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INTEGRATED AND MAXIMAL SIDELOBE LEVELS OF NOISE SIGNAL

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One of the most important characteristics of a radar signal is sidelobes level. It is known that it is possible to build a noise signal generator with power spectrum shape close to Gaussian. Such signal can provide rather low sidelobe level. On the other hand, it is well known that randomness of noise signals leads to randomness of resulting range profiles which is observed as residual fluctuations of autocorrelation also called as processing noise or noise floor. Increase of signal time-bandwidth product leads to decreasing of such residual fluctuations. Residual fluctuations can be a big drawback of noise signal for some applications and can be neglected in other ones. Current work is dedicated to numerical and experimental investigation of properties of noise signal. Because residual fluctuations are spread over the range profile, we have chosen such parameter as integrated sidelobe ratio of the signal (ISLR) to be used for analysis of the signal performance. We estimated ISLR for modeled noise signal with various parameters. Besides, through analysis of reference channel of existing noise radars we estimated ISLR for real systems.

Keywords: sidelobes, noise signal, residual fluctuations.

1. INTRODUCTION

Main characteristics of radar signal are range resolution and sidelobe ratio. Normally, resolution is specified by width of autocorrelation function of the signal. Resolution describes the minimal distance between targets responses at which they can be detected separately. Sidelobe level is measured as amplitude difference between the main peak and side peaks of the autocorrelation function. In practice low sidelobe level enables detection of weaker targets in the presence of stronger ones. In the case of correlation receiver both resolution and sidelobes level are specified by the frequency spectrum shape of the signal. There are numerous approaches to making signals having low sidelobe levels [1]. One of the possible solutions among them is generation of noise signal having power spectrum shape close to Gaussian [2]. This can be achieved by generation of low frequency noise signal with Gaussian probability distribution and using it for modulation of voltage controlled oscillator. This gives random signal with smooth frequency spectrum having low sidelobes. Besides low sidelobes level such noise waveform gives additional benefits to the radar such as best electromagnetic compatibility, high interference immunity, low probability of interception. On the other hand, noise signals suffer from residual fluctuations in range profiles [2, 3]. Those residual fluctuations are caused by randomness of the signal. They have noise-like structure and depend on the time-bandwidth product of the sounding signal rather than on spectrum shape. Nevertheless, their influence on the resulting performance of the radar is similar to influence of sidelobes: they lead to masking of weak responses by the strong ones. Current work is devoted to numerical and experimental investigation of sidelobes of noise waveform. In order to characterize the sidelobe levels over the range profile we have chosen such parameter as integral sidelobe ratio (ISLR). It is given as ratio between energies of mainlobe and sidelobes. We analyze variation of the ISLR as function of signal base. We start by description of basic principles through numerical simulation and then give some results of experimental investigation. The latter has been done using noise signal taken from channels of Ground-based Noise waveform SAR systems operating in Ka-band and X-band [4, 5]. In the first system noise signal is generated using frequency modulation of VCO by thermal noise. In the second one it is made using generator based upon dynamical chaotization of microwave oscillations. As the result we find parameters of the radar under which ISLR is limited by residual fluctuations and under which it is determined by the autocorrelation function sidelobes.

2. ISLR OF NOISE SIGNAL

ISLR is relation of total energy of the sidelobes to the energy of the mainlobe. Normal sidelobe ratio describes how effective the signal is for detection of two targets with various amplitudes. ISLR describes properties of the signal for conditions when multiple objects are likely to be present in the range profile. We evaluated it as sum of squares of all corresponding discrete values. It must be noted that integration is done for the limited time period which cuts off part of the sidelobes energy. This simplification was used because in most practical applications ranges of observable targets with significant response amplitude are limited by physical factors.

Fig. 1 shows example of modeling of ISLR for noise signal for various numbers of integrated pulses and ISLR for chirp and windowing function. Pulses are assumed to be independent from each other. It can be seen that integration of large numbers of pulses lead to approach of the resulting ISLR to that of the window. Residual fluctuations at lower widths of the window are caused by decrease of the time-bandwidth product of the signals.

