

# Adaptive clutter suppression method for three dimensional Doppler radar

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**Abstract.** The heuristic method for clutter suppression in three dimensional (3D) Doppler radar is proposed. The algorithm for suggested method was developed and experimentally verified. The working efficiency of this algorithm was confirmed.

## 1 Introduction

The radars work against natural clutters and jamming (intentional interference). That's why every secondary and tertiary data processing radar is necessary to have clutter suppression.

Current digital radars mostly use filtering methods against natural clutters and jamming. [1,2] This huge category starts with simple algorithms based on multichannel Doppler filters and ends with complex ones based on adaptive lattice filters [4, 5, 6]. The adaptive filter algorithms are common to tend to optimum [1, 6] but in a real jamming situation this optimum is not approached so the heuristic suppression methods are also popular.

The development of the heuristic methods is complicated by multifunction radar (MFR) characteristics which bring non-constant total scan time in area and clutter spectral characteristic changing in unambiguous interval in Doppler frequency.

This paper contains the heuristic method description and the results of its realization for adaptive clutter suppression in 3D Doppler radars.

## 2 The features and operating conditions of the modern three-dimensional radars

At present the customers and consumers used to ask radars to be multifunctional which means to be available in using one device for different aims. Such requests has become usual for up-to-date fighter onboard radars and other aircrafts [7]. However, the same tends for terrestrial and marine based radars.

The problems to be solved by multifunctional radars require three spatial coordinate measurements with its rates in a wide scan volume (from 360° bearing and 90° elevation). To fulfil these requirements they use phased or active or digital active antenna arrays which provide a wide-angle scanning together with high quality of object positional measurements. The accuracy of target location and its rates at the end of tracking with supported search frame time is provided for adaptive measurements per second (depending

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on the class and/or velocity) with the use of different radar waveforms. They use two-dimensional electronically scanned antennas to carry out the adaptive rate tracking which launches not easy sequence to interlace the regular review beams with tracking ones.

So the present and perspective multifunctional radars can have characteristics:

- phased/active/digital active antenna arrays available with the two-dimensional wide-angle scanning;
- a digital beamforming and signal processing with a wide range of characteristics (the pulse width and the pulse repetition interval, coherent processing interval and waveform bandwidth);
- a wide changing range and high radio frequency tuning rate while working against jamming;
- the adaptive target tracking is provided for program-algorithmic support.

The multifunctional radar operating modes are available in relation with characteristics shown above and lead to:

- the spectral clutter characteristics change in an unambiguous interval in Doppler frequency;
  - non-constant total scan time due to jamming situation;
- The jamming situation can be changed significantly while tracking process:
- the clutter velocity shifts from radar;
  - the range to the clutter also changes;
  - the nature of meteo formations is changing (density, physical state, the cloud particle size etc.).

All of these bring to the time shifting of clutter spectral characteristics, and also the location, the size and mark number from the spatially distributed clutters.

The effective suppression method should take into consideration these peculiar features of jamming situation together with the radar itself.

### **3 The description and implementation of adaptive clutter suppression method**

The analysis of the experimental data working in different jamming situations shows the spatial stationarity for the majority of meteo formations in four-dimensional phase field (three dimensional coordinates and radial velocity —  $S_1S_2S_3V_r$ ) in the limited time interval. This made it possible to develop suggested adaptive clutter suppression method.

The method content is to divide four-dimensional phase field into elements (channels) and to estimate the number of received marks and to suppress these marks in case of going over a threshold level.

The algorithm is developed to work out the supported clutter suppression method.

#### **3.1 The choice of data processing stage for parameter estimation and suppression of clutter marks**

The traditional radar processing diagram is considered with intention of apparent dividing for primary and secondary data processing. The marks come out after the primary data processing and usually pass the local optimum search after having been clustered in coordinates time-Doppler — amplitude or range — radial velocity — amplitude. After being clustered the received mark can have additional parameters such as the cluster size, for example.

