Ground Target Signal Simulation by Real Signal Data Modification

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SUMMARY

Simulation techniques offer very often the only realistic methods of signal processing quality assessment. Standard approach to signal simulation needs prior definition of signal model before construction of signal simulation algorithm. Sufficient number of signal data are necessary for definition of good signal model. Signal data available are not always satisfactory numerous. An approach is proposed to cope with this problem by simulating signal realizations as modifications of real, registered signal. Methods of modification of real signals in time-space domain as well as in frequency domain are proposed. Results of simulation experiments are presented.

1.0 INTRODUCTION

Simulation of an object or phenomenon consists in generation of their replicas similar in a sense with the original. Simulation of a signal **x** should produce an artificial signal **s** having the same probabilistic characteristics as simulated signal. In the case of a stationary signal the probabilistic criterion of comparison is most frequently defined on the basis of marginal probability distribution (MPD) and autocorrelation function (ACF) or equivalently power spectral density (PSD). Simulation of a signal can though be looked at as a generation of a random process of given MPD and ACF. Such an approach requires prior definition of a signal model before a simulation algorithm design. Reliable modelling needs sufficient number of real signal data collected during open-air experiments. This condition is usually difficult to be satisfied in the case of ground target radar signals for technical as well as economic reasons. The difficulties mentioned above are even more serious in the case of air-borne radar systems. The efficient use of available real signal data is of primary importance.

Simulation of a signal is usually a processing of a sequence of independent random samples of appropriate probability distribution. The processing should be such as to produce the output signal of desired properties i.e. MPD and AFC. Thus any simulation experiment generates a signal realization that should be positively verified by successful estimation of both functions. Such an approach is a classical simulation of a signal. The proposed approach to signal simulation is based on an idea that simulation by independent random samples processing can be replaced by real signal samples processing that is the white noise signal processing is replaced by the processing of real signal. It means that in the latter case the processing should be an appropriate modification of real signal producing a new signal realization on the basis of a real one.

2.0 PROBLEM DEFINITION

The two approaches to simulation are presented schematically on Fig.1. If we assume that a signal x(t,**A**) depends on time t and a random variable **A** then the result of any simulation is its realization x(t,α).

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Looking at a real signal (real is used here in a sense physical, registered in a physical experiment for example) as a realization x(t,α_1) of the signal x(t,**A**) we want to produce its new hypothetical realization x(t,α_2) by a modification of the real signal (i.e. the realization x(t,α_1)). The

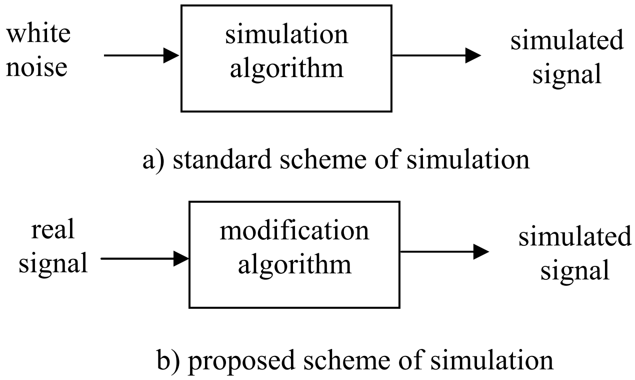

Fig.1 Two schemes of signal simulation

time t is used for simplicity of simulation idea presentation. In a case of 2-d signals (like SAR signals) t should be replaced by two variables t and u [Sou] representing range and cross-range signal dependence. In discrete case the signal realizations takes on the form x(m,n,**A**) with m=1,2,…M and n=1,2,…N. It is necessary that the modification algorithm be of nondeterministic character. It will enable to generate many new realizations x(m,n,α_n) on the basis of one real signal and to cope with the problem of limited number of data available. As mentioned earlier the modified version of the signal is a hypothetical realization. To be sure that such a hypothesis can be accepted it should be verified which needs a definition of appropriate criteria.

The basic difference between the two approaches lies in the role played by the simulated signal model. In the first case the signal model ought to be defined on the basis of signal data in order to design the simulation algorithm and in the second one the signal model is hidden in the internal structure of the available signal data and need not to be defined. So the problem of number of signal data necessary for reliable model definition looses its importance and instead the problem of appropriate algorithm of real data modification arises. The modification algorithm should preserve the MPD and ACF. While defining the algorithm of modification one should consider signal structure. The problem will be presented below.

