

DRFM-Modulator for HRR-Jamming

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ABSTRACT

The Digital RF Memory (DRFM) is a key component in modern radar jamming systems. To introduce false targets in a High-Range-Resolution (HRR) radar and other high-resolution imaging radars, a new generation DRFM-system is being developed with far better range resolution and modulation properties. The DRFM also needs better performance in the D/A-converter than in the systems used today, because of the high fidelity jamming signal. This paper is a part of a Master thesis [6] and describes a new type of DRFM-modulator that uses digital signal processing in the frequency-domain for generation of false targets [1]. The modulator is able to produce a radar scene with a number of complex false targets constructed of many single reflectors with individual modulation and with a credible background. Some of the different strategies for the modulator topology will be introduced and discussed. The modulator is being implemented using parallel digital logic in a number of Field Programmable Gate Arrays (FPGA) on a single printed circuit board (PCB) for use in FFIs experimental radar jammer named EKKO II [4].

1.0 BACKGROUND

High-resolution imaging radar is of increasing importance in numerous tasks, both civilian and military. This has resulted in a requirement for research on Electronic Countermeasures (ECM) against this class of radar. Over the last five years one main task in a research program at FFI has been to demonstrate the capability of introducing false information in a controlled, programmable manner in high-resolution radars of various kinds [2]. The work has included theoretical studies, computer modelling, field tests using existing hardware, and development of a whole new system, named EKKO II, designed with the above mentioned task in mind. Figure 1 shows the EKKO II system in X-band configuration.



Figure 1: EKKO II in X-band configuration

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2.0 PROBLEM TO BE ADDRESSED

In the EKKO II experimental radar jammer the synthesis of false targets are realised with *direct modulation* and are implemented in FGPA. Direct modulation is a method where range delay, frequency and amplitude changes for each false point scatterer are generated in dedicated digital branches, as an imitation of the physical reflection process in the nature. This method is easy to understand and synthesises credible targets, but the hardware complexity increases as the number of targets increases.

Thus, new methods for synthesising false targets that are independent of the number of targets are of interest. This paper describes a new type of DRFM-modulator that uses digital signal processing in the frequency-domain. The method is sketched in [1] and presents a possibility to achieve large numbers of false targets without an increasing hardware complexity.

The new DRFM-modulator should produce a radar scene with a number of complex false targets constructed of many single reflectors with individual modulation and with a credible background. The modulator is to be used for synthesis of high-resolution range profiles, as illustrated in Figure 2 and for synthesis of *Synthetic Aperture Radar (SAR)* / *Inverse Synthetic Aperture Radar (ISAR)* images.

Figure 2 contains a SAR image of a cultivated landscape that is overlaid a high-resolution range profile. For synthesising a SAR scene, new high-resolution range profiles with different appearance have to be generated continuously.

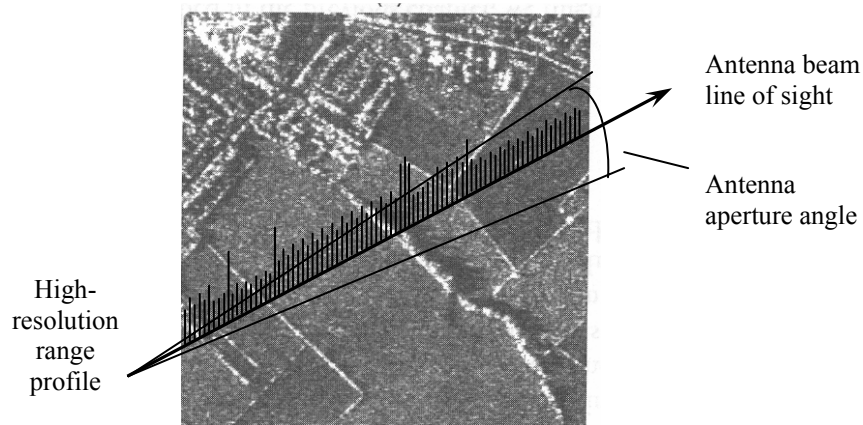


Figure 2: SAR image of cultivated landscape with high-resolution range profile drawn

3.0 INTRODUCTION

A system designed to present false credible information in an arbitrary high-resolution radar system should be designed as a repeater that is able to store the radar signal, for modulation and retransmission. The central component of such a system is the storage device, the *Digital Radio Frequency Memory (DRFM)*, ref Figure 3.

