USING HIGHER ORDER STATISTICS FOR THE DIGITAL PROCESSING OF SUPERWIDE-BAND RADAR SIGNALS

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Abstract. A method for the estimation of the parameters of exponentially damped sinusoids based on the higher order statistics (HOS) observation of signal in the presence of additive Gaussian white and colored noise is presented. It is shown that the using of the higher order statistics for parameter estimation of the resonant model reduces to increasing of the exactitude of the estimation of poles on 5-7 dB by a comparison with traditional algorithms. Thus the gain in the signal-to-noise ratio is 10-15 dB that can allow to increase the range of superwide-band radar systems up to three times.

I. Introduction

It is well known that the transient response of an object, induced by superwide-band impulse waveform, contains all the information about the electromagnetic scattering properties of the target in the frequency band that is defined by the spectrum of the incident impulse. So this impulse response can be used as a characteristic signature of the object [1]. Most adequately the transient response of conducting objects are described by the resonant model based on the singularity expansion method [2]. The mathematical model of the late-time portion of the radar target response can be decomposed into a finite sum of damped sinusoids (excited by an incident field waveform of finite usable bandwidth), oscillating at frequencies determined purely by target geometry and size.

Many recent radar target discrimination methods have utilized the late-time natural oscillation behavior of conducting targets. Traditional parametrical methods are based on an estimation of a finite quantity of parameters describing an object, for example, the well-known Prony's method, pencil-of-function method etc. In recent years, in the scientific literature the increasing attention is given to using higher order statistics in digital signals' processing. This promotes the following facts [3]:

– the cumulants of order greater than two of Gaussian processes are zero and so they can be used to suppress noise under certain conditions;
– the cumulants of non-Gaussian processes carry higher order statistical information about the signal;
– cumulants are phase sensitive statistics.

The main purpose of this paper is investigation and development of the method of resonant model parameter estimation based on using of the higher order statistics at presence of Gaussian band-limited noise and comparison of this method with traditional methods.

II. The resonant model of superwide-band radar target signals

It is well known that the response of a conducting radar target to a band-limited transient excitation in the late time can be represented as a model consisted of a finite sum of damped sinusoids:

$$y_k = x_k + n_k = \sum_{t=1}^{M} |b_t| \exp\left[(\sigma_t + j\omega_t)k + j\varphi_t\right] + n_k , \tag{1}$$

where $k = 0, 1, ..., N-1$ are numbers of samples of signal y_k; M is the number of dominant resonances induced by an exciting field; n_k are samples of additive Gaussian noise; $|b_t|$, φ_t are the aspect and excitation dependent amplitude and phase of t-th target mode; α_t, ω_t are the aspect independent damping factor and natural frequency of t-th target mode. The signal-to-noise ratio for additive Gaussian band-limited noise was calculated according to the formula:

$$\mathrm{SNR} = 10 \cdot \lg\left(\frac{\mathrm{M}\left(x_k^2\right)}{\mathrm{M}\left(n_k^2\right)}\right), \tag{2}$$

where M(•) – denotes the mean value.

III. Numerical results

As a result of the carried out numerical experiments it was established that the 1-D slice of the third-order cumulants, consisted of the diagonal elements of the HOS sequence, is not optimum for our model. For the 2-D third-order cumulants sequence the most informative from our point of view is the 1-D slice conterminous to one of coordinate axises of the HOS sequence.

Earlier it was established, that with signal-to-noise ratio SNR = 20 dB traditional methods of parameter estimation of the resonant model, such as a Prony's method and pencil-of-function method, cease to work. So we have carried out a comparison of these methods with a third-order statistics method.

For the quantitative comparison of effectiveness of the different methods of parameter estimation of the resonant model we have used a variance of poles:

$$D = \sum_{i=1}^{K} \left(\frac{\left| z_{t,i} - z_t \right|}{б_t} \right)^2 \Big/ K, \quad (3)$$

where z_t is t-th pole of the signal; $z_{t,i}$ is estimation of t-th pole for i-th run of y_k (1); α_i is damping factor of t-th pole; K is a number of independent runs. Each sample of variance was computed from K = 50 estimates, which were perturbed by K independent Gaussian band-limited noise sequence added to x_k. The signal-to-noise ratio estimated according to the (2). The simulation results for the HOS method are depicted on Fig. 1.

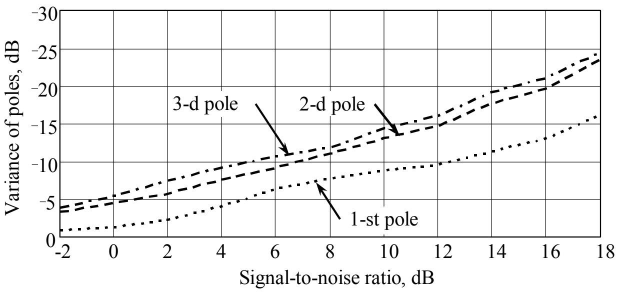

Fig. 1. Variance of the poles estimated by TOS method

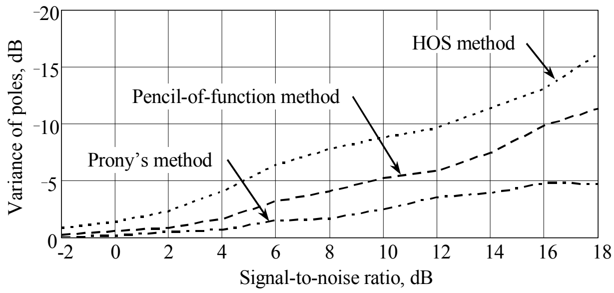

Fig. 2. Variance of the 1-st pole estimated by Prony's method, pencil-of-function method and HOS method

The analyzing of Fig. 1 shows that the exactitude of the estimation of a low-frequency pole is less than of high-frequency one and is increasing with magnification of the signal-to-noise ratio monotonically. So we have made a comparison of various methods by estimation of variation of the first pole, which has the largest variance. Fig. 2 shows that the TOS method gives estimations of poles on 5-7 dB more exact than Prony's method and pencil-of-function method for the same signal-to-noise rations. Fig. 2 also shows that if a threshold level of an exactitude of the definition of signal's poles is set, for example, by variance D = -5 dB, the Prony's method gives for the low-frequency pole only at the signal-to-noise ratio SNR = 16 dB, while the HOS method ceases to work only with SNR = 5 dB.

IV. Conclusions

The third-order statistics were used for the purpose of parameter estimation of the targets resonant models. We have determined the most informative 1-D slice conterminous to one of coordinate axises of the HOS sequence of the 2-D sequence of higher order cumulants. Comparison estimation of the HOS method with the traditional methods proved its high accuracy of the poles determination. The higher order statistics can be used as an effective tool for the determination of resonant model parameters as well in the superwide-band radar systems as in the others different applications of signals processing.

V. References

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