We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,300

Open access books available

172,000

International authors and editors

190M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Methodology for investigation of the factors for georadar signals influencing the directional pattern of synthetic aperture radar

Zolotarev I.D.
Omsk State University (OMSU)
Russia

Miller Ya.E.
ACADEMY MBF
Russia

1. Introduction

The SAR pattern width is the most significant characteristics of modern georadars providing remote sensing of the Earth within the specified radar swath. A simplified consideration of formation of the SAR directional pattern is given for an idealized case of signal pickup from the equidistant points along the vehicle trajectory at its constant travel speed. Nevertheless, the signal parameters influencing the character of the directional pattern of the synthetic aperture radar are not constant at implementation of the georadar with SAR. This results in swinging in time of the SAR directional pattern in addition to its widening; therefore, the characteristics of the detected extended object on the Earth may differ from the real ones.

The given chapter contains a new methodology for research and optimization of the directional pattern for the interferometric SAR and the calculated examples of the above-mentioned methodology. A peculiar method of transients determination in the selective filters entering the SAR path at the radar signal passing through them lies in the basis of the calculation procedure for determination of swinging of the radar antenna directional pattern. There is taken into account influence on the SAR characteristics of non-equidistance of the readings along the vehicle trajectory. The Doppler effect influence on formation of the antenna directional pattern is also under consideration. There is given the method of taking into account the out-of-parallelism of the beams for each point of the sensed surface at formation of the SAR directional pattern.

It is worth mentioning that even a small deviation of the SAR directional pattern caused (in particular) by dynamic mode of the georadar path operation may result in a considerable inaccuracy of information acquisition at remote sensing of the Earth. For example, at the vehicle altitude of $h = 500$ km and the antenna direction error of 1° , the error in determination of the coordinates of each detected point of the Earth surface is around 10 km (which is not permissible for information acquisition at remote sensing of the Earth).

The given chapter deals with consideration of a combined influence of the above-mentioned factors on the SAR characteristic. There are given recommendations on minimization of a dynamic error of the directional pattern of synthetic aperture radar.

2. Influence of transients on the interferometric SAR characteristics for the sensing pulse with rectangular envelope curve

Numerous works on the SAR equipment are devoted to formation of the directional pattern of the required type for detecting and ranging the objects with provision of the required angular resolution. The use of an interferometric approach at SAR designing permits to increase the angle resolution. A high range resolution is achieved by the maximum possible shortening of a pseudorandom sequence discrete. Formation of the antenna directional pattern (ADP) with synthetic aperture requires sampling at the specified points of the radar carrier trajectory of the amplitude and the phase of the received signal that is significantly lower than the noise level before the correlator. The task of the signal correlation processing is obtaining the required signal-to-noise ratio with the equivalent gain equal to 60-80 dB (Boerner, 2000; Boerner, 2004; Antipov et al., 1988; Filippov et al., 1994).

A significant limiting factor is the transients that inevitably take place in various sections of the signal processing path that have the frequency selective properties; these sections include a physical antenna, the phase-shifting circuits, the summers and the multipliers. Despite the fact that the problems of a steady-state mode for SAR are represented by a broad scope of research, operation of the given systems in the dynamic mode has hardly been described (Vendic & Parnes, 2002). Most probably, this may be justified by a high level of laboriousness of the oscillatory systems research with the accuracy up to a signal phase. Potential possibilities to increase the range resolution are defined by a minimal realizable duration of the sequence discrete. In this case, phase overshooting at each discrete occurring due to the transients limits the informational possibilities of the radars with the PSK and FSK signals.

The impact of transients on the SAR directional pattern is revealed in the work. The given result was acquired on the base of the "fast" inverse Laplace transform (FILT) method developed earlier by one of the authors (the method permits to get a selective system response with the accuracy up to a signal phase and provide solution to the amplitude-phase-frequency problem in radio electronics on the FILT base) (Zolotarev, 1969; Zolotarev, 1996; Zolotarev, 1999; Zolotarev et al., 2004; Zolotarev et al., 2005).

There are used the analog frequency converters for the ultra wideband signals with duration of about 1 ns after the antenna path in the SAR. In this case, the subsequent selective filters determine the resulting channel bandpass. That is why the given work deals with analysis of impact of the transients occurring in these filters on the SAR directional pattern.

There will be analyzed 2 identical unilateral selective elements as a bandpass filter (BF). The BF transfer characteristic can be written down in the form of a fractional rational function

$$K(s) = K_0 \left[\frac{s + b}{s^2 + 2\alpha s + \omega_r^2} \right]^2 = K_0 \left[\frac{s + b}{(s + \alpha)^2 + \omega_0^2} \right]^2.$$

Here the damping constant α equals to a half of the bandpass of a separate selective section, ω_r – the resonance frequency, $\omega_0 = (\omega_r^2 - \alpha^2)^{1/2}$ – the filter free frequency; let's assume $b = 2\alpha$.

The image of the radio pulse of intermediate frequency ω_{imd} with τ duration

$$f_{in}(s) = A_0 \left[\frac{s \cdot \sin \psi + \omega_{imd} \cos \psi}{s^2 + \omega_{imd}^2} - \frac{s \cdot \sin \psi_\tau + \omega_{imd} \cos \psi_\tau}{s^2 + \omega_{imd}^2} e^{-s\tau} \right], \quad \psi_\tau = \psi + \omega_{imd} \tau.$$

For the signal image at the BF output we have $f_{out}(s) = f_{in}(s)K(s)$.

