Design and implementation of cross-channel interference suppression for polarimetric LFM-CW radar

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ABSTRACT

This paper presents design and practical implementation of the method for cross-channel interference suppression in polarimetric LFM-CW radar with dual-orthogonal sounding signals. Simultaneously transmitted and received signals have limited orthogonality, what results in the interfering signals in the processing channels of the radar receiver. The suppression of the interfering signals is implemented in real time, characterized by simplicity and low increase of computational resources. The efficiency of the cross-channel interference suppression is demonstrated experimentally.

Keywords: PARSAX; polarimetric radar; cross-channel interference suppression

1. INTRODUCTION

Polarimetric radar allows the utilization of complete electromagnetic vector information about observed objects [1]. It is based on the fact that in general any radar object (or any resolution cell) can be described by an 2x2 scattering matrix (SM) with four time-variable complex elements describing amplitude, phase and polarization transformation of a wave scattering radar object. Two signals with orthogonal (e.g. horizontal and vertical) polarizations are used for SM-elements estimations. Each sounding signal is applied for two co- and cross-polarization reflection coefficients in two SM columns. Cross-polarization reflection coefficients define the polarization change of the incident wave. So the signals with dual-orthogonality are needed in polarimetric radar with simultaneous measurement of all scattering matrix elements [1,2].

In addition to the first (polarimetric) orthogonality, the additional one may be realized as orthogonality in waveforms using sophisticated signals, e.g. linear frequency modulated (LFM) signals having opposite frequency slopes. The distinct advantage of sounding LFM signals is the low computational cost in linear frequency modulated continuous wave (LFM-CW) radar receiver due to the de-ramping processing. However, real sounding LFM signals having finite duration (finite sweep time) can not be completely orthogonal [2,3].

The limited orthogonality of the waveforms results in the interfering signals existing in the processing channels of the multi-channel polarimetric radar receiver what can limit detection of weak reflections and accuracy of SM-estimation significantly.

We note that the interfering components in the polarimetric LFM-CW radar receiver have linear frequency modulation and occupy the definite part of the analyzed time interval for every sweep [3]. The knowledge of their localization provides the possibility to their suppression.

This paper is structured as follows. In Section II the de-ramping processing basics and the interfering signals' creation are explained. Section III provides the design and implementation of the cross-channel interference suppression in the polarimetric PARSAX radar developed by IRCTR, TU Delft. In Section IV the experimental example is presented. Section V includes conclusions.

2. PROBLEM DEFINITION

For the problem definition the de-ramping processing basics should be explained.

A. De-ramping Processing

The sounding signals are the LFM signals with opposite frequency slopes (up-going and down-going) used for simultaneous measurement of scattering matrix elements [1,2]:

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$$\begin{cases} e_H(t) = \exp\left[j2\pi \left(f_c \cdot t + k_0 \cdot t^2/2 \right) \right] \\ e_V(t) = \exp\left[j2\pi \left(f_c \cdot t - k_0 \cdot t^2/2 \right) \right] \end{cases}, \quad -\frac{T}{2} < t \le \frac{T}{2} \tag{1}$$

where e_H and e_V are the signals transmitted on orthogonal (horizontal and vertical, subscripts H, V) polarizations. The signals are determined for one sweep time interval $t = [0...T]$, have frequency band ΔF ; $k_0 = \Delta F/T$ is the sweep rate of the sounding signal; f_c is carrier frequency.

Each signal scattered by radar object undergoes a number of modifications connected with the scattering properties of the object. The distance to the observed object determines the roundtrip time delay for the received signals.

It is known that roundtrip time delay for received LFM signals corresponds to frequency shift. De-ramping processing utilized in four processing channels of the polarimetric radar receiver calculates SM estimations as functions of frequency (range).

