RADAR SIGNAL PROCESSING JAMMING RESISTANCE OPTIMIZATION

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Abstract

Radar signal processing includes large group of algorithms. These algorithms are in modern radar one of the most important element protecting radar against jamming and interference.

The paper presents use of the design and verification of sidelobe canceller algorithms (SLC) and analysis of Wi-fi signal interference to radar for detector optimization. Algorithms design is based on mathematical model of received signal. Algorithms are usually verified by reference implementation in MATLAB using generated (model based) data and real signal records. Processing of real signal records provides opportunity to verify model and requires processing of large data sets.

1 The SLC algorithms

Sidelobe canceller algorithm (SLC) is described in [1],[2] and provides output signal with adaptively suppressed sidelobe jamming component (1). Real performance of the algorithm relies on adaptation source data extent, adaptation frequency radiation patterns of antennas and signal to noise ratios of individual signals.

$$\mathbf{Z} = \mathbf{s} + \mathbf{J} + \mathbf{J}_a^T \mathbf{W} \tag{1}$$

$$\mathbf{S}_a << \mathbf{J}_a \tag{2}$$

Where Z is a vector of output signal samples, s is a vector of interesting signal samples (target echo) received by main antenna, J is a vector of jamming signal received by main antenna, $\mathrm{J_a}$ is a vector of jamming signal received by auxiliary antennas and W is a vector of complex weights $\mathbf{W} = [w_1 \quad w_2 \quad \cdots \quad w_N]$. As the algorithm is intended for suppression of jamming signal received through main antenna sidelobes, echo signal in auxiliary channel is weaker than jamming signal (2).

Optimal weights can be found by evaluation of (3) [1][2][3].

$$\mathbf{M}'\mathbf{W}' = \mu \mathbf{T} \tag{3}$$

Where $\mathbf{M}'$ .... covariance matrix of (noise) antenna channels output signals (4).

$\mathbf{W}'$ .... antenna arrays complex weights vector $\mathbf{W}' = [w_0 \quad \cdots \quad w_N]^T$

μ .... scale coefficient

$\mathbf{T}$ .... vector of optimal power contribution of individual channels[1]

$$\mathbf{M}' = \mathrm{cov}\left([\mathbf{s}_m \quad \mathbf{s}_{a1} \quad \cdots \quad \mathbf{s}_{aN}]^H [\mathbf{s}_m \quad \mathbf{s}_{a1} \quad \cdots \quad \mathbf{s}_{aN}]\right) \tag{4}$$

Where $\mathbf{s}_m$ .... vector of signal samples received by radar main antenna

s_{an} .... vector of signal samples received by radar n^th auxiliary antenna

N .... Number of auxiliary channels

Equation (3) can be further modified by division into two parts, main antenna channel and auxiliary channels (5).

$$\mathbf{M}'\mathbf{W}' = \begin{bmatrix} p_0 & \mathbf{\Lambda}^H \\ \mathbf{\Lambda} & \mathbf{M} \end{bmatrix} \begin{bmatrix} w_0 \\ \mathbf{W} \end{bmatrix} = \begin{bmatrix} \mu \\ 0 \end{bmatrix} \tag{5}$$

Where p_0 .... power of main antenna channel output

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[1] For our case of main antenna and several auxiliary antennas $\mathbf{T} = [1 \quad 0 \quad \cdots \quad 0]^T$.

$\boldsymbol{\Lambda}$ .... $\boldsymbol{\Lambda} = [\mu_{10}{}' \quad \mu_{20}{}' \quad \cdots \quad \mu_{N0}{}']^T$

$\mu_{p0}{}'$ .... mutual correlation of p^{th} auxiliary antenna output and main channel

$\mathbf{M}$ .... covariance matrix of auxiliary channels (4).

$\mathbf{w}$ .... auxiliary antennas weights coefficient vector

w_0 .... main antenna weights coefficient vector

Implementation of this algorithm can look easy, as whole procedure were described before. Unfortunately real application cannot be based on exact covariance matrix, while only estimates are available. The real application must include many additional aspects, like selection of sample data for covariance estimates calculation, adaptation rate selection, design of auxiliary channels radiation patterns, evaluation of impact on Doppler processing performance, etc. All these issues can be efficiently supported by MATLAB™.

