Signal Channel Mixing for Simulation of Extended Radar Objects

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Abstract

This paper is concentrated on designing a model of simulator, which can be used to simulate a radar signal reflected from a target or underlying surface. So it is useful to create and parameter tuning of the hardware-in-the-loop simulator. Here the key principle of signal channel mixing that aimed to simplify hardware architecture of the simulator is discussed. The dynamic variation of the simulating parameters of a radar scene (a surface type, an airborne altitude, etc.) also may be implemented.

Keywords: altimeter, radar target, radar echo simulator, linear frequency modulation, DRFM

1 Introduction

Device for simulating false radar targets is intended to simulate the time-frequency structure of radar signals reflected from an underlying ground surface, from one or more targets located in a fixed direction. Such hardware can be used to simulate different types of radar echoes in aim to test them in desired typical or special circumstances. For example, to check a radio altimeter (a flight altitude meter) a reflected and backscattered signal from an underlying terrain can be produced. Because of modern radar systems use coherent signal processing the emitted signal should be used to generate the appropriate echo. So, the laboratory hardware-in-the-loop simulators are widely used to evaluate different onboard radar's features.

Nowadays the development of such electronic simulation systems is based on modern methods of digital signal processing and conversions [1, 2]. Thus, it allows real-time simulation of a reflected signal in presence of the motion of an aircraft along virtual trajectories over the modeled underlying surfaces of various types. Simultaneous evaluation of the correspondence of the characteristics of the radar (radio altimeter, synthetic aperture radar, etc.) to the technical condition requirements is made by accurately comparing an analyzing of the laboratory results.

The possibility of technical realization of such complex and multipath signal propagation algorithms is feasible due to the appearance of digital signal processing processors with a performance that provides the conversion of the emitted signal (changing of power, delay and Doppler frequency shift values) in real time with the width of the probe signal spectrum of tens of megahertz [2, 3, 4].

2 Development of an algorithm

The rule of converting a radar probing signal to the combination of its reflections from set of facets of extended radar objects and also from set of bright points of an underlying surface [4, 5] can be reproduced by using hardware signal channels controlled by software which work together and synchronously in real time. So, it can be done by summation of emitted signal replicas with different amplitudes, delays and frequency shifts in parallel signal channels as shown in figure 1. Here all the parameters may be variable to represent as typical as really complex radar scenarios.

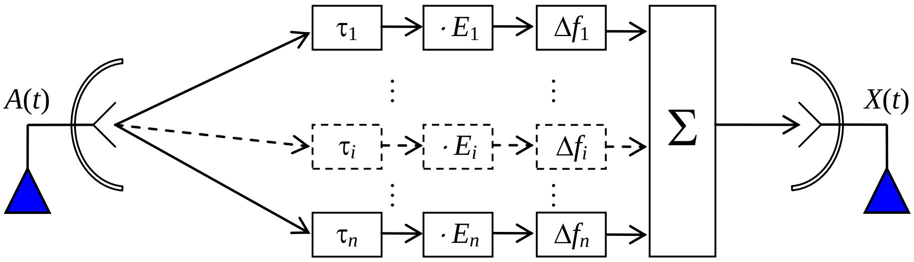

Figure 1: Multipath signal propagation representation

Some developers use the filtering method to converting a probing signal. So, they use calculation of the filter impulse response; and transform the data array of the recorded sounding signal into the simulated reflected signal data by convolution made by the fast digital filter [6].

Our method is similar to the one. It is also suitable for real-time simulating of reflected signals and includes the following steps:

- definition of the trajectory of radar platform motion, properties and directions of radar antenna;
- definition of the relative geometry and properties of all illuminated radar scene objects, which can be presented by the bright points, facets, etc.;
- grouping the bright points or facets into decreased number of signal channels; grouping by range (R_i) can be done, for example of hovered helicopter, by using the range rings (r_i), as shown in the figure 2;
- calculation of the conversion parameters for all used signal channels.
- transformation of digitized samples of the emitted signal into the simulated reflected signal samples.

The overall accuracy and quality of the simulation will depend on the number of levels of quantization of signals and model parameter's variables, sampling frequency, intrinsic noise of analog circuits and converters, the clock of calculation and updating of simulation parameters. But one can note that the most challenging issue is including of enough amount of signal channels with different signal conversion parameters.