3. EXPERIMENTAL INVESTIGATION OF NOSE RADAR ISLR

We estimated ISLR using the described above approach for two radar systems designed in LNDES. An X band coherent pulse radar uses chaotic oscillator for generation of noise signal with bandwidth of

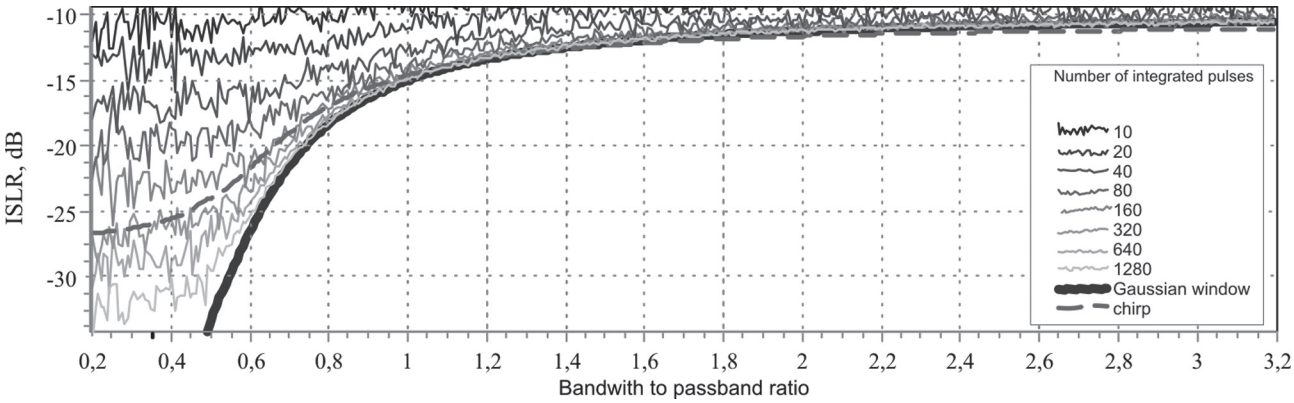

Fig. 1. ISLR for noise signal with various numbers of integrated pulses

250 MHz. This signal is used to form succession of 100 ns pulses filled up with noise. The number of radiated pulses can be varied in order to tune between low residuals and fast acquisition. Part of the transmitted signal is coupled, down-converted and fed to ADC as a reference. We used this reference signal in order to estimate the ISLR. It has to be noted that this approach doesn't take into account the influence of non ideal receiver to the signals. Figure 2 shows example of autocorrelation function estimated over 9400 pulses (time-bandwidth product of the signal is about 235000). It can be seen that the first sidelobe has quite high amplitude (about -12 dB with respect to the maximum). Besides, there is a peak in the autocorrelation at 39 ns which is caused by reflections of the signal in antenna feeding path and not ideal isolation.

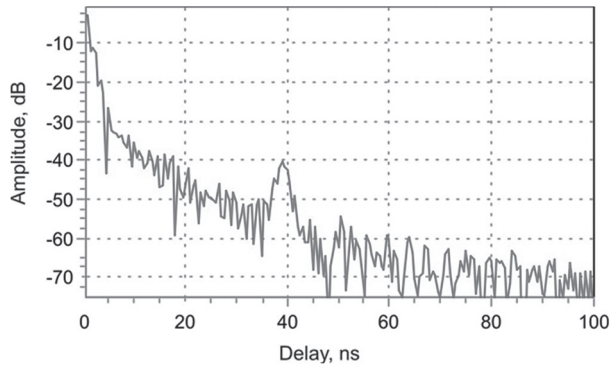

Fig. 2. Autocorrelation of pulsed noise radar signal

Figure 3 shows dependency of the ISLR on the number of integrated pulses. Maximum time-bandwidth product of the signal in the plot (at number of pulses equal to 94) is 2350. ISLR sets at value of -8 dB at 15 integrated pulses and doesn't get lower at higher numbers. This is caused by high level of sidelobes inherent to the radiated signal shape so that noise residuals doesn't make strong impact on the ISLR when integration time exceeds 2 μs.

In a Ka-band noise radar low frequency noise signal is generated using thermal noise, this signal is used for modulation of high frequency VCO oscillations. Parameters of the modulation can be adjusted leading to changes in the frequency spectrum of the signal such as central frequency and bandwidth. The shape of the spectrum is determined by both amplitude distribution of the modulating signal and by high frequency filters of the transmitter. In the case of relatively narrow low amplitude of the modulating signal the spectrum has bell-like shape and low bandwidth, otherwise, the spectrum has complex shape and higher bandwidth. The radar operates in continuous regime. As in the previous case, we used only the reference signal for the estimations.