To keep the interbeam and interscan jamming stationarity with nonzero radial velocity, the estimation of their characteristics and the suppression itself should be realized in the generalized coordinates. For example, such coordinates can be bearing — elevation —

range — radial velocity ( $\alpha\beta RV_r$ ) or Cartesian coordinates complemented with radial velocity ( $XYHV_r$ ).

To minimize the false suppression probability the estimation of mark parameters and its suppression have to be made after all the primary data processing which implements mark filtering. Such processes are active jamming cancellation, sidelobe suppression for antenna system, sidelobe suppression of range and radial velocity.

So the mark parameter estimation and their suppression is better to be realized as the last stage of the primary processing.

### 3.2 The adaptive clutter suppression algorithm

The visual scheme of the algorithm is shown in fig.1.



Fig. 1. The visual scheme of adaptive clutter suppression algorithm.

This scheme is conditional because the mark suppression is made right after the parameters estimation but the suppression mask formation proceeds once a search frame time. However, this scheme is much simpler for comprehending of the algorithm.

#### 3.2.1 The channel fragmentation of the field

The channel is regarded as the cell of a particular width in four-dimensional phase field  $S_1S_2S_3V_r$ . The channels width corresponds to the clutter stationary field.

The channel partition is made when switching on the new stage in radar processing, so, it is made once for the preset mode. Due to the mode and accuracy parameters for radars various coordinate systems can be used for  $S_1S_2S_3V_r$  field fragmentation (see 3.1).

While fragmentation they use total (duplicated) channel overlap to avoid jamming sidelobe to get into the channel. This leads to false clutter nonsuppression. The obtained  $S_1S_2S_3V_r$  field cells are subchannels. The volume of each channel is equal to the 16 subchannels volume. After fragmentation the position of each subchannel is declared unambiguously by four indexes  $(i,j,k,v)$  in four-dimensional array.

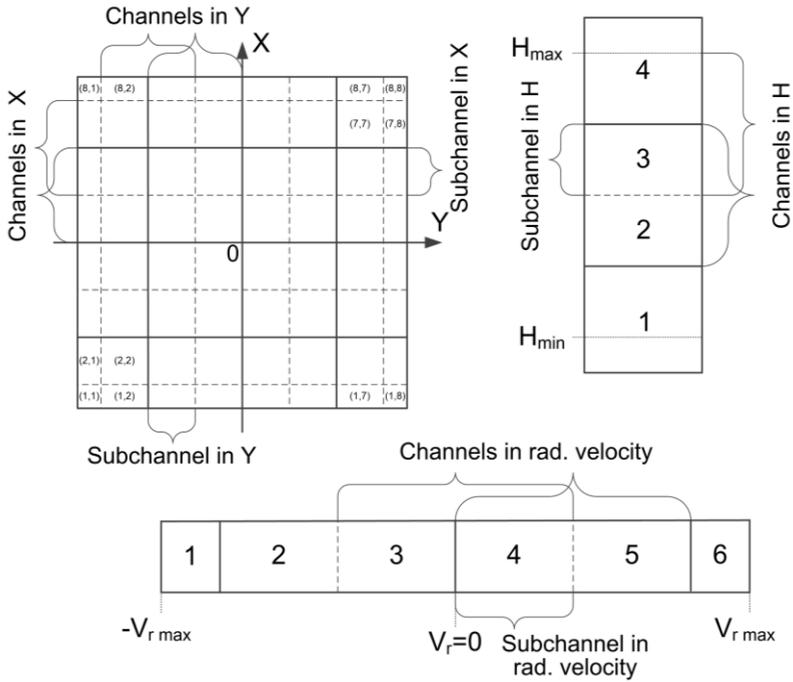
The examples of field channel fragmentation for  $XYHV_r$  and  $\alpha\beta RV_r$  coordinate systems are shown in fig.2 and 3.