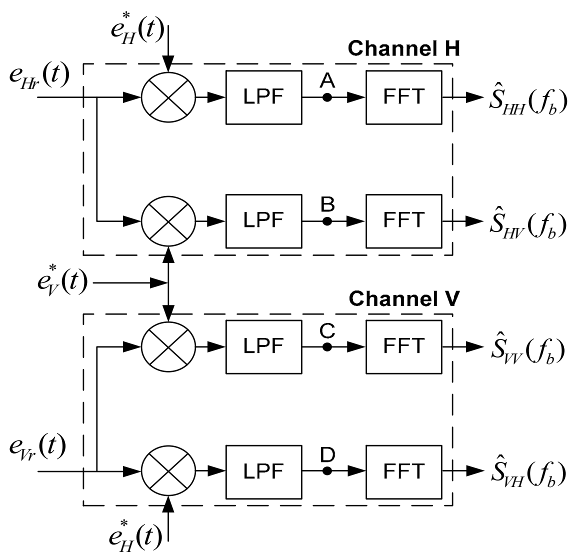

Figure 1. Simplified scheme for the de-ramping filter

Fig. 1 shows a simplified scheme of a de-ramping filter for polarimetric radar with simultaneous measurements of scattering matrix elements. For estimating of all scattering matrix elements each received signal ($e_{Hr}(t)$, $e_{Vr}(t)$) is mixed with complex conjugated replicas of the transmitted signals ($e_H^*(t)$, $e_V^*(t)$). As a result, the signals are reduced in slope, i.e. the signals are de-ramped [4]. The signals after mixing and after low-pass filtering (LPF) are called the beat signals. The beat signals (signals in the key-points A-D) are transformed into the frequency domain using Fast Fourier Transform (FFT). We obtain SM elements estimations as functions of beat frequencies (f_b):

$$\begin{bmatrix} \hat{S}_{HH}(f_b) & \hat{S}_{HV}(f_b) \\ \hat{S}_{VH}(f_b) & \hat{S}_{VV}(f_b) \end{bmatrix} = FFT\left[LPF\begin{bmatrix} e_{Hr}(t)\cdot e_H^*(t) & e_{Hr}(t)\cdot e_V^*(t) \\ e_{Vr}(t)\cdot e_H^*(t) & e_{Vr}(t)\cdot e_V^*(t) \end{bmatrix}\right] . \tag{2}$$

where $t \in [\tau_{\max}...T]$ is the analyzed time interval.

For analysis, the beat signals at points A-D have been presented in the time-frequency plane (Fig. 2) using a moving Short Time Fourier Transform (STFT). The beat signals are calculated along the analyzed time interval $[\tau_{\max}...T]$ within the beat frequency band $[0 \ldots f_{b\max}]$ (for the PARSAX signals $[100 \ldots 1000]$ µs and $[0 \ldots 5]$ MHz respectively). The FTFT parameters were chosen for better visibility of the interfering LFM signals. Therefore, the useful signals look extended along the frequency axis (thick horizontal lines). This time-frequency representation of the beat signals does not influence the range resolution of the PARSAX radar system.