Thus, according to FILT (Zolotarev et al., 2005), transition into the space of the originals gives a complex representation of the signal at the filter output

$$\begin{aligned} \dot{f}_{out}(t) = & A_0 \dot{K}(j\omega_{imd}) e^{j(\omega_{imd}t + \psi)} [1(t) - 1(t - \tau)] + 2jK_0 \sum_{l=0}^{n-1} \dot{B}_l t^{n-l-1} e^{(-\alpha + j\omega_0)t} 1(t) - \\ & - 2jK_0 \sum_{l=0}^{n-1} \dot{B}_{l,\tau} (t - \tau)^{n-l-1} e^{(-\alpha + j\omega_0)(t - \tau)} 1(t - \tau). \end{aligned} \quad (1)$$

where the complex constants $\dot{B}_l$ may be found from the expression

$$\dot{B}_l = \sum_{h=0}^s \frac{(-1)^h C_{n+h-1}^h}{(n-l-1)!(l-h)!} \cdot \frac{1}{(2j\omega_0)^{n+h}} \frac{d^{l-h}}{ds^{l-h}} \left[\frac{(s \sin \psi + \omega_{imd} \cos \psi)(s + b)^n}{s^2 + \omega_{imd}^2} \right]_{s=-\alpha + j\omega_0}.$$

Let's look for the real signal as $f_{out}(t) = \text{Im}\{\dot{f}_{out}(t)\}$.

Let's represent the complex output signal as

$$\dot{f}_{out}(t) = \dot{f}_{norm}(t) \dot{N}(t), \quad (2)$$

where the BF response to a Monoharmonic signal is assumed as a normalizing function represented as $\dot{f}_{norm}(t) = A_0 \dot{K}(j\omega_{imd}) e^{j(\omega_{imd}t + \psi)}$. $\dot{N}(t)$ – the normalized complex envelope curve of the signal at the output of the BF under investigation, module $N(t)$ characterizes the behavior of the signal envelope curve at the BF output, and function $\delta(t) = \arg\{\dot{N}(t)\}$ determines the current behavior of its phase.

For a plane wave front, the phase difference (caused by the wave arrival under the θ angle) for the base between the adjacent readings a , is determined with the expression

$$\Delta\varphi = \frac{2\pi a}{\lambda} \sin \theta. \quad (3)$$

For the side-lobe suppression, the law of the amplitude distribution along the aperture L is

chosen in the following way: $I(z) = 1 + \Delta \cos(2\pi z/L)$, $z \leq L/2$, where Δ is assumed to be equal to 0.4 (Sazonov, 1988). SAR directional pattern $F(\theta)$ for 100 readings along the spacecraft trajectory is represented in Figure 1, where θ is given in radians.

Fig. 1. SAR directional pattern

In fact, $\Delta\varphi$ will have the increment $\delta(t)$ caused by the transient. It will result in dependence of real θ on the time, i.e.

$$\theta(t) = \theta + \Delta\theta(t), \quad \Delta\theta(t) = \delta(t) \frac{\lambda}{2\pi a \cdot \cos \theta}. \quad (4)$$

Figure 2 shows the calculated charts in nondimensional time αt for the transient and the corresponding positions of the SAR directional pattern for various transient time points. The number of the readings along the spacecraft trajectory chosen for calculation equals to 100.

Fig. 2. Design parameters: Q-factor $Q = \omega_r / 2\alpha = 2$, pulse duration $\alpha\tau = 4$; 1 - $t = 0.5\tau$, 2 - $t = 0.8\tau$, 3 - $t = \tau$, 4 - $t = 1.4\tau$.

The above-mentioned charts show that “swinging” of the SAR directional pattern in respect to the one calculated for the steady-state mode increases along with the increase of the signal bandwidth and the bandpass filter. Thus, there is limited the accuracy of the direction finding according to the angular coordinates of the detected object. As modern SARs use ultra wideband signals, one should take into account the directional pattern time shift that constitutes the values comparable with the SAR beam width.

Proceeding from the actual dynamic operation mode of the system with SAR, the obtained results make it possible to estimate the limit capabilities of building the synthetic antennae that apply the interference principle.

3. Influence of transients on the interferometric SAR characteristics for sensing pulse with bell-shaped envelope curve

As it is shown in the work (Zolotarev et al., 2005), transients in the elements of the SAR formation circuit provide a significant impact on the direction of the directional pattern major maximum. In this case, when implementing the SAR radars, it is necessary to pay serious attention to the actual SAR characteristic obtained in the result of the corresponding signal conversion. Ignoring of this factor may result in rough errors at determination of the detected surface parameters. A lot of works contain a supposition that smoothing of the envelope curve shape will decrease the influence of transients on the SAR characteristic. Due to this, it seems to be important to consider the SAR formation at the use of a bell-shaped sensing signal with the Gaussian envelope curve. The radio pulses with a sinus-quadratic envelope curve are the characteristics similar to the given signal. Let's consider the SAR formation for the given signal type at various Q-factors of the antenna filters and signal duration.

There will be analyzed 3 identical unilateral selective elements as a band pass filter. The BF transfer characteristic will be written down as a fractional rational function

$$K(s) = K_0 \left[\frac{s + b}{s^2 + 2\alpha s + \omega_r^2} \right]^3, \text{ Q-factor of the filter } Q = \frac{\omega_r}{2\alpha}.$$

Here, damping constant α equals to a half of the bandpass of a separate selective section, ω_r – the resonance frequency, let's assume $b = 2\alpha$.