#### 3.2.2 The mark parameters estimation

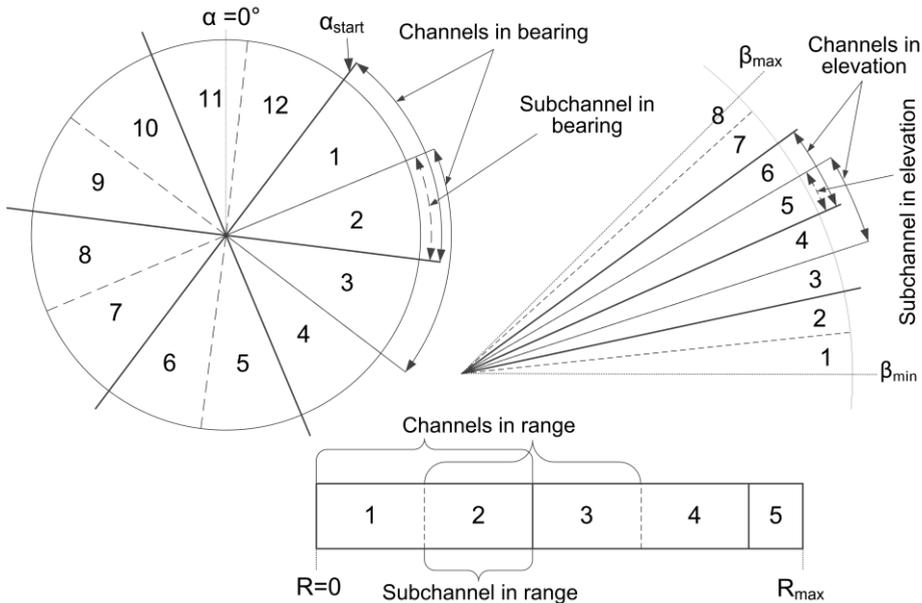
The mark parameters estimation is considered to be statistic gathering which means the information about the mark number is stored when the marks get into subchannel field  $S_1S_2S_3V_r$ . If the process of cluttering was being made, the storage itself could be provided with the use of cluster size.

The statistics from every search frame time is stored in an additional vector of four dimensional data array *stat\_buf*. Its length is  $N+1$ , where  $N$  — the search time frame amount, which provides the mark information storage. The  $N$  parameter determines time interval of a total data renewal. That is the base for making the decision about mark suppression in subchannels.

The indexes  $(i,j,k,v)$  are calculated for each detected mark and determine its subchannel implement. The indexes calculation has some features shown in fig. 2 and 3:



**Fig. 2.** The example of channel fragmentation of the field  $XYHV_r$ .

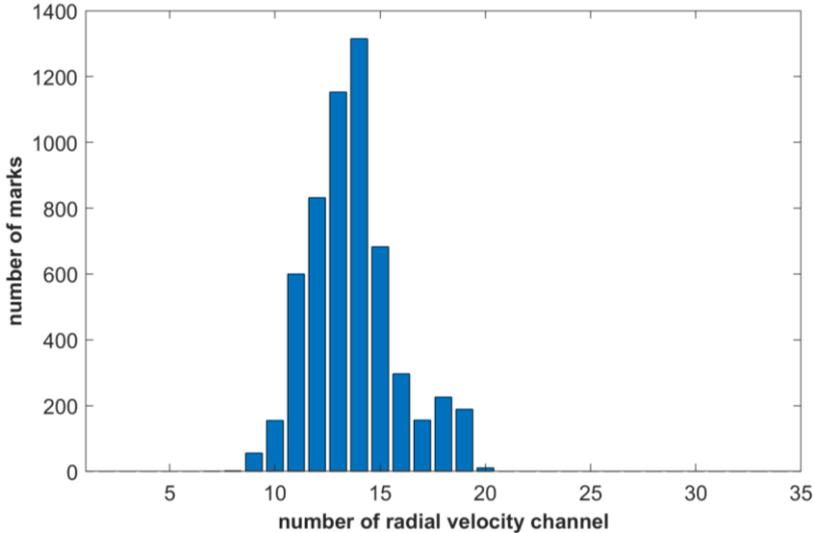


**Fig. 3.** The example of channel fragmentation of the field  $\alpha\beta RV_r$ . The fragmentation in  $V_r$  coordinates is analogic to shown in fig. 2.