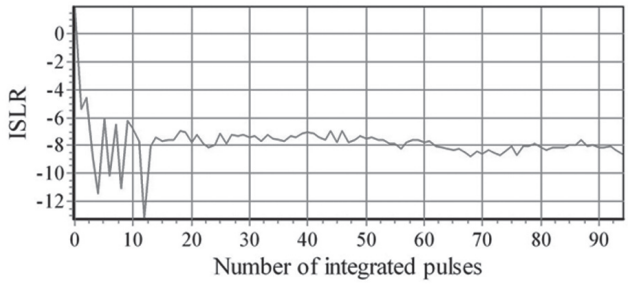

Fig. 3. Dependence of ISLR on the number of integrated pulses

We fixed the integration period for ISLR at 2 μs which corresponds to scene length of 300 m (this value is practical for our radar). The data were divided into chunks each containing 2 μs of sounding signal. Autocorrelation was estimated using each chunk and such estimations were integrated. Fig. 4 shows example of autocorrelation for the case of signal bandwidth 385 MHz and 96 MHz for and integration time 0.1 s (Time-bandwidth product of the signal is about 38500000 and 9600000, respectively). It can be seen that the signal with higher bandwidth has much higher sidelobes. This is explained by the shapes of the spectra shown in fig. 5: signal with narrower band has smoother power spectrum shape and, consequently, has lower sidelobes of correlation function.

Fig. 6 shows dependence of ISLR on the amount of integrated data (or integration time) for various bandwidths of the sounding signal. Corresponding power spectra are shown in figure 5. Linear in logarithmic coordinates part on the plot starting at integration time 10000 ns corresponds to the improving of signal to noise ratio with increase of integration time (at this level ISLR is limited by the random residuals in the response). Above the certain integration time the random residuals are not the limiting factor and the ISLR is determined by the sidelobes of the signal.

This is seen as a horizontal part on the plots at higher integration times. This means that we observe influence of two factors on the ISLR level.

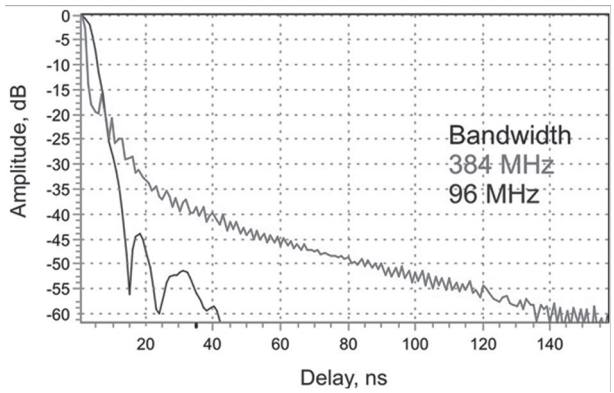

Fig. 4. Autocorrelation of CW noise radar signal

CONCLUSIONS

In the work, we have carried out experimental investigation of integrated sidelobe level of noise signal using example of two noise waveform radars operating in X-band and in Ka-band. It has been shown that in practice both the sidelobes and residual fluctuations can be limiting factor for the ISLR level. Increasing of signal time-bandwidth product enables to decrease influence of the residual fluctuations. Besides, it has been shown that noise waveform generator using noise modulation of voltage controlled oscillator can generate noise with frequency spectrum rather similar to Gaussian shape and as the result having low ISLR. The results can be used for specifying practical regimes of noise radar operation whereas integrated levels of residual fluctuations and sidelobes are of the same order.

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Vyplavin Pavel Leonidovich, for photograph and biography, see this issue, p. 94.

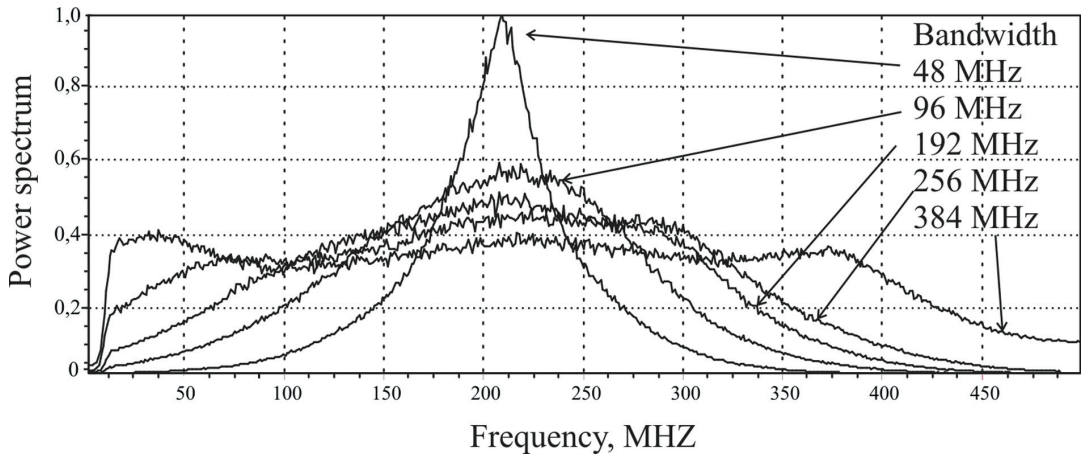

Fig. 5. Frequency spectra of sounding signal of Ka-band noise radar for various bandwidths