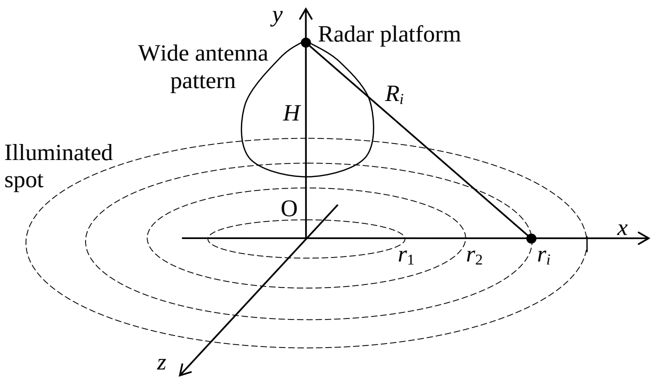

Figure 2: Irradiating a portion of the underlying surface with the radio altimeter antenna

Increasing the number of reflectors (the range rings should have the step value about or less than radar spatial resolution) significantly complicates the hardware for implementing the model with variable signal parameters. So to simplify the model it is advisable to group reflectors with similar parameters: the number of channels will be equal to the number of elements of the subdivision into areas of close frequencies or delays. In this case, the equivalence of the main characteristics and modeling dependencies and the formation of the reflected signal will be determined by the hardware and software capabilities of the chosen model implementation, as well as the actual resolving power of the radar meter with the corresponding parameters of the probing and received signals.

Immediate implementation on the extra high frequencies with the current development of technology is not possible, so the processing and generation of signals are performed at a low frequency in the working area of the DSP block frequencies [7, 8].

The use of signal mixing has shown the possibility to multiply the number of simulated bright points or significantly simplify the construction of the simulator. The possibility of coherent processing is preserved, because the phase of the signal being formed (imitating the reflection from each target point) is determined by the distance (delay) and the initial phase of the probe signal, and the possible amplitude fluctuation is averaged over several periods of modulation and scanning [7].

The basis of all high-speed digital systems of signal storage is DRFM (digital radio frequency memory) or digital signal memory (DSM) [8, 12, 13]. One of the applications of such schemes is electronic warfare complexes. For example, in [1] a simulator of the false purpose of the ship is described. In this simulator, a "bundle" of DRFM and ASIC architectures was used, under the control of a high-performance microprocessor [3, 9].

3 Forming a beat signal spectrum

The reflected signal is generated by irradiating a section of the underlying surface with the radio altimeter antenna, as shown in the figure 2. The elements of this section are at different distances from the radio altimeter, which leads to a difference in the delay of the reflected signals. So, the reflected (and formed) signals are random, since they represent the sum of the signals from the elementary areas of the reflecting surface section, each of which may have a random or controlled by the surface model parameters: amplitude, delay and phase.

The typical beat signal spectrum is shown in the figure 3. The main feature of the spectrum is the presence of discrete components at frequencies that are multiple of the modulation frequency F_M [1].

The envelope of the beat signal spectrum depends on the antenna pattern shape and the nature of the underlying surface. The spectral component that has the minimum difference frequency, and will correspond to the true altitude of the flight, and all the others “tail” spectral components will reduce the accuracy of the radar altimeter. The extent of this inaccuracy is determined by the width of the beat signal spectrum. In practice the simplest method to evaluate the altitude is measuring if the central of the spectrum, which is made in time domain by the counter of zero-crossing for the beat signal [1, 8]. The more accurate methods is based on evaluating of the first spectral component which is made by appliance a Fourier transforming. So to represent the real structure of beat signal the simulator’s signal should consist of partial signals with different delays and amplitudes. Some surface models are discussed in [6, 8, 11].

