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SAR IMAGING WITH STEPPED FREQUENCY NOISE RADAR

K.A. LUKIN, J.P. KIM, P.L. VYPLAVIN, AND V.P. PALAMARCHUK

In the paper, a radar scheme combining benefits of noise and stepped frequency waveforms is considered. Noise signal provides the best electromagnetic compatibility, LPI performance and interference robustness but design of conventional noise radar requires expensive high speed ADCs. Stepped frequency radar uses narrowband signals for sounding. This enables to use low speed ADCs which can have much higher dynamic range and are much cheaper. But periodicity of the sounding signal leads to range ambiguity and high sensitivity to monochromatic interference. The proposed approach consists in generation of narrowband noise signal with step-like variation of its central frequency. Sounding signal and radar return are fed to mixer and then digitized. The digitized signal is processed like conventional stepped frequency one. This gives range profile, but radar is sensitive to targets only within the correlation range of noise signal. The obtained range profile contains phase information which enables to use it for SAR imaging. In the paper, the proposed approach is experimentally tested using noise radar based upon digital arbitrary waveform generator.

Keywords: SAR, stepped frequency, noise radar.

INTRODUCTION

Ground Based Synthetic Aperture Radar (SAR) are used for microwave coherent imaging of an area of interest and may be applied for detection of small objects, Ground Penetrating Radar, through-the-wall vision and many others. Stepped frequency technique is a common technique for SAR design. Transmission of single frequency signal enables application of ADC with rather slow sampling rate, which may provide rather high dynamic range since they have up to 36 bits of amplitude resolution. However, this technique also has some drawbacks, such as: ambiguity in range measurements; high level of range sidelobes; and low resistance against narrowband coherent interferences. We suggest application of *random* waveforms [1] with synthesized spectrum to go around these drawbacks.

In the paper we realize step-like increase of the central frequency of a narrow band random signal using fast Arbitrary Waveform Generator (AWG) from EUVIS Company. In this approach the target range can be measured within the range limited by correlation function width of the transmitted noise signal. Because of continuity of probing signal spectrum the use of this approach enables eliminating ambiguity in range measurements, which is inherent drawback of conventional stepped frequency radar. Part of the processing is to be done in analog way using a wideband phase detector. The phase detector output should be sampled with a slow multi-bit ADC and transferred to a PC for further processing consisting in performing Fourier transform over whole frequency mesh. This gives a range profile [2]. After that the azimuth compression technique for generation of the SAR image may be applied.

In the paper, the developed stepped frequency noise radar (SFNR) and results of SAR imaging experiments using this approach have been described.

1. LABORATORY TESTS OF UWB AWG-BASED STEPPED FREQUENCY NOISE RADRAR

We elaborated a prototype of the stepped frequency noise radar based upon digital generation of signals in arbitrary waveform generator (AWG). Sounding signal shape is digitally formed in a PC in advance. This signal is uploaded to AWG memory. After uploading it can be used for generation of analog signal with the waveform specified by the digital signal. This device is used in radar scheme shown as block diagram in fig. 1. Output of the AWG is fed to power amplifier unit where it is being filtered and amplified. Part of the sounding signal is coupled to be used as a reference and other part is transmitted through antenna. Radar return signal is received by the same antenna. It goes to a mixer where it is mixed with the reference. Output of the mixer is low pass filtered and sampled with comparatively low sampling rate. AWG enables to generate signal of any shape. In current series of experiments we generated two types of signal: stepped frequency and stepped frequency with narrowband noise modulation. Stepped frequency signal was generated as 500 frequency steps with 1 MHz spacing. Phase changed smoothly between the steps. Signal repetition period was 1 ms. Noise stepped frequency signal was generated as a narrowband random signal with constant bandwidth and varying in steps central frequency. Central frequency varied with the same step as in the case of free of noise stepped frequency regime. At the output of phase detector signal in spectral domain is obtained. Fig. 2. shows example of such signal realization. If stepped frequency signal is used, the output corresponding to each frequency step is supposed to be constant within the step. If noise modulation is present the output has random structure and can be averaged out to certain mean level using low pass filter. Step-like linear variation of frequency in time enables to obtain data in frequency domain, where complex amplitude of product of sounding