2 Modelling, verification and analysis of SLC performance

At the very beginning of military radar system design, system parameters as well as electronic protection (counter-counter measures) must be defined and verified. For SLC auxiliary antenna radiation pattern must be selected and noise performance estimated. Upon selection of auxiliary channel impact noise levels (signal to noise or jamming to noise ratio at both main and auxiliary channels)

SLC algorithm operation was evaluated using model of both antennas radiation pattern. Main antenna beamwidth was defined by system gain requirement (and contemporary by dimension limits) and auxiliary antenna beamwidth was selected to provide sufficient gain and cover main antenna dominant sidelobes. Both radiation patterns are depicted on figure 1.

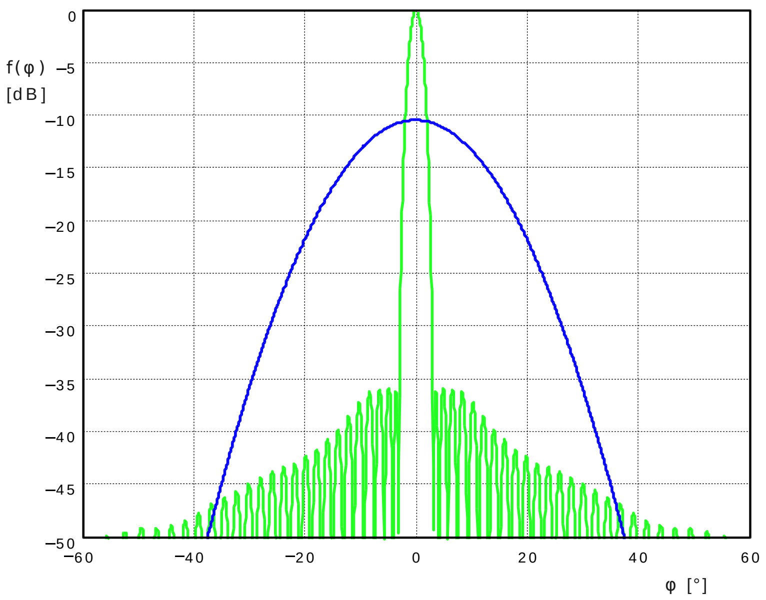

Figure 1: Radar system main and auxiliary antenna radiation patterns

Algorithms performance relies heavily on data segments utilised for adaptation. First found issue is mainlobe jamming causing suppression of mainlobe signal and relevant destroy of (not only) Doppler processing performance. Another disruption group of effects are caused by strong mainlobe targets received together with sidelobe clutter (e.g. ground clutter echoes). All these effects were identified on very simple model of received signal including background (white) noise, point target and jamming noise signal. Degraded performance is illustrated on figure 2.

Upon identified performance limitations sidelobe to mainlobe amplitudes ratio conditions were added to the adaptation data selection and resukting performance is illustrated on figure 3.