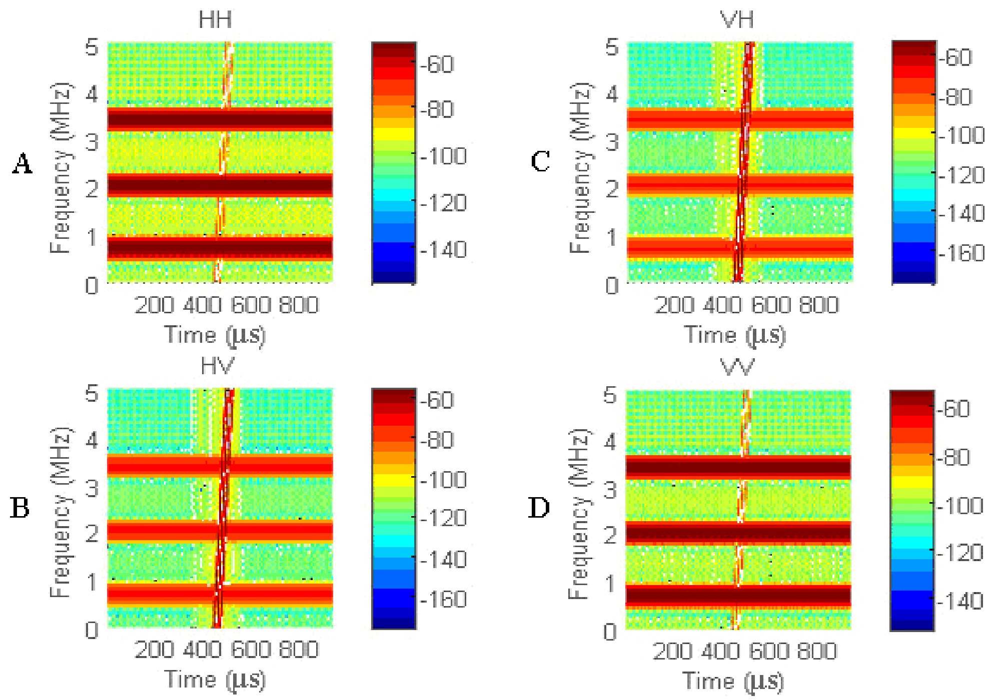

Figure 2. Time-frequency representation of beat signals (HH, VH, HV and VV processing channels)

The beat signals correspond to the simulated radar scene representing three point scatterers. The useful (tone) signals from every target are the horizontal lines. Their amplitudes and initial phases characterize the values of SM elements. The frequencies of these tone signals have the unique correspondence with the observed ranges. The interfering signals are composed by the LFM signals with the same frequency modulation (the same positive sweep rate) and the same time localization for all four processing channels. The interfering LFM signals are non-stationary along the time axis, however, occupy the whole beat frequency bandwidth.

We note here that the interfering signals are up-going LFM signals if the processing data have complex values. For real values the interfering signals are V-shaped LFM-signals [2,3].

B. Interference Analysis

The multipliers (see Fig. 1) change slopes of the received signals. The received signals (e_{Hr}, e_{Vr}) consist of both up-going and down-going LFM-signals, which are useful for different processing channels within one (H or V) polarimetric receiver channel. The same multiplier in every processing branch transforms useful for this branch signals into tone signals and interfering signals (with an opposite slope) into LFM signals with double sweep rate. For example, signals useful for the HH processing channel create interfering signals for the HV channel and vice versa. The same is true for the VH and VV channels.

The knowledge about the interfering signals' localization allows for the development of the design for their suppression.

3. SUPPRESSOR DESIGN AND IMPLEMENTATION

The design of the suppressors starts from the knowledge about the localization region for the interfering LFM-signals.

The interfering LFM component duration equals to $\tau_{\max}/2$ and occupies the definite position along the analyzed time interval [3]. The scattered signal received with the maximal time delay $\tau_{\max}$ after mixing has the delay $\tau_{\max}/2$ due to the doubled slope of the interfering LFM signals. So, the possible interfering LFM components caused by the signals received with the roundtrip time delay from 0 to $\tau_{\max}$ occupy the time region equals to $2\cdot\tau_{\max}/2=\tau_{\max}$ (0.1 ms for the PARSAX radar). We note that the presence of the interfering LFM signals within this time region is defined by the observed radar objects.

The digital configuration of the PARSAX radar receiver allows for definition of any type of windowing. The number of the windows was developed and programmed within the PARSAX project. Three examples of window types are shown in Fig. 3. Choosing the window, the compromise between the efficiency of the interfering components' suppression and the possible suppression of the useful tone signals can be found.