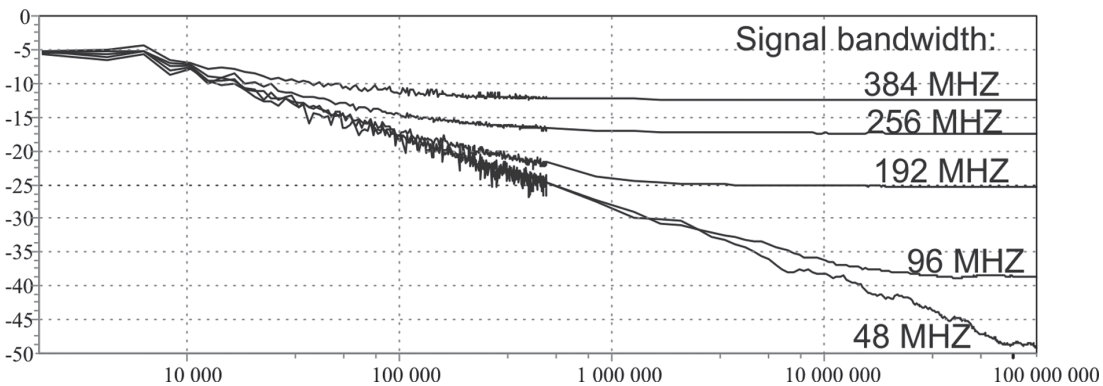

Fig. 6. ISLR sounding signal as a function of integration time for various bandwidths

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Уровень боковых лепестков является одной из наиболее важных характеристик радиолокационных сигналов. Известно, что возможно создание генераторов шума с формой спектра, близкой к гауссовой. Такой сигнал обеспечивает малый уровень боковых лепестков. С другой стороны, известно, что случайная природа шумового сигнала приводит к случайности результирующих профилей дальности, наблюдаемых в виде остаточных флуктуаций автокорреляции, называемых также шумом обработки, или фоновым шумом. Повышение произведения длительности сигнала на ширину полосы приводит к уменьшению таких остаточных флуктуаций. В одних радарах остаточный шум может быть большой проблемой, в других он может быть, наоборот, пренебрежимо мал. Данная работа посвящена численному и экспериментальному исследованию свойств шумового сигнала. Поскольку остаточные флуктуации распределены по профилю дальности, мы использовали такой параметр, как интегральный уровень боковых лепестков (ИУБЛ), для анализа свойств сигнала. Мы оценили ИУБЛ для моделированного шумового сигнала с различными параметрами. Кроме того, посредством анализа опорного сигнала существующих шумовых радаров мы оценили ИУБЛ реальных систем.

Ключевые слова: боковые лепестки, шумовой сигнал, остаточные флуктуации.

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Рівень бічних пелюсток є однією з найбільш важливих характеристик радіолокаційних сигналів. Відомо, що можливо створення генераторів шуму з формою спектра, близькою до гаусової. Такий сигнал забезпечує малий рівень бічних пелюсток. З іншого боку, відомо, що випадкова природа шумового сигналу призводить до випадковості результуючих профілів дальності, спостережуваних у вигляді залишкових флуктуацій автокореляції, званих також шумом обробки, або фоновим шумом. Підвищення добутку тривалості сигналу на ширину смуги призводить до зменшення таких залишкових флуктуацій. В одних радарах залишковий шум може бути великою проблемою, в інших він може бути, навпаки, зневажно малий. Дана робота присвячена чисельному та експериментальному дослідженням властивостей шумового сигналу. Оскільки залишкові флуктуації розподілені за профілем дальності, ми використовували такий параметр, як інтегральний рівень бічних пелюсток (ІРБП), для аналізу властивостей сигналу. Ми оцінили ІРБП для модельованого шумового сигналу з різними параметрами. Крім того, за допомогою аналізу опорного сигналу існуючих шумових радарів ми оцінили ІРБП реальних систем.

Ключові слова: бокові пелюстки, шумовий сигнал, залишкові флуктуації.

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