The sensing signal with a sinus-quadratic envelope curve is written down as

$$f_{in}(t) = A_0 \sin^2(2\Omega t) \sin(\omega_c t + \psi) [1(t) - 1(t - \tau)]. \quad (5)$$

Let's transform the last expression into the form of

$$f_{in}(t) = A_0 \left\{ \frac{1}{2} \sin(\omega_c t + \psi) - \frac{1}{4} \sin[(\omega_c - 2\Omega)t + \psi] - \frac{1}{4} \sin[(\omega_c + 2\Omega)t + \psi] \right\} [1(t) - 1(t - \tau)]$$

The image of a radio pulse with the ω_c frequency, τ duration and the bell-shaped envelope curve

$$f_{in}(s) = \frac{A_0}{2} \left[\frac{s \cdot \sin \psi + \omega_c \cos \psi}{s^2 + \omega_c^2} - \frac{s \cdot \sin \psi_\tau + \omega_c \cos \psi_\tau}{s^2 + \omega_c^2} e^{-s\tau} \right] -$$

$$- \frac{A_0}{4} \left[\frac{s \cdot \sin \psi + (\omega_c + 2\Omega) \cos \psi}{s^2 + (\omega_c + 2\Omega)^2} - \frac{s \cdot \sin \psi_\tau + (\omega_c + 2\Omega) \cos \psi_\tau}{s^2 + (\omega_c + 2\Omega)^2} e^{-s\tau} \right] -$$

$$- \frac{A_0}{4} \left[\frac{s \cdot \sin \psi + (\omega_c - 2\Omega) \cos \psi}{s^2 + (\omega_c - 2\Omega)^2} - \frac{s \cdot \sin \psi_\tau + (\omega_c - 2\Omega) \cos \psi_\tau}{s^2 + (\omega_c - 2\Omega)^2} e^{-s\tau} \right],$$

$$\psi_\tau = \psi + \omega_c \tau.$$

We have $f_{out}(s) = f_{in}(s)K(s)$ for the signal image at the BF output.

Then, according to the FILT (Zolotarev, 1969; Zolotarev et al., 2004; Zolotarev et al., 2005), the transition into space of the originals gives a complex representation of the signal at the filter output $\dot{f}_{out}(t)$, the real signal will be found as $f_{out}(t) = \text{Im}\{\dot{f}_{out}(t)\}$.

Let's represent the complex output signal as

$$\dot{f}_{out}(t) = \dot{f}_{norm}(t)\dot{N}(t),$$

where the BF response to a Monoharmonic signal is assumed as a normalizing function represented as $\dot{f}_{norm}(t) = A_0 \dot{K}(j\omega_c) e^{j(\omega_c t + \psi)}$. $\dot{N}(t)$ - the normalized complex envelope curve of the signal at the output of the BF under investigation, module $N(t)$ characterizes behavior of the signal envelope curve at the BF output and function $\delta(t) = \arg\{\dot{N}(t)\}$ determines the current behavior of its phase.

Concerning the plane wave front, the phase difference (caused by a wave arrival under the θ angle) for the base between the adjacent readings a , is determined with the expression

$$\Delta\varphi = \frac{2\pi a}{\lambda} \sin \theta.$$

In fact, $\Delta\varphi$ will have increment $\delta(t)$ caused by the transient. It will result in dependence of real θ on the time, i.e.

$$\theta(t) = \theta + \Delta\theta(t), \quad \Delta\theta(t) = \delta(t) \frac{\lambda}{2\pi a \cdot \cos \theta}.$$

Figure 3, 4 shows the calculated charts in nondimensional time at for the transient and the corresponding positions of the SAR directional pattern for various time points of transients. The number of readings along the spacecraft trajectory chosen for calculation at the SAR formation equals to 1000, $a = \lambda/2$, $\lambda = 0.1$ m.

Fig. 3. Design parameters: Q-factor $Q = \omega_r / 2\alpha = 25$, pulse duration $\alpha\tau = 8$; 1 - $t = 0.5\tau$, 2 - $t = 0.8\tau$, 3 - $t = \tau$, 4 - $t = 1.4\tau$.

Fig. 4. Design parameters: Q-factor $Q = 5$, pulse duration $\alpha\tau = 8$; 1 - $t = 0.5\tau$, 2 - $t = 0.8\tau$, 3 - $t = \tau$, 4 - $t = 1.4\tau$.

As it proceeds from the calculated charts (Figure 3, 4), the maximum of the SAR directional pattern turns out to be shifted for the bell-shaped (sinus-quadratic) pulse regarding the case of the transients' absence. This shift depends on the filters Q-factor value and rises together with the increase of the signal bandwidth and also depends on the current time of the transient. With the flight altitude being $h = 5000$ m, this shift in the horizontal plane for the object that is being detected reaches considerable values of about several hundreds meters. That is why when designing radars with the SAR, it is necessary to pay serious attention to minimization of the error caused by the transients in the antenna circuit.

