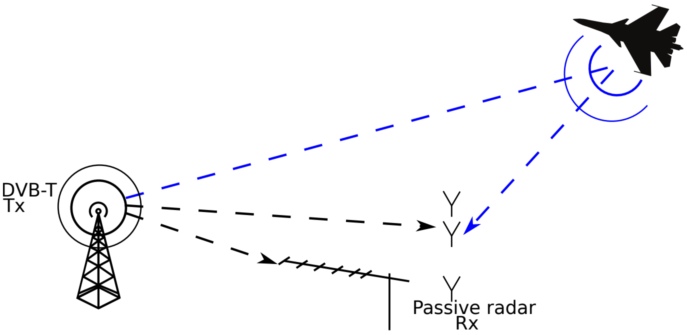

Fig. 1. Considered signal paths in passive radar application

II. SIGNAL MODEL

Passive radars are detecting targets with processing two individual signal processing channels. One of these channels is the reference channel $x_r(t)$ (RC) while the other one is the surveillance or target channel $x_s(t)$ (SC). The reference channel is prepared in such a way that it maximizes the signal-to-noise-ratio (SNR) of the transmitted illuminator signal. In contrast the surveillance channel must suppress this signal component and has to maximize the SINR of the reflected signal.

In light of these considerations for the reception of the reference signal directional antenna with narrow main beam is often used. While on the surveillance channel flexibility is needed thus antenna systems with the capability of beamforming is advantageous. A receiver system having this antenna configuration is illustrated in figure 1.

The illuminator signal transmitted from the broadcast tower reach the receiver of the passive radar on a number of different signal paths. For simplicity, let us consider only the direct path signals and the signal reflected from the target. Then the reference channel is composed of the transmitted illuminator signal denoted by $s(t)$ and the noise collected by the receiver $n_r(t)$

$$x_r(t) = \alpha_{ref} s(t) + n_r(t)\,, \tag{1}$$

where α_{ref} is complex scaling factor describing the different propagation effects of the reference signal. The surveillance channel is composed of the transmitted illuminator signal with a different scaling factor α_{direct}, the time delayed and Doppler shifted copy of the same reference signal which is the sought reflection component and the receiver noise $n_s(t)$.

$$x_s(t) = \alpha_{direct} s(t) + \alpha_{reflect} s(t-\tau) e^{j2\pi f_D (t-\tau)} + n_s(t) \quad (2)$$

In order to achieve good detection performance in the reference channel $\alpha_{ref} s(t)$ must be maximized, in turn in the surveillance channel $\alpha_{direct} s(t)$ must be minimized.

III. HARDWARE STRUCTURE

The block scheme of the applied receiver architecture is shown in figure 2.

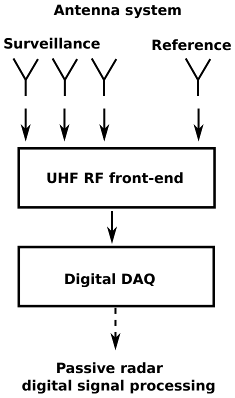

Fig. 2. Block scheme of the quad channel receiver system

A. Antenna system

The antenna system of the receiver is made up of two individual parts. For the reception of the reflected signal a linear antenna array is used and for the reception of the reference signal a Yagi antenna is used. The antenna array is composed of four inverse Koch fractal patch antenna elements. We are using this architecture to achieve small antenna size resulting in proper antenna spacing (less than half-wavelength) and high cross-talk between elements. The high front-to-back ratio is also crucial for the static direct path interference supression. A picture from the antenna array can be seen in figure 3.

As we had to grant one receiver channel for the reference channel to obtain clean reference signal with a directional antenna, we could connect only three receiver channels to the antenna system. Thus we used the antenna array in minimum redundancy alignment connecting only the first, the second and the fourth antenna element to the receiver. This consideration can lead us to a better spatial resolution in the SC.

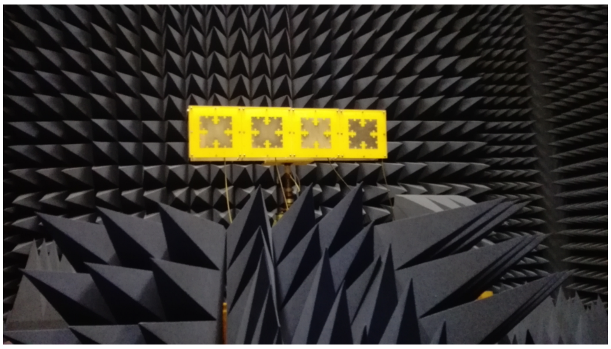

Fig. 3. Linear antenna array with inverse Koch fractal patch antenna elements is used in the surveillance channel

B. UHF receiver

RF signals coming from the antenna system are first received by the RF front-end unit. This unit is responsible for down-mixing the RF signal to the intermediate frequency which can be processed further by the digital data acquisition card. The RF unit is operating from $480 MHz$ to $800 MHz$ covering the complete DVB-T band in Hungary. After the RF stage the IF (Intermediate Frequency) signals are then digitalized by an ADC with $100 Msps$. The digitalized data is then forwarded to a System on Chip module consisting of an FPGA and a dual core ARM processor.