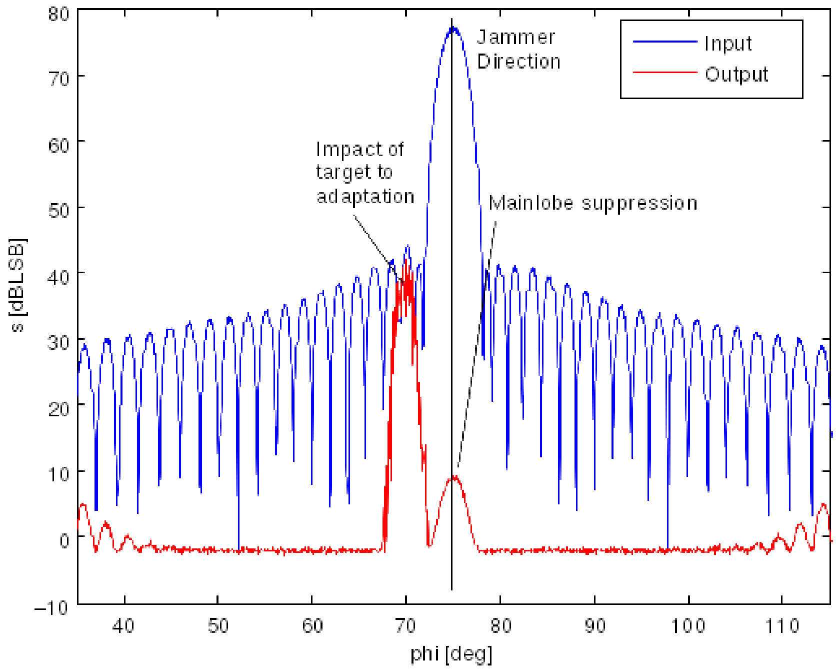

Figure 2: Input and output signal of original SLC algorithm

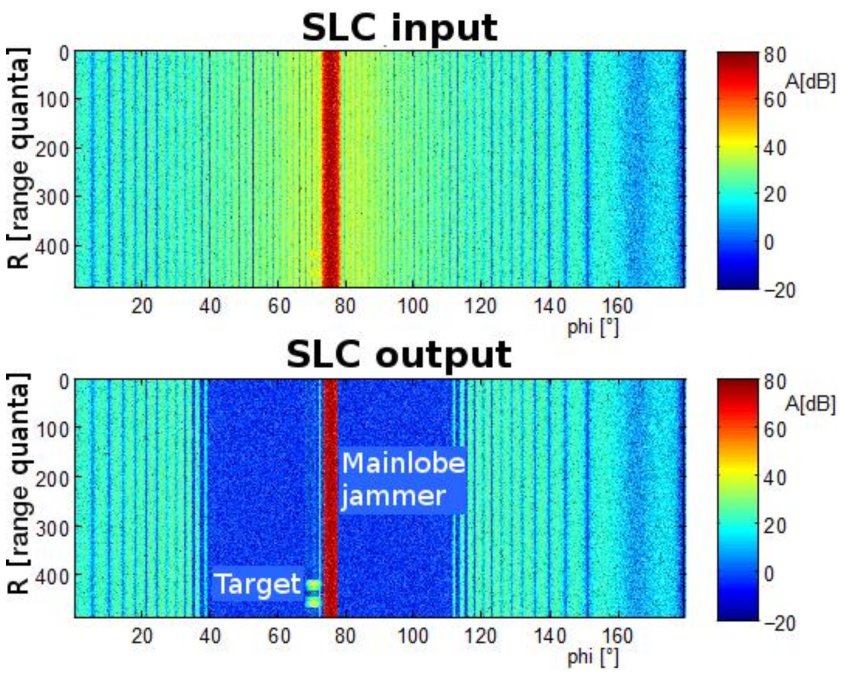

Figure 3 Performance of modified SLC algorithm (target is surrounded by strong range sidelobes of matched compression filter)

Another effect limiting the SLC algorithms performance is adaptation ageing (change of sidelobe and mainlobe amplitude (radiation pattern) ratio. As the algorithm aims to get zero out of two large numbers subtraction, it would be quite sensitive to these changes. Performed analyses are described in [7], where equation (6) is derived.

$$\Delta TR = \frac{\frac{\partial A_m(\varphi)}{\partial t} T + \frac{f_m(\varphi_0)}{f_a(\varphi_0)} \frac{\partial A_a(\varphi)}{\partial t} T}{A_m(\varphi_0)} = \frac{A_0 T}{A_0} \frac{\frac{\partial f_m(\varphi(t))}{\partial t} + \frac{f_m(\varphi_0)}{f_a(\varphi_0)} \frac{\partial f_a(\varphi(t))}{\partial t}}{f_m(\varphi_0)} \qquad (6)$$

Where T .... Time of adaptation

TR .... Coefficient of transfer of the mainlobe signal into SLC algorithm output

$f_m(\varphi)$ ... Radiation pattern of radar main antenna

$f_a(\varphi)$ .... Radiation pattern of auxiliary channel antenna

φ_0 .... Antenna position at the time of the SLC algorithm adaptation

A_m .... Main antenna signal amplitude

A_a .... Auxiliary antenna signal amplitude

Performance of the SLC algorithm is depicted on figure 4. It can be seen that suppuration degrades quite fast as the time difference from adaptation goes up.