4. Research of the effect produced by transients on the correlation properties of the signals with pseudorandom phase shift keying in the systems of the radar remote sensing of the Earth

Significance of modern radar methods of sensing the Earth caused rapid development of the given scientific and engineering areas and their practical application in various research fields of the Earth geostructure. The most important parameters determining quality of these systems are the lock range in the plane that is perpendicular to the carrier path, narrowing of the directional pattern owing to the antenna aperture synthesis as well as the duration of a sensing radio pulse signal providing sequential scanning of the Earth surface along the narrow directional pattern of the synthetic antenna. Nowadays the range resolution of about ten centimeters (at sequential scanning) is treated as the upper reachable limit for the systems of the Earth Remote Sensing (ERS) (Zolotarev et al., 2006). In this case, the value of High Frequency (HF) filling of the radar signal is usually about 3-10 GHz. One of the most important requirements for the given systems is a high level of coherence of HF filling of the sensing signals that is required to form the narrow directional pattern of the antenna with a synthetic aperture. The second requirement proceeds from the necessity to ensure the signal level high increase over the interference signal when making the decision concerning the properties of the Earth surface sensed area. The above-mentioned requirement justifies formation of a pseudorandom sequence of the sensing radar signal with phase shift keying. In this case, the extraction of a low-level signal from the noise is carried out by the correlation device (Varakin, 1985) which is the "heart" of the ERS system. As the sensing signals are distinguished by high frequencies of HF filling, it is necessary to convert frequency (for their primary processing) with use of the intermediate frequency (IF) filters. In this case, the minimal filling frequency constitutes the value of around 1 GHz. With the current level of the processor equipment development, the given condition requires usage of the analogous IF filters at primary processing of the received signal. The unavoidable transients appearing in this case lead to distortion of the phase and envelope curve of each sequence element, and in the end they may result in a significant deterioration of the ERS system correlation device operation (Zolotarev et al., 2004; Zolotarev et al., 2005). However, laboriousness and inconvenience of obtaining the accurate solutions for analyzing the correlator operation with the filters resulted in almost complete lack of the research conducted in the given direction. This prevents from obtaining reliable recommendations when building the ERS system correlator and makes one decide in favor of the idealized model of its operation.

The new results obtained in the given work on the basis of the fast inverse Laplace transform method (Zolotarev, 1969; Zolotarev, 2004) ensuring description of the transient

with the accuracy of up to a signal phase, make it possible to get reliable recommendations when building the high-precision ERS equipment that applies correlation processing of the signals. Figure 5 shows an example of a pseudorandom sequence (PRS) at the output of the correlation device for the ERS system.

Fig. 5. Calculated parameters: element duration $\tau = 10$ ns, IF filter frequency 1 GHz, sequence length $N = 31$, interference-to-signal ratio $P_n / P_s = 10$.

In the system under implementation the PRS duration constitutes 1023 elements which allows a significant signal level increase above the noise. This permits (owing to the use of the polarity effects and a thin phase structure of the central peak of the correlation function) to obtain important additional information on the results of scanning the Earth.

Fig. 6. 1 – ACF for the signal undistorted by the transient; 2 – CCF for the signals from the main path and the reference one; 3 – CF, the reference signal coincides (in its form) with the input signals that have passed through the filters.

One of the ways of building the correlation function for the correlator with filters is that a high frequency component is filtered after the signal correlation processing by means of frequency conversion. Figure 6 shows the output signal for the given case. Curves *b* and *c* correspond to the PRS passing through the detuned filter (the value of detuning equals to a half of the bandpass filter).

The proper operation of the system may be ensured only with the transients taken into account, and in particular, when applying normalization of the levels subject to combination of the parameters of the filters and the signal.

Fig. 7. Correlation function for the sequence with a 1023-element length.

Fig. 8. The correlation peak at the enlarged scale: 1 – ACF for the signal undistorted by transient; 2 – CCF for the signals from the main path and the reference one.

As it proceeds from Figure 6, the transients provide a significant impact on the form of the signal at the correlator output in case of a relatively small number of the elements of

sequence. Thus the range resolution of the ERS system becomes worse. If there is a considerable increase in the sequence length (in this case it is 1023 elements), the influence of the transients on the range resolution reduces significantly. However, as the research conducted revealed, the transients provide a considerable impact on the dynamic shift of the synthetic antenna directional pattern and therefore, there is a decrease in the accuracy of the object location on the Earth surface (Zolotarev et al., 2005; Zolotarev et al., 2006).

5. Research of the influence of transients, non-equidistance of the taken readings, divergence of beams on the interferometric SAR characteristics

There is under consideration a combined influence of the transients in the filters of the radar system selective circuits, non-equidistance of the taken readings and divergence of the beams at the distance up to the Earth surface reflecting elements that is comparable with a synthetic antenna aperture value. There is taken into account influence of the above-mentioned factors on the resolution capability of the radar system for the Earth remote sensing. The transients lead to swinging of the SAR antenna pattern; the other indicated factors result in widening of the synthetic antenna pattern. There are given the corresponding relationships and diagrams that make it possible to take into account the influence of the above-mentioned factors and determine the ways for reduction of the destructive factors influence on the synthetic antenna pattern.

The results of the work are original as a combined influence of the factors has not been under consideration before. According to the calculation results, the factors provide a rather considerable influence on the form of the antenna directional pattern that may result in serious errors when determining the characteristics of the extended object lying within the radar swath.

The research conducted in the given work has revealed that it is impossible to develop the radar system with application of the interferometric SAR without an obligatory consideration of the combined influence of the indicated factors on the SAR ADP.

1. Influence of the transients in the selective filters and the antenna-feeder section of the system path forming the SAR. In this case, there is under consideration the case of application of the identical filters in the selective path that is extremely complicated for analysis. To conduct research of the transients influence, there was applied the method developed in (Zolotarev, 1969; Zolotarev, 2004), providing a fast inverse Laplace transform at conducting research of the dynamic modes of oscillatory systems. As the systems of interferometric SAR formation are the phase ones, it is highly necessary to apply the given method, as it allows obtaining of the exact analytical expressions with the accuracy of up to a phase for the response of the system selective path to the radiofrequency pulse excitation.

