Imitation of Reflected Signals for Radar with Chirp Modulation

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***Abstract*— in this paper features and hardware simplification for seminatural modeling of signals reflected from an extended surface are described. Main results can be used for precision and functional real-time tests of radio altimeters with chirp frequency modulation and other radar systems with continuous or long radiated signals.**

Keywords—chirp modulation; airborne radar; simulation; computational modeling; spectral analysis; surfaces

I. INTRODUCTION

For laboratory control of microwave circuit parameters, algorithms, precision, for functional testing of different equipment radar operating with/above the earth's surface, we needs to generate signals equivalent reflected from extended objects and surfaces. Existing electronic complexes scaled-down simulation is able to solve the problem of simulation of radar signals reflected from one or more point targets. For forming a signal corresponding time-varying reflection from an extended underlying surface is necessary to implement a view model situation in real time.

II. MAIN PART

A. Phenomenological model

According to the phenomenological model approach [1] extended object or any surface can be represented as a lot of discrete reflectors - facets. Then the space of the direct and reflected signals between the antennas of the radar station and a separate reflector can be interpreted as some elementary signal channel with variable time parameters and transfer function $K_i(j\omega, t)$ – see Fig. 1, which can be determined at any point in time by values of relative positions and speed of relative movement [2].

The transfer function $K_i(j\omega, t)$ of each channel can accidentally change over time (agitation of the water surface, swaying vegetation under the influence of wind, movement of radar). So, after passing through the channel, the radiated signal $A(t)$ in any moment has own random amplitude, phase and Doppler frequency shift.

Between the channels can be a mutual correlation, which cover both the individual channels or groups of channels, however, to simplify these dependencies are often neglected.

Current hardware does not allow to implement a model which directly working with lots of variety reflectors in real time.

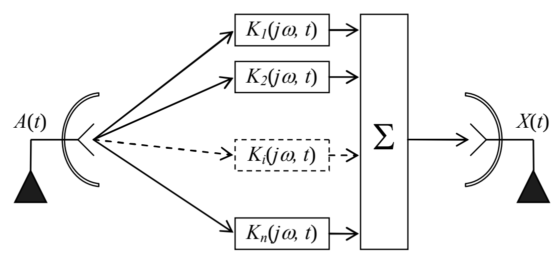

Fig. 1. Phenomenological model.

So to simplify a model, it is advisable to group all reflectors with close parameters: the number of channels is equal to the number of groups of the partition areas close frequency/delay. The quality (accuracy and equivalence of the main characteristics and dependencies) modeling and generation of the reflected signal will be determined by hardware and software model capabilities.

B. Model with delay line

For radar applications, we can divide the total transform of the signal $A(t)$ in the transmission channel, into several conversions performing delays τ_i, Doppler shifts df_i and amplitude multiplying E_i. These parameters are sufficient to account for the relative speed of reflectors and radar, individual reflection coefficients, the coefficients accounting patterns of receiving and transmitting antennas, the signal attenuation in accordance with the distance to the reflector. Then multi-channel distribution model “transmitting antenna – reflective object – receiving antenna” can be represented by the model with delay line [3], [4] as shown in Fig.2.

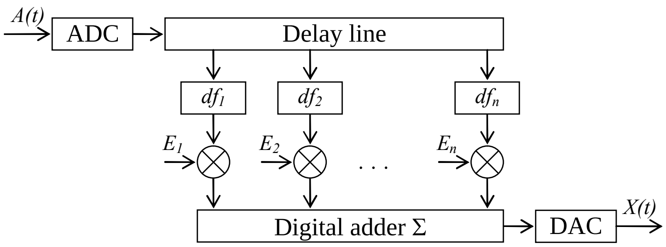

Fig. 2. Signal formation scheme on the basis of DSP blocks.

Quality implementation with ability to real-time changing parameters in analog form is not possible. For implementation on the basis of digital signal processing (DSP) blocks, we must link high-speed ADC, digital delay lines, signal conversion modules and DAC. For digitizing the signal enough to use one high-speed ADC, but for generate an output signal, we must use a variety of DACs and one analog adder or multi-input digital adder and one DAC as shown in Fig. 2. Direct implementation on high frequency in todays development of technology is impossible, therefore, it is understood that the processing and generation of the signals is performed at a low frequency in the working frequency range of DSP blocks.