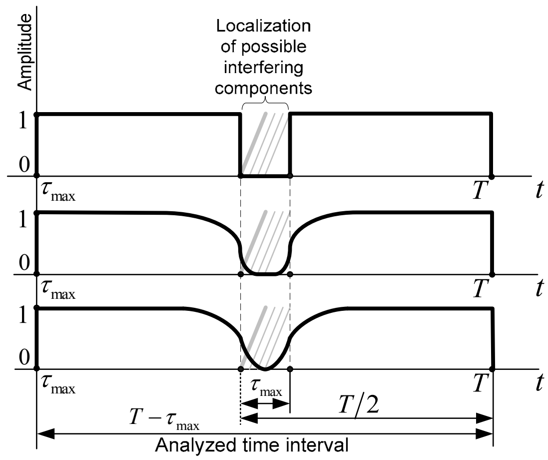

Figure 3. Windowing in time domain

Fig. 4 shows a scheme for the suppressor. With such suppressors additionally located in the key points A-D (see Fig. 1) cross-channel interference suppression becomes feasible. The time window coefficients are stored in the Read Alternate Memory (RAM) and multiplied by the beat signals from the LPFs' outputs. Memory resource requirements are the same for different windowing in time domain.

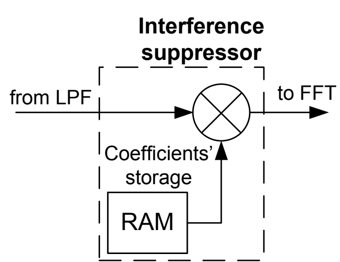

Figure 4. Interference suppressor scheme

The cross-channel interference suppression has been implemented in the FPGA-based digital receiver of the high-resolution polarimetric PARSAX radar which operates in real time.

One chip of Virtex5st95 with the total memory capacity 8,784Kb is used for each processing channel in the PARSAX receiver. For one processing channel, 16K points FFT, windowing coefficients are 16bits, the total memory used is 256Kb, just consume 2.9% of the memory capacity. The memory requirements are the same for all four processing channels of the receiver.

4. EXPERIMENTAL EXAMPLE

In the previous section the design for the cross-channel interference suppression is presented for polarimetric LFM-CW radar. In this section the efficiency of the cross-channel interference suppression is shown visually.