- the channels are centered over zero in radial velocity, X and Y coordinates, that means that zero is located between the subchannels;
- the upper (lower) subchannels are not limited above (below) in bearing and elevation;
- the disambiguate is considered in radial velocity, that means one mark can match several subchannels with different index  $\nu$ .

The statistics from the current search frame time is stored in the last vector *stat\_buf* element. Here the only marks are used which were received from data processing of a regular scan signals. The marks received from tracking signals can significantly spoil the statistics because the measurement per second is nonuniform for different objects.

The fig.4 shows the example of radial clutter velocity distribution whent  $i = const, j = const, k = const$ . The fig. 5 shows the example of mark distribution for atmospheric particles in XY-plane for  $k = const, v = const$ .



**Fig. 4.** The example of clutter radial velocity distribution for  $i = const, j = const, k = const$ . The information about the marks is gathered from 3 scan intervals.

### 3.2.3 The suppression mask formation

The suppression mask formation is presented as making a decision of suppression or nonsuppression of the marks in each channel at the next scan interval.

The mask *mask* is formed in a bitarray at the end of each scan period in keeping with the following algorithm:

- the calculation of the mark amount in each subchannel in  $S_1S_2S_3V_r$  field together for the last  $N$  scan periods (1);
- the calculation of the mark amount in each channel by summing the 16 nearby subchannels (2);
- the comparison of the mark amount in each channel with the  $n_{thr}$  threshold level and mask recording (3).

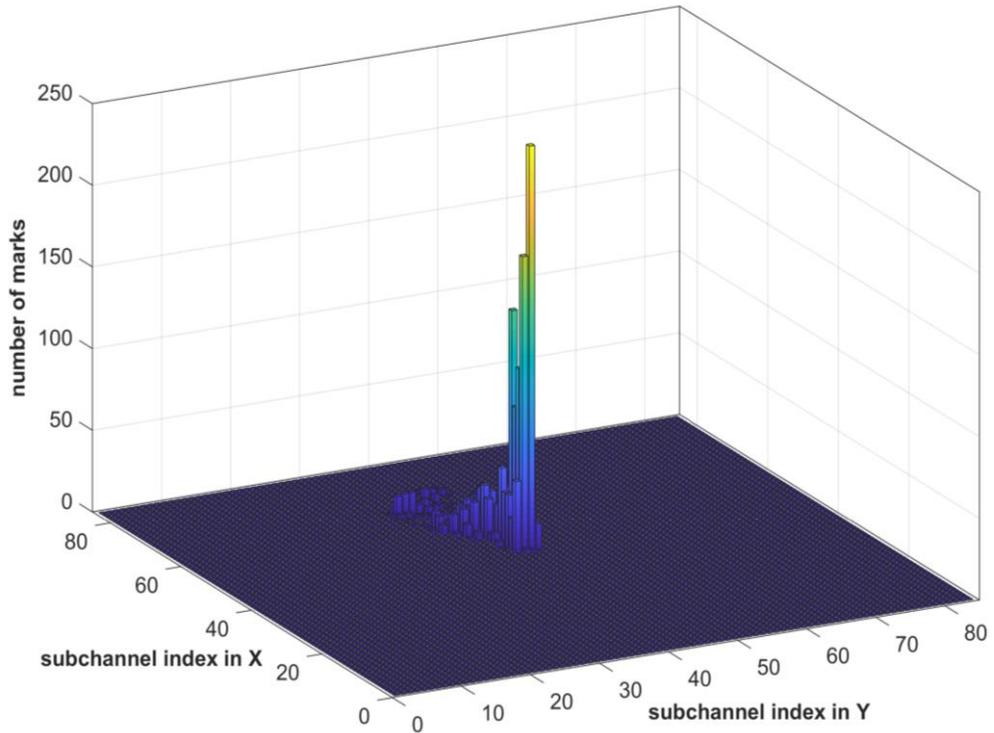
$$\mathbf{stat\_subch} = \mathbf{stat\_subch} - \mathbf{stat\_buf}(1) + \mathbf{stat\_buf}(N+1); \tag{1}$$