The band filter represented by 4 identical unilateral selective elements will be under consideration as a selective path. The transfer characteristic of the BF will be written down as a fractional rational function

$$K(s) = K_0 \left[\frac{s + b}{s^2 + 2\alpha s + \omega_r^2} \right]^4, \text{ Q-factor of filter } Q = \frac{\omega_r}{2\alpha}.$$

Here damping constant α equals to a half of the bandpass of a separate selective section, ω_r – resonance frequency, let's assume $b = 2\alpha$.

The sensing signal with a rectangular envelope is written down as

$$f_{in}(t) = A_0 \sin(\omega_c t + \psi) [1(t) - 1(t - \tau)]$$

The image of a radio pulse with the ω_c frequency and τ duration

$$f_{in}(s) = A_0 \left[\frac{s \cdot \sin \psi + \omega_c \cos \psi}{s^2 + \omega_c^2} - \frac{s \cdot \sin \psi_\tau + \omega_c \cos \psi_\tau}{s^2 + \omega_c^2} e^{-s\tau} \right],$$

$$\psi_\tau = \psi + \omega_c \tau$$

We have $f_{out}(s) = f_{in}(s)K(s)$ for the signal image at the BF output.

In this case, according to the FILT (Zolotarev, 1969; Zolotarev, 2004), transition into the space of the originals gives a complex representation of the signal at the filter output $\dot{f}_{out}(t)$, the real signal may be found as $f_{out}(t) = \text{Im}\{\dot{f}_{out}(t)\}$.

Let's represent the complex output signal as

$$\dot{f}_{out}(t) = \dot{f}_{norm}(t)\dot{N}(t),$$

where the BF response to a Monoharmonic signal is assumed as a normalizing function represented as $\dot{f}_{norm}(t) = A_0 \dot{K}(j\omega_c) e^{j(\omega_c t + \psi)}$. $\dot{N}(t)$ - the normalized complex envelope curve of the signal at the output of the BF under investigation, module $N(t)$ characterizes behavior of the signal envelope curve at the BF output and function $\delta(t) = \arg\{\dot{N}(t)\}$ determines the current behavior of its phase.

Concerning the plane wave front, the phase difference (caused by a wave arrival under the θ angle) for the base between the adjacent readings a , is determined with the expression

$$\Delta\varphi = \frac{2\pi a}{\lambda} \sin \theta$$

In fact, $\Delta\varphi$ will have the increment $\delta(t)$ caused by the transient (Zolotarev et al., 2006). It will result in dependence of the real θ on the time, i.e.

$$\theta(t) = \theta + \Delta\theta(t), \quad \Delta\theta(t) = \delta(t) \frac{\lambda}{2\pi a \cdot \cos \theta}.$$

Figure 9 shows the calculated charts of the corresponding positions of the SAR directional pattern for various time points of the transients. The number of the readings along the vehicle trajectory chosen for calculation at the SAR formation $N = 500$, $a = \lambda/2$, $\lambda = 0.1$ m.

Fig. 9. Calculated parameters: Q-factor of selective system $Q = \omega_r / 2\alpha = 25$, pulse duration $\alpha\tau = 4$; 1 – $t = 0.2\tau$; 2 – $t = 0.4\tau$; 3 – $t = 0.6\tau$; 4 – $t = 0.8\tau$

As it proceeds from the calculated charts (Figure 9), the maximum of the SAR directional pattern turns out to be shifted regarding the case of the transients' absence. This shift depends on the filters Q-factor value and rises together with the increase of the signal bandwidth and depends on the current time of the transient. When the flight altitude $h = 4,000$ m, this shift in a horizontal plane for the detected object reaches considerable values of about several hundred meters. That is why when designing radars with the SAR, it is necessary to pay special attention to minimization of the error caused by the transients in the antenna circuits.

2. Non-equidistance of the taken readings along the vehicle trajectory is an important factor that shall be taken into account at the SAR ADP formation.

Now, unlike the previous point, we will consider the base between the adjacent readings as a random quantity corresponding to the Gaussian law. Let $\{a_i\}$ be a sequence of the distances between the adjacent readings of the reflected signal along the vehicle trajectory with the mean value equal to a and the dispersion σ . So, the difference of the phases between the adjacent readings may be determined with the following expression:

$$\Delta\varphi_i(\theta) = \frac{2\pi \cdot \sin(\theta) \cdot a_i}{\lambda}, \quad i = 1..N. \quad (6)$$

Then there is used an interferometric approach for building the SAR ADP, the number of the readings taken along the vehicle trajectory is assumed equal to 500 (Figure 10). For a sidelobe suppression (Figure 11) the amplitude distribution law along the aperture L is chosen in the following way $I(z) = 1 + \Delta \cos(2\pi z/L)$, $z \leq L/2$, where Δ assume equal to 0.4 (Sazonov, 1988).

Fig. 10. Interferometric SAR ADP.

Fig. 11. Interferometric SAR ADP with sidelobe suppression.

The obtained charts show that the increase in dispersion for the distance between the adjacent readings results in a significant increase in the value of the SAR ADP sidelobes. As the research shows, to minimize the ADP sidelobe level, it is necessary to decrease the dispersion value. Introduction of the cosine amplitude distribution of the readings due to aperture (Figure 11) also contributes to it.