C. Cyclic switch

Use of high-speed multi-input digital adder or set of DACs with analog adder for each channel is expensive to implement. So instead of a digital adder in some cases (for signals which current moment spectral density concentrated in a narrow frequency band, for example, radio altimeters chirp signals with “slow” modulation), we can use the switch. A similar technique is often used in the circuitry of multiple-input ADC in some microcontrollers. But in this application, the switch cyclically connects to the single DAC output n signals converted in accordance with the specified parameters df_i and E_i as shown in Fig. 3:

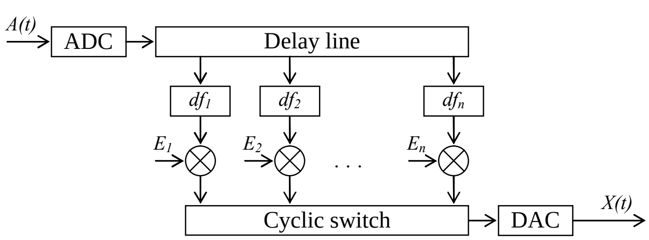

Fig. 3. Signal processing scheme with cyclic switch.

This switching method can be called the “mixing in time”. The total transformation can be described by the expression:

$$X(t) = E_i\, K\left(A(t-\tau_i),\ df_i\right), \quad i = 1 + \left(round\left(\frac{t}{\Delta t}\right) \bmod n \right)$$

where E_i – the amplitude corresponding to the power of the i-th signal; $K(f(t), df)$ – the result of the Doppler shift of the function $f(t)$ on value df; τ_i – delay of the i-th group of reflected signals; df_i Doppler shift of the i-th signal; Δt – mixing interval; mod – calculate remainder from integer division.

The output signal will contain equal time segments of different signals. In the frequency domain it will lead to appear original harmonic signals with additional harmonics corresponding to the sum and difference frequencies of "useful" signals and mixing frequency multiplied by an integer. When choosing the mixing frequency several times higher than the working frequency band of the receiver, the resulting signal in the low frequency region of spectral composition will be equivalent to the signal formed in the usual summation signals, but, of course, amplitude will be weaker on n times.

D. Switch controlled by synchronizer

The method of forming the equivalent of the reflected signal with the switch can be simplified when using a switch, controlled by a synchronizer: output signal will contain segments of different signals with a given duration as shown in Fig. 4. This allows to replace individual amplitude conversions in such clocking operation synchronization so that the switch to the duration of different signals segments were proportional to the respective amplitudes $E_1 \ldots E_n$.

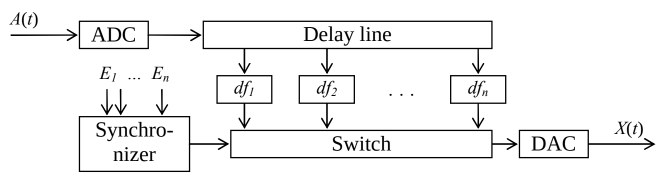

Fig. 4. Scheme with the switch controlled by the synchronizer.

This “mixing in time” with variable duration of signals can be described by the expression:

$$X(t) = E_i\, K\left(A(t-\tau_i),\ df_i\right), \quad i = find\left(T = \sum_{i=1}^{n} \Delta t_i,\, t \right),$$

where $find(T, t)$ is the mapping function of time t (for a total period of mixing all signals T) to the number i of mixed signal; Δt_i – duration interval of the i-th group of reflected signals.

E. Model of reflected signals

To verify the equivalence of the “mixing in time” model was developed, in which the radar altimeter was used. a working band of receiver of chirp signal was set to 60 KHz. Simulated in this case, the beating signal could made of pieces of sinusoids of equal or variable duration and we could study the influence of parameters on the resulting spectrum. Fig. 5 shows examples of the obtained signal beating composed of segments of sine waves and its spectrum.

Harmonics of “useful part” of signal have frequencies from 28 to 45 KHz: in Fig. 5 *c* all 6 set of harmonics “useful part” of beating signal viewed separately, because we selected large signal duration.

It is known that for the classical spectral estimates of the height of the spectral peaks is a reliable indicator of the relative power of the harmonic signal. When checking equivalence of the mixed signal with unequal duration segments we obtained similar beating signals (see Fig. 5 *d*) and its spectrums (see Fig. 5 *b*).