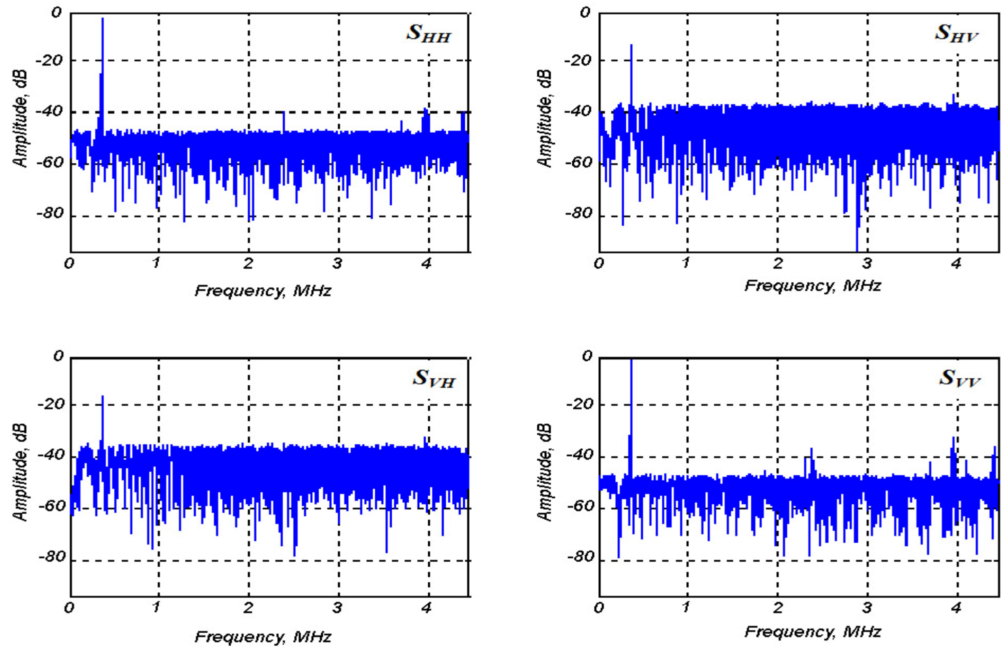

Figure 5. De-ramped signals' spectra before interference suppression

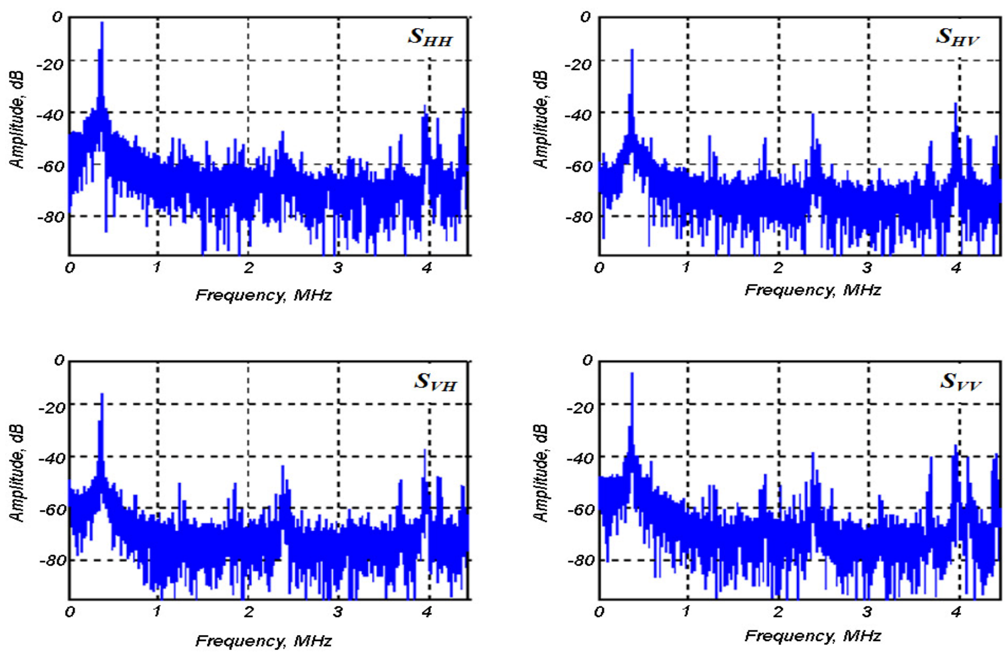

Figure 6. De-ramped signals' spectra after interference suppression

Fig. 5 represents the measured range profiles for the real radar scene calculated using the standard de-ramping processing technique. In Fig. 6 the same scene is presented using the suppression of the interfering cross-channel signals. The comparison of the figures clearly shows the efficiency of the interference suppression in the operating polarimetric radar. The detection of weak targets hidden for standard de-ramping processing becomes possible. The investigation of side effects of the suppression implementation is outside the scope of this work.

5. CONCLUSION

In this paper the design and implementation of the cross-channel interference suppression have been presented in the operational stage of the PARSAX radar. They characterized by simplicity, low computational increase and real time operation.

The experimental results presented here have shown the successful implementation of cross-channel interference suppression for polarimetric LFM-CW radar. Experimental results have shown high efficiency of the implemented suppression.

6. ACKNOWLEDGEMENTS

At the International Research Centre for Telecommunications and Radar (IRCTR), Delft University of Technology a major research project is executed concerning the design and development of a full polarimetric FM-CW radar with dual-orthogonal signals for simultaneous measurement of all elements of radar target's polarization scattering matrix. This project is performed under a contract with the Dutch Technology Foundation STW.

7. REFERENCES

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