The verification of simulation results should allow to found the similarity of MPD and AFC of the real and simulated (modified) signals. The principal rule adopted for all simulation algorithms was that signal modification should not change its ACF and if so the changes produced should be of minor importance. In effect only the MPD needed to be verified and typical goodness of fit test T were applied.

$$T = \sum_{i=1}^{K} \frac{(s_i - x_i)^2}{x_i}$$

where: K – number of equal subintervals in the range of real signal variation [x_{min}, x_{max}],
{s_i; i=1,…K} set of numbers describing how many samples of the simulated signal **s** belong to i-th subinterval,
{x_i; i=1,…K} set of numbers describing how many samples of the real signal **x** belong to i-th subinterval.

The hypothesis that the real and simulated signals MPD functions were identical was rejected if the statistic T known as Pearson's test statistic was greater than the critical value c defined by the equation

$$P\{T \geq c\} = \alpha$$

If the hypothesis on goodness of fit of MPD functions is sustained and the assumption of AFC invariance is made the result of simulation by real signal modification can be accepted at the α significance level.

3.0 SIMULATION ALGORITHMS

The real signal x( ) can be modified either in the time-space domain or in the frequency domain. The modification should guarantee invariance of typical signal properties or insignificant changes of them. In the case of SAR signal its inherent property is a spherical phase modulation [Sou]. The information on signal phase is contained in in-phase and quadrature components of complex SAR signal. The available signal data used in simulation experiments were all in base-band form. Examples of image representation of real and imaginary parts, magnitude and phase as well as amplitude and phase spectra of a base-band SAR signal used for simulation experiments are shown on Fig.2. The rectangles on the magnitude image represent windows for analysis of an object (red) and noise background (blue) properties. This colour convention will be used for verification result presentation. Considering complex nature of SAR signal it is necessary to define the modification algorithm of its complex form or equivalent simultaneous modification of its components. An inspection of the signal data and an analysis of the processes generating the real signal in SAR systems lead to a conclusion that modification algorithm should change the signal in such a way that the relation among arguments of samples whose pixels are situated in one line of image signal representation will not undergo significant variations. This conclusion defines an important constraint on a strategy of phase value manipulation. Taking this into account three types of modification algorithms were proposed for numerical simulation experiments. In all algorithms modifications are introduced to both signal components individually. It is especially convenient in the case of discrete Fourier transformation because the spectra of signal components (both composed of real elements) are symmetric.

3.1 MODIFICATION OF REAL SIGNAL COMPONENT PHASE SPECTRA ON LINE-BY-LINE BASIS – ALGORITHM NO 1

The assumption made for the algorithm was that the phase spectra of analogous lines in both signal components can be slightly changed independently. Generally any change in phase spectrum does not influence the ACF. However, it affects the MPD and the changes produced depend on an intensity of phase modification. As was supposed earlier the modifications should not destroy the phase relations among signal samples in each component as well as between both components. Signal data in $x_{re}(m,n)$ and $x_{im}(m,n)$ define set of complex samples arranged in M lines each having N elements. Each line of both components can be modified according to the scheme presented on Fig.3 provided that the power of additive phase noise is not too great. In the simulation experiments the value of its variance σ^2_{Noise} was chosen such as to assure a positive verification of simulation results. The results of simulation verification are presented on Fig.4. Pearson's test statistic for K=20 intervals is shown as a function of ratio of variances of additive noise component σ^2_{Noise} and phase spectrum variance σ^2_{Ph}. Green line represents critical value c=30,14 equal chi-square percentile $\chi^2_{0.95}(19)$. Particular simulated background and object were obtained for variance ratio equal 0,16.

3.2. MODIFICATION OF REAL SIGNAL COMPONENT VALUES ON LINE-BY-LINE BASIS – ALGORITHM NO 2

The assumption made for the algorithm was that the values of elements of analogous line in both components can be slightly modified provided that the modifications will not change the argument of the complex signal elements. In contrast to the algorithm No 1 the modification of both signal