$$\mathbf{stat\_ch} = \sum_{k_1}^{k_1+1} \sum_{k_2}^{k_2+1} \sum_{k_3}^{k_3+1} \sum_{k_4}^{k_4+1} \mathbf{stat\_subch}(i, j, k, v); \tag{2}$$

$$\text{if } \mathbf{stat\_ch} > n_{thr} \tag{3}$$

$$\mathbf{mask}(\overline{k_1, k_1 + 1, k_2, k_2 + 1, k_3, k_3 + 1, k_4, k_4 + 1}) = \text{true}$$

where  $k_1 = \overline{1, n_{S_1} - 1}, k_2 = \overline{1, n_{S_2} - 1}, k_3 = \overline{1, n_{S_3} - 1}, k_4 = \overline{1, n_V - 1}, n_a$  – the number of subchannels in  $a$  coordinate.



**Fig. 5.** The example of atmospheric particles marks distribution in XY plane ( $H = 3750 \dots 5000$  m,  $V_r = -8,7 \dots -7,0$  m/sec). The information about the marks is gathered from 3 scan interval.

The fig. 6 shows the example of suppression mask which was formed for the data from fig.5 where  $n_{thr} = 12$  is the threshold level.

### 3.2.4 The mark suppression

The mark suppression takes place in accordance with the mask suppression right after mark parameter estimation (see 3.2.2). Meanwhile the marks received both from regular scan signals and accompaniment signals are also suppressed.

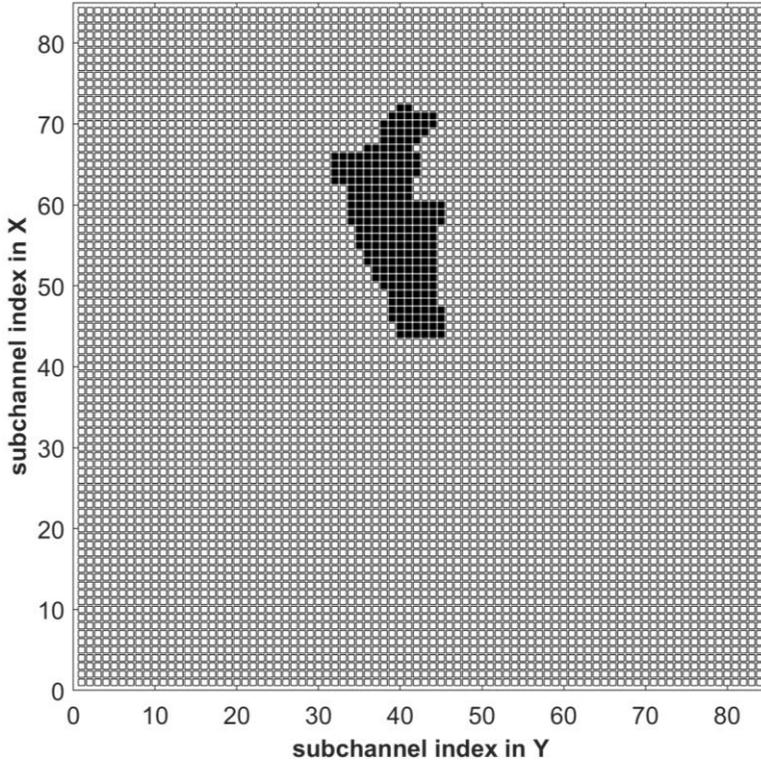
As the index of a subchannel with the mark has already been calculated, the suppression resolves itself into the varification of the appropriate mask cell and, if needed, mark rejection.

The fig. 7 shows the example of mark distribution in meteo situation in XY-plane after suppression in accordance with the mask in fig.6.