C. Digital signal preprocessing

The digitalized IF signal is preprocessed in the FPGA circuit with a DDC (Digital Down Converter) logic. In order to obtain processing gain the signal is first filtered and then decimated with 8 from $100 Msps$ to $8.33 Msps$. The digitally down converted signal is then transferred from the FPGA circuit to the ARM processor with DMA transactions. Then the digital IQ samples can be accessed via Gigabit Ethernet interface for further processing.

IV. SIGNAL PROCESSING CHAIN

The passive radar signal processing scheme is illustrated in figure 4. In the first stage the quad channel IQ samples are corrected with a previously recorded calibration matrix. This correction procedure is used to mitigate the receiver system's inherent amplitude and phase distortions between the different channels. After the IQ correction procedure the reference signal is extracted from the quad channel data and the remaining three antenna channels from the linear antenna array are forwarded to a Direction of Arrival (DOA) estimation algorithm. With performing DOA estimation we can determine the exact incident angles of the broadcast towers. Using this knowledge the beamformer of the surveillance channel can be configured to synthesize the proper beampattern to suppress the direct path interference. For the DOA estimation the Maximum Entropy Method (MEM) has been applied as it has high resolution. Equation 3 describes the used calculation method for the MEM.

$$PAD(\theta) = \frac{1}{\mathbf{s}(\theta)^H \mathbf{r}_j \mathbf{r}_j^H \mathbf{s}(\theta)} \tag{3}$$

Where $\mathbf{s}(\theta)$ is the steering vector and $\mathbf{r}_j$ is the j-th column of the inverse of the spatial correlation matrix. As the surveillance antenna system is used in minimum redundancy alignment, the deficient cells of the correlation matrix are corrected before performing any beamspace processing algorithms in the surveillance channel. This operation utilises the Hermitian and Toeplitz properties of the correlation matrix.

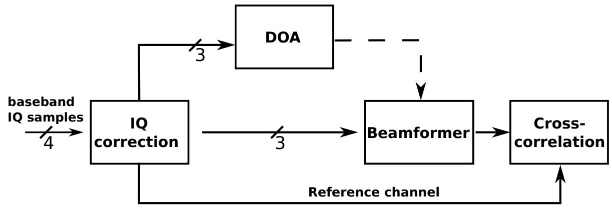

Fig. 4. Passive radar signal processing

In the knowledge of the exact incident angles of the direct path interference, the surveillance beampattern is synthesized in the next stage. It has to be noted that DOA information is not required by the adaptive beamforming algorithms such as the MMSE (Minimum Mean Square Error) or the MVDR (Minimum Variance Distortionless Response) method. For this experiment we have obtained results both with using fixed and adaptive beamforming algorithms, namely the MSIR (Maximum Signal to Interference Ratio) method and MVDR method. The MSIR method is applied with using

$$\mathbf{w}^H = \mathbf{u}^T \mathbf{A}^{-1}, \tag{4}$$

where $\mathbf{w}$ denotes the calculated coefficient vector, $\mathbf{u}$ is the constraint vector and the $\mathbf{A}$ matrix is the array response matrix which is created from the previously determined incident angles of the DPI and the target . The $\mathbf{u}$ vector is filled up in a way to place unity response in the direction of the expected target direction and to place nulls in the direction of the DPI. Besides this, the MVDR method is calculated using equation 5.

$$\mathbf{w}^H = \mathbf{R}^{-1} \mathbf{s}(\theta_d) \tag{5}$$

In (5) $\mathbf{R}$ is the spatial correlation matrix, θ_d is the incident angle of the target reflection and $\mathbf{s}(\theta_d)$ is know as the steering vector.

Using the calculated beamformer coefficients the surveillance channel is prepared applying (6).

$$x_s(n) = \mathbf{w}^H \mathbf{x(n)} \tag{6}$$

Once the signal processing channels have been produced from the received antenna signals the 2 dimensional cross-correlation calculation is performed to obtain the range-Doppler matrix using (7).

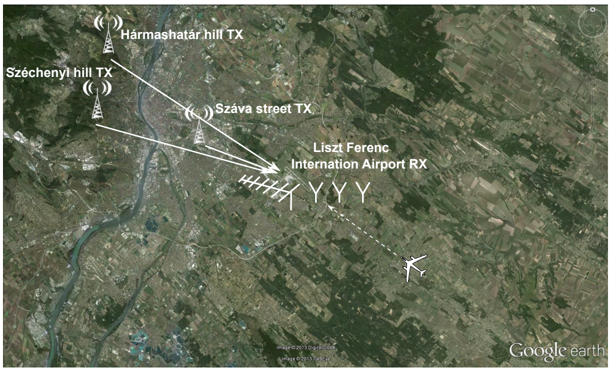

Fig. 5. Locations of the DVB-T transmitter towers and the Liszt Ferenc International Aiport at Budapest

$$|\chi(f_D,\tau)|^2 = \left| \sum_{n=0}^{N-1} \left(x_r(n-\tau) e^{j2\pi f_D (n-\tau)} \right)^* x_s(n) \right|^2 \tag{7}$$

In (7) N denotes the number of signal samples used in the coherent integration, $x_r(n)$ and $x_s(n)$ are the digitalized versions of the reference and surveillance channel signals. The coherent integration time for the presented results is $N = 2^{20} \rightarrow 125ms$.