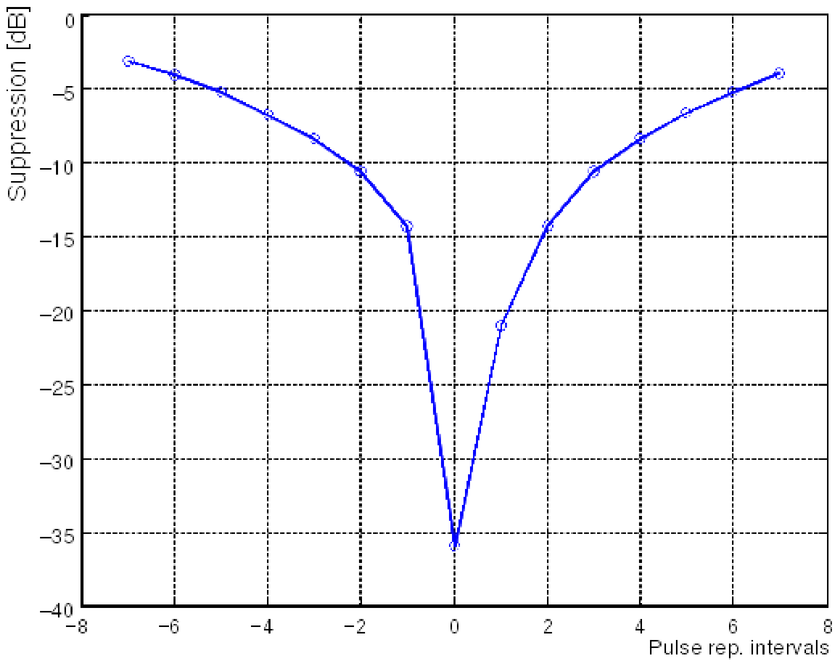

Figure 4 Suppression of sidelobe jamming signal as a function of time difference of processed samples and adaptation data (antenna turn rate 30 rpm)

3 Verification using real data records

Next step in implementation of the SLC algorithms was verification on real data records. This was performed, as well as initial simulations, in MATLAB^{TM}. These processing is even more challenging as the amount of processed data (complex envelope, complex baseband signal samples) is enormous. MATLAB scripts performance depends heavily on problem formulation (set of linear equation instead of matrix inversion) coding practice (logical indexing, avoidance of making additional copies of large matrices, etc.) as well as on available memory.

Performance of the SLC algorithm is illustrated on figure 5 (for extremely strong signal). Algorithm was adapted using data set around medium range and output signal presents expected malfunction (limited suppression) for short and distant ranges. Output signal discloses directions of strong reflection (unsuppressed strips) causing mainlobe signal dominance.

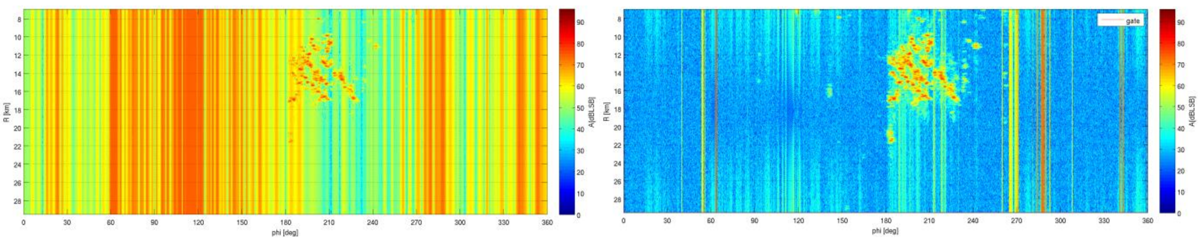

Figure 5: Input (left) and output (right) signal of the SLC algorithm (azimuth- range plane)

Another example of the SLC algorithm performance is depicted on figure 6. Sidelobe jamming signal is nearly supressed and only ground clutter echoes, mainlobe jamming remains.

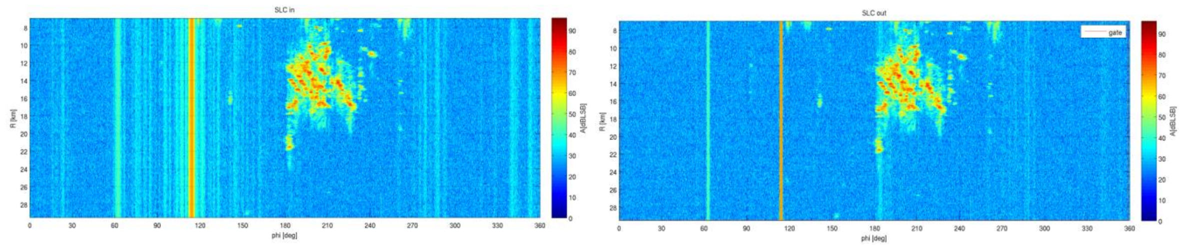

Figure 6: Another input (left) and output (right) signal of the SLC algorithm

The last step was coding into signal processor and testing. I this stage MATLAB™ helps to routinely evaluate performance and find errors.

Conclusion

Application of ready to publish principles is often quite challenging task if designer and/or customer insist on reliability and performance. Sometimes if hard to find reasonable resources leading efficiently to expected performance.

The paper presented implementation of the SLC algorithms into real radar system. Description, as well as design work, were focused on both performance and efficiency. MATLAB™ proved to be the right tool for signal processing

References

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