3. A significant deterioration of the angle selectivity at the SAR directional pattern formation is determined by out-of-parallelism of the beams for each point of the sensed surface (Figure 12). The vehicle altitude increase above the surface is also a means for reducing out-of-

parallelism of the beams. As a rule, the vehicles with a greater altitude have a greater velocity (for example, the low-altitude vehicles - up to 5 km, jet planes - about 10 km, medium-altitude satellites - about 1,500 km). Correspondingly, there is increase in the number of the readings taken within the same time interval that contributes to narrowing the SAR ADP.

In case of taking into consideration out-of-parallelism of the beams, the difference of the phases between the signals of the adjacent readings is written down in the following way:

$$\Delta\varphi(\theta) = \frac{2\pi}{\lambda} h \left(\sqrt{1 + \left(\operatorname{tg} \theta + \frac{a}{h} \right)^2} - \frac{1}{\cos \theta} \right). \quad (7)$$

Building of the SAR directional pattern shall be carried out as in the previous cases.

Fig. 12. SAR ADP at $N = 500$; beam parallelism case — 1, out-of-parallelism case: 2 — vehicle's altitude $h = 4,000$ m; 3 — $h = 3,000$ m

One shall keep in mind that increase in the velocity altitude for maintaining the radio links energetics requires increase in the radiant power of the transmitter installed on the vehicle. The research conducted revealed that all the above-indicated factors provide a significant impact on the SAR ADP characteristics. It is worth mentioning that when designing the corresponding systems (for example, radar remote sensing of the Earth), it is necessary to pay special attention to minimization of the locating angle dynamic error by means of time shifting of the directional pattern. In this sense one should refer to the methods of compensation of the transients in the selective filters of the path.

Another significant factor providing an impact on the SAR ADP is out-of-parallelism of the beams. Here one can come across some contradictions as at present a special attention is paid to the large-scale ground maps that require application of the flight vehicles at relatively low altitudes.

Non-equidistance of the readings also provides an impact on the quality of the formed SAR ADP. That is why it is important to ensure the equipment building with a rigid timing of the reflected signal readings.

6. Influence of a combination of factors on the character of synthetic aperture radar directional pattern: transients, non-equidistance of the readings and out-of-parallelism of the beams at the Earth remote sensing

There is under consideration a combined influence of the transients in the filters of the radar system selective circuits, non-equidistance of the taken readings and divergence of the beams at the distance up to the Earth surface reflecting elements that is comparable with the synthetic antenna aperture value. The transients lead to swinging of the SAR antenna pattern; the other indicated factors result in widening of the synthetic antenna pattern and a sidelobe increase.

A combined influence of the factors was not under consideration before, though they provide a rather considerable influence on the form of the antenna directional pattern which may result in serious errors when determining the characteristics of the extended object lying within the radar swath (Zolotarev et al., 2007).

There is under investigation influence of the transients in the selective filters of the system path forming the SAR. In this case, there is under consideration application of the identical filters in the selective path that is extremely complicated for analysis. To conduct research of the transients influence, there was applied the method developed in (Zolotarev, 1969; Zolotarev, 2004), providing a fast inverse Laplace transform at conducting research of the dynamic modes of oscillatory systems. As there are interferometric SARs under investigation, it is necessary to apply the given method, as it allows obtaining of the analytical expressions with the accuracy of up to a phase for the response of the system selective path to the radiofrequency pulse excitation.

The band filter represented by 4 identical unilateral selective elements will be under consideration as a selective path. The transfer characteristic of the BF will be written down as a fractional rational function

$$K(s) = K_0 \left[\frac{s + b}{s^2 + 2\alpha s + \omega_r^2} \right]^4, \text{ Q-factor of filter } Q = \frac{\omega_r}{2\alpha}, \text{ assume } b = 2\alpha.$$

The sensing signal with a rectangular envelope curve will be written down as

$$f_{in}(t) = A_0 \sin(\omega_c t + \psi) [1(t) - 1(t - \tau)]$$

The image of a radio pulse with the ω_c frequency and τ duration

$$f_{in}(s) = A_0 \left[\frac{s \cdot \sin \psi + \omega_c \cos \psi}{s^2 + \omega_c^2} - \frac{s \cdot \sin \psi_\tau + \omega_c \cos \psi_\tau}{s^2 + \omega_c^2} e^{-s\tau} \right],$$

$$\psi_\tau = \psi + \omega_c \tau.$$

We will have $f_{out}(s) = f_{in}(s)K(s)$ for the signal image at the BF output. According to the FILT (Zolotarev, 1969; Zolotarev, 2004), transition into the space of the originals gives a complex representation of the signal at the filter output $\dot{f}_{out}(t)$, the real signal can be found as

$$f_{out}(t) = \text{Im}\{\dot{f}_{out}(t)\}.$$

Let's represent the complex output signal as

$$\dot{f}_{out}(t) = \dot{f}_{norm}(t)\dot{N}(t),$$

where the BF response to a Monoharmonic signal is assumed as a normalizing function represented as $\dot{f}_{norm}(t) = A_0 \dot{K}(j\omega_c) e^{j(\omega_c t + \psi)}$, module of multiplicative function $N(t)$ characterizes behavior of the signal envelope curve at the BF output and function $\delta(t) = \arg\{\dot{N}(t)\}$ determines the current behavior of its phase.