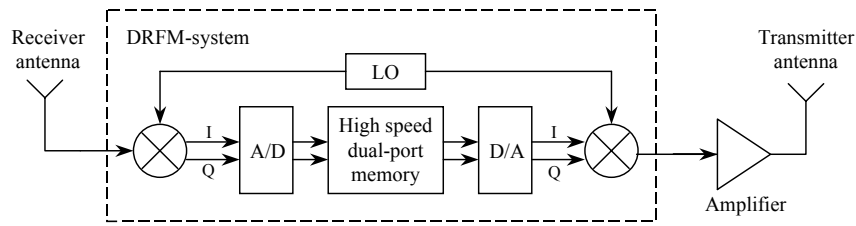


Figure 3: A DRFM radar jamming system

The retransmission of a perfect replica of the radar signal will generate a point target response in the radar. To generate false credible information in a high-resolution radar image though, a target or a scene with spatial extent must be created. Basically this can be done in the time-domain by a digital *Finite Impulse Response (FIR)* filter [3], shown in Figure 4.

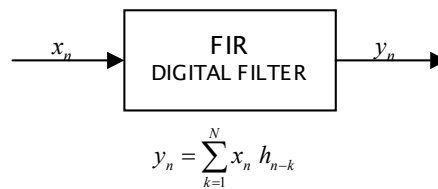


Figure 4: A digital FIR-filter

If the radar signal is the input sequence x_n and the point targets are the filter coefficients in the impulse response h_n , the output sequence y_n is the convolution between sequence x_n and h_n . Sequence y_n is then the desired jamming signal.

The structure in Figure 5 is a parallel realisation of a digital FIR-filter, where the branches with filter coefficients equal to zero are omitted. Here, the output sequence is generated by adding a number of radar signal replicas, each with individual modulation in time, amplitude and phase. This capability is made possible by modern high-speed digital electronics using multiple *Field Programmable Gate Array (FPGA)* circuits. Figure 5 illustrates the parallel time-domain realisation.

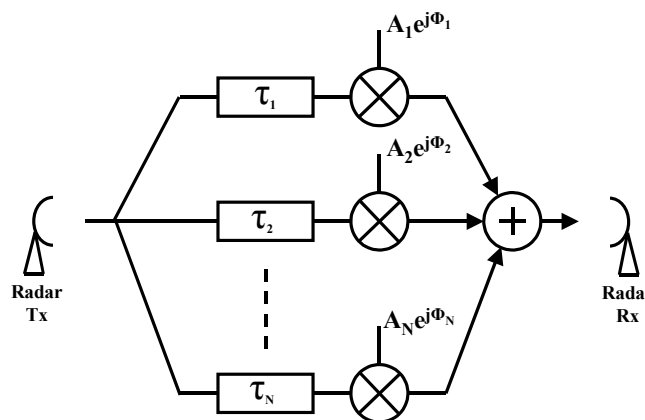


Figure 5: Time-domain realisation of time overlapping radar replicas

Alternatively the convolution between the radar signal and the point targets can be calculated using the *Fast Convolution Process (FCP)* algorithm, which make use of the *Fast Fourier Transform (FFT)* implementation of the *Discrete Fourier Transform (DFT)*. The FCP-convolution is much more efficient with respect to computational requirements than the standard convolution, especially with long sequence lengths, ref [5].

Table 1 shows a computational comparison of number of additions and multiplications for FCP-convolution versus standard convolution. N is the length of the two sequences and L is a legal FFT size ($L=2^m$, where m is an integer) that is greater or equal to N_1+N_2-1 , where N_1 and N_2 are the two sequences.

Table 1: Computational comparison for FCP-convolution versus standard convolution

	# Complex additions	# Complex multiplications
Standard convolution	$(N-1)^2$	N^2
FCP-convolution	$3L\log_2L$	$3L/2\log_2L+L$

Figure 6 gives a graphical illustration of the equations in Table 1 for some data set sizes of N.