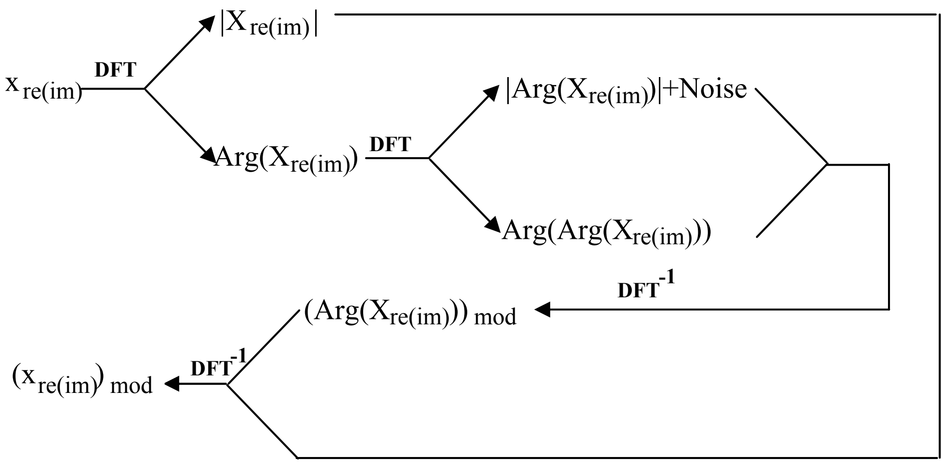

Fig.3 Algorith No 1

components are not independent. The algorithm proposed is presented schematically on Fig. 5. The procedures of simulation and verification were the same as in the case of algorithm No 1. The result of simulation are shown on Fig. 6. Particular simulated background and object were obtained for variance ratio equal 0,30.

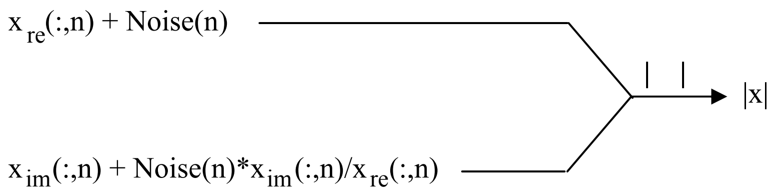

Fig.5 Algorithm No 2

3.3 MODIFICATION OF 2-D PHASE SPECTRUM – ALGORITHM NO 3

Two previously described modification algorithms used 1-d processing that utilize the relations among the signal samples that form lines of the image signal representation. A 2-d processing of the whole signal image seems interesting as a more advanced form of processing. In the case of 2-d spectrum the modification of phase spectrum does not influence the ACF too. The changes of the signal form and changes of the MDP in consequence are fine if the phases of the dominating spectrum components rest untouched. The problem is how to induce phase changes and not to destroy the spherical phase modulation structure. It can be done if chosen at random spectrum elements are modified in such a way that their phases are interchanged with the nearest neighbours of the same spectrum line. The chosen elements should not be dominant elements of the spectrum which means that a threshold value should be defined. It can easily be done by defining an appropriate region of great spectrum elements that are clustered due to the low pass character of the baseband SAR signal. The proposed algorithm is presented schematically on the Fig.7. The choice of random position consist in making m equal to an integer out of {2,3,…M} and n equal to an integers out of {2,3,…N-1}. The result of simulation are shown on Fig. 8. Particular simulated background and object were obtained for KK=200 modification iterations.

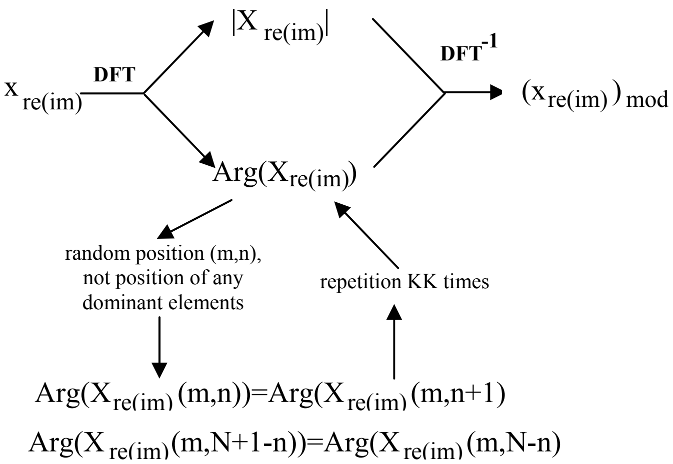

Fig.7 Algorithm No 3

The algorithm No 3 has 2 parameters: the radius rr of circular exclusion region around constant component of real signal spectrum and the number of iterations KK. The first enables to eliminate an eventual choice of a position of a dominant spectrum component, the second determines the number of phase changes done during the simulation experiment. Both parameters make it possible to simulate an object on the noise background with different signal to noise ratio. Pearson's test statistics in function of number of iteration for different radii rr are shown on Fig.9. As is clearly seen the dynamics of Pearson's test statistics becomes greater for smaller radii due to involvement of strong spectrum elements in the process of signal modification. Similar results can be obtained by making greater the number of iteration KK. Signal images with different signal to noise ratios obtained for different numbers of iterations are shown on Fig.10.

4.0 REMARKS AND CONCLUSIONS

A common feature of the simulation algorithm presented in this paper is the role played by the real signal which is treated as a sort of template. But it should be taken into consideration, that the real signal takes on one of many possible forms and can be treated as a realization of the signal we want to simulate. For this reason Pearson's test statistic can be assessed less rigorously. It seems possible to simulate successfully signals of interest in spite of greater than acceptable values of Pearson's test statistic. This remark is valid for all three algorithms. The results of numerical experiments show qualitatively the properties of the algorithms. The numerical values of algorithm parameters should be determined experimentally.