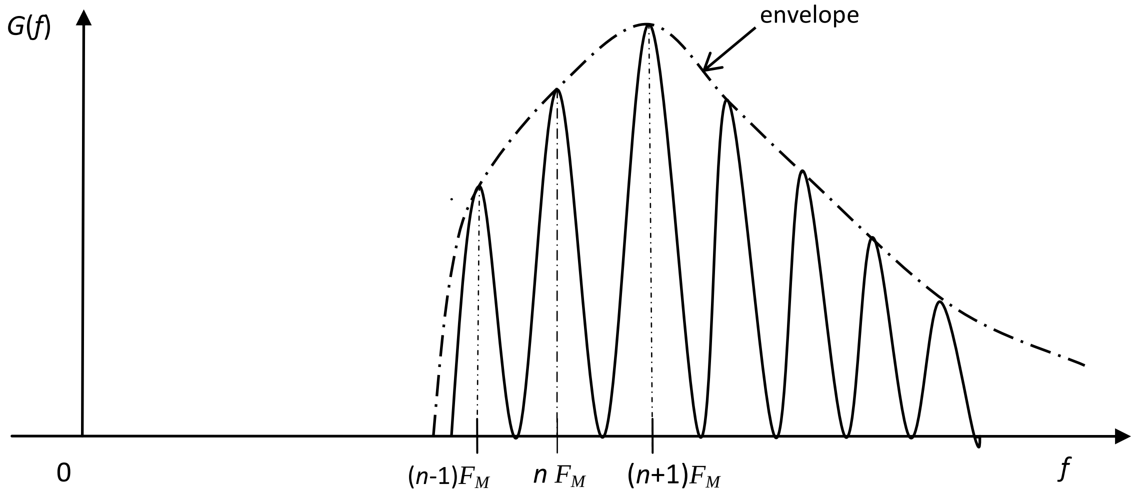

Figure 3: The spectrum of a beat signal

4 The designed scheme of the simulator

When the previous scheme was designed [10], we decided to develop an additional circuit capable of receiving and processing signals with different (variable) durations, rather than with the same ones, as was done in the previous case. In this case, it was necessary to modify the circuit of the cyclic counter with which the switch is smart controlled.

Some new elements were added: an additional counter and logical comparison device (each with an exit value of 1 or 0, corresponding to the truth, or a lie).

As a result, we developed a model that supports the processing of an incoming signal with none of multipliers in signal channels. With using variable durations, the form of the output signal with controlled power of different partial signals is obtained. It then will be proved by the spectrum of this signal in the frequency domain. The base part of our model of multipath signal propagation with the help of a simulator based on a cyclic switch with a variable duration in the Simulink environment is present in Figure 4.

The model of the simulator consists of different types of elements of the Simulink library, and main of them are: the sources of the chirp signal, the blocks with amplitudes (which are also responsible for the relative amplitudes of partial signals), and the cyclic switch, which is being controlled by a special law (smart rule). The cyclic switch that is suggested here is responsible for switching the signal channels with variable time durations.