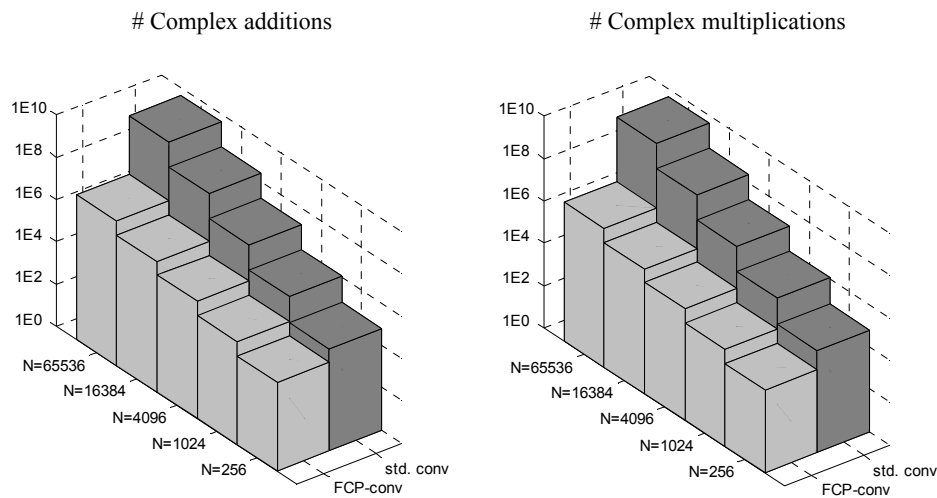


Figure 6: Graphical illustration of the computational loads from Table 1

Using FCP-convolution the total response can be computed fast and directly, rather than implementing the individual delays and modulations in hardware. This can be done by transforming the radar signal and the targets to the frequency-domain, performing calculations, and transforming the combination back to the time-domain. This concept is referred to as *Computed ECM* in [1].

There is a potential for achieving a considerably higher number of radar resolution cells using this approach. Whereas in the direct time-domain implementation the number of targets or resolution cells achieved is limited by the space within the FPGAs, in the Computed ECM case the limiting factors are

system dynamic range, number of sampling bits, calculation speed etc. This is a planned future capability for the EKKO II radar jammer [4]. Figure 7 illustrates the concept of the frequency-domain realisation.

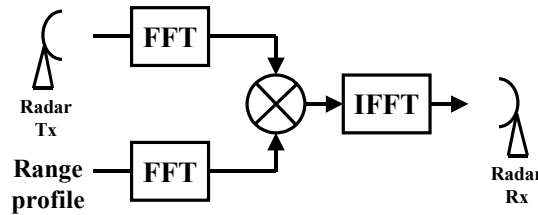


Figure 7: Frequency-domain realisation of time overlapping radar replicas

The advantage of frequency-domain realisation is that the jammers complexity is nearly constant with increasing number of targets in the jamming scene. On the other hand, the complexity does increase with increasing number of samples in the radar signal and with increasing size of the radar scene.

4.0 COMPUTER MODEL

To examine the proposed DRFM-modulator structures, a computer model of the modulator, the target and the high-resolution radar is used. Figure 8 gives a brief description of the simplified computer model.

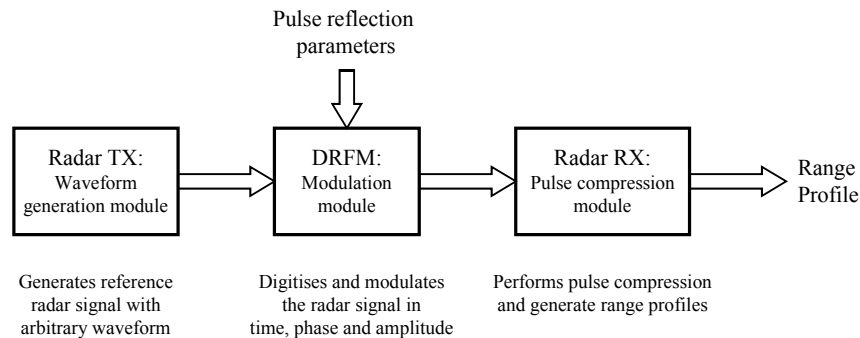


Figure 8: Schematic description of the computer model

Figure 9 gives an example of a HRR profile generated in the computer model. An aircraft with marked reflection points in red is illuminated from a selected angle and with a chosen waveform. In this case the pulse compression leads to range cell size of approximately 4 samples and a total of 125 range cells over the aircraft. Different compression waveforms and factors are supported.