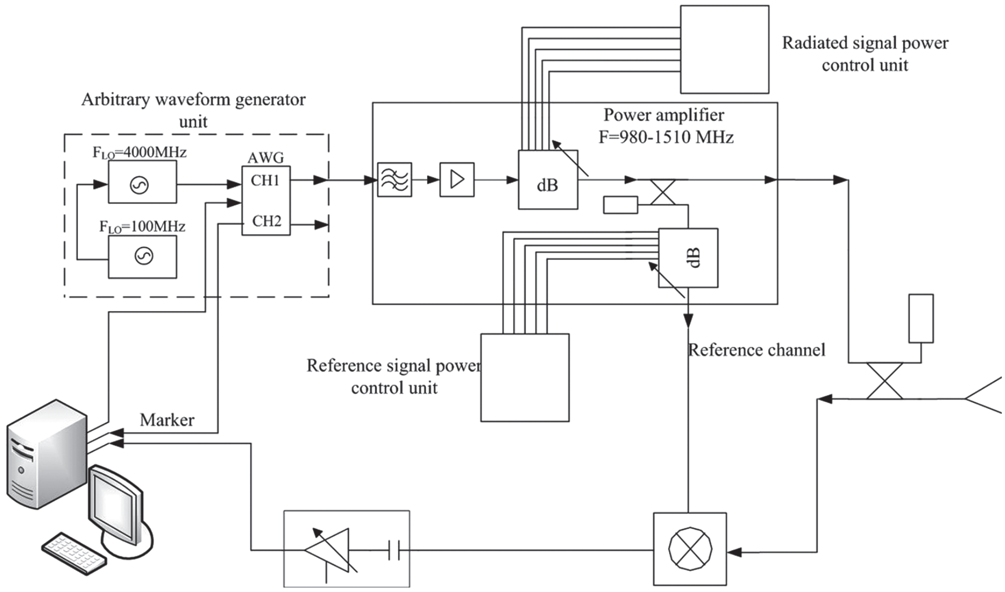


Fig. 1. Block diagram of experimental setup of stepped frequency noise radar

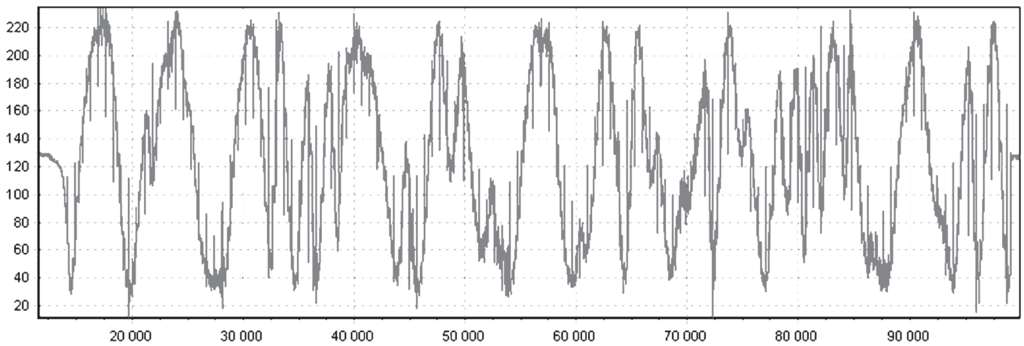


Fig. 2. Realization of signal acquired at the output of stepped frequency noise radar

and reference signals is a function of frequency. Inverse Fourier transform of such signal produces range profile of the scene. We have carried out experiment aimed on generation of range profile of scene containing a spherical target. High RCS sphere covered by aluminum foil was placed in a room in front of Tx-Rx antennas of the SFNR. Obtained in experiment range profile is shown in fig. 3. This range profile has been obtained by performing two scans – with and without target and subtraction of range profiles in order to decrease effects of antenna cross-talk and multiple targets in the room.