Concerning the plane wave front, the phase difference (caused by the wave arrival under the θ angle) for the base between the adjacent readings a , is determined with the expression

$$\Delta\varphi = \frac{2\pi a}{\lambda} \sin \theta.$$

In fact, $\Delta\varphi$ will have the increment $\delta(t)$ caused by the transient (Zolotarev et al., 2006). It will result in dependence of the real θ on the time, i.e.

$$\theta(t) = \theta + \Delta\theta(t), \quad \Delta\theta(t) = \delta(t) \frac{\lambda}{2\pi a \cdot \cos \theta}.$$

Non-equidistance of the taken readings along the vehicle trajectory is an important factor that shall also be taken into account at the SAR ADP formation.

Let's consider the base between the adjacent readings as a random quantity corresponding to the Gaussian law. Let $\{a_i\}$ be sequence of the distances between the adjacent readings of the reflected signal along the vehicle trajectory with the mean value equal to a and the dispersion σ . So, the difference of the phases between the adjacent readings may be determined with the following expression:

$$\Delta\varphi_i(\theta) = \frac{2\pi \cdot \sin(\theta) \cdot a_i}{\lambda}, \quad i = \overline{1..n}.$$

A significant deterioration of the angle selectivity at the SAR directional pattern formation is conditioned by out-of-parallelism of the beams for each point of the sensed surface. The vehicle altitude increase above the surface is also a means for reducing out-of-parallelism of the beams. Correspondingly, there is increase in the number of readings taken for the same time interval that contributes to narrowing the SAR ADP.

In case of taking into consideration out-of-parallelism of the beams, the difference of the phases between the signals of the adjacent readings is written down in the following way:

$$\Delta\varphi(\theta) = \frac{2\pi}{\lambda} h \left(\sqrt{1 + \left(\operatorname{tg} \theta + \frac{a}{h} \right)^2} - \frac{1}{\cos \theta} \right).$$

For a sidelobe suppression (Figure 13) the amplitude distribution law along the aperture L is chosen in the following way $I(z) = 1 + \Delta \cos(2\pi z/L)$, $z \leq L/2$, where Δ is assumed equal to 0.4 (Sazonov, 1988).

Fig. 13. Synthetic antenna directional pattern without taking into account the destructive factors (transients, non-equidistance of the taken readings, out-of-parallelism of the beams). $n = 500$, $a = \lambda / 2$, $\lambda = 0.1$ m.

Fig. 14. Dynamic of the SAR directional pattern behavior when taking into account influence of the transients. The calculated parameters are chosen the same as the ones in Figure 13, but there is taken into account availability of 4 identical filters in the system selective path, Q-factor of the selective system $Q = \omega_r / 2\alpha = 25$, pulse duration $\alpha\tau = 4$.

Fig. 15. In this figure there is taken into account a combined influence of the 3 indicated factors determining deformation of the SAR directional pattern: $\sigma = 0,25$, vehicle altitude $h = 4,000$ m.

7. Conclusion

The conducted research revealed that transients provide the most critical influence on the SAR directional pattern. It is difficult to eliminate the dynamic error of the SAR ADP, and at a high flight altitude of modern vehicles even a small angle deviation results in a wrong estimation of the location of a surface-reflecting element. It is worth mentioning that when designing the corresponding systems (for example, a radar remote sensing of the Earth), special attention shall be paid to minimization of the dynamic error of the locating angle due to the directional pattern time shifting.

Increase in the distance dispersion between the adjacent readings results in a significant increase in the SAR ADP sidelobes. That is why it is important to ensure equipment building with a rigid timing of the reflected signal readings. As research shows, to minimize the ADP sidelobe level, it is necessary to decrease the dispersion value.

Another significant factor providing an impact on the SAR ADP is out-of-parallelism of the beams. At present a special attention is paid to the large-scale ground maps that require application of the flight vehicles at relatively low altitudes. In this case, the factor of out-of-parallelism of the beams demonstrates itself more vividly.

In general, when designing the SAR implementation systems, it is necessary to take into consideration a combined influence of all the discussed factors.

8. Acknowledges

The authors would like to express our sincere gratitude to T.O. Pozharsky, an OmSU post-graduate student for the calculations he made and for his active participation in the debates of the results. Mr. Pozharsky derived the formula (7) that takes into account the influence of divergence of the beams.

9. References

- Antipov, V.N.; Goryainov, V.T. & Kulin, A.N. (1988). *Radar Stations with Digital Synthesizing of Antenna Aperture*, under the editorship of V.T. Goryainov, M.: Radio and Communication, 1988. – p. 304.
- Boerner, W.-M. (2000). *Invited Lecture for the Fifteens Anniversary of Radio Engineering Faculty of Tomsk State University of Control Systems and Electronics*, Tomsk, Russia, 2000 October 12.
- Boerner, W.-M. (2004). *From Airborne Via Drones To Space-Borne Polarimetric-Interferometric SAR Environmental Stress-Change Monitoring – A Comparative Assessment Of Its Applications*, Proceedings on EUSAR2004 5th European Conference on Synthetic Aperture Radar, Ulm, Germany, 2004, May 25-27.
- Filippov, V.S.; Ponomarev, L.I. & Grinev, A.Y. (1994). *Antennae and Microwave Devices. Designing of the Phased Array Antennae* / under the editorship of D.I. Voskresensky, M.: Radio and Communication, 1994. – p. 592.
- Sazonov, D.M. (1988). *Antennae and Microwave Devices*, Book for the University Radio-Technical Specialties. - M.: Higher School, 1988. – 432 p.
- Varakin, L.E. (1985). *Communication Systems with Noise-Like Signals*, M.: Radio and Communication, 1985.