Algorithm No 3 seems to be the most efficient because of relative computational simplicity and lesser time consuming.

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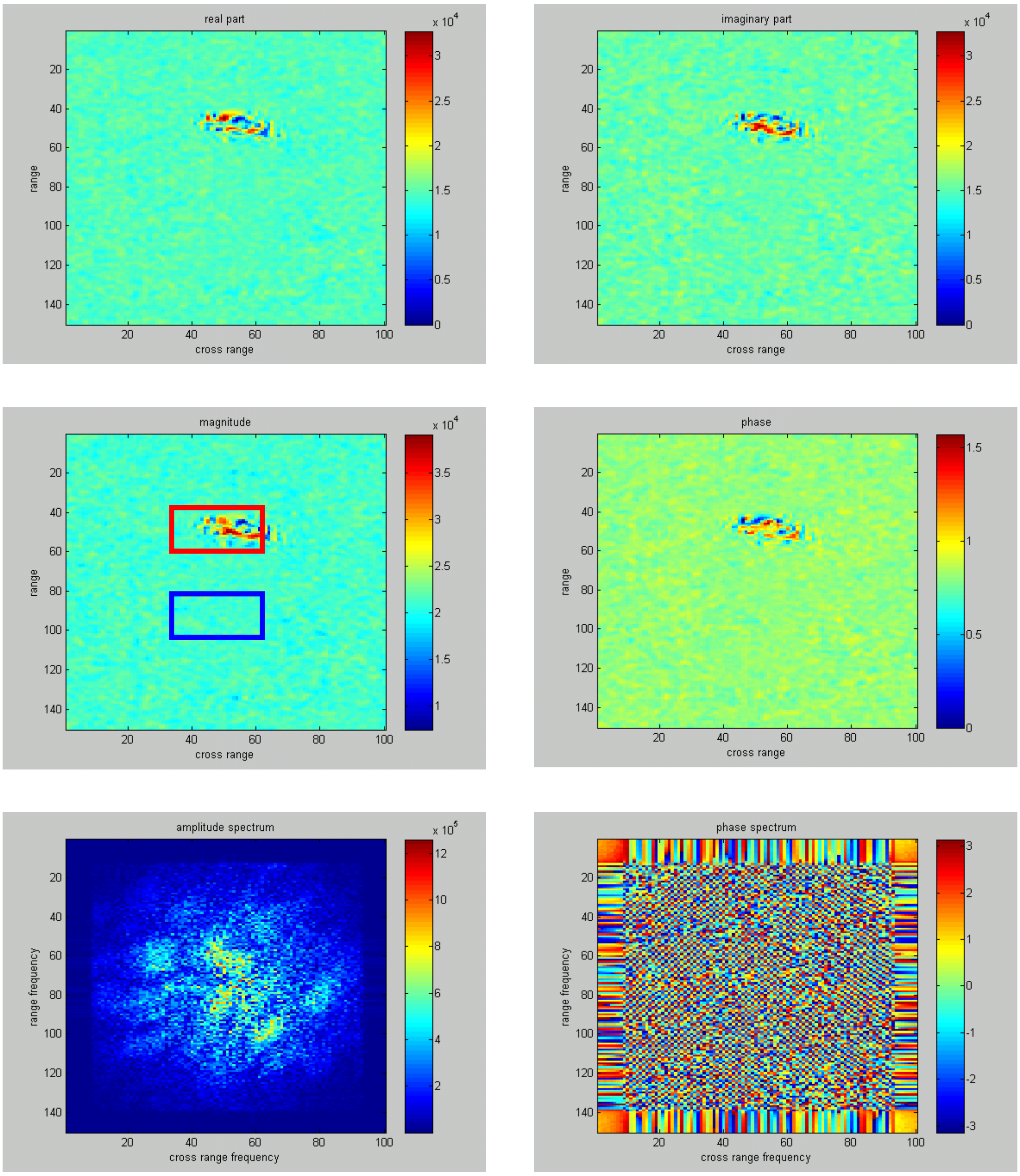