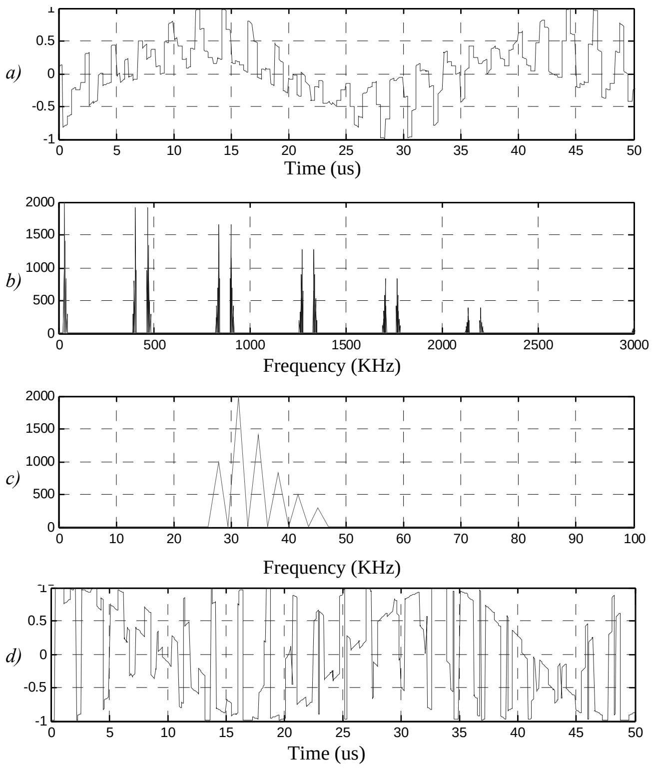

Fig. 5. Checking equivalence of the mixed signal for chirp altimeter: *a* – beating signal composed of identical duration segments of sine waves; *b* – its spectrum; *c* – harmonics of "useful part" of beating signal; *d* – beating signal of unequal duration segments of sine waves.

The actual periods of the switching channels are integers, in this example, from 1 to 32 samples therefore, the values specified amplitudes of the sinusoids formed the shape of the signal spectrum of the beating due to the discreteness of the period change channels differ slightly from the set. In General, the accuracy of this representation of the signal can be estimated as the average deviation of the harmonic amplitudes (compare with needed values), which will be $1/32/2 \approx 1.6\%$.

If mixing signals of different amplitudes with equal periods, then accuracy of signal representation will be similar determined by the half of the "price of the Junior category" for used digital amplitude multiplier. Therefore, for a given error variance of the amplitude of the harmonics, it is easy to choose the appropriate discrete amplitude multiplier or duration of the mixing period.

The ratio of amplitudes of harmonics in the absence and presence of mixing with equal and unequal periods are approximately the same, therefore, the received signals can be considered as equivalent to each other in spectral composition.

Frequency mixing is determined by the quantum of work dt (quantization time ADC), switching period st and the number of mixed signals N:

$$F_{\text{mixing}} = 1/(dt \cdot st \cdot N) .$$

With increasing frequency harmonics "useful part" of beating signal and/or reducing the frequency mixing F_{mixing} each signal there is a gradual convergence and the subsequent imposition of harmonics corresponding to the sum and difference frequencies "useful part" and mixing frequency multiplied by an integer.

Fig. 6 shows the situation of convergence of the spectra, in which radar altimeter may not increase the value of the measured height at the expense of getting into the working bandwidth of the filter beating signal in the tail of the spectrum spurious harmonics caused by mixing ($F_{max} \approx 45$ KHz). In this case, due to the increased value of the period change channels st = 75 points, frequency mixing signals $F_{\text{mixing}} \approx 92{,}6$ KHz. Control inequality $F_{\text{mixing}} - F_{max} > F_{max}$ here is still running, but at the expense of reduced spectral resolution (none multiplicity of periods harmonics and frequency of the FFT) overlapping harmonics are already visible.

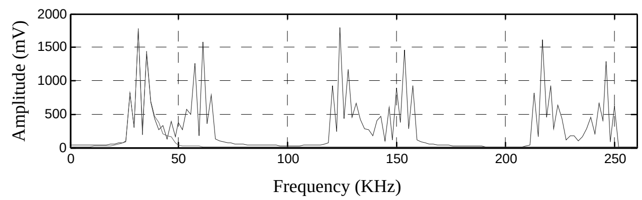

Fig. 6. The spectrum of the beating signal is obtained by mixing: here the first peak shows also the spectrum of the signal without mixing.

To exclude the effects of harmonics appear due to the mixing of signals, it is necessary that the frequency of the first harmonic ($F_{\text{mixing}} - F_{max}$) was above the upper frequency bandwidth F_{b_max} for filter beating signal of radio altimeter:

$$F_{\text{mixing}} - F_{max} > k\, F_{b\_max},$$

here k – factor, taking into account the imprecise knowledge of the parameters of the radio altimeter.

Then the allowable number of mixed signals:

$$N_{max} = 1/(\mathrm{dt} \cdot \mathrm{st} \cdot (F_{max} + k\, F_{b\_max})) .$$

It is seen that the permissible number of mixed signals depends on radio altimeter parameters and performance of DSP blocks.

F. *Some experimental results*

In accordance with these ideas and [5] the simulator of reflected signals was created. It can be used to test altimeters using radiated signals with linear frequency modulation in the frequency range from 4.2 to 4.4 GHz. The resulting signal spectrum of the beating can be statistically equal to smooth rough underlying surface.

Example of experimental spectrum with a width of up to 10 KHz with seminatural modeling of signals for typical altimeter is shown in Fig. 7: seven reflectors with ranges from 500 to 555 m in increments of 9.2 m, obtained by mixing seven signal channels (or seven discrete reflectors or groups of reflectors).