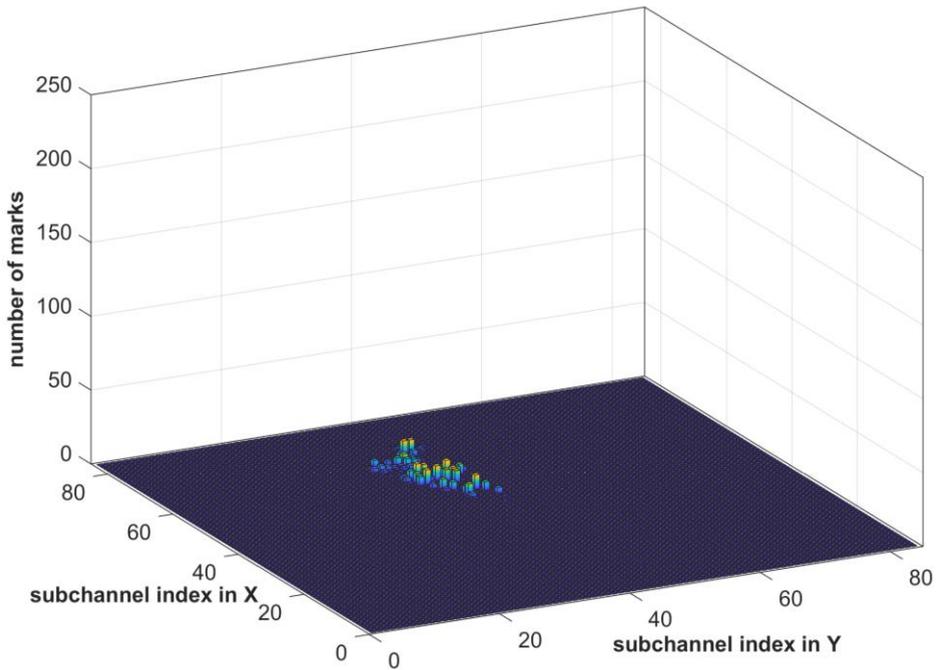
## 4 Conclusion

The proposed heuristic method of adaptive cluster suppression for three-dimensional Doppler radar is realized in some products. In case of exploitation the working ability of used algorithm is experimentally proved

The experience of exploitation of the products with developed algorithm shows that the atmospheric particles are the most difficult to suppress. The mark distribution from such clutters doesn't differ much from distribution of group objects marks. Such clutters are better to be suppressed at the secondary processing stage.



**Fig. 6.** The example of suppression mask. The subchannels of marks which will be suppressed at the next scan are shown black.



**Fig. 7.** The example of mark distribution from atmospheric particles in XY-plane after suppression in accordance with the mask in fig. 6.

## References

1. Vovshin B.M., Vylegzhanin I.S., Korneev A.N., Lavrukevich V.V., Pushkov A.A. Teoretiko-eksperimentalnoe sravnenie adaptivnykh i traditsionnykh ustroystv selekcii dvizhushchikhsya celey v impulsnykh RLS // *Uspekhi sovremennoy radioelektroniki*. No 4. P. 40-56 (2018)
2. Bakulev P.A., Stepin V.M. *Metody i ustroystva selekcii dvizhushchikhsya celey*. M.: Radio i svyaz (1987)
3. Gorbunov Y. N. *Cifrovye sistemy SDC i ikh optimizatsiya: Monographiya / GOU VPO «Moscovskiy gosudarstvennyy institut radiotekhniki, elektroniki i avtomatiki (tekhnicheskoy universitet)» – Moscow, 132 p. (2008)*
4. Frilander B. Reshyotchatye filtry dlya adaptivnoy obrabotki dannykh / *TIIER*. **V. 70**. No 8. P. 54–97 (1982)
5. *Adaptive filters / edited by C.F.N. Cowan and P.M. Grant*. Englewood Cliffs, N.J. : Prentice-Hall (1985)
6. Lekhovichy D. I.; Rachkov D. S.; Semenyaka A. V.; Ryabukha V. P.; Atamansky D. V. «Adaptivnye reshyotchatye filtry. Chast I. Teoriya reshyotchatykh struktur» *Prikladnaya radioelektronika*, **V. 10**, No 4, P. 380–404 (2011)
7. *Mnogofunktsionalnye radiolokacionnye sistemy*. P.I. Dudnik, A.R. Ilchuk, B.G. Tatarsky. – M.: Drofa, 283 p. (2007)