Fig.2 SAR signal

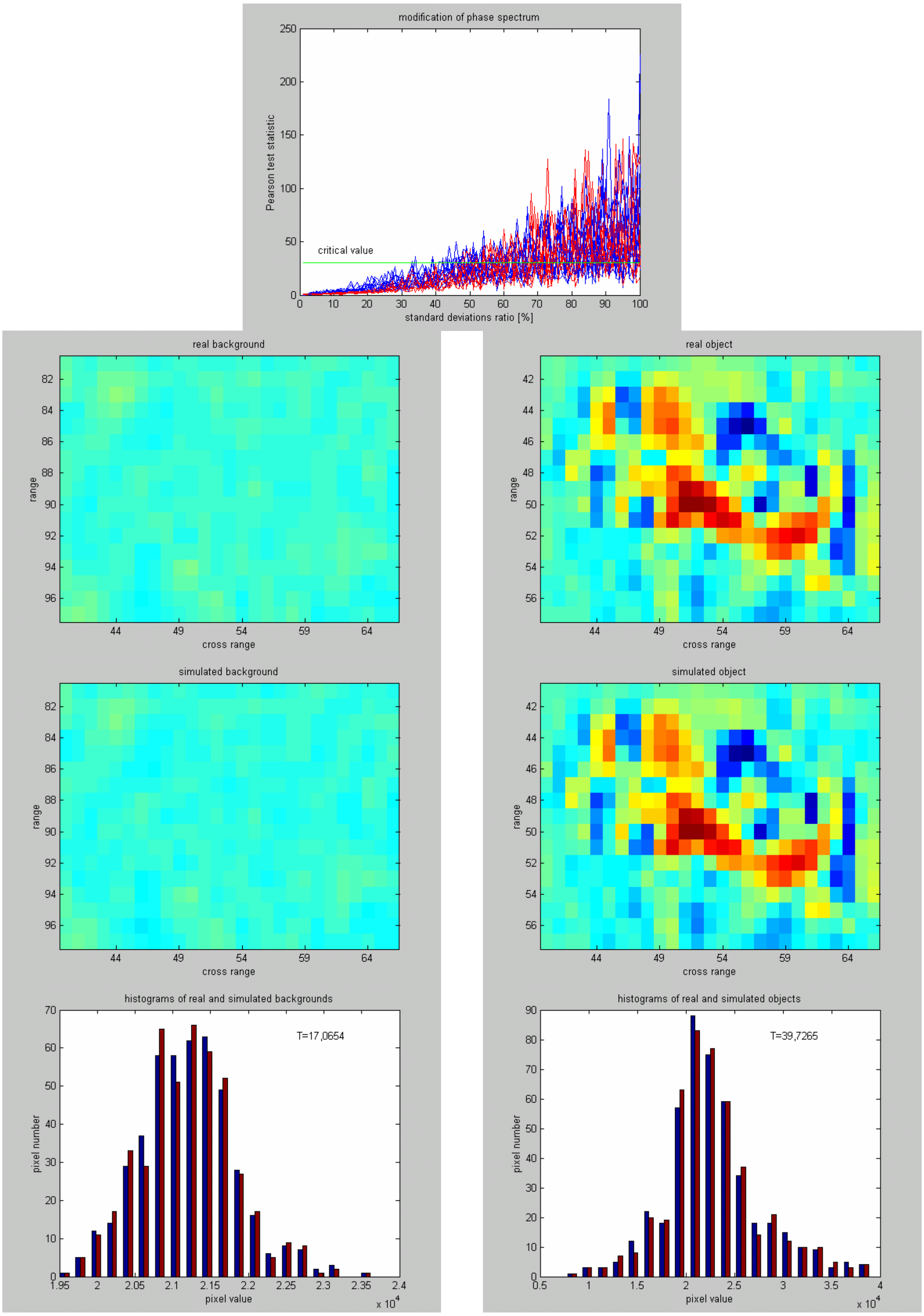

Fig.4 Results of simulation – algorithm No 1.