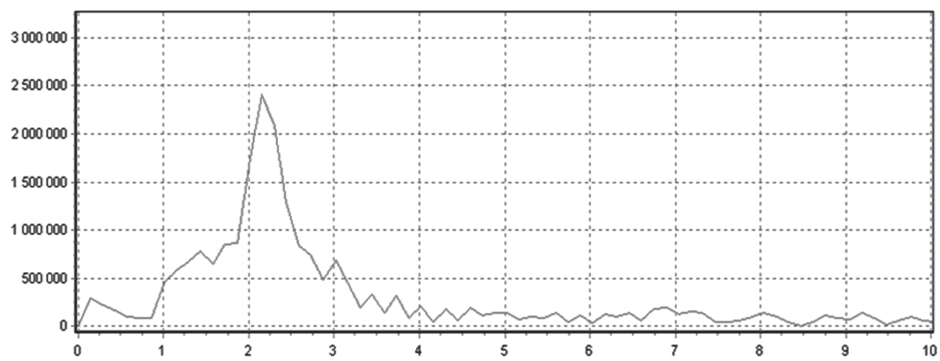


Fig. 3 Range profile obtained by subtraction of one image from another. Target was placed at distance of 2 m from the radar

2. DOPPLER FREQUENCY SHIFT MEASUREMENTS IN UWB SFNR

SAR imaging is based upon phase sensitivity of the radar. In order to confirm ability of the designed radar to generate SAR images we have tested phase sensitivity of the system via Doppler frequency measurement. Experiments were carried our using the AWG – based SFNR. The setup of the experiment was following: the radar was placed in a laboratory room. In front of its Tx/Rx antenna a vibrating target was placed. Sphere covered by aluminum foil was used as a vibrating reflector. Special mechanism was used for its sinusoidal movement. The target had high RCS but amplitude of the vibration was much lower than wavelength of the signal. This lead to low Doppler signal output from such target. Obtained range-Doppler map for the case of distance to target of 3 m is shown in fig. 4.

Next experiment was carried out in the same situation but distance to the vibrating target was 6.5 m. Corresponding range-

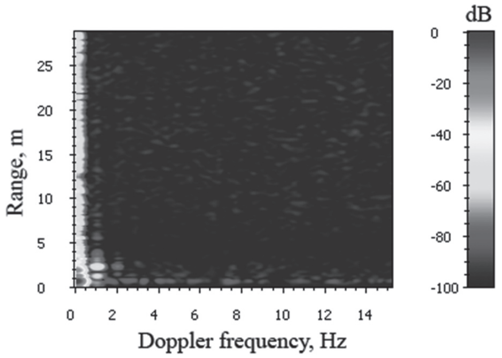


Fig. 4. Range-Doppler map of 1 Hz vibrating target at distance of 3 m obtained using stepped frequency signal with 30 MHz noise modulation

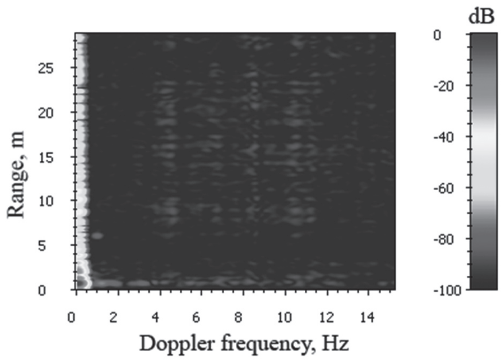


Fig. 5. Range-Doppler map of 1 Hz vibrating target at distance of 6.5 m obtained using stepped frequency signal with 10 MHz noise modulation

Doppler map is shown in fig. 5. When the target is placed at higher distance, influence of noise modulation is much more significant: it can be seen that in the second experiment at bandwidth 10 MHz the response from the target is weak. Increasing of bandwidth to 30 MHz leads to disappearing of the response because of low correlation interval of such noise signal. Thus it is possible to isolate the area of radar sensitivity by choosing proper noise signal bandwidth and adding delay to the reference channel. Combination of such isolation with stepped frequency radar concept enables obtaining range profiles within the observable ranges. Stepped frequency radar concept can be realized with comparatively low speed ADCs. The obtained range-Doppler maps show that the system has good phase sensitivity even if noise modulation with high bandwidth is used.