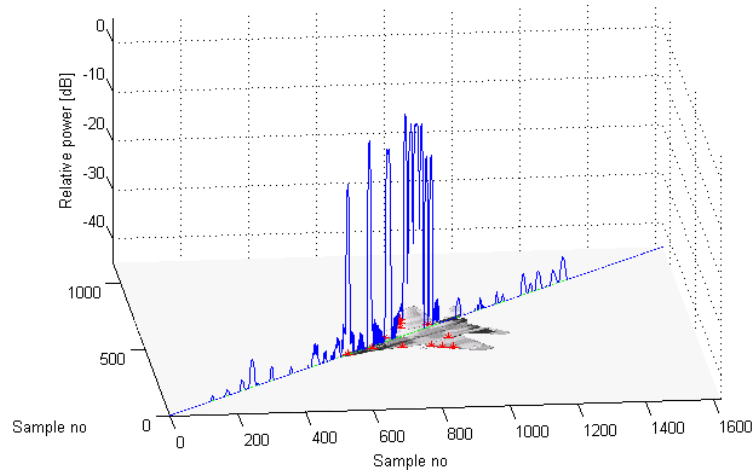


Figure 9: Example of a HRR range profile generated in the computer model

In this paper the computer model is configured with a simplified complex reference target constructed of twelve single point reflectors. Each of the reflectors has different position, amplitude and phase. A chirp radar signal with *Time-Bandwidth product (TBW)* of 127 is then applied to the modulator and the jamming signal is calculated. The last step in the computer model is the pulse compression stage and the generation of the HRR range profiles. Figure 10 shows the simplified complex reference target.

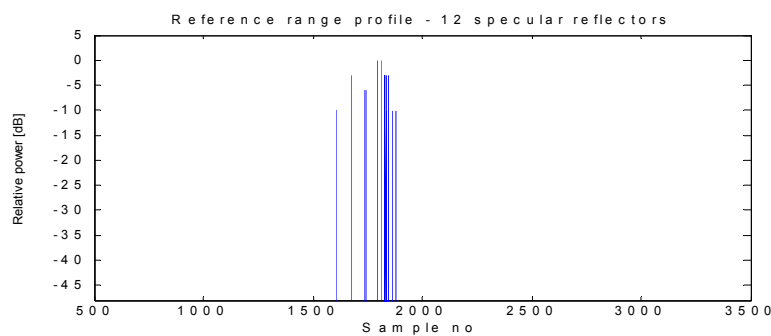


Figure 10: The simplified complex reference target with twelve single point reflectors

For verification of the proposed realisation concepts, the modulator structures and their corresponding range profiles from the computer model are compared and discussed.

5.0 PROPOSED CONCEPTS FOR FREQUENCY-DOMAIN DRFM-MODULATOR REALISATIONS

The following DRFM-modulator realisation concepts are developed for generation of credible targets on HRR-radar, but the conclusions will also be valid for the more advanced SAR and ISAR as well, since a lot of the fundamentals are common to all imaging radars.

The goal for the development is a modulator design with minimum insertion delay and maximum coverage in range. It is desirable to synthesise the complex reflections from each of the targets, and to manage the generation of the background scene. The acceptable values for insertion delay and range

coverage are strongly dependent of the actual radar system. Since the modulator is planned used against different type of radars, the modulator design will make use of the reconfigurable structure of the FPGA.

5.1 FCP-convolution structure

A single FCP-convolution structure is the simplest modulator realisation found using frequency-domain. This structure has however limited throughput and will introduce some delay in the signal flow through the modulator. The throughput is dependent of the implementation of the FFT and the inverse FFT (IFFT), which can be supplied as *Intellectual Property (IP)* cores from for example the FPGA manufacturer. Xilinx CoreGen IP-library supports FFT / IFFT up to 16384 data points at ~170 MHz clock speeds. Specialised manufactures deliver state of the art pipeline IP-cores for high performance transformations for more than 131072 data points at 400 MHz clock rate.

When using FCP-convolution, the length of the FFT transforms i.e. the number of data points in the transform, determine the range extent of the covered scene since the FFT length equals the sum of the number of samples in the radar signal and the covered scene. The available calculation time is usually equal to the radar's *Pulse Repetition Interval (PRI)*, but it varies depending of the actual radar system.