V. MEASUREMENT SCENARIO

The experimental measurement has been carried out at the immediate vicinity of the Liszt Ferenc International Airport in Hungary. Currently there are three DVB-T broadcast towers operating at Budapest. The location of the transmitter towers and the airport is depicted in figure 5. The measurement has been done at $f = 634MHz$. At this frequency all of the three DVB-T towers are operating in SFN (Single Frequency Network), thus they are emitting the same signal with finely tuned delays relative to each other. As they are transmitting on the same frequency with relatively high power it is more difficult to deal with interferences on the surveillance channel. At the same time without adopting filtering algorithms in the reference channel the SINR of the reference signal is also affected.

Antennas are configured in such a way that the linear array used for the surveillance channel is set up in the direction of the landing airplanes, while the high gain Yagi antenna of the reference channel is set in the direction of the broadcast station located at the Szchenyi-hill.

VI. RESULTS

The evaluated results can be seen in figure 6 and in figure 7. Figure 6 shows the range-Doppler (RD) matrix at the output of the cross-correlation detector. The picture display the time lapse of the RD matrix with holding its maximum values. The presented result is calculated using the MSIR beamfroming algorithm.

For comparison purposes the SINR of the reflected signal is estimated from the range-Doppler matrix on the entire trajectory of the target. This value is determined using traditional

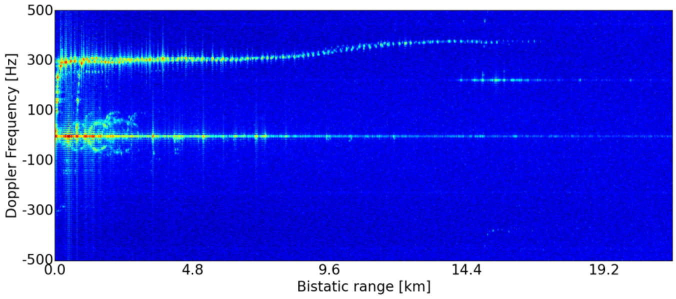

Fig. 6. Track of a landing airplane in the range-Doppler matrix using MSIR method. The illuminator located at the Szchenyi-hill is used as the reference.

CFAR (Constant False Alarm Rate) algorithm with calculating the ratio of the target peak and the average power in the environment leaving out the guard cells. This estimation is performed with using the MSIR, the MVDR beamformer and with bypassing the surveillance beamformer. Figure 7 depicts the obtained results.

It can be concluded that using spatial filtering the SINR of the target can be increased, but the realized improvement is very limited. At the same time it it very important to note that the SINR value of the target at the output of the cross-correlation detector is not only dependent on the power level of the DPI, it is also limited by the SNR of the reference signal in the reference channel. Besides, the degree of freedom of the surveilance beamformer is very low compared to the number of interferences. In other words the realized improvement is very specific to this measurement scenario, but the operation of the spatial DPIS procedure is clearly demonstrated.

VII. CONCLUSION,PERSPECTIVES

Spatial filtering techniques applied in passive radar systems have been investigated in this paper. According to the results of the field measurement approximately $5-7dB$ SINR improvement is obtained with using bemforming techniques in the SC. The adaptive MVDR beamfromer has slightly better performance over the fixed MSIR beamformer. The achieved results clearly verify the basic theory of this method. However the realized improvement is strongly limited which can be attributed to the conditions of the environment in this measurement scenario.

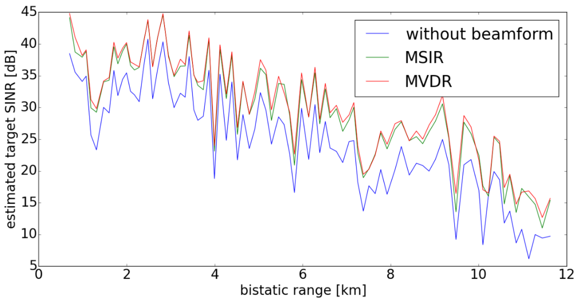

Fig. 7. Estimated target SINR using different surveillance beamformers

In the future work robust beamforming algorithms in real passive radar scenarios will be investigated. The increase of the number of receiver channels must be considered to empower the system to deal with more interference sources. Furthermore, to the correct analyzation of the applied algorithms the envrionment related parameters must be measured such as the reference signal purity.

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