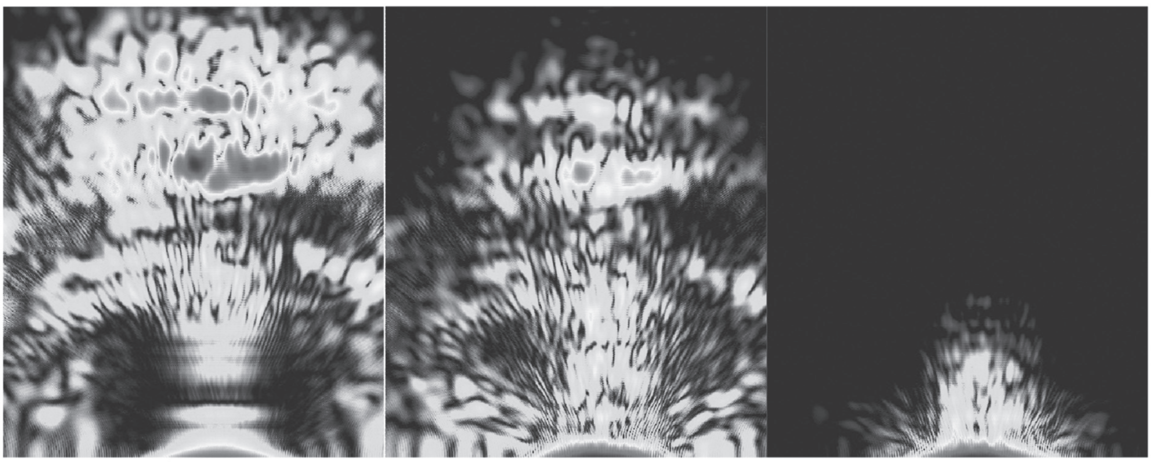
3. 3D SAR IMAGING WITH UWB SFNR

UWB SNFR radar enables obtaining range profiles using the described above approach. After performing of Fourier transform of the acquired signals one obtains information not only about amplitude, but also about phase of reflected signals. This enables using UWB SNFR with concept of synthetic aperture radar. In order to use this approach one needs to perform operation of UWB SFNR with variable position with respect to the scene. One can achieve this by moving of the antenna or all the radar on special positioning system. All positions of antenna phase center with respect to the scene form synthetic aperture. It can be either one dimensional either two dimensional. In the first case obtaining of 2D images in range-azimuth plane is possible, in the second case one can obtain 3D image with additional cross-range axis resolution.

Principle of SAR operation is based on processing of signal obtained by radar at various positions of transceiver antenna with respect to observed objects. Antenna positions form certain virtual antenna aperture. The range resolution in our case is obtained by processing of stepped frequency data. The range resolution is determined by bandwidth of the signal. Angular resolution is obtained by processing of signals from the antenna positions and depends on length of antenna path rather than dimensions of antenna.

Experiments were carried out in the laboratory room. In order to provide scanning transmitter and receiver antennas were moved mechanically with respect to the scene. Example of SAR image of laboratory room and complex target is shown in fig.6. It can be seen that increasing of noise modulation bandwidth limits the operation range of the radar.

We have considered linear scanning. This approach is valid for two-dimensional apertures as well. In this case scanning is performed in such a way that antenna is moved over a two-dimensional array forming a 2D aperture. As the result of such processing a 3D image can be formed.



Monochromatic 10 MHz noise 30 MHz noise

Fig. 6 SAR images obtained with stepped frequency noise radar with three values of noise modulation bandwidth

CONCLUSIONS

In the work, stepped frequency noise radar approach has been tested. This approach combines solutions of stepped frequency radar and noise radar in the following way: noise signal is radiated by the radar in the same way as in noise radar, but its central frequency is varied in stepped-like manner. This approach provides such benefits as low instant bandwidth of the signal, high dynamic range, high electromagnetic compatibility and resistance to interference. Main principles of the approach have been described. Experimental tests have shown that the approach works well for both Doppler processing and SAR imaging and that variation of noise modulation bandwidth enables to choose size of the observable area.