Figure 11 shows a simplified schematic for a modulator using a single FCP-convolution.

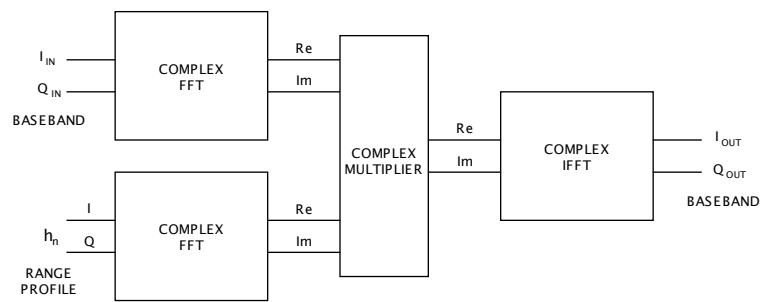


Figure 11: FCP-convolution realisation

The modulator structure is examined using the data model described in chapter 3.0. Figure 12 gives a simulated HRR range profile of the simplified complex target. The range profile in Figure 12 is identical to range profiles generated in the modulator using time-domain realisation.

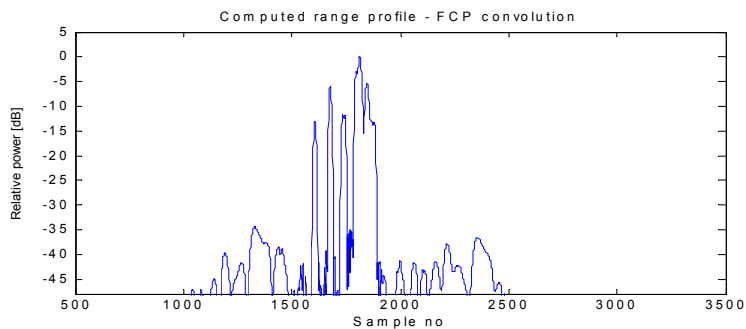


Figure 12: Simulated HRR range profile after pulse compression of example target generated with FCP-convolution

Figure 12 also shows that the pulse compression process generates side lobes at both shorter and longer ranges than the targets reflectors. If the coded radar waveform had better performance on side lobe suppression, the spurious signals in the range profile would have been lower.

5.2 FCP-convolution structure with separate synthesis of object and background

In some instances, a possibility for separate synthesis of object and background is preferable. Figure 13 shows a simplified schematic for a modulator that covers this approach. The complexity grows compared to a modulator without separate synthesis, but the insertion delay is almost the same.

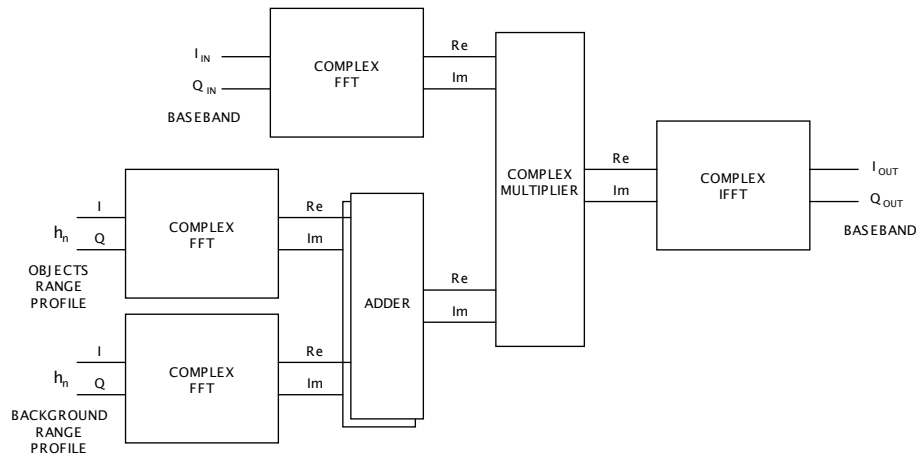


Figure 13: FCP-convolution realisation with separate synthesis of object and background

This modulator realisation is examined in the same manner as last structure by using the data model described in chapter 3.0. Figure 14 shows the simulated high-resolution range profile containing both the simplified complex target and a background profile. The synthesised target is identical to the target in the last structure and the generated background has a uniform and almost constant reflection level throughout the range scene.