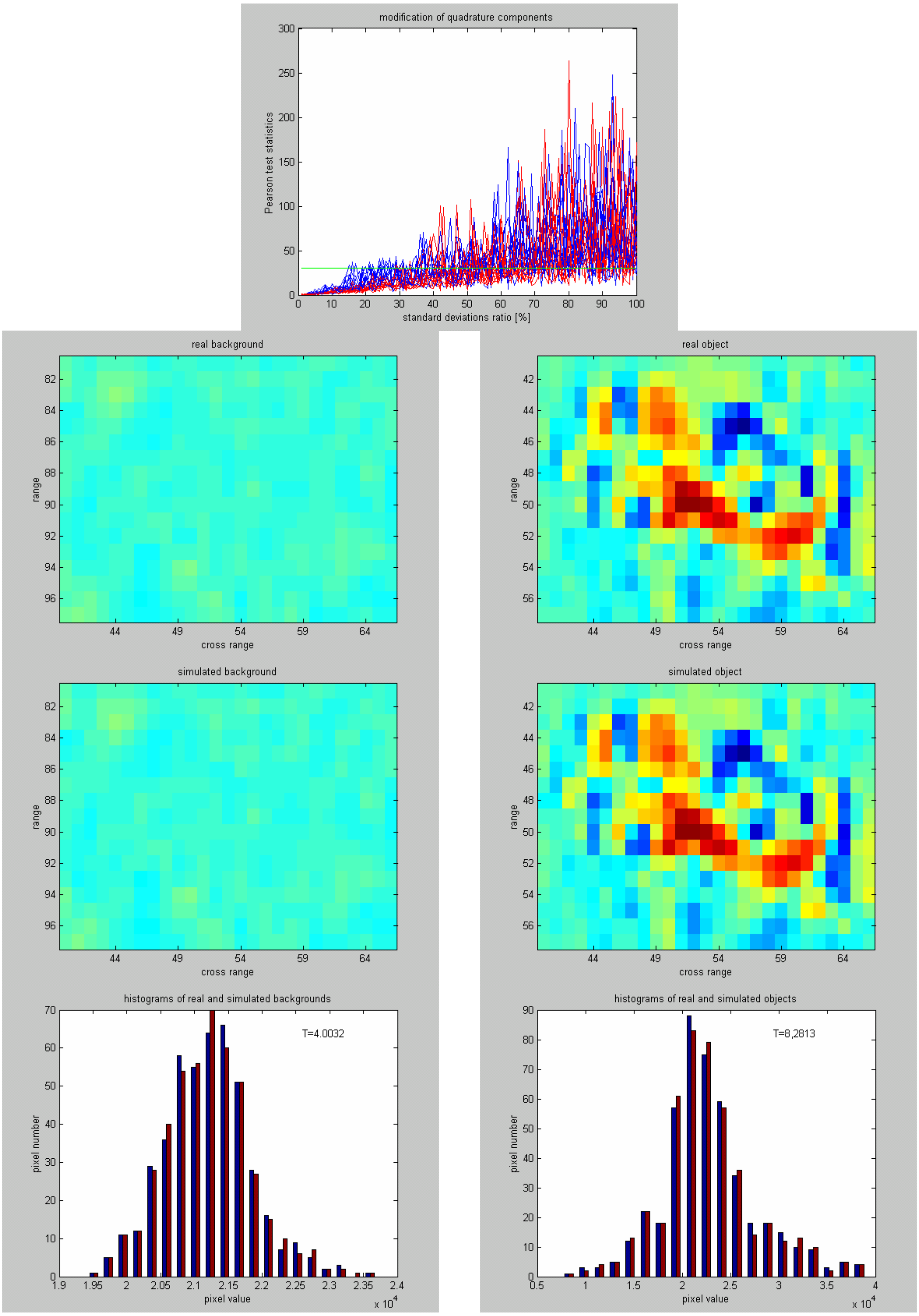

Fig.6 Results of simulation – algorithm No 2.