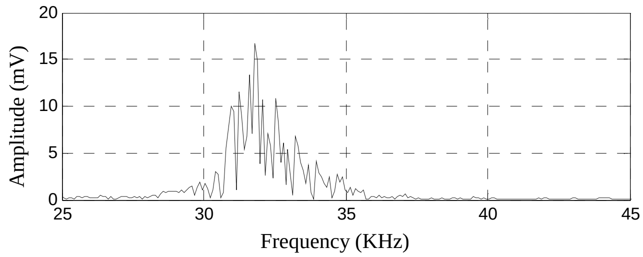

Fig. 7. The spectrum of beating signal is obtained by mixing seven discrete reflectors.

The appropriate view of signal beating at two scales (three and a half and part of the modulation period 11 ms) shown in Fig. 8.

The maximums of beating signal level in fields near 11, 22, 33 ms duration 0.3 ms corresponds to “reverse course” of modulated saw, which usually not used in measurements. Amplitude modulation has explicit periodic character, indicating that we have there are few strong harmonics.

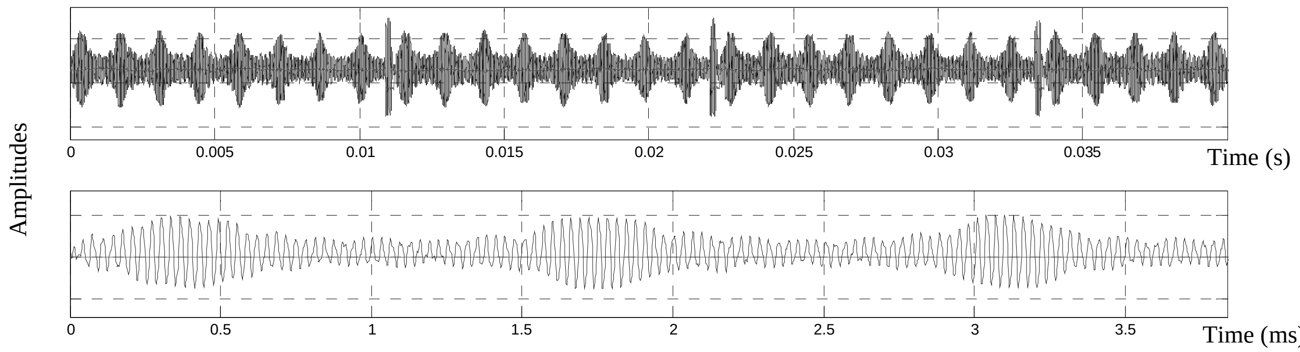

Fig. 8. Examples of beating signal if we mixing seven discrete reflectors.

III. Conclusion

For signal equivalent to the reflection from extended objects must summation of multiple signals with different delays, amplitudes, frequency shifts. Using the facet model with simultaneous consideration of angular motion and speed of aircraft, antenna pattern and reflection coefficients can be grouped reflectors, to calculate the parameters specified number of channels of the processing of the radiated signal, and send them to signal simulator based modules DSP in real-time. Characteristics of the simulated signal in the time and spectral region will be close to the theoretically expected, therefore, the results must conform obtained by experimental flight testing.

For example, the formation of a reflected signal for the radar altimeter, the result of simulation shows that the ratio of the amplitudes of the harmonics in the absence and presence of mixing with equal or unequal periods are the same, so the resulting signals will be equally perceived by radar altimeter equipment that will show the same value of height estimates for these equivalent signals.

The formation of the shape of the envelope spectrum of the beating is not due to the amplitude of the multiplications, and by mixing the component signals with unequal periods more effectively, because for all harmonics obtained the same maximal ratio signal/noise.

The obtained results can be used in the development of hardware and software complexes for scaled-down simulation for verification of radio altimeters with frequency modulation and other radar systems with continuous or long radiated signals.

References

[1] S.G. Zubkavich, Statistical characteristics of radio signals reflected from the earth surface. Moscow, Sov.radio, 1968, 224 p.

[2] G.N. Tverskoj, S.C. Terent'ev, and I.P. Kharchenko, The simulated echo signals for ship radio altimeters stations. Moscow, Shipbuilding, 1973, 224 p.

[3] R.S. Kennedy. Fading dispersive communication channels, Wiley Interscience, London, 1969.

[4] Electronically adjustable delay-simulator for distance-measuring apparatus operating on the frequency-modulated continuous wave principle. Patent US 4661818, 1987, 15 p.

[5] A.S. Bokov, V.G. Vazhenin, N.A. Dyadkov, V.V. Mukhin, D.E. Shcherbakov, and L.I. Ponomarev, “Radar simulator aims with mainly long radiated signals”, Patent RU 2504799, 2014, 12 p.