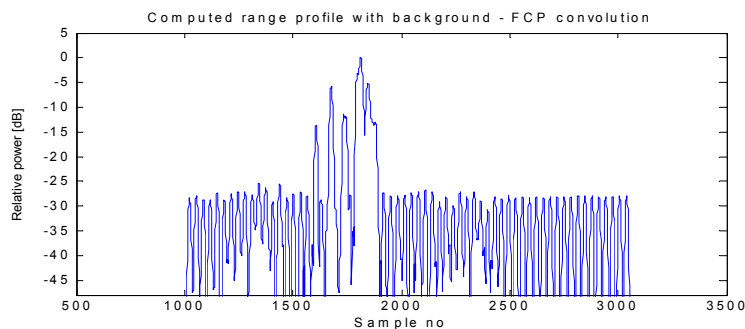


Figure 14: Simulated high-resolution range profile after pulse compression of example target generated with FCP-convolution and separate synthesis of object and background

The background profile in Figure 14 is synthesised with an artificially ideal appearance for demonstration, but with use of other reflection coefficients a credible background can be generated.

5.3 Distributed FCP-convolution structures with parametric generator for background profile

This structure is an example of a versatile, fast and complex modulator realisation. It contains several parallel FCP-convolutions, for higher speed and less insertion delay, connected in a distributed configuration for less complexity. The structure includes a parametric generator for the background profile, which gives a high level description of the appearance over time (mean level, smoothness, distribution, sample rate) throughout the range profile. Usually the background synthesis requires huge amount of reflection coefficients, but with the parametric generator the requirements for configuration data is greatly reduced.

The last feature included in the proposed structure is a set of dual-port memory circuits that separate the high-speed convolution circuits and the modulation coefficient generation process. The circuit separation makes it possible to update the modulation coefficients at a lower sample rate than the convolution-processing rate. In some instances this reduction in update rate gives noticeable improvements. Figure 15 and Figure 16 show a simplified schematic for an extended modulator using multiple FCP-convolutions and a parametric generator for background synthesis.

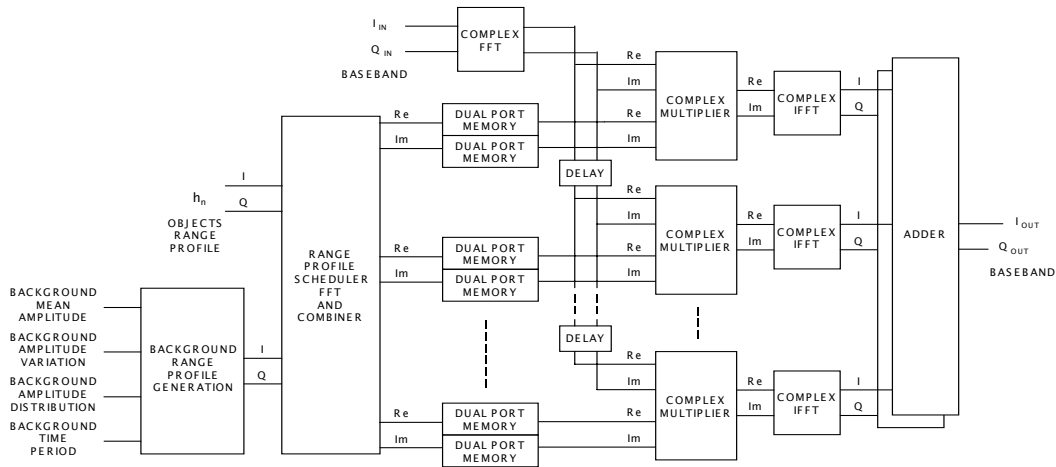


Figure 15: Distributed FCP-convolution realisation with parametric generator for background profile

Because of the separate synthesis of object and background, and the multiple convolution circuits, the complexity increases a lot. Specially the *Range profile scheduler, FFT and Combiner* block grows, as seen in Figure 16.