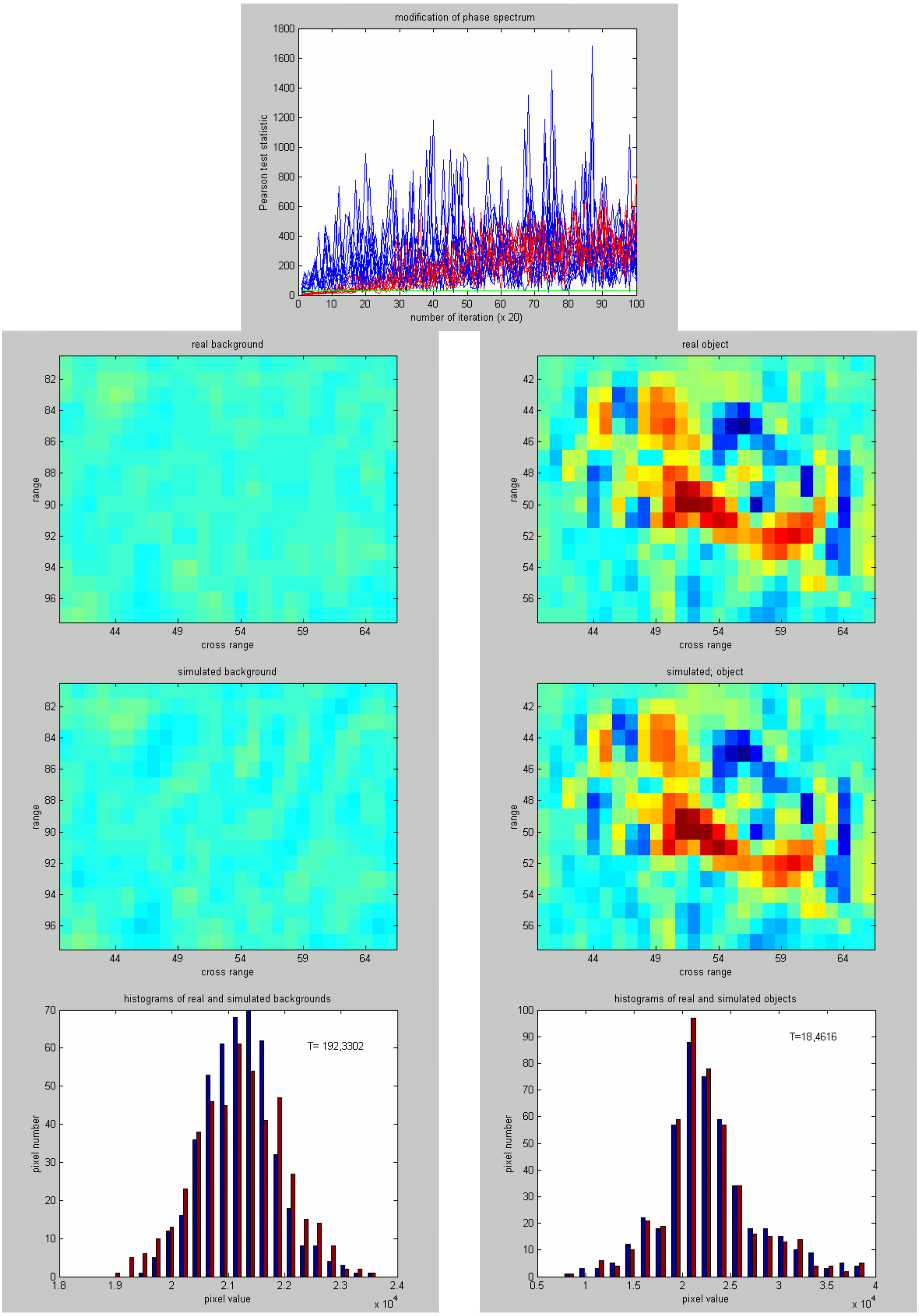

Fig. 8 Results of simulation – algorithm No 3.

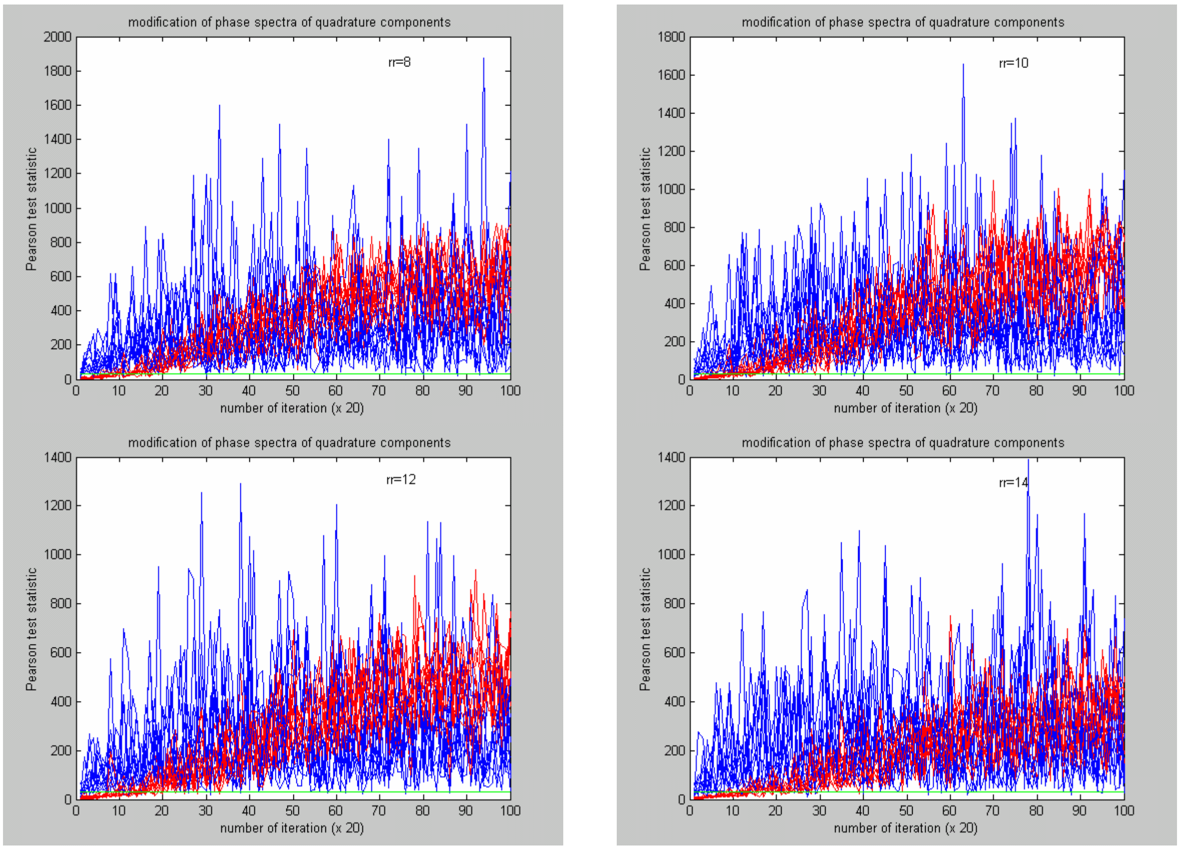

Fig.9 Pearson's test statistic for different radii of circular exclusion region rr