References

[1] Lukin K.A. Noise Radar Technology. Radiophysics and Electronics, Kharkiv, Institute for Radiophysics and Electronics of NASU, 1999, vol.4, #. 3, pp.105-111 (In Russian). Translation is published in Telecommunications and Radio Engineering, V.55, #12, 2001, pp.8-16.

[2] A.A.Mogyla, K.A. Lukin, V.V.Kulyk. Statistical error of measurement made using double spectral analysis method with noise signals. 6th International Conference "Radars, navigation and telecommunications ", 25-27 April 2000, Proc. V.1, pp. 420-428.

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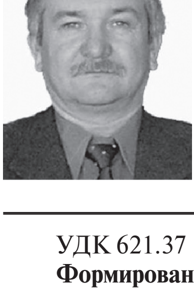
Konstantin A. Lukin, for photograph and biography, see this issue, p. 24.

Jeong Phill Kim, professor of Chung-Ang University, Seoul, Korea. Current research interests include the design of antennas, RF and microwave components, on-chip tunable filters RFID systems applications and various communication applications of true random signals.

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



Palamarchuk Vladimir Petrovich, leading engineer of Laboratory for Nonlinear Dynamics of Electronic Systems of Usikov Institute for Radiophysics and Electronics NAS of Ukraine. The field of scientific interests: radar microwave technology.

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В данной работе рассматривается система, комбинирующая достоинства шумовых сигналов и сигналов со ступенчатым изменением частоты. Шумовые сигналы обеспечивают лучшие характеристики электромагнитной совместимости, низкой вероятности перехвата, устойчивости к шуму. С другой стороны, создание обычных шумовых радаров требует использования дорогих высокоскоростных АЦП. Радары со ступенчатой перестройкой частоты излучают узкополосные сигналы. Это позволяет использовать низкоскоростные АЦП с большим динамическим диапазоном и меньшей ценой. Но периодичность излучаемого сигнала приводит к наличию неопределенности по дальности и высокой чувствительности к монохроматическим помехам. В работе предлагается подход, заключающийся в генерации узкополосных шумовых сигналов со ступенчатой перестройкой центральной частоты. Излучаемый сигнал и радарный отклик подаются на смеситель и оцифровываются. Цифровой сигнал обрабатывается аналогично обычному радару со ступенчатой перестройкой частоты. Это позволяет сформировать профиль дальности, но чувствительность радара ограничена зоной корреляции шумового сигнала. Получаемые профили дальности содержат фазовую информацию, позволяющую использовать их для формирования РСА изображений. В данной работе предлагаемый подход экспериментально исследован с использованием шумового радара, основанного на цифровом генераторе произвольных сигналов.

Ключевые слова: РСА, ступенчатая перестройка частоты, шумовой радар.

Ил. 6. Библиогр.: 2 назв.

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У роботі розглядається система, що комбінує переваги шумових сигналів і сигналів зі ступінчастою зміною частоти. Шумові сигнали забезпечують кращі характеристики електромагнітної сумісності, низької ймовірності перехоплення, стійкості до шуму. З іншого боку, створення звичайних шумових радарів вимагає використання дорогих високошвидкісних АЦП. Радари зі ступінчастою перебудовою частоти випромінюють вузькосмугові сигнали. Це дозволяє використовувати низькошвидкісні АЦП з великим динамічним діапазоном і меншою ціною. Але періодичність випромінюваного сигналу призводить до наявності невизначеності за дальністю і високої чутливості до монохроматичних перешкод. У роботі пропонується підхід, який являє собою генерацію вузькосмугових шумових сигналів зі ступінчастою перебудовою центральної частоти. Випромінюваний сигнал і радарний відгук подаються на змішувач і оцифровуються. Цифровий сигнал обробляється аналогічно звичайному радару зі ступінчастою перебудовою частоти. Це дозволяє сформувати профіль дальності, але чутливість радара обмежена зоною кореляції шумового сигналу. Одержувані профілі дальності містять фазову інформацію, що дозволяє використовувати їх для формування РСА зображень. У даній роботі пропонований підхід експериментально досліджено з використанням шумового радара, заснованого на цифровому генераторі довільних сигналів.

Ключові слова: РСА, ступінчаста зміна частоти, шумовий радар.

Іл. 6. Бібліогр.: 2 найм.