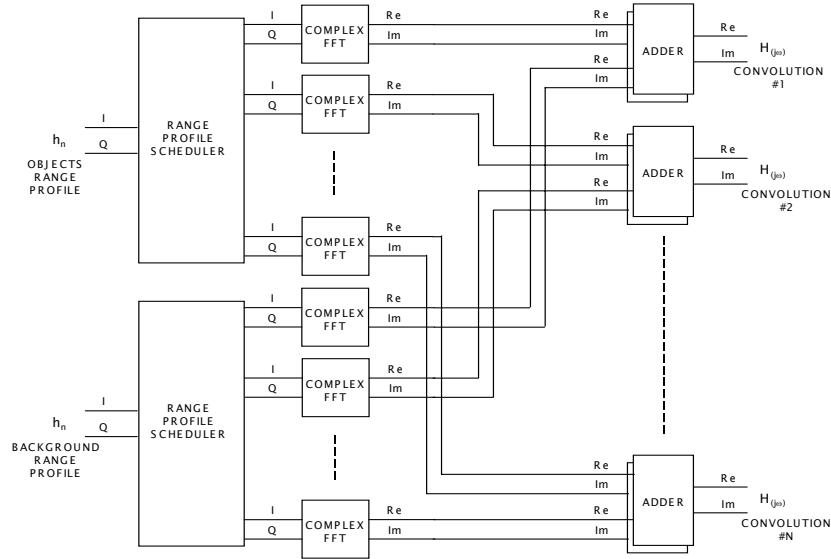


Figure 16: Detail schematic of Range profile scheduler, FFT and Combiner in Figure 15

Figure 17 shows the simulated high-resolution range profile synthesised with the parametric background generator. The generated background has sections with different mean reflective level and smoothness, and some minor areas with highly reflective objects. In the middle of the range profile, a typical shadow can be seen – an area with low reflection. Figure 17 demonstrates of the possibilities and versatility of the parametric generator.

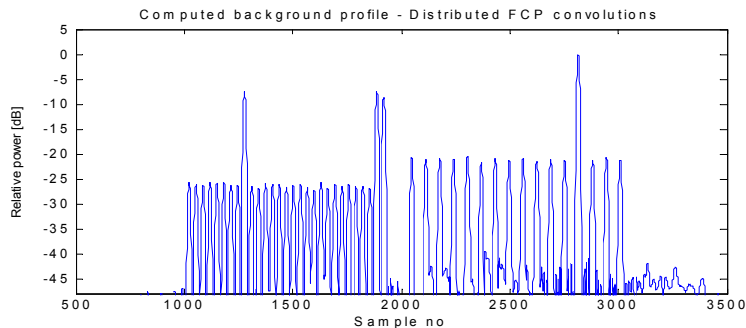


Figure 17: Simulated high-resolution range profile after pulse compression of example background profile generated with parametric generator

To illustrate how the parametric background generator can be used to synthesise credible landscape, a SAR image is used with a high-resolution range profile drawn on top, ref Figure 2. For synthesising a whole SAR scene, the background generator has to be supplied new parameters regularly.

5.4 Future developments

Input parameters for the proposed DRFM-modulator structures have been a radar waveform that has relatively short duration in time and hence short extension in range, and a covered scene with long extension in range. This is not always the case; sometimes the radar waveform has an extension in range as long as the covered scene or even longer. To deal with this situation, the modulator structures have to

be further developed. In the proposed structures only the covered scene is divided in different convolutions, but maybe in the future both the radar waveform and the covered scene have to be divided in individual convolutions.

6.0 DISCUSSION

A single FCP-convolution structure is the simplest modulator realisation and with large FFT/IFFT transformations the covered scene can be large in range as well. On the other hand the processing speed for large FFT/IFFT transformations is quite slow, which result in large insertion delay. Usually, the actual requirements for processing time limits the available range extent of the false radar scene.

An FCP-convolution structure with separate synthesis of object and background is convenient, specially when processing of the two are generated with different processing tools. Separate handling of object and background lead to higher complexity, but not to larger insertion delay. All the other advantages and disadvantages are inherited from the single FCP-convolution structure.

A distributed FCP-convolution structure with parametric generator for background profile is a complex modulator realisation, but it will handle different radar systems and scenes very well. The structure is unique since it generates a credible background profile based on only a parametric description of the background.

7.0 CONCLUSION

All of the proposed structures are suitable for a DRFM modulator realisation, but they are dependent on the actual radar system and the desired range coverage. A distributed FCP-convolution structure with parametric generator for the background profile is the most general construction for different operations, but also the most complex.

8.0 REFERENCES

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