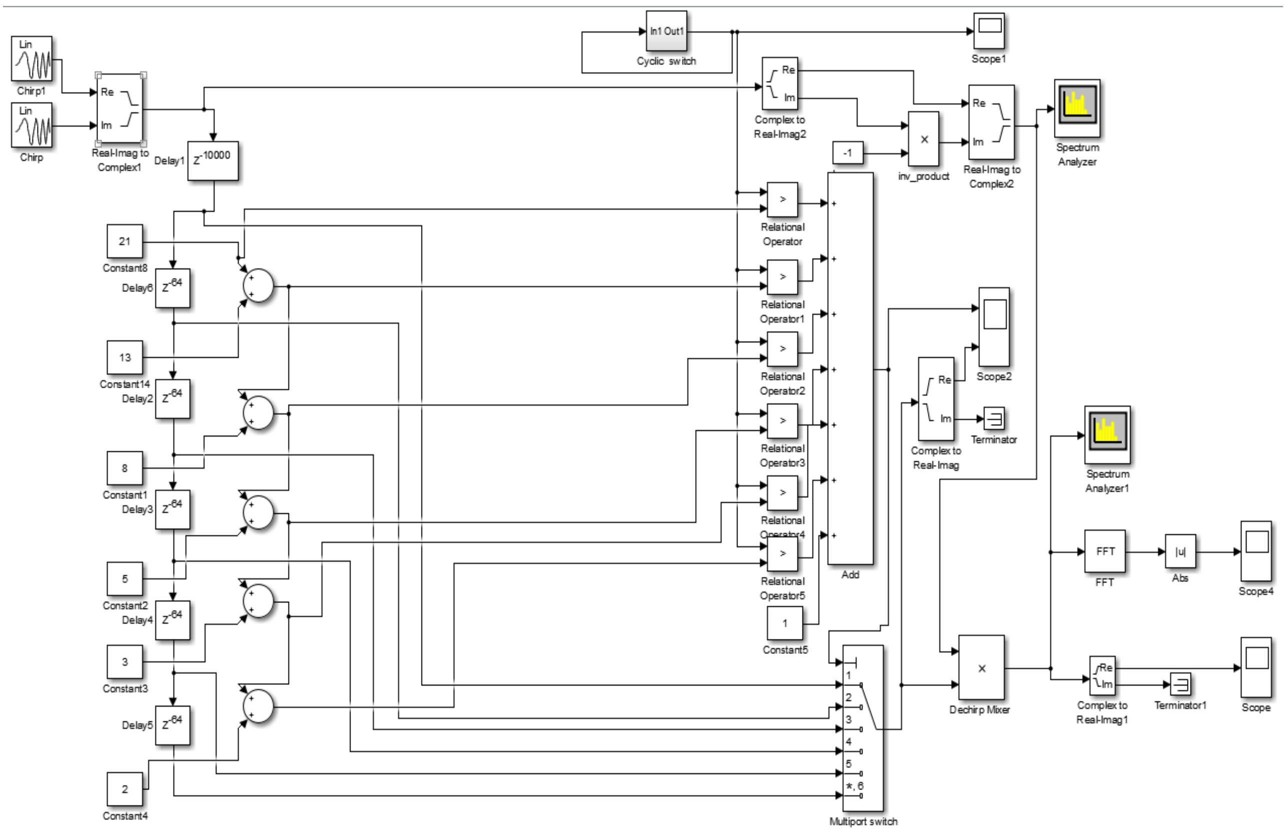

Figure 4: The model of multipath signal propagation with the help of a simulator with a cyclic switch with variable durations in the Simulink environment

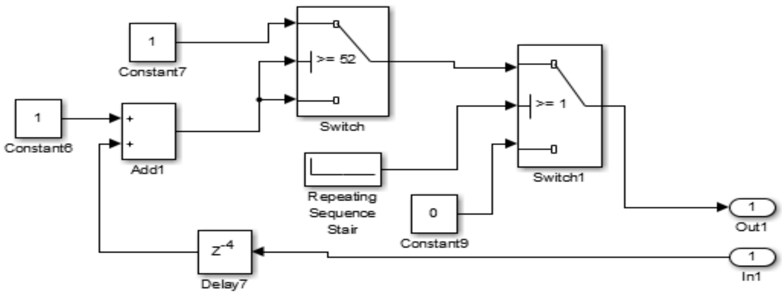

Figure 5: The scheme of the cyclic switch

As shown on the figures 4 and 5, relational operators are controlled by the cyclic switch shown on the fig. 5: the threshold (maximum value) of the main switch is 52 – it is a sum of the constants (2, 3, 5, 8, 13, 21, i.e. values from the blocks on the left of the fig. 4) and the cycle runs from 1 to 52. Each time step this value changes, therefore it is being compared to the following values from the adders in the relational operators. If 1-st value in each relational operator is more than current value of the switch, the relational operator outputs a value of 1 (truth), and this one passes to the main adder.

The possible values on the main adder's output are: 1, 2, 3, 4, 5, or 6. So, this is the key information for the control port of the multiport switch. The switch connects one of its six ports and the signal passes through to the Dechirp mixer. The Dechirp mixer is a multiplier of two our complex signals.

So, the multichannel propagation model "transmit antenna → reflecting object → receiving antenna" can be represented as the model with one multitap delay line, and one switcher that is used instead of the combiner to simplify the hardware implementation. It is important to admit, that in our model, all the Doppler shifts are neglected to simplify the model. And, amplitude values simultaneously act with the delays in the corresponded signal channels. So, such signal processing does not include multiplication along all the signal channels; it can be described by the expressions:

$$X(t) = A(t-\tau_i), \quad i = 1 + \sum_{j=1}^{n} if\left(cnt(t) > \sum_{k=1}^{j} E_k \right), \tag{1}$$

where τ_i is the desired delay of the i-th partial signal;

$A(t-\tau_i)$ is the delayed replica of the input signal;

n is the number of partial signals (signal channels);

E_i is the relative normalized amplitude that corresponds to the desired spectral power of the i-th signal;

$cnt(t)$ is the value of digital counter that cyclically count from 1 to maximum value equal to $\sum_{k=1}^{n} E_k$.

$if(bool)$ is the simple math function that gets 1 if the argument *bool* is true, or 0 otherwise.

5 Model experiment results

The results of a model experiment are presented in Fig. 4-7. Here were used the following parameters: the spectrum width 1 kHz; the simulation stop time is 80 ms; 6 signal channels (suitable for simplified modeling).