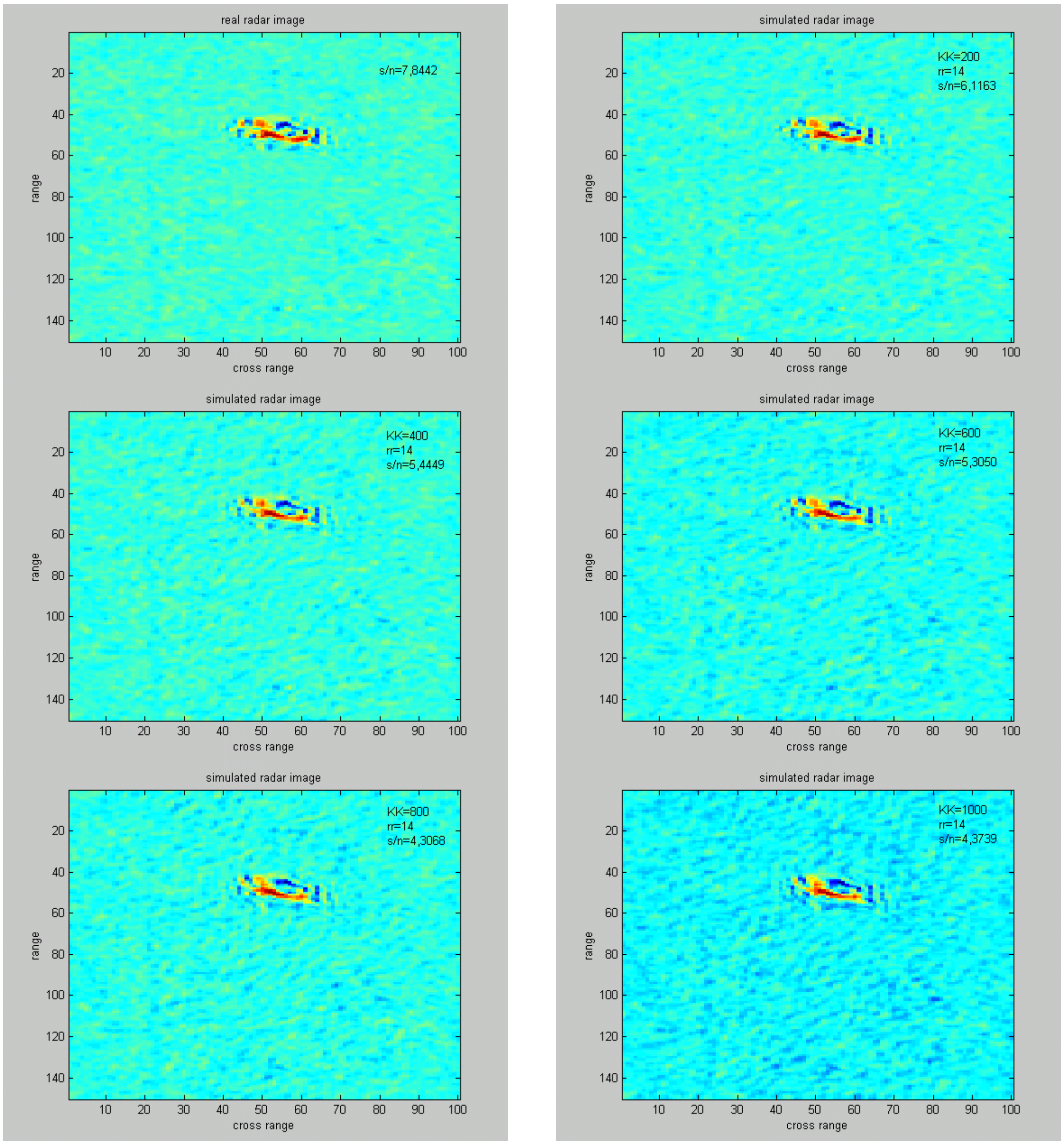

Fig.10 Signal images of different signal to noise ratio s/n obtained for different number of iteration KK and constant radius of circular exclusion region rr=14 – algorithm No 3