- Vendic, O.G. & Parnes, M.D. (2002). *Antennae with Electric Scanning*, M.: Science-press, 2002, - p. 232.
- Zolotarev, I.D. (1969). *Transient Processes in Resonance Amplifiers of the Pulse-Position Measuring Systems*, Novosibirsk: - Science. - Siberian Division of USSR Academy of Sciences. - 1969.
- Zolotarev, I.D. (1996). *The new Approach in Determination of the Problem "Amplitude, Phase, Frequency" in the Theory of Signals and Systems*, Abstracts of the XXV General Assembly URSI. - Lille. - France. - 1996.
- Zolotarev, I.D. (1999). *Complex Signal and the Problem of the Amplitude-Phase-Frequency for Ultra Wideband Processes*. Collection of the papers of the V international scientific and technical conference "Radiolocation, Navigation, Communication". - Voronezh: VNIIS, 1999. - v. 1. - p. 348-356.
- Zolotarev, I.D. (2004). *The Method Simplifying Inverse Laplace Transformation At Oscillatory Processes Researches. The "Amplitude, Phase, Frequency" Problem In Radioelectronics And Its Solution*, Tutorial. - Omsk: OmsU Publishing, 2004. - 132 p.
- Zolotarev, I.D.; Miller, Ya.E. & Pozharsky, T.O. (2004). *Research of Passing of Ultrawideband Phase-Shift Keyed (PSK) Radar Signals Through Selective Filter at Various Forms of Enveloping Curves of Discrete*, Abstracts RADAR2004 International Conference on Radar Systems, Toulouse, France, 2004, October 18-22.
- Zolotarev, I.D.; Miller, Ya.E. & Pozharsky, T.O. (2005). *Research of Deformation of Fine Phase Structure of Ultra Wideband Radar Signals when Passing Through System of Identical Selective Filters*, IGARSS 2005 Proceedings, 0-7803-9051-2/05 2005 IEEE, COEX, Seoul, Korea, 2005, July 25-29.
- Zolotarev, I.D.; Miller, Ya.E. & Pozharsky, T.O. (2005). *Influence of transients on the interferometric SAR characteristics*, "CEOS SAR Workshop 2005" Materials. - Adelaide. - Australia. - 2005.
- Zolotarev, I.D.; Miller, Ya.E. & Pozharsky, T.O. (2006). *Influence of transients on the interferometric SAR characteristics*, 6th European Conference on SAR "EUSAR 2006" Materials, Dresden, Germany, 16-18 May, 2006.
- Zolotarev, I.D.; Miller, Ya.E. & Pozharsky, T.O. (2007). *Research of influence of transients, non-equidistance of the taken readings, divergence of beams on characteristics of interferometric SAR*, Proceedings of the IEEE International Geoscience And Remote Sensing Symposium "IGARSS 2007", Barcelona, Spain, 23-27 July, 2007.

Geoscience and Remote Sensing

Edited by Pei-Gee Peter Ho

ISBN 978-953-307-003-2

Hard cover, 598 pages

Publisher InTech

Published online 01, October, 2009

Published in print edition October, 2009

Remote Sensing is collecting and interpreting information on targets without being in physical contact with the objects. Aircraft, satellites ...etc are the major platforms for remote sensing observations. Unlike electrical, magnetic and gravity surveys that measure force fields, remote sensing technology is commonly referred to methods that employ electromagnetic energy as radio waves, light and heat as the means of detecting and measuring target characteristics. Geoscience is a study of nature world from the core of the earth, to the depths of oceans and to the outer space. This branch of study can help mitigate volcanic eruptions, floods, landslides ... etc terrible human life disaster and help develop ground water, mineral ores, fossil fuels and construction materials. Also, it studies physical, chemical reactions to understand the distribution of the nature resources. Therefore, the geoscience encompass earth, atmospheric, oceanography, pedology, petrology, mineralogy, hydrology and geology. This book covers latest and futuristic developments in remote sensing novel theory and applications by numerous scholars, researchers and experts. It is organized into 26 excellent chapters which include optical and infrared modeling, microwave scattering propagation, forests and vegetation, soils, ocean temperature, geographic information , object classification, data mining, image processing, passive optical sensor, multispectral and hyperspectral sensing, lidar, radiometer instruments, calibration, active microwave and SAR processing. Last but not the least, this book presented chapters that highlight frontier works in remote sensing information processing. I am very pleased to have leaders in the field to prepare and contribute their most current research and development work. Although no attempt is made to cover every topic in remote sensing and geoscience, these entire 26 remote sensing technology chapters shall give readers a good insight. All topics listed are equal important and significant.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Zolotarev I.D. and Miller Ya.E. (2009). Methodology for Investigation of the Factors for Georadar Signals Influencing the Directional Pattern of Synthetic Aperture Radar, Geoscience and Remote Sensing, Pei-Gee Peter Ho (Ed.), ISBN: 978-953-307-003-2, InTech, Available from:
<http://www.intechopen.com/books/geoscience-and-remote-sensing/methodology-for-investigation-of-the-factors-for-georadar-signals-influencing-the-directional-patter>

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai

www.intechopen.com

Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

IntechOpen

IntechOpen

© 2009 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](https://creativecommons.org/licenses/by-nc-sa/3.0/), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.

IntechOpen

IntechOpen