The processing of the cyclic switch is presented in the figure 6. It is important to note that all the six steps are different in durations, and the durations are proportional to the relative normalized amplitude values defined by E_i.

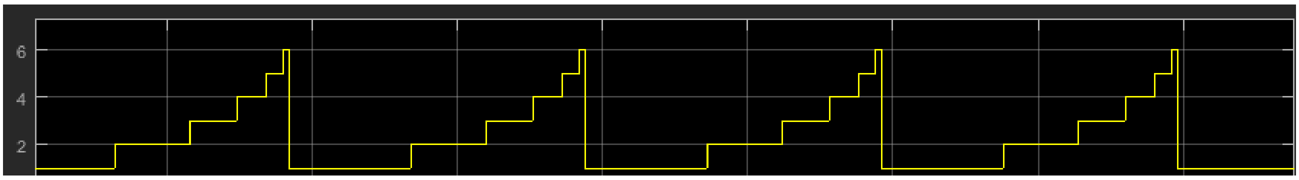

Figure 6: Example of cyclic switch operation (duration variables)

In the figure 7 the input signal (in-phase component) is presented:

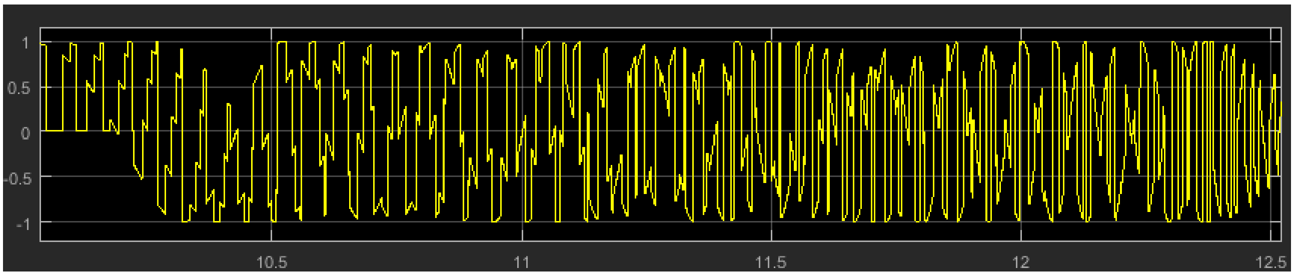

Figure 7: The signal before the mixer Dechirp (duration variables)

After that, we can obtain a form of the beat signal, an example of which is shown in figure 8:

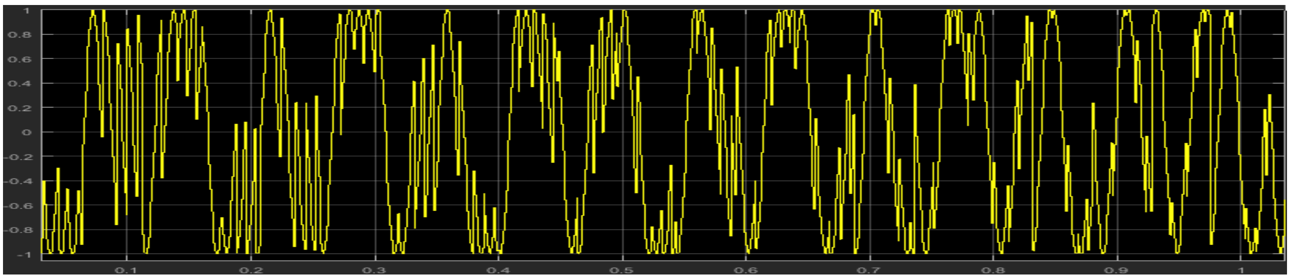

Figure 8: The beat signal as a result of switching 6 discrete channels

Next, we get a spectrum view that is presented similar to a fence in figure 9:

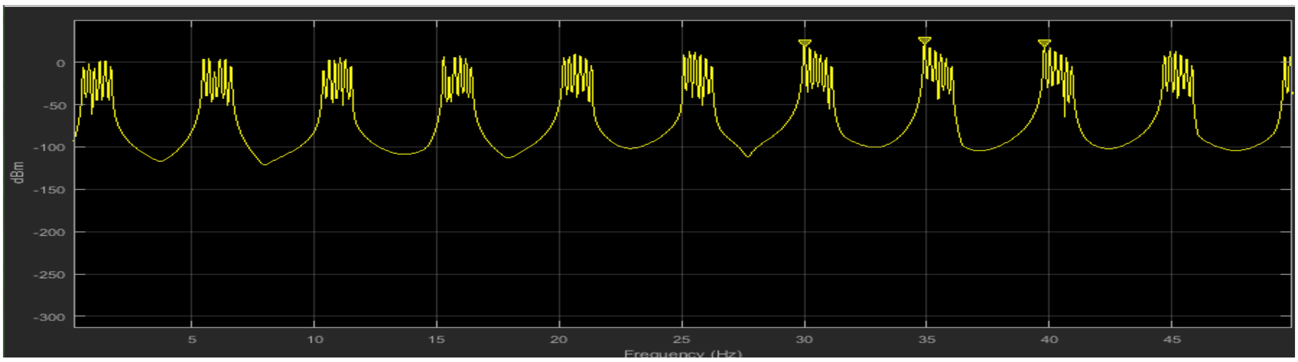

Figure 9: The spectrum of the beat signal as a result of switching 6 discrete signal channels (duration variables)

And finally, the zoomed single spectrum part is presented in figure 10. One can see that power values of the spectrum correspond to the values defined by E_i in the model experiment.

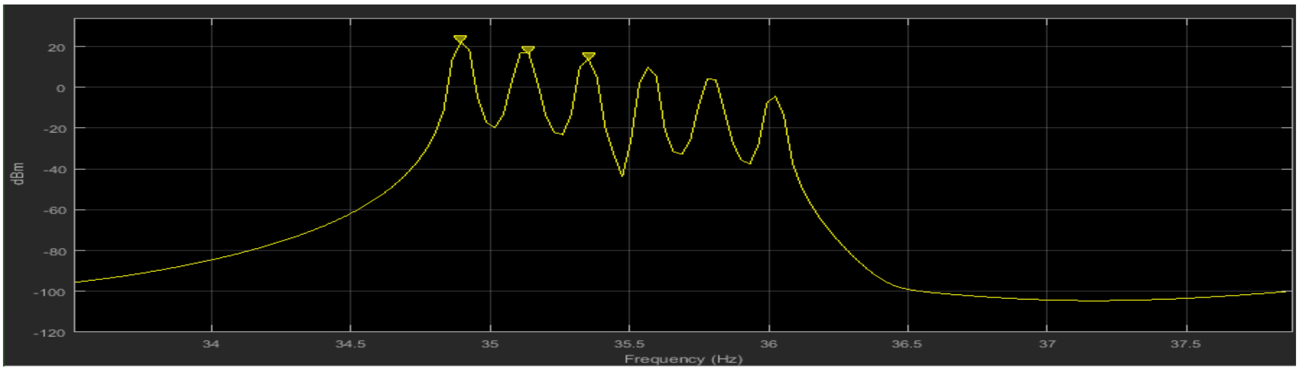

Figure 10: The spectrum of the beat signal as a result of switching of 6 discrete signal channels (in approximation, duration variables)

The characteristics of the signals simulated in the Simulink in the time and spectral domain are close to theoretical and expected features [9, 11]. Therefore, the results will correspond to the desired experimental signals for simplified tests and analyzing of altimeter's operation while it works with multipath propagation signals.

The number of signal channels can be increased by a number of model improvements. What is more, a facet model [8], which allows us to form reflected signals from typical terrains, may be implemented in our model. The model allows us to evaluate software control signals for the simulator which may be constructed with same signal processing ideas.

6 Conclusion

In this paper, we have presented the simulator for radio altimeters, especially for extended radar objects. At the beginning we designed the method for building the simulator for multipath propagation of radar signals with variable durations of signal's switching intervals. Then the simulator scheme was formed. It gives us an opportunity to form reflected signal by switching the hardware channels with different signal parameters that can be changeable in real time [8, 11]. After this, we have presented some experimental results, which in common correspond to practical and theoretical results [8]. Formed characteristics of the simulated signal in the time and spectral domain are close to the theoretical and real flight results in similar conditions for simple natural surfaces.

The relevance of this project is rather significant, because we finally managed to simplify the hardware structure of the simulator via presenting this device in the MATLAB. Moreover, it is important that the solution mentioned above is working properly with mixing intervals, which are unequal in duration [10] of a simulator implementation.

The obtained results can be helpful in the development and improvement of hardware-in-the-loop simulators for checking and verification of various autonomous airborne radars or altimeters with frequency modulation, as well as for other radar systems with continuous or long emitted signals.

Acknowledgments

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